# Foreword

The Sixth Symposium of the International Society for Tropical Root Crops held in Lima, Peru, 20-25 February 1983 gave the opportunity to more than 150 scientists to get together to discuss recent progress on the improvement of root and tuber crops, which are staple foods in many developing countries. These Proceedings testify to the interest and time that scientists are devoting to the development of this important group of food crops that are vital sources of energy to many people in the world.

I would like to take this opportunity to thank the International Potato Center for helping to organize the Symposium, and for financing the editing and printing of these Proceedings. In particular, to Mr. Frank Shideler for editing and to Dr. Hernan Rincon and his staff for coordinating and supervising the printing, and to many of the other staff of CIP's Training and Communications Department for their help in numerous ways.

SIDKI SADIK
President ISTRC
1984

# Welcome Address

Welcome to all of the participants at this tropical root crop symposium. The International Potato Center (CIP) is very pleased to host this conference and to have the potato included in the concerns of this society.

The commodities being addressed by this society will have to be given greater attention in the future as population growth makes increasing demand on the use of marginal land. The size of farms is already decreasing in Asia, leading to more intensive use of land. Many of the tuber-root crops have a comparative advantage over cereals in intensive agriculture.

Until now, the nutritional value of most tuber-root crops has not received sufficient attention. Their value is well known but has not been publicized, and all too frequently the tuber-root crops have been classified as only starchy foods. The value of their vitamins, minerals, and even protein has been overlooked by a majority of the general public.

You are scheduled later in the week to visit the facilities at CIP headquarters. I hope that many of you can take the time to also visit some of our experimental stations representing the major agroecological zones of the developing world where potatoes are grown.

The highland area around Lake Titicaca, between Peru and Bolivia, is where the cultivated potato originated. Peru is also the birthplace of several other tuber-root crops that are still used in a minor way, but these crops could increase in importance in the future due to population pressures. While you are here, there is opportunity to learn more about the future potential of these minor commodities.

We will do our best to help you have a successful conference. Please let us know if you have special interests that we may help you with while you are here in Peru.

Richard L. Sawyer
Director General
International Potato Center

## PROCEEDINGS OF PAST ISTRC SYMPOSIA

| Symposia | Venue | Order from | Price |
|---|---|---|---|
| 1st 1967 | Trinidad | Department of Crop Science<br>University of the West Indies<br>St. Augustine, Trinidad & Tobago | Out of print |
| 2nd 1970 | Hawaii | Publications Office<br>College of Tropical Agriculture and Human Resources<br>University of Hawaii<br>Honolulu, Hawaii 96822 U.S.A | US$5/2 volumes |
| 3rd 1973 | Nigeria | Philippine Root Crop Research and Training Center<br>Visayas State College of Agric.<br>Baybay, Leyte 7127<br>Philippines | |
| 4th 1976 | Columbia | International Development Research Center<br>Box 8500<br>Ottawa, Canada KIG 3 H9 | US$12.00 |
| 5th 1979 | Philippines | Philippine Council for Agriculture & Resources Research & Development<br>Los Baños, Laguna<br>Philippines | |
| 6th 1983 | Peru | International Potato Center<br>P.O. Box 5969<br>Lima, Peru | US$20.00 |

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OF GREENWICH

Presidential Address: Tropical Root Crops in the Eighties

Author: Donald L. Plucknett.

On the occasion of the 6th International Symposium on Tropical Root Crops it might be useful to examine the present status of research and development in tropical root crops and to discuss briefly the role of the International Society for Tropical Root Crops (ISTRC) in that work. Sixteen years have passed since the first symposium was held in Trinidad. Since then a number of activities and promising developments have occurred that affect interest in, and production of, tropical root crops.

Our past President, D.G. Coursey, will present a history of the first 13 years of the ISTRC at the banquet later this week, so I will not review that history, but I will say a few words about the status of the Society, its activities and some recent developments that may be of interest.

It is a great privilege to meet in Peru, a major center of origin for the potato, and in Latin America, the continent that is the home of so many tropical root crops, e.g., cassava, sweet potato, Xanthosoma, and the less well-known Andean tuber-bearing crops. We are also privileged to have as our host the Centro Internacional de la Papa (CIP), the international center devoted to improvement of the potato. We are grateful to CIP for their hospitality and hard work in arranging the sixth symposium.

## Present Status of the Tropical Root Crops

Changes are evident in tropical root crops. In general, with the exception of the Near East, root crop production has expanded in the last 15 years or so. In developing countries, production of all root crops increased by 44% during the 15-year period 1961/65 - 1979 (CIP, 1982). This increase in production is rewarding, but all of us know of places where root crops production has declined because of devastating diseases and insects, marketing problems, or other reasons.

Root crops are still staple foods for many people, particularly in developing countries. I don't have to remind you that often the populations most dependent on root crops are the very poor, and research focused on their problems can yield significant benefits.

## New Developments Affecting Root Crops

There is increasing interest in root crops in some quarters because of some new developments. The research for "energy" crops has included a new look at roots and tubers. Best-known is the interest in cassava as a source of alcohol. But other crops such as sweet potato and taro have also received attention. This interest will probably slow somewhat in the near future because of current low prices of petroleum, but should oil prices rise again, interest may quicken once more. I suspect the cost of production of root crops must be reduced considerably

before energy uses of root crops will become important, but it is too early to know.

Root crops are also receiving attention because several can tolerate marginal or difficult land conditions. Pressures for land and increased food production have caused farmers to move onto marginal lands with difficult soil, weather or other environmental conditions. Cassava is valued because it can tolerate drought and high aluminum soils. Taro has always received interest because it can be grown in hydromorphic soils or under flooded conditions. Xanthosoma can grow in some hydromorphic soils, but it can also tolerate quite dry conditions and a wide range of soils, from those with high aluminum content, as well those composed mostly of coral rock. The potato is adapted to cool or cold high elevations, lands where few other crops could survive. I consider the tolerance of many root crops to marginal land conditions to be a major factor in better land use, and we root-crop scientist should do all we can to understand the degree of tolerance as well as the reasons for it and to exploit it for the good of man.

In some quarters there is new interest in root crops or root-crop by-products as animal feed. There has also been increasing interest in improved processing and storage of tropical root crops.

The movement of people as refugees of war or for other reasons is also changing the markets for root crops and in some cases is making certain tropical root crops available in markets where they were unknown before. In my own country the new Cuban populations in Florida have created new markets causing Xanthosoma and cassava to be grown as field crops; taro is marketed regularly on the West Coast for the use of Pacific Islanders who have migrated there; and several root crops used in Southeast Asia are now marketed in locations across the United States because of demand caused by refugees from Indochina. Such movements of people may bring about new markets for root crops.

## Major Weaknesses or Problems of Root Crops

All of us probably know the major root crop limitations, but it is useful to review them from time to time. Vegetative propagation is probably the most important single limitation because:

(1) it causes high seed costs;
(2) it increases labor and handling costs;
(3) it can present special storage or multiplication problems;
(4) it causes major disease and quarantine problems.

The order of priority of the other limitations is not as easy to judge as vegetative propagation, but other limitations include: high costs of production and hence very high fresh product prices, perishability, long crop duration, diseases and pests, and uncertain markets.

Poor crop statistics are a severe limitation. Most of us believe root crop statistics are understated and therefore lower priorities for research support are given to these crops.

## The Crops

An important development during the past two decades has been establishment of the international agricultural research centers (IARCs). Several tropical root

crops are now included in the mandates of four IARCs. These will be covered briefly on a crop by crop basis, as well as some of the major strengths and weaknesses of each crop, from my personal perspective.

1. Potato. The potato is the most important root crop in the world, ranking fourth among all crops. CIP was established in 1972 to improve potato production in developing countries. The World Potato Collection is a major germ plasm resource for the world. Seed production and virus diseases still are major limiting factors, while susceptibility to high temperatures and bacterial wilt limit potato production in the humid tropics. The use of true seed (TPS) for planting could markedly reduce seed costs as well as certain virus disease problems.

2. Cassava. Cassava is a major world crop, ranking sixth in total production. CIAT has a major cassava program and maintains the world germ plasm collection. IITA is responsible for cassava improvement in Africa. Cassava research has increased dramatically around the world, due to the efforts of CIAT, IITA and financial support by IDRC. National programs are stronger. Tissue culture is being used increasingly for rapid multiplication, for germ plasm preservation, and to clean up viruses in cassava tissues. Insects and diseases have caused severe damage to cassava crops in Africa. Cassava chips for livestock feed face an uncertain market in Europe. The perishability of cassava is still a problem although there is much information available on processing. There is much research information and new technology that needs to be utilized.

3. Sweet potatoes. Sweet potato is a major world crop, ranking seventh among all crops in total production. The People's Republic of China is the largest producer. IITA has responsibility for breeding sweet potato in Africa. Most of the IITA program is focused on weevil resistance. AVRDC works to improve sweet potato production in Asia. Short-crop duration, generally low fertilizer requirements, and tolerance to low-moisture conditions are major strengths. Sweet potato is usually a low-cost food, but its sweetness is a drawback to its use as a staple food.

4. Yams. IITA has responsibility for improved yam production. IITA's achievement in obtaining flowering and seed set in yams provided a basis for yam breeding. A major limitation is still the large amount of planting material required. Another major limitation is the requirement for staking in some cultivars. Demand for yams is still high in many places.

5. Taro. IITA has responsibility for taro, but its aroid program is small. The major strengths of taro are tolerance to flooding and hydromorphic conditions, plus possibly some salinity tolerance. Yields can be high. Taro can be devastated by some diseases, notably taro blight. Lethal viruses in Melanesia cause concern in movement of germ plasm. Taro prices are often too high to maintain its role as a staple food, unless it is grown as a subsistence crop. The International Foundation for Science (IFS) has provided much needed financial support for aroid research in developing countries.

6. Xanthosoma. IITA has responsibility for cocoyam. IITA has worked mostly on diseases and production problems of West Africa. Xanthosoma is tolerant of certain difficult soils and is less susceptible to diseases than taro. For that reason Xanthosoma is replacing taro in some areas.

## Root Crop Germ Plasm

Germ plasm conservation for rot crops is difficult because of heavy dependence on vegetative propagation. Potatoes and cassava germ plasm can be maintained as true seed, but the fear of virus transmission still exists. In general, germ plasm conservation for potato, cassava and sweet potato is improving and may be satisfactory; however, for the other root crops the situation is, at best, mixed and probably inadequate. Except for potato, cassava, and sweet potato, root crops usually have not been assigned high priority in germ plasm efforts by the International Board for Plant Genetic Resources (IBPGR). Instead, most are given secondary status or are assigned regional priorities.

Conservation of root crop germ plasm must be a high priority for root-crop scientists, and we must do all we can to convince our administrators to take on responsibility for the root crop genetic resources in our respective locations. This means field space, labor, and supervision must be provided to grow the germ plasm in glasshouses or field nurseries. If this is not done, many cultivars and land races will be lost.

## Breeding

Plant breeding efforts are well established in cassava, potato and sweet potato and both IARCs and national programs are involved in breeding these crops. Breeding in yams is still in its infancy and should receive more attention. In taro and *Xanthosoma*, breeding has begun, but I fear that little collection and evaluation of cultivars has been done, and that breeding objectives are as yet too little understood.

## Agronomic Research

Good agronomic trials of most root crops are still lacking. Agronomic research should be based on an understanding of the physiology of the crop to make best use of existing cultivars or the improved varieties being produced by breeding programs.

The wide range of conditions in which our crops grow, from flooded to arid, demands better understanding of crop response to environment. Good agronomic research can help to ensure that better understanding.

The role of root crops in farming systems must be understood better, especially since root crops can play an important role in improved land use. Some root crops can tolerate partial shading and are, therefore, satisfactory understory intercrops for three crops.

## Impact of Research

Root-crop researchers must be concerned about the rather poor rates of adoption of new technology and research results. There are exceptions of course. Some national programs are having a degree of impact, CIP has seen 17 varieties named by national programs from its genetic materials and African farmers have adopted some of IITA's cassava varieties. But in general, adoption has been less than would be desired, and the Society may wish to do something about it. Probably the need for vegetative propagation of the root crops may be the major factor limiting adoption. Perhaps the Society may wish to form a special working

group on this topic, or a future symposium should address it by organizing a special program to address it.

The International Society for Tropical Root Crops

Our Society has much cause for pride. We have a constituency of almost 1,000 and a membership of more than 300. We have organized five symposia since our formation in 1970 and provided a basis for communication among root crop scientists. I believe we can justifiably claim some credit for the increased interest in root crop research land production. The Society has experienced growing pains, including financial stringency, delays in publication of two symposium proceedings, and inadequate communication with the membership. But we have established that there is an interest in such an international society, both in the developing and in the developed world. I believe this interest augers well for the future.

We can claim several achievements. All of the proceedings of the past symposia have been published. Regional meetings have been held. An African branch of ISTRC has been organized and is now planning for its second meeting. The proceedings of its first meeting have been published. A Pacific Region taro workshop was held in Fiji in 1981, and a regional taro workshop was just completed in Costa Rica. These are just examples of some activities that have been held during the past 3 years.

At the Manila meeting the Council established six Working Groups: Root Crop Statistics, Taxonomy and Nomenclature; Non-Food Utilization; Plant Quarantine/ Tissue Culture/Germ Plasm Exchange; Research Cooperation and Priorities; and Germ Plasm Preservation and Utilization. Members of the Council have been assigned responsibility for a Working Group. Some Working Groups have been active and will report briefly at our business meeting later this week. More could be organized if the membership should want them. But Working Groups will only be successful if they function and receive support. I encourage all members to participate in one or more of the Working Groups that have been set up to deal with several important problem areas.

Our Newsletter has experienced problems. It has not been as regular in publication as is desired; it costs more to produce and mail than we can afford; and an inadequate number of news items and articles is sent to the Editor. We thank the University of Hawaii for its help and support in publishing and mailing the Newsletter.

We have attempted to keep our dues low so more people would be able to join. This means, however, that our finances are short. We have received gifts from a number of companies and organizations in the past. We are very grateful for this assistance. A list of sustaining members and donors over the past several years will be published in the proceedings of this symposium.

It is with great pleasure that I can announce that one of our members, Dr. S.K. Hahn, was honored twice in 1982 for his research achievements. He received the Guinness for Scientific Achievement Award for his contributions to tropical agriculture through his research on cassava and sweet potato, and was honored by the Government of Korea with one of its highest medals for individual achievement. I want to extend on behalf of the Society our heartiest congratulations to Dr. Hahn for this deserved recognition.

It is my pleasure to announce that the ISTRC has received a gift to establish a scientific achievement award for excellence in research on tropical root crops. Part of this gift will be used to provide an Outstanding Paper Award at this symposium. During the next year nominations will be received, and the first Scientific Achievement Award will be made. The award will be made thereafter at each symposium. The Outstanding Paper Award will also continue. Your Council hopes this award will help to stimulate excellence in research on tropical root crops, as well as to provide a measure of recognition for our colleagues who have devoted so much effort to the improvement of these important food crops.

Root Crops in Developing Countries - An Economic Appraisal

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ABSTRACT

Recent developing country patterns and trends in production and use of cassava, potato, sweet potato, yam, and taro are documented and analyzed. Production costs for these crops are estimated and related to their marketing and uses. The roles of these crops in different ecological zones and farming systems are discussed. Research and development programs are reviewed. Some tentative projections of root and tuber crops production and use are made to the year 2000.

## Introduction

Historically, tropical root crops have received little attention from scientists and policymakers (Coursey and Haynes, 1970). In recent years several national and international organizations have undertaken research and development programs involving these crops. Actual and potential contributions of these crops to the world's food supply remain poorly understood. Several recent publications, including the proceedings of the five symposia sponsored by the International Society for Tropical Root Crops, contribute to an understanding of the origin and spread of root crops, their biology, and technological advance. But few serious studies of the socioeconomic aspects of their production and use have been conducted. Those available generally draw on a restricted information base, such as case studies or surveys of only one or a few crops in a single country, or draw comparisons among crops or countries in a rather haphazard fashion.

This paper seeks to contribute to the understanding of tropical root crops from an economic point of view. Wherever possible, data are presented on, and comparisons are drawn among, the major root crops and their production and use in different world regions. Time series of production in developing countries are charted and factors likely to influence future developments are discussed.

Discussed here are five major root crops: potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), yams (*Discorea* spp.), and cocoyams: taro (*Colocasia esculenta*) and tannia (*Xanthosoma* spp.). An attempt was made to present each crop in balanced perspective, however, more space is allocated to cassava and potato, the crops for which the authors had most information at hand. The focus is on developing countries and the role root crops may have in development.



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## Production Patterns and Trends

### a. Source of Data

The origins and historical spread of tropical root crops are traced in several publications (León, 1977; Coursey and Booth, 1977; Coursey and Haynes, 1970; Salaman, 1949; Burton, 1966; Yen, 1982), but nowhere are their present distribution patterns and recent trends in production and yield well documented. In this section an attempt to fill this void is made presenting information compiled from published and unpublished data from the Food and Agriculture Organization of the United Nations (FAO).

The authors are aware that FAO data have many limitations. For example, national averages conceal important regional differences within countries. And since root crops are generally grown and consumed on small, isolated farms, underreporting of production and use is likely. Nevertheless, no better data set is available for comparative analysis of crop production and use. Hopefully, this analysis will stimulate much-needed improvement in country-level estimates, and comparative analysis based on micro-level (rather than country-level) information.

### b. World Distribution of Root Crops

#### Global Patterns

According to FAO estimates for 1980, every country in the world produces one or more root crops. These crops occupy approximately 50 million hectares and have a total worldwide production of 560 million tons. Developing market economies account for about a third of world production, followed by the Asian centrally planned economies (mainly China) with just under 30%. Potatoes are produced in more countries than any other root crop (Table 1). In fact, potatoes are grown in more countries than any other single crop, with the exception of maize. In developing countries, however, sweet potatoes and cassava are grown in an equal or larger number of countries. Potato is the only root crop produced in significant amounts in developed countries. Because cassava, yams, and cocoyams can only be grown under tropical conditions, they are produced exclusively in Asia, Africa and Latin America. Sweet potatoes are also grown primarily in developing countries.

The world's five leading producers of root crops, in descending order of importance, are China, Russia, Poland, Nigeria, and Brazil. China produces large volumes of both sweet potatoes and potatoes; Russia and Poland produce potatoes; Nigeria produces mainly yams and cassava; Brazil produces mainly cassava. Total world potato production is roughly 260 million tons, sweet potato production 150 million, cassava production 120 million, yam production 20 million, and cocoyam production only around 6 million tons.

#### Developing Country Patterns

Within the developing market economies, cassava stands out as the leading root crop, with 115 million tons of annual production. Potato totals 30 million tons, followed by yam (20 million), sweet potato (15 million), and cocoyam (5 million tons).

Cassava is produced in large volumes in Africa, the Far East, and Africa. Twenty-two developing countries produce over 500,000 tons of cassava annually, but more than 60% of total world production is concentrated in five: Brazil (with 25 million tons), Thailand, Indonesia, Zaire, and Nigeria (Table 2).

Table 1. Number of countries producing root crops and root crop production 1981.

| | Potato | Sweet potato | Cassava | Yam | Cocoyam |
|---|---|---|---|---|---|
| No. producing countries | | | | | |
| World | 130 | 106 | 95 | 43 | 29 |
| Market economies | | | | | |
| Developed | 28 | 6 | 0 | 2 | 1 |
| Developing | 91 | 96 | 92 | 41 | 27 |
| Centrally planned economies | | | | | |
| European | 7 | 0 | 0 | 0 | 0 |
| Asian | 4 | 4 | 3 | 0 | 1 |
| Production ($10^6$t) | | | | | |
| World | 258(298) | 146(139) | 127(128) | 22 | 6 |
| Market economies | | | | | |
| Developed | 72 | 2 | 0 | 0 | 0 |
| Developing | 33 | 15 | 120 | 22 | 5 |
| Centrally planned economies | | | | | |
| European | 135 | 0 | 0 | 0 | 0 |
| Asian | 18(58) | 129(122) | 7(7) | 0 | 1 |

Sources: All estimates are from FAO Production Yearbooks and unpublished data supplied by FAO Basic Data Unit, except figures in brackets ( ) which are based on estimates of China production supplied by B. Stone, personal communication.

Potatoes are grown in all developing regions but in much smaller volumes than cassava. Twelve developing countries produce more than 500,000 tons of potatoes. India, the largest producer (with 10 million tons) is followed by Turkey, Argentina, Colombia, and Brazil. These five countries account for over 50% of total potato production in the developing market economies but only 7% of world production.

Sweet potatoes are grown in more developing countries than any other root crop, but generally in small volumes. Only nine countries produce over 500,000 tons; Indonesia, the largest, produces only 2.2 million tons.

Yams and cocoyams are grown primarily in West Africa. With an annual yam production of 15 million tons, Nigeria accounts for 70% of total world production of this crop. Nigeria is also the world's largest producer of cocoyam. With 2.0 and 1.4 million tons, respectively, Nigeria and Ghana produce three-fifths of the world's cocoyams.

Several developing countries are highly dependent upon root crops in their diet (Table 3). In Zaire, for example, more than 50% of the total caloric intake is provided by cassava. In Tonga, the Solomon Islands and Burundi sweet potatoes provide 20% or more of all calories consumed. In the Ivory Coast yams and cocoyams provide over 20% of all calories.

c. Recent Trends in Root Crop Production

According to FAO statistics, world potato production has fallen slightly over the last two decades and sweet potato production has increased by 25%. These world trends are strongly influenced by estimates for China, which are subject to

considerable debate. The FAO estimates that Chinese potato production has increased by about 50% since the early 1960's and that sweet potato production has increased by 30% over the same period. Based on a detailed examination of Chinese statistics, Bruce Stone, of the International Food Policy Research Institute, has concluded that Chinese potato production has increased by 180% and sweet potato production has increased by 45%. Assuming that Stone's estimates for Chinese root crop production are reasonably accurate, world production of both potatoes and sweet potatoes has increased by approximately 10% and 35%, respectively, over the last two decades, while production of cassava, yams, and cocoyams has increased by 65%, 35%, and 80%, respectively (Table 4).

In developed market economies, the area seeded to potatoes-- the only root crop of economic significance --has fallen by approximately 40% since 1960, yields have increased by 30% and total production has fallen by 20%.

In developing market economies, the area under potatoes has increased over the same period by 40%, yields have increased by 45% and total production has doubled. Sweet potato production, area, and yields are about the same now as they were in the early 1960's. Production of cassava, yams, and cocoyams has increased by roughly 50%, 30%, and 60%, respectively, due mainly to increases in their seeded area. Average yields of cassava and yams have increased by only about 10% and 20%, respectively, over the last two decades; cocoyam yields have reportedly fallen by 20%.

In recent years potato production has increased most rapidly in Asia and Africa (where per capita production levels are low) and least rapidly in Latin America (where the potato is a staple food item in the diet). Since the early 1960's sweet potato production has increased slightly in Africa and the Near East and has fallen in the Far East and in Latin America. Over the same period, cassava production has doubled in the Far East, due primarily to rapid growth in Thailand. African cassava production has increased moderately; Latin American production rose in the 1960's but fell in the 1970's. Production of yams has increased from a very small base in Latin America, and decreased (again from a small base) in Asia. In Africa, yam production has increased moderately over the same period. Production of cocoyam has increased substantially in Africa but has fallen in all other regions (Table 5).

d. Value of Root Crop Production

While total value of root crop production in developing countries falls far behind that of cereals, three of the 10 food crops with highest production value are root crops: cassava, potato, and yam.

Average prices for potatoes and yams tend to be high (US$140-$160/t) relative to prices for cassava and sweet potatoes ($70-$90/t). Cocoyam prices are intermediate ($120/t). A higher proportion of sweet potatoes, cocoyams and potatoes are consumed directly by humans than is the case with cassava and yams. (Losses and waste are higher for the latter two crops, a substantial proportion of cassava is exported to Europe for livestock feed, and the reproductive rate of yam is low). For these reasons, while the ranking of root crops in terms of the value produced and value destined for human consumption is the same as their ranking in terms of total production, the differences between the crops become smaller (Table 6). For example, the volume of cassava produced is nearly 300% greater than that of potatoes, but the value produced is only 80% greater and the value destined for human consumption only 40% greater.

Table 2. Ten largest producers of root crops in developing market economies and production 1979/81.

| Potatoes | | Sweet Potatoes | | Cassava | | Yam | | Cocoyam | |
|---|---|---|---|---|---|---|---|---|---|
| Country | $10^6$T | Country | $10^6$T | Country | $10^6$T | Country | $10^6$T | Country | $10^6$T |
| India | 9.3 | Indonesia | 2.2 | Brazil | 24.5 | Nigeria | 15.3 | Nigeria | 2.0 |
| Turkey | 2.9 | India | 1.5 | Thailand | 14.5 | Ivory Coast | 2.0 | Ghana | 1.4 |
| Brazil | 2.0 | Korea Rep. | 1.2 | Indonesia | 13.7 | Ghana | 0.7 | Ivory Coast | 0.3 |
| Colombia | 1.9 | Philippines | 1.1 | Zaire | 12.4 | Benin | 0.7 | Pap. N.Guinea | 0.2 |
| Argentina | 1.8 | Burundi | 0.9 | Nigeria | 10.8 | Togo | 0.4 | Philippines | 0.1 |
| Peru | 1.6 | Rwanda | 0.9 | India | 5.9 | Cameroon | 0.4 | Egypt | 0.1 |
| Egypt | 1.1 | Brazil | 0.8 | Tanzania | 4.6 | Ethiopia | 0.3 | Madagascar | 0.1 |
| Bangladesh | 0.9 | Bangladesh | 0.8 | Mozambique | 2.8 | Cent.Af.Rep. | 0.2 | Centr.Af.Rep. | 0.1 |
| Chile | 0.9 | Uganda | 0.7 | Philippines | 2.3 | Zaire | 0.2 | Gabon | 0.1 |
| Mexico | 0.8 | Pap. N.Guinea | 0.4 | Colombia | 2.1 | Pap.N.Guinea | 0.2 | Zaire | --- |

Source: FAO (1982), and unpublished data supplied by FAO Basic Data Unit.



Table 3. Ten developing market economies with highest percent of calorie intake derived from root crops.

| Potatoes | | Sweet potatoes | | Cassava | | Yam | | Cocoyam | | All roots | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | % | Country | % | Country | % | Country | % | Country | % | Country | % |
| Bolivia | 9.3 | Tonga | 39.4 | Zaire | 55.7 | Ivory Cst. | 18.1 | Samoa | 15.9 | Zaire | 57.9 |
| Peru | 6.7 | Solomon Is. | 30.2 | Congo | 50.6 | Togo | 15.5 | Ghana | 11.4 | Congo | 54.2 |
| Ecuador | 5.6 | Burundi | 20.3 | Cnt.Afr.Rep. | 38.6 | Nigeria | 15.5 | Solomon Isl. | 6.8 | C.Afr.Rep. | 49.4 |
| Colombia | 3.8 | P.New Guinea | 15.6 | Mozambique | 36.1 | Benin | 12.0 | P.New Guinea | 4.5 | Tongo | 45.7 |
| Chile | 3.3 | Rwanda | 15.5 | Angola | 31.9 | C.Afr.Rep. | 8.5 | Fiji | 3.7 | Solomon Is. | 44.2 |
| Turkey | 3.2 | Martinique | 5.0 | Comoros | 25.2 | Solomon Is. | 7.2 | Gabon | 3.1 | Burundi | 38.2 |
| Argentina | 3.0 | Comoros | 4.6 | Tanzania | 24.1 | Gabon | 5.4 | Ivory Coast | 2.3 | Mozambique | 37.1 |
| Burundi | 2.7 | Uganda | 4.5 | Liberia | 21.0 | Jamaica | 5.3 | Cnt.Afr.Rep. | 2.3 | Ghana | 35.5 |
| Rwanda | 2.4 | Guadaloupe | 3.1 | Benin | 20.4 | Ghana | 5.3 | Nigeria | 2.2 | P.N.Guinea | 35.2 |
| N.Caledon. | 2.3 | Madagascar | 3.0 | Togo | 19.8 | P.N.Guinea | 5.0 | Togo | 1.0 | Angola | 35.2 |

Source: FAO (1980).

Table 4. Percent change in production, area, and yield of root crops 1961/65.

| | Potato | Sweet potato | Cassava | Yam | Cocoyam |
|---|---|---|---|---|---|
| Production | | | | | |
| World | - 3(8) | 23(33) | 65(66) | 34 | 81 |
| Market Economies | | | | | |
| Developed | -20 | -70 | NA | 171 | -16 |
| Developing | 101 | 0 | 49 | 33 | 58 |
| Centrally Planned Economies | | | | | |
| European | - 8 | NA | NA | NA | NA |
| Asian | -62(178) | 33(47) | 119(126) | NA | NA |
| Area | | | | | |
| World | -18(-5) | 11 | 55 | 12 | 99 |
| Market Economies | | | | | |
| Developed | -39 | -66 | NA | 190 | -22 |
| Developing | 38 | 0 | 32 | 12 | 92 |
| Centrally Planned Economies | | | | | |
| European | -21 | NA | NA | NA | NA |
| Asian | 21(107) | 13 | 167 | NA | NA |
| Yield | | | | | |
| World | 20 | 44 | 13 | 18 | - 9 |
| Market Economies | | | | | |
| Developed | 30 | -10 | NA | 10 | 9 |
| Developing | 45 | 0 | 13 | 18 | -18 |
| Centrally Planned Economies | | | | | |
| European | 18 | NA | NA | NA | NA |
| Asian | 20 | 58 | 7 | NA | NA |

Sources: All estimates are from FAO Production Yearbooks and unpublished data supplied by the FAO Basic Data Unit, except figures in brackets ( ) which are based on estimates of China production supplied by B. Stone (IFPRI), personal communication.

NA = not applicable or not available.

## Technology, Productivity, and Costs

### a. Production Zones and Farming Systems

Few detailed studies of root crop farming in the tropics have been published. Village-level anthropological studies are available for specific locations, but few comparative studies have been made. For these reasons, the present section is exploratory, rather than definitive. By bringing together information from a number of sources and venturing some generalizations, we hope to encourage debate, the exchange of information, and more serious comparative research on root crop farming systems. A brief overview of production zones and farming systems is presented for each of the major root crops, followed by a brief comparative analysis.

Table 5. Root crop production in developing market economies 1979/81 and percent change in production 1961/65 - 1979/81.

| | Potato | Sweet Potato | Cassava | Yam | Cocoyam |
|---|---|---|---|---|---|
| Production ($10^6$t) | | | | | |
| Africa | 3 | 5 | 46 | 21 | 4 |
| Latin America | 10 | 2 | 30 | 0 | 0 |
| Near East | 6 | 0 | 0 | 0 | 0 |
| Far East | 11 | 7 | 36 | 0 | 0 |
| % change in production | | | | | |
| Africa | 135 | 24 | 43 | 33 | 58 |
| Latin America | 40 | -27 | 16 | 128 | -16 |
| Near East | 138 | 21 | -90 | -33 | -12 |
| Far East | 114 | - 9 | 109 | -33 | -22 |

Source: FAO Production Yearbooks and unpublished data supplied by FAO Basic Data Unit.

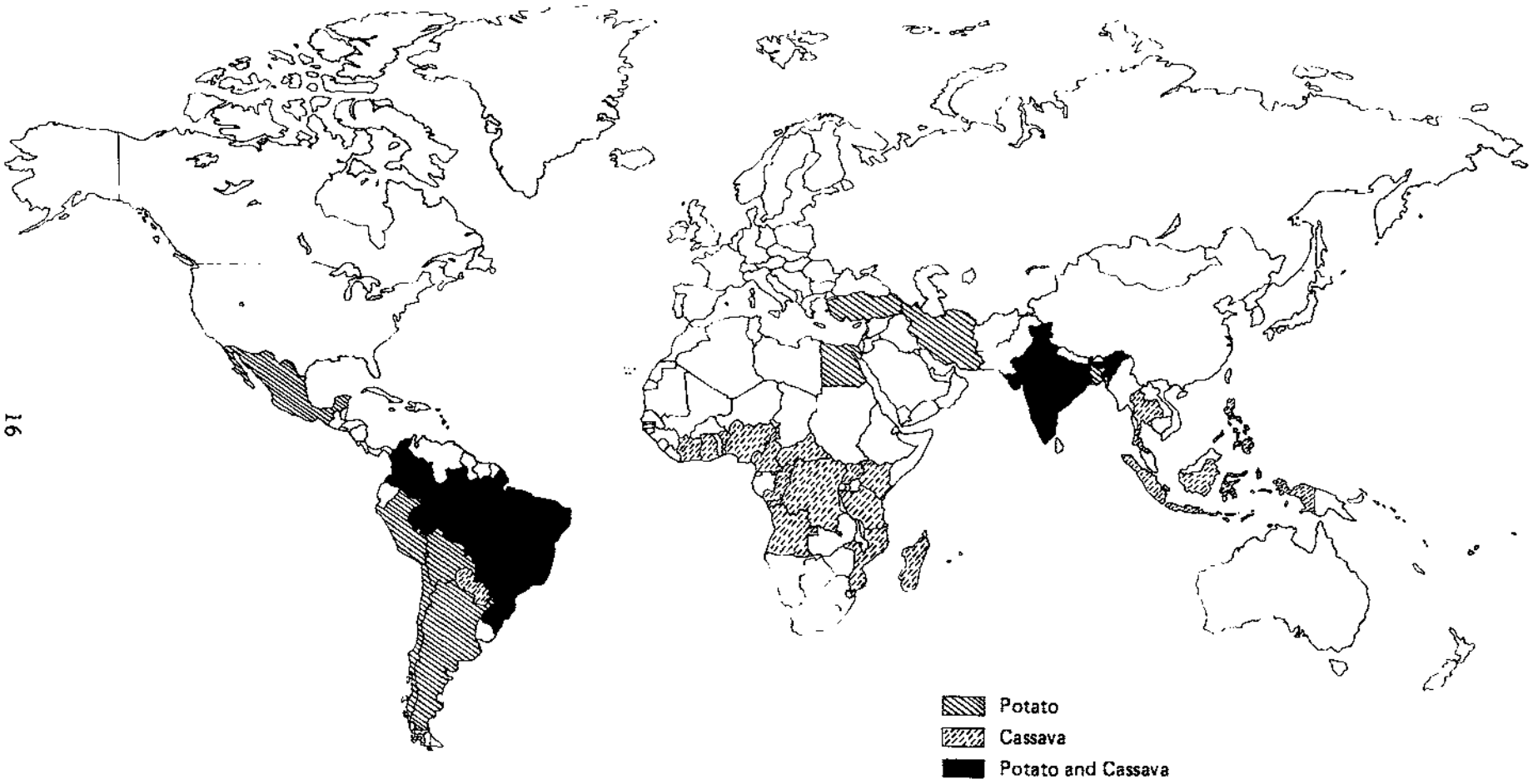
Table 6. Value of root crop production in developing market economies.

| | Total Production | | | Human consumption | |
|---|---|---|---|---|---|
| | Volume ($10^6$t) | Price (US$/t) | Value ($10^9$US$) | % Prod. | Value ($10^9$US$) |
| Cassava | 113 | 70 | 7.9 | 56 | 4.4 |
| Potato | 30 | 142 | 4.3 | 71 | 3.1 |
| Yam | 22 | 163 | 3.5 | 58 | 2.1 |
| Sweet Potato | 15 | 89 | 1.3 | 82 | 1.1 |
| Cocoyam | 5 | 123 | 0.5 | 77 | 0.4 |

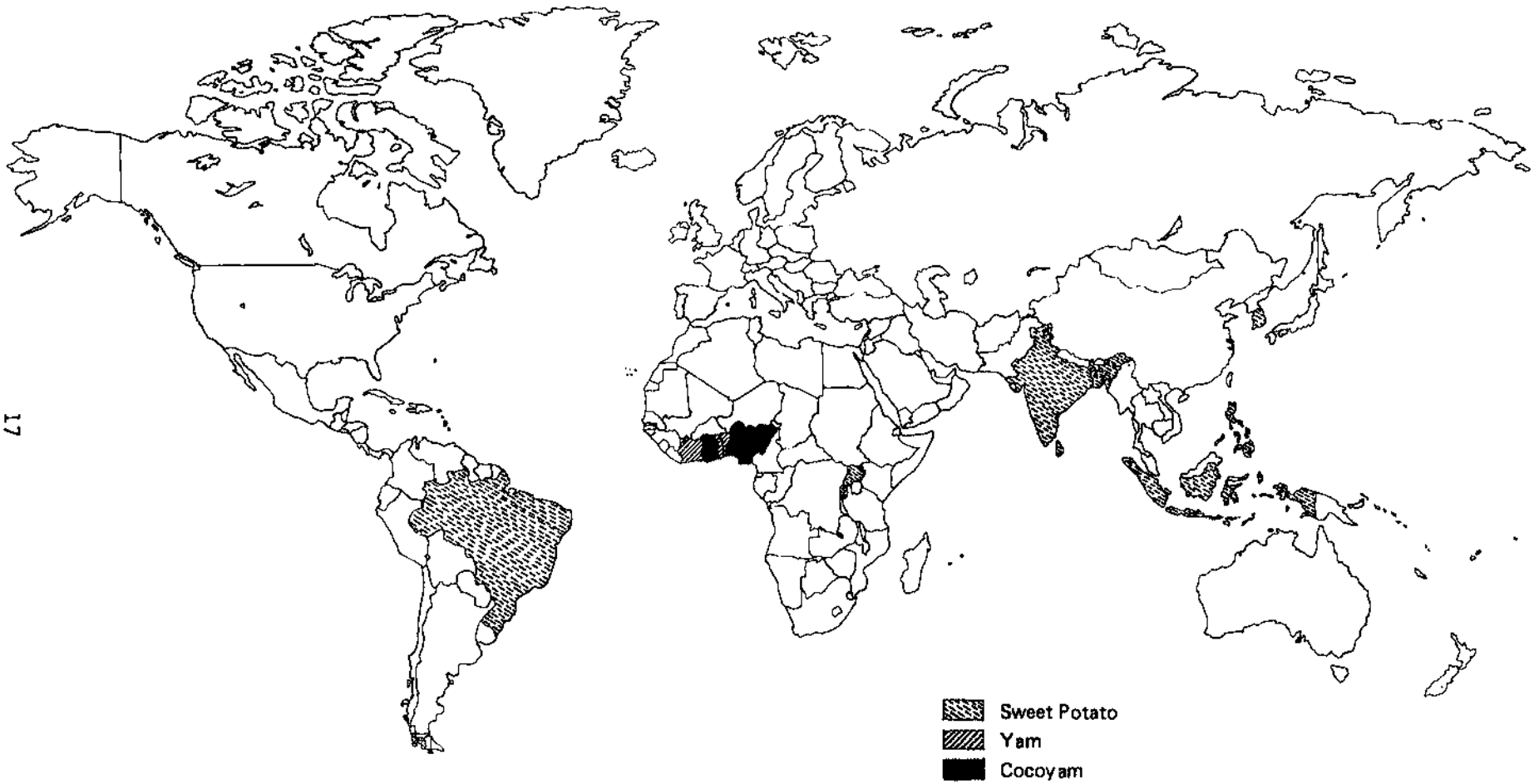
Sources: Volume: 1980 estimate for all developing market economies, from FAO (1982). Price: 1977 estimated weighted average farm-gate price for all developing market economies, provided by FAO Basic Data Unit (unpublished). Percent production destined to human consumption: average estimate corresponding to period 1975/77, derived from FAO (1980). Value of total production: total production volume multiplied by price. Value of human consumption: value of total production multiplied by percent human consumption and divided by 100.

## Cassava

Cassava is unknown in a wild state and its evolution as a species is directly linked to selection by man under cultivation. Cassava's center of origin is tropical America but exact time and location of domestication and the direct ancestor are not known. During its evolution, cassava was probably selected for enlarged roots, ability to germinate from stem cuttings, and erect plant type (Jennings, 1976).




Map 1. Developing market economies producing over 500,000 tons of cassava and potato, 1980.




Map 2. Developing market economies producing over 500,000 tons of sweet potato, yam, and cocoyam, 1980.

Certainly by the beginning of the 19th century cassava had been effectively distributed worldwide throughout the tropics. Expansion of cassava production in the 19th century was hastened by import of gari processing technology into West Africa, by the promotion of cassava as a famine reserve by colonial governments such as the Dutch in Java and the British in West Africa and Southern India, and by establishment of a cassava processing and export industry in Malaya in the 1850's. By the 1880's the tapioca trade was well established in Malaya and by the turn of the 20th century production and trade in cassava products, particularly starch, had been started by the Dutch on Java and by the French in Madagascar, with Brazil also exporting modest amounts.

Because of cassava's long growth season, cultivation is limited to the tropics and subtropics. Cassava is nevertheless the most widely grown root crop in the tropics and is grown across a wide range of agro-climatic conditions (Flach, 1982). It is grown from sea-level to almost 2,000 meters in the American tropics and in areas with as little as 70 mm of rainfall to conditions representing tropical rainforest. However, cassava's defining characteristic is its ability to produce economic yields under relatively marginal soil and rainfall conditions. Cassava is efficient in water use and is able to withstand dry periods of up to 4 to 5 months. Also, it is particularly adapted to tropical soils, being tolerant to low pH and high aluminum content. Cassava forms an effective mycorrhiza association and is efficient in phosphorous uptake and utilization. Economic rather than physical factors are the principal determinants of where cassava is grown.

Cassava has several salient characteristics which define its economic competitiveness with other carbohydrate staples and its role within farming systems:

(a) High carbohydrate yields per unit of land and labor.
(b) Adaptation to poor soils and water stress with little use of purchased input.
(c) Compatibility with a variety of crops in association.
(d) An indeterminate harvest period.
(e) Relatively high costs and completely mechanizing cassava production.
(f) Bulkiness, 60% to 70% water content, and extreme perishability after harvest.

Because of these characteristics cassava is particularly adapted to small farm production systems. Commercialization is either costly or requires a processing component.

Cassava is essentially a small farm crop. In the Americas, where there is such a disparity in farm size, 75% of cassava farmers operate farms of 20 hectares or less --small farms by American standards, particularly for the more marginal, lowland areas where cassava is principally produced. In Asia cassava is cultivated in populous areas such as on Java in Indonesia and in Kerala in India. Almost by definition cassava is cultivated in these areas on small farms, rarely exceeding 2 ha in size. Cassava is exclusively an upland crop in these areas and is usually cultivated in poorer soil areas and where rainfall is limiting. In Thailand 73% of cassava farmers have farms less than 6.4 ha in size. As most cassava is cultivated in the northeast, it is usually on relatively marginal land with few other cropping alternatives. In Africa the role of cassava is defined not so much by farm size as by population pressure and the length of the following period in shifting cultivation systems. Here again, cassava has become a principal crop where fallow systems are particularly short and soil fertility conditions are poor.

Cassava has been widely characterized as a subsistence crop. This has arisen partly from colonial experience where cassava either was a plantation crop or was cultivated as a famine reserve crop. The locus of cassava production principally on small farms has also tended to support this view. However, a closer scrutiny of existing data suggests that cassava is very much a commercial crop. In the Americas an estimated 70% of production is marketed (Lynam and Pachico, 1982). This is as well the case in Asia, even in countries such as India and Indonesia where cassava is used principally as a food source (Unnevehr, 1982). In Africa, where the population is still essentially rural-based and where cassava is almost solely used as a food, it is more closely identified as a subsistence crop. Nevertheless, an extensive trade in gari exists in Nigeria (Coursey, 1978) and kokonte (dried cassava) in Ghana (Southworth et al, 1979). Thus, part of the reason cassava is so widely produced is not because it is the subsistence crop par excellence but because it is a cash crop with an existing market. Future development of cassava will depend on reinforcing the commercialization of the crop.

Cassava is produced not only under relatively marginal agricultural conditions but also under low input conditions, in the sense of purchased inputs. First, as cassava is vegetatively propagated through stem cuttings, seed costs are nil. Second, rarely are fungicides, insecticides or herbicides used in cassava production systems. This is not to imply that cassava is not susceptible to diseases and pests but apparently the varieties that farmers plant are either resistant to the dominant diseases and pests or can yield well under attack. In the latter case traditional varieties appear to be excessively leafy, a tolerance mechanism for the major portion of the insect-disease complex which attacks the leaves (Cock, 1978). Moreover fertilizer is not used to any great extent in cassava production systems. For example, in Brazil only 9% of the cassava area is fertilized. Even on Java in Indonesia, where land use is intensive and fertilizer prices are heavily subsidized, only an average of 8.1 kg of fertilizer per hectare is used for cassava, compared to 178.9 kg/ha averaged over all crops (Roche, 1982).

Outside of Asia a defining characteristic of cassava production is a fallowing system. In most of Latin America this fallowing system occurs within a permanent farm system while in Africa fallowing is more often associated with shifting cultivation systems. In eastern Nigeria cassava yields have been linked to population density and average fallowing period, which varied from 0 to 7 years (Lagemann, 1977). Moreover, in Colombia preliminary evidence suggests that fertilizer cannot perfectly substitute for fallowing in maintaining yield levels (CIAT, 1982).

## Potato

The potato is of highland origin. Domesticated in the Andes of South America, it has achieved major importance as a food crop near its origin and in similar mountainous areas elsewhere (the Himalayas and cool highland areas of Central and Eastern Africa). After being taken to Europe in the early 16th century, the potato remained as a botanical curiosity for two centuries because of the plant's maladaptation to Europe's long-day, short-season growing conditions (Salaman, 1949). However, once varieties were selected which produced well under European conditions, the potato became an important food of rural peasants and low income urban wage earners across Europe, and in North America. Most research on the potato has been done in Europe and North America, and most varieties now grown in the tropics (outside the Andes) are of northern latitude origin.



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In highland farming systems the potato is generally grown by small farmers cultivating no more than 1 to 2 hectares in a number of distinct parcels of land. The crop is typically rainfed and subject to a number of hazards, including droughts, excessive rain, frost, hail, or typhoons, depending upon the location. Highland farmers generally retain a substantial part of their harvest to use as seed the next season. In areas where potatoes are a relatively inexpensive food (the Andes, Central Africa and the Himalayas) farmers also store large amounts for home consumption. Where potatoes are relatively expensive (Central America and South East Asia) farmers usually consume less of their own potatoes, sell the harvest and purchase other cheaper foods with the proceeds of their sales.

In recent years potato production has spread gradually out of its traditional mountainous environment into hotter, generally drier, areas. Typical of such non-traditional cultivation areas are Peru's coastal valleys, the plains of India, Bangladesh and Pakistan, and the irrigated oases of north Africa.

In many irrigated, arid areas potatoes are becoming an increasing attractive winter crop, grown on relatively large, commercially oriented farms. Since harvesting is done at the beginning of summer, storage and marketing present major problems for this perishable crop in these areas. Refrigerated storage is generally required both for seed and table potatoes in these areas.

Recently, potato production has begun to expand in relatively warm, humid zones which harbor a number of pests and diseases of the potato. In such areas, farmers often apply high levels of chemical pesticides and prefer varieties which are resistant or tolerant to pests and diseases. Production is generally on a small scale, as part of complex multiple cropping systems. Traditional slash-and-burn systems prevail where land is relatively abundant and potatoes are cheap; intensive horticulture systems prevail where land is scarce and potatoes are dear (Harmsworth and Albert, 1982; Rhoades, 1982).

In temperate zones, under arid, irrigated conditions, and in cool highland areas, potatoes are generally produced as a sole crop. At lower elevations, particularly in humid zones, relay cropping and intercropping are common.

In most areas where they are grown, potatoes generate returns which are high on average but highly variable. For this reason, the few farmers who specialize in potato production tend to be large, financially well-off producers. The majority of developing country farmers are highly diversified and plant a small proportion of their land to potatoes with a dual purpose: home consumption and limited market sale.

Sweet Potatoes

Sweet potatoes are grown in more developing countries than any other root crop, yet little is known about the crop's production zones and practices. Lack of attention given to this crop by agriculturists reflects that while sweet potatoes are grown in many places they are usually of secondary importance in relation to other crops. Sweet potatoes are important in many poor isolated areas where few agricultural studies have been conducted.

The sweet potato is a relatively short maturity crop tolerant to a wide range of growing conditions. It is grown in the tropics, sub-tropics, and in warmer temperate zones (such as southern USA). It is relatively cold-tolerant, and hence is grown in many tropical highland zones (East Africa and highland New Guinea).

Sweet potatoes can be grown on relatively infertile soil with few inputs, and can withstand periods of irregular rainfall and drought. Tubers can be left in the ground after maturity, but once harvested they generally have a short storage life. For these reasons, in developing countries sweet potatoes are generally grown by small farmers on marginal land as a subsistence crop for immediate consumption. Culls are often fed to livestock. In times of war or famine, populations in several countries (Taiwan, the Philippines, South Korea, and Rwanda) have survived on the sweet potato. It is believed these unpleasant circumstances may have led to a degree of consumer prejudice against the sweet potato as a food (Tsou and Villareal, 1982). In recent years per capita consumption of sweet potatoes has fallen sharply in many areas.

## Yams

Yams are grown in tropical regions scattered throughout the world, but the main production center is the savanna region of West Africa. White yam (*Discorea rotundata*) is believed to be indigenous to the area stretching from Ivory Coast to Cameroon (Okuli, 1981) and is generally considered to be the best edible yam in that region (Irvine, 1976). Yam is a prestigious component of the West Africa diet, and its taste is regarded to be superior to that of all other root crops.

Yam, as with nearly all African food crops, is generally intercropped. Intercropping advantages include minimizing risks associated with diseases, pests, and price fluctuations, evening the distribution of food and income supply over the whole year, and intensifying land use (Norman, 1975). Because yams are generally intercropped, yield figures can be misleading unless presented with the yield of the intercrops (which is seldom the case).

African production of yams, as well as cassava, cocoyams, and sweet potatoes, is concentrated in areas within 15 degrees of the equator, labeled the African Root Crops Belt (Nweke, 1981). In this region about 40% of the daily energy intake is derived from root crops (22% from cassava, 10% from yam, 4% from cocoyam and 2% from sweet potatoes). The principle producing (and consuming) country for most root crops in the Belt is Nigeria, which also accounts for more than 50% of the area's population.

## Cocoyams

The two main genera of cocoyams are *Colocasia* (taro) and *Xanthosoma* (tannia). Colocasia originated in Southeast Asia and spread across Africa to the Americas. In Nigeria it is called "old" cocoyam to distinguish it from the "new" cocoyam, or tannia, which originated in South or Central America and reached West Africa later. It is believed that tannia is rapidly replacing taro in West Africa (Doku, 1981). In Nigeria, the largest producer of this crop, cocoyam is appreciated for its easy digestibility. Farmers distinguish "soft" and "hard" varieties. The soft ones are often used for pounding a yam-cocoyam mixture.

In Nigeria cocoyam is typically a secondary crop ranking far behind yam and cassava (gari) in production and consumption. However, in parts of Ghana, Cameroon, and Gabon, cocoyam is a staple food. Here, the usefulness of cocoyam as an intercrop between tree crops is one reason for its popularity.

Cocoyam is adapted to hydromorphic soils but is generally grown on well-drained, relatively fertile upland soils. Its cultivation has been associated with that of tree crops, especially cocoa (hence, the name "cocoa-yam").

Although most farmers use a rotation, cocoyam is sometimes grown without interruption up to 6 years in succession. It is often planted in clusters between scattered trees. Spacings within clusters differ from those between clusters. Hence, in comparing yields it is important to know if the sample is based on a small area containing one or part of one cluster, or a large area containing several clusters. In the latter case, yield estimates will be substantially lower than in the former. A recent survey in Cameroon (Atayi and Knipscheer, 1980) found average yield to be as low as 1,172 kg/ha for cocoyam (compared with 1,267 kg/ha for cassava in the same, extensively cultivated area). In contrast, Nigerian sources (Phillips, 1976; Olayida and Olowude, 1972; Onwueme, 1978; Federal Office of Statistics, 1979) generally indicate an average yield of about 6 t/ha.

For cocoyam production, as for most food crops in tropical Africa, labor is the main input. Although good quality land and cash are scarce, farmers consider the availability of labor to be their main production constraint. A recent survey (Knipscheer and Wilson, 1981) indicated, rather surprisingly, that cocoyam requires less labor than does cassava. The same survey also showed that cocoyam was generally planted by women, and that hired labor was seldom employed.

Farmers use corms, cormels and headsets as planting material. Little is known about the reproduction factor for cocoyam but it is believed to be much higher than that for yam. Planting material is stored in shady places and is usually covered with (palm) leaves. Presprouted headsets and cormels are then selected for planting on low mounds, ridges or on the flat.

## Comparisons

Given the wide range of conditions under which many of the root crops are grown, and the sketchy nature and uneven quality of information on their production zones and systems, any general statements about them may be subject to considerable error and numerous exceptions. With this in mind, the following paragraphs are offered as a starting point for much-needed future comparative analysis.

From the comparative Table 7, derived from Kay (1973), some summarized data on root crops relates to their production zones and farming systems. From this Table it can be seen that potatoes have a shorter vegetative period than most other root crops, and do best under cooler temperatures. Potatoes can, in fact, be grown in areas with high daytime temperatures, but do not tuberize well if night temperatures are above 20 degrees C. For economic yields potatoes require relatively high inputs of fertilizer and organic matter. They do poorly in water-logged soils. For potato production, optimal rainfall is less than for the other root crops, but potatoes require relatively regular watering and are highly susceptible to drought. Potato tubers can be stored in the ground for short periods, and harvested tubers can be stored for long periods if they are pest and disease free and if adequate conditions of temperature (low) and humidity (high) are maintained.

Table 7. Comparative data on root crop characteristics.

| | Potato | Sweet potato | Cassava | Yam | Taro | Tannia |
|---|---|---|---|---|---|---|
| Growth period (months) | 3-7 | 3-8 | 9-24 | 8-11 | 6-18 | 9-12 |
| Plant annual or perennial | Annual | Perennial | Perennial | Annual | Perennial | Perennial |
| Optimal rainfall (cm) | 50-75 | 75-100 | 100-150 | 115 | 250 | 140-200 |
| Optimal temp. (°C) | 15-18 | > 24 | 25-29 | 30 | 21-27 | 13-29 |
| Drought resistance | No | Yes | Yes | Yes | No | No |
| Optimal Ph | 5.5-6.0 | 5.6-6.6 | 5-9 | NA | 5.5-6.5 | 5.5-6.5 |
| Fertility requirement | High | Low | Low | High | High | High |
| Organic matter requirement | High | Low | Low | High | High | High |
| Can be grown on swampy, waterlogged soil? | No | No | No | No | Yes | No |
| Planting material | Tubers | Vine cuttings | Stem cuttings | Tubers | Corms/ Cormels | Corms/ Cormels |
| Period crop can be stored in ground | Short | Long | Long | Long | Moderate | Long |
| Post-harvest storage life | Long | Short | Short | Long | Variable | Long |

Source: Derived from Kay (1973).

NA = Not available.

Other root crops have longer and more variable growing periods; cassava, the extreme case, with 9 to 24 months. Other root crops also do better under higher temperatures; yam, the extreme, with an optimal 30-degree (C). While sweet potatoes and cassava are responsive to fertilization, they can produce economic yields on poor, unfertilized soils with little organic matter. Their tubers cannot be stored more than a few days after harvest, but they can be left unharvested for long periods. Both these crops are highly drought resistant.

In contrast to cassava and sweet potatoes, yams and cocoyams require good soils and adequate moisture. While tannia and yams do not do well in swampy areas, taro can be grown on waterlogged soils. Both yams and cocoyams can be left on the plant after maturity and harvested as needed. If care is taken in harvesting and handling so not to damage tubers, they can also be stored well after harvest.

b. Input Use and Costs

Few cost-of-cultivation studies have been published for root crops in developing countries, and those available often have the following methodological weaknesses.

First, many inputs used in the production process are of household origin, not purchased. Several possible ways of estimating opportunity costs for these inputs are available but authors seldom specify their methods clearly. Hence, comparisons based on different sources may be misleading.

Second, where root crops are intercropped, many field inputs contribute to the productivity of two or more crops. Again, few authors detail the procedures they use for costing out these inputs. The yam studies by Diehl (1982) and Bachman (forthcoming) are valuable exceptions.

Third, published cost estimates are often based on conventional wisdom, guestimates, experimental trials, or recommended technological packages, rather than on detailed recording of actual farming practices. Hence, the representativity of the figures is often questionable.

Fourth, published cost estimates are generally presented in local currencies and conversion into a common currency base (dollars or pounds sterling) is sometimes problematic, due to artificial currency rates and lack of precise dates for costs in countries with high rates of inflation.

Realizing these difficulties, we have tabulated and analyzed available cost estimates for root crops to arrive at broad, tentative generalizations concerning input structure and level of costs associated with different root crops (Tables 8, 9, and 10).

The figures support three general statements:

First, production costs per hectare are lowest for cassava and highest for potatoes. The general range of variable costs is $100 to $200/ha for cassava and $1,300 to $1,800/ha for potatoes. Available sweet potato cost estimates are in the range of $300 to $600/ha. And yam and taro estimates are $600 to $800/ha. While these cost estimates are imprecise and based on very little information, their relative magnitudes are consistent with the observation that in most developing areas potatoes and yams are costly crops to produce, whereas sweet potatoes

and cassava are cheap. They are also consistent with the observation that potato and yam crops are given special attention by farmers. They tend to be grown on the best land and in the first year of rotation cycles, whereas sweet potatoes and cassava are typically grown on marginal lands and/or at the end of rotations, before fallow.

Table 8. Cassava: Variable costs of production and labor input/ha in selected locations.

| | Indonesia[1] Gurung Kidul | India[2] Salem | Brazil[3] Maranhao | Thailand[4] Cholburi | Thailand[4] Nakornrajsima |
|---|---|---|---|---|---|
| Variable cost Structure | | | | | |
| Labor | 97 | 55 | 100 | 44 | 64 |
| Land prepar. | -- | 8 | -- | 34 | 34 |
| Seed | 3 | -- | -- | 10 | 2 |
| Fertilizer | -- | 36 | -- | 10 | -- |
| Pesticides | -- | -- | -- | 2 | -- |
| Total | 100 | 100 | 100 | 100 | 100 |
| Total (US$) | 97 | 164 | 145 | 171 | 99 |
| Labor Input (days) | 346 | 138 | 84 | 75 | 67 |

Sources: [1]Roche (1982). [2]Subramanian and Uthamalingam (1980). [3]Ministerio da Agricultura, Brazil (1977). [4]Tinprapha (1979).

Table 9. Potatoes: Variable costs of production and labor input/ha in selected locations.

| | Peru[1] Coast | Ecuador[2] Machachi | Chile[3] Central | Pakistan[4] Punjab | Philippines[5] Bagui | Rwanda[6] Ruhengeri |
|---|---|---|---|---|---|---|
| Variable Cost Structure | | | | | | |
| Labor | 17 | 37 | 24 | 18 | 16 | 62 |
| Land Prepar. | 11 | 7 | 25 | 6 | 2 | -- |
| Seed | 38 | 27 | 37 | 53 | 55 | 38 |
| Fertilizers | 20 | 19 | 12 | 20 | 17 | -- |
| Pesticides | 14 | 10 | 2 | 3 | 10 | -- |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |
| Total (US$) | 1,653 | 1,496 | 1,444 | 1,352 | 1,893 | 306 |
| Labor Input (days) | 73 | 213 | 63 | 125 | 211 | 230 |

Sources: [1]CIP estimates (unpublished). [2]Soliz (1978). [3]Fu(1979). [4]Wustman and Mahfooz (1980). [5]PCARR(1979). [6]Dürr(1982).

Table 10. Sweet potatoes, yams, and taro: variable costs of production and labor input/ha in selected locations.

| | Sweet Potato Peru[1] | Sweet Potato Bangladesh[2] | Taiwan[3] | Yam Nigeria[4] | Taro Western Samoa[5] |
|---|---|---|---|---|---|
| Variable Cost Structure | | | | | |
| Labor | 45 | 59 | 39 | 66 | 52 |
| Land prepar. | 42 | 11 | 28 | 1 | - |
| Seed | 8 | 23 | 10 | 26 | 48 |
| Fertilizers | 3 | 7 | 22 | 6 | - |
| Pesticides | 2 | - | 1 | 2 | - |
| Total | 100 | 100 | 100 | 100 | 100 |
| Total (US$) | 300 | 408 | 586 | 612 | 787 |
| Labor Input (days) | | 353 | 400 | 344 | 203 |

Sources: [1]CIP estimates. [2]Elias et al (1980). [3]AVRDC (1977). [4]Diehl (1982). [5]Tupuola (1982).

A second generalization is that total variable cost figures are strongly associated with costs of planting material rather than such factors as the labor intensity of the crop. In cassava production, planting material generally represents only a few dollars/ha; in sweet potato production planting material is more costly, but well under $100/ha. In contrast, in taro production "seed" may cost $400/ha; in yam and potato production seed generally costs over $500 and sometimes more than $1,000/ha. Hence root crops with highest seed costs have highest production costs per hectare.

A third generalization is that fertilizers and pesticides are seldom applied to root crops, with the important exception of potatoes.

c. Measures of Productivity

Among numerous measures of crop productivity, yield/hectare -- the most common -- is not necessarily the most useful. Because of the high water content of root crops, total yield figures often have little relation to production of dry matter, energy, and protein per hectare.

Total yields of root crops generally exceed those of cereals and pulses by a wide margin and are on par with vegetable yields. Among root crops, potato has the highest average yield in the developing market economies (11 t/ha) and cocoyam the lowest (4 t/ha).

In terms of gross returns per hectare, potatoes also rank highest among root crops, followed closely by yams (Table 11). Sweet potatoes, cassava, and cocoyams generate only about 30% to 40% of the per hectare returns of these two top-ranking crops (due both to their relatively low prices and yields). Data for four important cereal crops illustrate the superiority of root crops over the cereals in gross return per unit of land.

Table 11. Average root crop and cereal grain yields, prices, and gross returns/ha in developing market economies.

| | Yield (t/ha) | Price (US$/t) | Gross Return (US$/ha) |
|---|---|---|---|
| Potato | 10.9 | 142 | 1,500 |
| Yam | 9.0 | 163 | 1,469 |
| Sweet Potato | 7.1 | 89 | 629 |
| Cassava | 8.8 | 70 | 613 |
| Cocoyam | 4.2 | 123 | 514 |
| Rice | 2.2 | 170 | 366 |
| Wheat | 1.5 | 148 | 217 |
| Maize | 1.5 | 119 | 177 |
| Sorghum | 1.0 | 123 | 117 |

Sources: Yield: average estimate for 1979/81 from FAO (1982). Price: weighted average farm-gate price corresponding to 1977, provided by FAO Basic Data Unit (unpublished). Gross return: yield multiplied by price.

It is well known that root crops and vegetables have high moisture content. Nevertheless, in terms of dry matter production per hectare, cassava, yams, potatoes, and sweet potatoes rank highest on the list of major food crops (Table 12). Potatoes and yams also rank first and second in of edible energy production per hectare per day; sweet potatoes rank sixth and cassava ninth. Among major food crops, only potato remains on the list of the most productive crops in terms of edible protein production per hectare per day.

Table 12. Top ranking foodcrops in terms of dry matter production/ha and edible energy and protein production/ha/day in developing market economies.

| | Dry Matter Production | | Energy Production | | Protein Production | |
|---|---|---|---|---|---|---|
| Rank | Crop | T/Ha | Crop | MJ/Ha/Day | Crop | Kg/Ha/Day |
| 1 | Cassava | 3.0 | Potatoes | 216 | Cabbages | 2.0 |
| 2 | Yams | 2.4 | Yams | 182 | Dry broad beans | 1.6 |
| 3 | Potatoes | 2.2 | Carrots | 162 | Potatoes | 1.4 |
| 4 | Sweet potatoes | 2.1 | Maize | 159 | Dry peas | 1.4 |
| 5 | Rice | 1.9 | Cabbages | 156 | Eggplants | 1.4 |
| 6 | Carrots | 1.7 | Sweet potatoes | 152 | Wheat | 1.3 |
| 7 | Cabbages | 1.6 | Rice | 151 | Lentils | 1.3 |
| 8 | Bananas | 1.5 | Wheat | 135 | Tomatoes | 1.2 |
| 9 | Wheat | 1.3 | Cassava | 121 | Chickpeas | 1.1 |
| 10 | Maize | 1.3 | Eggplants | 120 | Carrots | 1.0 |

Sources: Yield: FAO (1982) and FAO (unpublished). Vegetative period: FAO (1981) and Goering (1979). Edible portion, dry matter, and food composition: USDA (1975) and INCAP (1961).

Labor utilization and yields of individual root crops vary widely, making it difficult to state valid generalizations about labor productivity. Survey results from areas of Nigeria where labor is the principal input in production of yams, cocoyams, and cassava, indicate that on a per-hectare basis yams require more labor than cocoyams and cassava, and that the labor productivities of these three crops are approximately 30, 40, and 60 kg/man-day, respectively (Knipscheer and Wilson, 1981).

Chandra et al (1974, 1976) analyzed the efficiency of two production systems in Fiji, one based on root crops and the other on cereals. The conclusion was that the root crop system had a much higher total energy return per unit of cropped area, per total energy input, and per man-hour expended than that of the system based on cereal crops (Evanson and De Boer, 1978).

Based on production cost estimates and established energy conversion factors, energy budgets have been estimated for root crops in selected sites (Table 13). Given the small number of observations available and the numerous assumptions underlying the calculations, these estimates should be considered as rough approximations of true values.

Three broad generalizations can be made on the basis of these energy budgets.

First, for a given crop, budgets can differ radically between production systems. In the USA (Washington state), for example, the total energy input for one hectare of potatoes is six times that used in Rwanda. Moreover, in the USA over 95% of the energy input is from non-renewable sources, whereas in Rwanda practically all energy used is in the form of labor and seed.

Second, assuming that production conditions on Peru's coast are similar to those elsewhere in developing countries, potato production generally requires more energy than production of other root crops, and particularly more energy from non-renewable sources.

Third, the crops and systems which require the highest energy inputs also generate the highest net energy output, but they tend to have lower energy conversion ratios (energy output:energy input) than the more traditional systems based on hand labor and low total energy inputs.

## Marketing and Utilization

Reasonably complete, and presumably accurate, sets of country-level statistics on crop production and foreign trade are published in FAO Production Yearbooks and Trade Yearbooks, but no similar statistical base exists on domestic commodity utilization.

Periodically FAO publishes estimates of volumes used for seed, feed, fresh food, and processing in its Food Balance Sheets, but the estimates for root crops are highly inaccurate. Estimates of volumes processed are included, for example, only where processed commodities enter into foreign trade.

Even though accurate country-level statistics are not available, the general patterns and trends in root crop utilization can be summarized briefly for each main root crop.

a. Cassava

Cassava's extreme perishability after harvest, the resultant inability to store cassava, its bulkiness, and the large assembly costs due to many small-scale producers, all make marketing of fresh cassava expensive. Hence, advantages of cassava on the production side are lost by the disadvantages of marketing the crop, unless cassava is processed or consumed in the production zone. Processing, besides relieving these marketing restrictions, opens cassava to many end uses, some having higher growth prospects than others. However, only in a few cases has cassava been integrated into these growth markets, with cassava in Thailand produced for the EEC animal feed market being the most prominent example.

Apart from Thailand and Malaysia, cassava is principally used as a food source. In Africa it is used almost exclusively as food; in the Americas a significant percentage is also used as an on-farm feed source; and in Asia a sizeable portion goes into industrial uses or is processed and exported. Only in Asia where cassava production has been growing most rapidly, has there been a transition in traditional use patterns. In Africa and especially in Latin America use patterns have not changed markedly and during the past decade production has been virtually stagnant.

Prices for fresh cassava roots in representative countries of Latin America and Asia suggest high marketing margins. In general about 60% of the retail price goes to moving cassava from farm gate to the consumer. The result is high prices in urban areas for cassava on a calorie basis as compared to grains. High levels of fresh cassava consumption are thus found exclusively in rural production zones. Estimates of annual consumption per capita as high as 115 kg have been reported in Kerala, India; 250 kg in rural Nigeria; and 180 kg in rural Paraguay. However, because of marketing costs and high relative prices, per capita consumption of fresh roots is low outside production zones, particularly in urban areas.

Generalized consumption of cassava thus depends on trade in its products and this depends on processing. Countries with high per capita cassava consumption levels in general, consume it in a processed form, such as farinha da mandioca in Brazil, gari in Nigeria, casabe in Haiti, and gaplek in Indonesia. Cassava consumed in these forms is often the cheapest available calorie source. However, traditional staples based on processed cassava are notoriously difficult to introduce into other non-consuming countries, since their consumption is usually tied to locally prepared dishes. Moreover, consumption of these traditional cassava staples is difficult to increase in consuming countries.

Income elasticities for processed forms of cassava tend to be low or negative. Income elasticities for gaplek in Indonesia have been estimated to be -0.62 (Dixon, 1982) and for farinha da mandioca in Brazil at -0.34 (Lynam and Pachico, 1982). Rapid replacement of gari by imported rice and wheat in Nigeria during the last decade would suggest a similar situation in Africa. In general, the market potential for traditional processed forms of cassava is limited. However, while consumption of processed cassava is high among the poor, income elasticities are still positive and quite high among the poorest income strata -- 0.85 in Indonesia (Dixon, 1982). Lowering relative costs of these staples would thus tend to raise consumption in this group without the higher income strata competing for supplies and putting pressure on prices (Timmer and Alderman, 1979). Thus, reduced prices of these products can play a key role in nutrition policies in developing countries.

Table 13. Illustrative energy budgets for root crops (gigajoules per ha).

| | Potatoes | | | Cassava | Yam | Taro | |
|---|---|---|---|---|---|---|---|
| | USA | Peru Coast | Rwanda | Thailand | Cameroon | Western Samoa | |
| Labor | 0.14 | 0.43 | 1.35 | 0.39 | 2.30 | 1.19 | |
| Oxen | - | 1.44 | - | 0.30 | - | - | |
| Seed | 1.13 | 9.75 | 3.97 | 0.81 | 13.70 | 7.68 | |
| (1) Sub-total | 1.26 | 11.62 | 5.32 | 1.50 | 16.00 | 8.87 | |
| Tractor and equipment | 12.43 | - | 0.11 | - | - | - | |
| Fertilizers | 16.59 | 15.0 | - | - | - | - | |
| Pesticides | 1.70 | 0.31 | - | - | - | - | |
| (2) Sub-Total | 30.73 | 15.31 | 0.11 | - | - | - | |
| (3) Total Energy Input | 31.99 | 26.93 | 5.43 | 1.50 | 16.00 | 8.87 | |
| (4) Gross Energy Output | 82.48 | 53.74 | 19.08 | 40.32 | 38.03 | 47.15 | (28.29) |
| Net Energy Output (4)-(3) | 50.48 | 26.81 | 13.65 | 38.82 | 22.03 | 38.29 | (19.42) |
| Gross energy output per unit of non-renewable energy (4)/(2) | 2.68 | 3.51 | 173.45 | ∞ | ∞ | ∞ | ( ∞ ) |
| Gross energy output per unit of total energy input (4)/(3) | 2.58 | 2.00 | 3.51 | 26.88 | 2.38 | 5.32 | ( 3.19) |
| Crop yield (t) | 25.6 | 16.9 | 6.0 | 7.3 | 9.0 | 11.5 | ( 6.9 ) |

Sources: Input structure and yield: same sources as Tables 12-14. Energy conversion factors: Pimentel (1974)

Note: Numbers in brackets () under Taro refer to yields on previously cropped land (assumed yield = 6.9 t/ha); other figures for taro refer to yields on land after fallow (assumed yield = 11.5 t/ha).

Demand growth for cassava in traditional markets is limited. As economies urbanize and sources of demand shift to urban areas, fresh cassava as a food source in the economy will lose the comparative advantage it has in rural production zones. For traditional processed staples, consumption will decline with increasing income. In Africa countries, such as Zaire and Ghana, where population remains mainly rural, population growth is high, and growth in per capita income is nil, demand for cassava will continue to be strong. However, where economies are rapidly changing, per capita incomes are growing, and there is rapid urbanization, as in Latin America, demand for cassava in its traditional consumption forms will be stagnant or declining. However, such structural changes could induce rapid growth in other markets for cassava. Particularly prominent markets are those for starch, animal feed concentrates, and composite flour.

Market development for cassava is most clear in Latin America. Rapid growth in the poultry industry has resulted in a rapid increase in feed-grain demand, which has outstripped domestic production. Development of a dried cassava industry in this area would not only achieve a reduction in foreign exchange but also increase small farmer incomes and make more productive use of marginal agricultural areas. In Asia market development is more varied. Indonesia is developing a large domestic market for cassava starch and India is doing the same thing to a more limited extent. The Philippines, Malaysia, and possibly China are likely to focus on the animal feed market. Most of Africa outside Nigeria, on the other hand, will probably continue to focus on the human consumption market.

Current trends in export markets for cassava products indicate that development of these alternative markets must rely on expansion of domestic uses. Only about 4% of world starch production moves in trade, most of which is cassava starch. Through technical change, the developed countries, which make up the principal importers, are replacing imports with domestically manufactured starch. Traditional starch exporters, such as Malaysia, Togo, Madagascar and Brazil, have either substantially reduced their exports or ceased trading entirely. Thailand remains as the only exporter of any importance.

Over the past decade there has been a rapidly increasing trade in cassava pellets for animal feed. This market was created by a gap in the EEC tariff structure, by which grains came under the variable levy and cassava under a 6% ad valorem duy. World market prices for cassava were determined by high internal grain prices in the EEC. Exports of cassava pellets from Thailand reached a level of over 6 million tons in 1981, and because cassava was displacing domestically produced grains, the EEC in 1982 imposed a "voluntary" quota on cassava imports. Hence cassava exporters must search for alternative markets. It is not clear if cassava can compete against coarse grains in the broader world market, but certainly for most cassava producing countries higher returns will be achieved by developing domestic markets.

b. Potatoes

About 45% of the world potato crop is used for human consumption (fresh and processed), 30% is fed to livestock and 15% is kept for seed. Only about 2% is used for starch production; the remainder (just under 10%) is waste (van der Zaag and Horton, 1983). Production of fodder potatoes is practically limited to Europe. Some western European countries previously grew fodder potatoes on a large scale, but this practice is disappearing. At present only eastern European countries grow potatoes for stock feed in large quantities. In Russia and Poland nearly one-half and two-thirds of the potato crop is used for fodder, respec-

tively. Potato production for starch and alcohol is of limited importance in the world. Only in the Netherlands, where more than one-third of the total crop is grown for starch, is production of potatoes for starch really important. Other countries where potato production for starch is of some importance are Poland, the USSR, and Japan. Since the World War II processing of potatoes for human consumption has been a growth industry, particularly in the USA where more than half the potatoes are consumed in processed forms --primarily frozen french fries, dehydrated instant potatoes, snack foods including potato chips (USDA, 1979).

In developing countries practically no potatoes are grown for livestock feed or for production of starch or alcohol, although culls are sometimes used for these purposes (primarily fodder). Nearly all potatoes are grown for human consumption in fresh form. In the Andes, the Himalayas, and elsewhere some potatoes are processed for human consumption, often using age-old methods (Werge, 1977; Rhoades, 1983). Accurate estimates of the amounts involved are unavailable, but they are believed to be small relative to total production. Industrial processing of potatoes for consumption in fast-food restaurants and as snack foods (potato chips) or convenience foods (dehydrated instant mashed potatoes) is expanding in several countries, but account for a small fraction of total production. Consumers of these products are limited to relatively high income earners in urban areas.

In Europe and Latin America, potato consumption appears to have stabilized. In many parts of Africa and Asia per capita consumption is increasing at a rapid rate.

Farm-level and retail prices for potatoes, wheat, and rice in major world regions have been analyzed by van der Zaag and Horton (1983). Their analysis indicates that, on average, potatoes are more expensive in developing than in developed countries. In contrast, wheat and rice are cheaper in developing than in developed countries. It is often argued that the high retail price of potatoes in developing countries is due to high marketing costs and profits of middlemen. However, evidence presented by the same authors indicates that marketing margins are higher in developed than in developing countries. The principal reason for high potato prices in developing areas is high production cost rather than excessive marketing margins. Still, marketing margins for root crops are higher than those for grains, and will remain a considerable factor in price.

It is generally assumed that potato consumption is insensitive to changes in prices and income levels. This assumption is based primarily on results of household surveys in Europe and the USA. To study the relation between incomes, potato prices, and potato consumption van der Zaag and Horton (1983) calculated income and price elasticities using data from 51 countries. The estimated coefficients were 0.965 and -2.209, respectively. The postulated consumption function explained 75% of the variation in per capita potato consumption. These results, which indicate that potato consumption is much more responsive to price and income changes than previously assumed, are consistent with the observed rapid growth rates of potato consumption in many developing areas.

c. Sweet Potatoes, Yams, and Cocoyams

Sweet potatoes are used primarily as human food (Kay, 1973). In some developed countries, such as the USA, a significant proportion of the harvest is processed (canned, frozen, dehydrated) for consumption in the form of such products as pie fillings and purees, but in the developing countries the major pro-

portion of the crop is cooked and eaten directly after harvest. In a few areas, where production costs are especially low, large amounts of sweet potatoes are fed to livestock (Taiwan and South Korea) or converted into low-grade starch (Japan). In parts of Asia and Africa tops of vines and leaves are eaten as a vegetable. In most areas sweet potato consumption is declining.

Yams have been since ancient times one of the basic staple foods in West Africa. Prior to the introduction of American foodcrops, such as maize, cassava, and tannia, and Asian rice and taro they were of more central importance than they are today. But still they are one of the most popular and prestigious foods of the region (Coursey and Booth, 1977). Yams are also important staple foods in parts of Melanesia, Polynesia and the Caribbean.

Neither taro nor tannia is indigenous to Africa, but have become important foods in many areas, particularly in forest zones. In Ghana, for example, cocoyam production is second only to that of plantain among the staple crops (Coursey and Booth, 1977).

Yams and cocoyams are produced almost exclusively for human consumption. While an active domestic trade in these root crops exists in many areas, only insignificant volumes are traded internationally as a high-cost tropical specialty food (Lambert, 1982; Tupula, 1982). Being relatively expensive, yams and cocoyams are not used for production of starch or alcohol. Only the overly mature tubers, unfit for human consumption, are fed to hogs. Both taro and tannia contain an irritant that causes scratchiness in the mouth if eaten raw or poorly cooked. As a general rule tannia contains less irritant and requires less cooking than does taro (Knipscheer and Wilson, 1981).

## Future Prospects

If present trends continue, cassava and potato production will continue to increase through the end of this century. The projected rate of potato production is higher than that for cassava, but cassava will continue to be the major root crop in the developing market economies. In contrast, yam production will increase only slightly and sweet potato production is likely to decline. In this final section we review factors which may influence future trends in production and use of root crops.

### a. Cassava

The future of cassava in developing countries depends principally on ability of production and marketing systems to respond to changing economic conditions. Increasing rural population densities and population expansion into more marginal areas will continue to be the principal impetus for cassava expansion in most of Africa. Gari and kokonte will become important as cheap calorie sources for low income populations in the growing urban areas. In Latin American, on the other hand, growth in production will depend on cassava becoming competitive in domestic markets for carbohydrate supplies for mixed animal feeds. Balance of payments constraints and lack of a tropical wheat technology may as well provide stimulus for the development of a composite flour industry. Moreover, given proper planning, improved cassava technology and new markets can be used as one of the few means of increasing small-farmer incomes in the more marginal agricultural areas of the American lowland tropics.

The future of cassava in world trade will essentially depend on technical change in Thailand and policy toward cassava on the part of the EEC. It is probable that the Common Agricultural Policy cannot afford to allow unrestricted cassava imports and that access to that market will become increasingly restricted. This will force Thailand to look to other markets. The structure of the world starch market and trade restrictions in principal importing countries --apart from the USA-- would argue for continued stagnation in world trade in cassava starch. Thailand in the longer term must thus attempt to realign prices with world grain prices and compete in these markets. The recent movement of Thai exports to hard pellets will help in this but Thailand's success in achieving this realignment will depend on longer term trends in the world feedgrain market and on a substantial increase in farm level productivity.

For the rest of Asia the prospects for cassava are mixed. In Indonesia and southern India cassava is likely to continue to be a principal component of food and nutrition strategies. In Indonesia cassava is likely to continue to expand, especially in the older transmigration schemes and will principally serve an expanding domestic starch market with some potential for the production of high fructuose sweeteners to replace the sugar imports. In Malaysia the cassava industry will probably continue to stagnate as it must compete for the same land with higher value tree crops. The future of cassava in the Philippines is in the animal feed market and this will depend on developing low cost drying technologies.

Cassava's multiple uses, its adaptation to many soil and climatic stresses typical of the lowland tropics, and its carbohydrate production potential should provide a niche for the crop in the agricultural development plans of many developing countries. As the above highlights, development of cassava is not undimensional but will depend on land use patterns and land potential, the stage of urban and industrial development and economic policy objectives. Certainly cassava deserves a close look in agricultural development plans in tropical countries.

b. Potatoes

Trends in future production and use of potatoes in the tropics and subtropics will depend in large part on their price to consumers, which, in turn, depends largely on production cost per unit of output.

As many authorities have noted, many developing countries have little additional land to bring under cultivation. Hence, as population expands and man/land ratios increase, productivity of land now under cultivation must be increased. Crops that produce large amounts of energy and protein per unit of time and land area, such as the potato, will become increasingly attractive. Although we emphasize the importance of reducing production costs we should not forget that this should not be at the expense of the potato's productivity per hectare and per unit of time.

As discussed by van der Zaag and Horton (1983), possibilities of reducing the total cost of potato production per hectare are rather limited. Breeding varieties which are resistant to major diseases, improving tuber seed programs, and in specific regions use of true potato seed may allow perhaps a 25% reduction in total production cost per hectare. On the other hand, increasing prices and rates of application of chemical fertilizer and pesticides may be expected offset these cost reductions.

Possibilities of reducing production cost per unit of output seem to be much greater. In some cases yields could be increased substantially with only a modest increase in production cost per hectare. This would allow potato prices to decline while grower's profits increased.

Given the present high level of tuber seed costs, research and development programs should emphasize better production and distribution of healthy and cheap seed. More attention should also be paid to making it easier for farmers to produce potatoes under difficult growing conditions. Needed are varieties which are tolerant to drought, heat, and frost. Such varieties would help growers increase yields with only moderate increases in production costs per hectare. Better technologies are also needed for storage of both consumption and seed potatoes over long, hot periods. Attention should be paid to development and introduction of simple storage systems and means of transforming fresh potatoes into more easily stored, high value products. Breeding for keeping quality should receive more attention than it has in the past.

If research and development programs are successful, in the future potatoes may be produced and made available to consumers year-round at considerably lower prices than at present (discounting for inflation). This, in turn, would stimulate an increase in potato consumption.

Taking all factors into account, it seems likely that in many areas where the potato is now a luxury vegetable it will become a staple vegetable, and in some places where it is now a staple vegetable it may become a basic staple food. However, in many parts of the tropics and sub-tropics where the potential yield of the potato crop is low it is unlikely that in the near future potatoes can become competitive in price with alternative food crops which are better adapted to local growing conditions.

As a final point, it should be noted that limited potato production in low-potential areas does not necessarily lead to low consumption in these areas. Many lowland areas can be supplied by nearby high-potential areas. In particular, as transportation systems improve, the high-potential areas can be expected to supply growing urban markets more cheaply.

c. Sweet Potatoes, Yams, and Cassava

In relation to the situation with potatoes and cassava, little research has been conducted on factors influencing trends in production and use of sweet potatoes, yams, and cocoyams.

As noted above, in recent years sweet potato production has been relatively stable in Africa and the Far East and has declined in Latin America and the Near East. Consequently, average per capita production has fallen significantly in the developing market economies as a whole.

In Taiwan, where production has declined to about one-third of its peak 1964 level, two major factors have been identified as bringing about this decline (Chen, 1982). First, as the standard of living has risen in Taiwan, people have tended to eat more rice at the expense of sweet potato. Second, hogfeed based on corn rather than on sweet potato has been adopted by the large-scale hog-raising industry that has developed in recent years. Shrinking market demands have made sweet potato production unprofitable relative to other crops. The cited study concluded that future expansion of sweet potato production would require creation

of a new market image for sweet potatoes for human consumption and development of appropriate technology for utilizing sweet potatoes in ready-mixed hogfeeds.

A major constraint in the development of the feed concentrate market is the trypsin inhibitor in sweet potatoes, which can only be deactivated at high temperatures. Whether inhibitor-free varieties can be bred remains to be determined. Specialized varieties are needed for food and feed uses, and new market channels and handling techniques need to be developed for sweet potatoes destined for human consumption.

Yams and cocoyams do not face consumer resistance, as is the case with sweet potatoes. On the contrary, they are preferred foods in many tropical areas. But, as with potatoes, they are often expensive relative to other foodstuffs, such as cassava and rice. Several authors conclude that major barriers to expanding yam production are its high labor requirement and the high cost of planting material. Extremely little research has been conducted on these crops' production constraints, marketing, and demand, and with the present state of knowledge little can be said about the future prospects for their production and use.

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# Tropical Root Crop Statistics: A World Perspective

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ABSTRACT

Analysis of the world root crop statistics show that main producers are China, Nigeria and Brazil. The main crops are cassava and sweet potatoes. Most of the world production is consumed as subsistence products on the farms. Contribution of tropical root crops in the national economy of Papua New Guinea, Fiji and Japan, representing a subsistence, semi-subsistence and commercialized economy, respectively, showed a sharply declining influence. Future outlook for tropical root crops is likely to be strongly influenced by population growth and urbanization. Urbanization is likely to pose major problems for food production in the developing nations.

Cassava, sweet potatoes, yams and taro are the most important tropical root crops produced and consumed in the world. About 3 billion people or 70% of the world's population consume these crops on a fairly regular basis. At least half consume tropical root crops as staple foods. Most production is consumed as subsistence products in the tropical world. Both rural and urban populations dependent on tropical root crops for subsistence, comprise some of the poorest people on earth. Theirs is a world of poverty, malnutrition and hunger. In some societies strong dietary preferences have developed for certain root crops going back as long as recorded human history. As such, tropical root crops have strong connotations with the culture and traditions of many nations in the world (Coursey, 1978). Hence development efforts in tropical root crops are very much a part of the overall development efforts directed at the world's poor.

## Production and Consumption

The harvested area and the production statistics of cassava, sweet potatoes, yams, taro and potatoes by major world divisions are shown in Tables 1 and 2. These Tables are derived from FAO Production Yearbooks (various years) which annually report the harvested area and production statistics by individual nations. Prior to 1975 the area and production of yams and taro were also reported individually by each nation but these have now been combined with other roots and tuber crops. Hence total and country estimates of yams and taro are now difficult to obtain.

In terms of total world production the important tropical root crops are cassava and sweet potatoes. These together account for 92% of the world's production of tropical root crops. Yams and taro are much less important. Potatoes are mostly produced in the subtropical and temperate regions of the world and their production in the tropics is limited to only about 18% of the world production.

Nevertheless, potatoes are important food crops in the tropical highlands of many nations in North Central America, South America and Asia.

Table 3 shows the ranking of the world's leading tropical root crop producers. Important features of this Table are the high concentration of total world production of sweet potatoes in China (81.2%) and yams in Nigeria (78.4%). In the case of cassava Brazil leads with 20.1% of the total world production but other nations such as Thailand, Indonesia, Zaire and Nigeria are also important producers. Nigeria, Ghana and Japan are important producers of taro. If the production of cassava, sweet potatoes, yams and taro in each country are combined then the world's leading producers are China, Nigeria and Brazil.

Table 1. Area harvested (1000 ha).

| | Cassava | Sweet potatoes | Yams | Taro | Potatoes |
|---|---|---|---|---|---|
| Africa | 7,294 | 767 | 1,928 | 669 | 595 |
| N. C. America | 160 | 211 | 18 | - | 675 |
| S. America | 2,610 | 196 | 9 | - | 995 |
| Asia | 3,841 | 12,046 | 7 | 61 | 3,129 |
| Oceania | 20 | 113 | 13 | 32 | 46 |
| Europe + USSR | - | 13 | - | - | 12,590 |
| World | 13,926 | 13,345 | 1,975 | 762 | 18,030 |

Note: All data are for 1980 except for yams and taro which are for 1974.

Source: FAO Production Yearbooks.

Table 2. Production (1000 t).

| | Cassava | Sweet potatoes | Yams | Taro | Potatoes |
|---|---|---|---|---|---|
| Africa | 46,773 | 4,955 | 18,643 | 3,397 | 4,918 |
| N. C. America | 1,024 | 1,269 | 227 | - | 17,447 |
| S. America | 30,556 | 1,699 | 50 | - | 9,332 |
| Asia | 43,559 | 98,596 | 30 | 699 | 34,434 |
| Oceania | 222 | 600 | 187 | 257 | 1,199 |
| Europe + USSR | - | 135 | - | - | 158,389 |
| World | 122,134 | 107,254 | 19,137 | 4,352 | 225,718 |

Note: All data are for 1980 except for yams and taro which are for 1974.

Source: FAO Production Yearbooks.

Table 3. Ranking of world's leading tropical root crop producers (% of total).

| Cassava | | Sweet potatoes | | Yams | | Taro | |
|---|---|---|---|---|---|---|---|
| Brazil | (20.1) | China | (81.2) | Nigeria | (78.4) | Nigeria | (40.1) |
| Thailand | (11.1) | Vietnam | ( 2.2) | Ivory Coast | ( 8.3) | Ghana | (27.6) |
| Indonesia | (10.9) | Indonesia | ( 1.9) | Ghana | ( 3.1) | Japan | (13.3) |
| Zaire | (10.2) | India | ( 1.5) | Dahomey | ( 3.1) | Papua New Guinea | ( 4.9) |
| Nigeria | ( 9.0) | Japan | ( 1.3) | Togo | ( 3.1) | Ivory Coast | ( 4.3) |
| Totals | (61.3) | | (88.1) | | (96.0) | | (90.2) |

Note: All data are for 1980 except for yams and taro which are for 1974.

Source: FAO Production Yearbooks.

Tropical root crops are a major source of food in the world. The annual global per capita consumption of cassava, sweet potatoes, yams and taro is 57 kg, comprised of 28 kg, 24 kg, 4 kg and 1 kg, respectively. To this could be added production and consumption of potatoes in the tropics, about 9 kg per capita per year for the world. Root crops compare favorably with other major world food crops such as rice (paddy) and wheat with corresponding figures of 90 kg and 100 kg per capita per year.

Consumption of tropical root crops by country varies considerably. The world's leading producers, China, Nigeria and Brazil, have annual per capita consumption of 107 kg, 364 kg and 217 kg, respectively. Nigeria has one of the highest per capita consumption rates in the world at 364 kg, comprised of 195 kg of yams, 143 kg of cassava, 23 kg of taro and 3 kg of sweet potatoes.

Most tropical root crops are consumed as fresh human food. Only a small fraction are used for animal feed, processed into human food or manufactured into industrial products. International trade in tropical root crops is also limited on a global scale. However, some countries, such as Thailand and Indonesia, are important exporters of cassava pellets for animal feed to EEC countries.

## Contribution to National Economy

The importance of tropical root crops to the national economies of each producing nation varies considerably. However, instead of reporting masses of intercountry data showing similar patterns, it was decided to choose three different countries and give detailed information on each so that the global range is covered. The countries chosen are Papua New Guinea, Fiji and Japan. In each country the tropical root crops have markedly different levels of influence on the overall national economy.

Papua New Guinea is representative of an almost pure subsistence economy, heavily dependent on tropical root crops for staple foods and where over 90% of the total production is utilized for farm family subsistence. Fiji represents a semi-subsistence economy where root crops are still very important in the peoples' diet and where about 67% of the total production is consumed by the rural population, the remainder by the urban population who purchase root crops for cash. Japan represents a highly commercialized economy, where root crops are one group among several staple foods and where over 70% of the total production is purchased

and consumed by the urban population. Each of these countries represent an interesting case into which other tropical root crop producing nations in the world can be categorized. Hence the following discussion applies to any nation in the world, depending on which group it belongs.

Table 4 shows the contribution of tropical root crops to the national economy of Papua New Guinea, Fiji and Japan. Highlights of this Table from an almost pure subsistence economy of Papua New Guinea to a highly commercialized economy like Japan reveal: (1) average yield of four root crops increase markedly; (2) annual per capita consumption decreases substantially; (3) degree of fresh food utilization decreases and that of processed foods, animal feeds and non-food useage increases significantly; (4) contribution of food energy and protein supply from root crops in the total diet of an adult decreases sharply; (5) degree of farm household subsistence decreases while consumption by urban population increases greatly; (6) in terms of total economic activity the per capita income levels and gross domestic product increases substantially; and (7) overall contribution of root crops in the agricultural economy decreases sharply.

What are the implications of these findings? First, tropical root crops are important food products in countries that are strongly agricultural, especially where subsistence and semi-subsistence characteristics are prevalent. In these situations production and consumption are an integral part of farm household decisions. Also the marketing structure and distribution channels are undeveloped or poorly developed and very little cash sales take place. Second, technological development, industrialization and urbanization lead to reduced dependence on root crops as fresh human food. Other foods, especially the storable grains such as rice and wheat products, may become important in the human diet. However a greater fraction of total production of root crops is processed into human or animal feeds or is utilized for non-food purposes. Marketing and distribution channels become well organized and developed. The urban populations become the major users of fresh root crops and processed products.

## Future Outlook

The future development of tropical root crops will be strongly influenced by population growth and urbanization. In those countries which are heavily dependent on root crops for human food the demand for root crops will be directly associated with population growth. Given the present population growth rates of 2.2% in many tropical root crop consuming nations of Central and South America, Africa and Asia, the problem of maintaining even the present levels of subsistence will become acute since national populations are likely to double within 32 years or by year 2015. That is, in just over three decades more than 3 billion people will be directly dependent on tropical root crops for their staple foods. Altogether more than 6 billion people will consume these crops on a fairly regular basis. Hence the problems of meeting such growth in food needs will be enormous both for national governments and on a global perspective. Major efforts must be directed to increasing tropical root crop production. Hence in many developing nations dependent on tropical root crops, staple food supply will be the major problem for the future and one that cannot be ignored from agricultural policy formulation and decision-making.

Table 4. Contribution of tropical root crops in three national economies.

| Parameters | Papua New Guinea | Fiji | Japan |
|---|---|---|---|
| 1. Main crops (in order of importance) | Sweet potatoes<br>Taro<br>Yams<br>Cassava | Cassava<br>Taro<br>Yams<br>Sweet potatoes | Potatoes<br>Sweet potatoes<br>Taro<br>Yams |
| 2. Area (1000 ha) | 144 | 9 | 229 |
| 3. Production (1000 t) | 914 | 116 | 5,346 |
| 4. Yields (t/ha) | 6.3 | 12. | 23.3 |
| 5. Population (1000) | 3,082 | 639 | 116,782 |
| 6. Consumption (kg/capita) | 297 | 182 | 46 |
| 7. Utilization: | | | |
| fresh food (%) | 99 | 94 | 42 |
| processed food (%) | - | 1 | 8 |
| animal feed (%) | 1 | 5 | 10 |
| non-food (%) | - | - | 40 |
| 8. Energy supply: | | | |
| % kJ per adult unit per day | 64 | 27 | 7 |
| 9. Protein supply: | | | |
| % g per adult unit per day | 36 | 12 | 3 |
| 10. Human consumption: | | | |
| subsistence farm products (%) | 93 | 67 | 28 |
| urban population (%) | 7 | 33 | 72 |
| 11. Income levels per capita (US$) | 646 | 1,360 | 13,662 |
| 12. Contribution to agricultural economy (%) | 25 | 10 | 2 |

Source: (1) Cooperators in Root Crop Statistics Project from various countries.
(2) FAO Production Yearbook, 1980 and 1974.
(3) UN Statistical Yearbook, 1979-80.

Urbanization is likely to have an opposite effect on the demand for tropical root crops in the fresh food form. Although there will be increased demand for processed human and animal food or for industrial products the sum total will be an overall reduction in demand. However this reduction will have to be compensated for by a concomitant increase in demands for storable convenience foods such as rice and wheat products. This, in itself, will be a major dilemma for the developing nations which can be demonstrated in this way. Tropical root crops, by their biological nature, are highly efficient producers of kilojoules (kJ) per unit of input such as land, labor or capital (Chandra, 1980; Evenson and De Boer, 1978). Under the same level of inputs the tropical root crops are capable of producing more kJ per ha per unit time than any other crop, except perhaps sugar cane. In other words, tropical root crops, compared to other crops such as rice, have particularly suitable production functions. Developing nations where tropical root crops are an important component of the diet of the majority of the population, should have a first priority for food production programs based on root crops. Thus tropical root crops have a major role in supplying food needs of future world populations.

## Conclusions

Tropical root crops are staple foods for more than a third of the world's population. Most production is concentrated in Central and South America, Central Africa and South and East Asia. The main producers are China, Nigeria and Brazil. The main crops are cassava and sweet potatoes. A large proportion of the total world production is consumed as subsistence products on the farms.

The contribution of tropical root crops was analysed for the national economies of Papua New Guinea, Fiji and Japan. They represent an almost pure subsistence economy, a semi-subsistence economy and a highly commercialized economy, respectively. The contribution of tropical root crops to the national economies decreases sharply from pure subsistence to highly commercialized economy. The future outlook for tropical root crops in each nation will be strongly influenced by two factors: population growth and urbanization. The former is likely to increase demands, the latter is likely to decrease demands. Urbanization will pose major problems for food production strategies in the developing nations in the future.

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# Developing Scientific Manpower for Root and Tuber Crops Research and Extension

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## ABSTRACT

Successful generation and diffusion of improved germplasm and production techniques on root and tuber crops depends not only on advancements made by international agricultural research centers such as the International Potato Center (CIP) and the Centro Internacional de Agricultura Tropical (CIAT) but also, and more importantly, on the abilities of national agricultural research and extension systems to conduct basic or applied research and validate and adapt technologies developed elsewhere. To perform these tasks, national programs, i.e., research, extension, and education systems, require available scientific manpower. The paper focuses on a strategy for developing scientific manpower for root and tuber crops research and extension adopted by CIP and CIAT. It requires collaboration between international agencies and national systems and hinges on five major elements: (1) existence of favorable conditions for national program development in the country, (2) assessment of the state of development of national programs using a well-conceived scheme, (3) training be directed at strengthening national programs, (4) positive interaction between international and national agencies, and (5)development of a national strategy for manpower development. The strategy is based on the contention that contributions made by international agricultural research centers through training may in the long run exceed those at research.

## Introduction

The overall objective of national agricultural research and extension should be generation and diffusion of improved technology. In addition to conducting basic or applied research, generation of technology includes validating and adapting technologies developed elsewhere. In order to achieve the objective it is imperative that scientific manpower capable of performing these tasks exist within national systems. As it pertains to root and tuber crops, international agricultural research centers such as the International Potato Center (CIP) and the Centro Internacional de Agricultura Tropical (CIAT), have the responsibility for collaborating with national systems in developing needed scientific manpower.

Until recently, national policy makers and research planners have given more attention to cash and export crops at the expense of food crops. Furthermore, among food crops, root and tuber crops have received even less attention, often completely neglected. Lately, sparked by the factors listed below political

1. Implementation of research must be based on a perceived need to overcome constraints to production. A feeling of necessity to solve problems to improve production must exist. In some cases, new programs are seen as "opportunities" to develop agricultural resources and may not be a "priority" for the country.

2. There must be an economic incentive to the country and the producers to improve production. Increases in production caused by improved technology - germplasm or production techniques - must be compensated by a high probability for economic gains.

3. It must be technically possible to improve production and utilize the increased production. Also, favorable conditions for applying research results or introducing improved germplasm or production techniques must exist.

4. Conditions to develop scientific manpower for research and extension through national training efforts, advanced graduate studies, or short-term international training must exist. A commitment to facilitate manpower development through training must be evident.

These factors considered collectively lead to a political decision to accept or reject national research and extension efforts to improve production. Efforts initiated within national institutions without political support are doomed to failure.

Scheme for analyzing state of development of national programs

Before national and international agencies initiate manpower development efforts through training an analysis of the current state of development of the national program is necessary. Working together production potential and constraints are analyzed, research needs identified, and training requirements assessed. For the purpose of determining national and international contributions to a training program the following classifications may be used:

Advanced Programs: These are programs in countries where there is a clearly demonstrated potential and a national policy to increase production, and these have been accepted as a goal by research and extension institutions who have credibility within the country. Continuity for research and extension in the crop is assured.

Intermediate Programs: These are programs in countries where the potential for increased production exists and, although there is a research or extension program, a national policy to increase production does not exist. In these countries objectives for the crop are not clearly defined and researchers may be responsible for several crops. Continuity for research is uncertain.

Developing Programs: Those are programs in countries where there is a potential for increasing production but marketing and utilization alternatives have not been explored. Economic incentives are not clear. Some government agencies may have an interest in improving production. Research in the crops may be carried out by a few specialists or universities.

Potential Programs: These programs are in countries where there could be a benefit from increased production, but where there is a lack of national interest

to increase production. In isolated areas some farmers may produce the crop and a few local researchers and extensionists may be interested but they do not get support. National programs simply do not exist.

The fundamental difference between countries in these four categories, is the favorable political decision in the first category and the lack of it in the other three.

The analytical nature of this scheme serves a a basis for dialogue between national and international organizations. Through open communication, collaborative research and associated training plan based on real needs may emerge. After all, it is the needs of the country that should be addressed.

A recent CIAT study in building of human resources for agricultural research and on participation in research networks revealed less participation in research networks by cassava researchers than rice or beans researchers. The study points out that although there are fewer cassava researchers than rice or beans researchers linkages among cassava researchers are more frequent. To a certain extent this situation was felt to be a consequence of less developed infrastructure for production and marketing in cassava. A contributing factor, of course, is that cassava is a relative newcomer to research interests, as reflected by the "local" scope of researchers' linkages.

Training directed at strengthening national programs

Improvements in production in the developing world will depend on what national researchers, extensionists, and educators do in their respective countries. As such CIP and CIAT's training programs are directed at national programs with the overall goal of improving national abilities to:

- identify research needs and priorities,
- identify and use existent technology relevant to the country's needs,
- conduct research in the most important problem areas,
- evaluate research results from other sources under home country production conditions,
- participate in the transfer of appropriate technology within their countries and surrounding countries, and
- train others to identify existent technology and research needs, conduct research, evaluate results, and participate in the transfer process.

To achieve these objectives CIP and CIAT have developed somewhat different types and categories of training activities, ranging from production courses in the countries to post-doctoral opportunities at the centers. However, essentially there are two types of training: multidisciplinary production training and discipline specific research training.

Multi-disciplinary production training focuses on general principles of production and is designed to enable researchers and extensionists to respond better to farm-level problems and situations. This type of training is conducted primarily through in-country, regional, and headquarters international courses.

Discipline-specific research training focuses on areas of research for which the centers have a comparative advantage. It is designed to enable national

scientists to conduct research. The research topics treated are of priority to the respective country and application of results could have a positive impact on production. Examples of this type of training are: specialized courses, mid-career training, individualized on-the-job training, M.S. and Ph.D. scholarships, thesis research support, and post doctorals.

Since 1970 CIAT has trained 413 national cassava workers and since 1978 CIP has trained 1,958 potato workers. Figures I and II for CIAT and CIP respectively, show the relation between multidisciplinary production and discipline specific research training.

Both centers recognize that they are not the sole source for training. Whenever another source has a comparative advantage to meet a country's training needs the centers attempt to arrange the training.

## Positive interaction of national and international organizations

Although the responsibility for ultimately reaching growers with improved technology rests with national programs, cooperation and collaboration between national and international organizations is imperative and must exist in a positive spirit.

While international agricultural research centers such as CIP and CIAT have comparative advantages, such as sources of germsplasm collected world-wide, providers of improved lines, pools of crop management technologies, and as colleges for training, national agencies have a comparative advantage to transfer the most appropriate technology to their producers. As such, the role of national programs is as important and crucial as that of international agencies. However, how well national programs are able to play this role depends, to some extent, on how well the international and national agencies have interacted and, particularly, what joint manpower development programs have been carried out. Unless national researchers and extensionists are capable of receiving and using new or improved technologies, there is little hope of conducting research and training that will benefit farmers.

## National strategy for developing scientific manpower

An overall national strategy is fundamental for developing national scientific manpower. The strategy must be a function of national agricultural research and extension objectives. Research and extension personnel must be able to respond to questions on production problems and on broader issues related to domestic and export market perspectives. To fulfill this type of responsibility national commodity programs should be composed of a wide range of areas of specialization. Each area of specialization's activities should relate to other parts of the program; but each should have separate, discernible objectives. Tasks and level of competency for each task can then be identified. All this requires careful analysis with the intent of developing an overall strategy for manpower development.

Development of a national strategy includes four steps:

First, an assessment of training needs must be conducted. While international centers may assist with this step, the assessment should be conducted by

national authorities and planners. The intent is to identify training needs based on national research objectives.

Second, a comprehensive plan based on the assessment should be prepared. Some options for satisfying training needs are:

- para-professional and bachelor-level training;

This type of training provides essential basic knowledge for both researchers and extensionists; this academic study is generally informative and broad rather than skill development -oriented with insufficient "hands on" field experience.

- post-graduate specialization;

This type of training generally provides the necessary theoretical background and practical application experience necessary to enable the student to conduct reasonable-level research. While some may argue the same may be achieved through short and medium term on-the-job experiences or courses it cannot be overlooked that degree-related training is not only more prestigious but also its benefits are generally longer-lasting.

- short courses; and

While short courses are used extensively to quickly cover the broad aspects of a food crop they have the added advantage of serving as a vehicle to update the participants on the status and availability of latest technology.

- in-country training:

This type of training is particularly appropriate for extensionists who may need to work directly with producers introducing new or improved technologies. It lends itself to teaching by national researchers and extension specialists in the language of the country.

Third, priorities for applying the strategy must be set. Strengthening national agricultural research and extension systems through training is a costly venture. Although the goal is to raise all national programs to the advanced state of development one must be pragmatic and recognize that this may not be possible or desirable either because it is expensive or because their national planning simply does not require it.

Fourth, the strategy is applied. Table I shows a proposed mix of strategy components according to characterization of a country. Assessment of needs is of paramount importance as it sets the precedence for all subsequent activity. In general, multidisciplinary courses at centers are less relevant than in-country courses which are ideal in countries in the more advanced stages. Of course, direct assistance from the centers will be needed in countries in the lesser developed stages.

It is important to maintain cognizance of the fact that implementing a national policy is a long term process that requires step-by-step planning and supportive political decisions from policy makers.

Table 1. Mix of Components for Development of Scientific Manpower of National Research Programs.

COMPONENTS OF DEVELOPMENT OF SCIENTIFIC MANPOWER

| | National Contribution | | | | | International Contribution | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Specialization | | | Short Courses | | |
| Country Category | Analysis of National | BS and Technical Level | Multidisciplinary Courses | | Post BS Studies | Post BS level | MS Thesis | Post MS & PhD Thesis | Multidis-ciplinary | Special Techniques | In country Training |
| | | | Research | Extension | | | | | | | |
| A | XX | XXXX | XXXX | XXXX | XXXX | XX | XXXX | XXXX | X | XXX | XX |
| B | XXX | XXXX | XX | XX | XX | XXX | XXXX | XXX | XX | XXX | XXXX |
| C | XXXX | XXX | O | XX | O | XXXX | XXX | X | XX | XX | XXX |
| D | XXX | XX | O | O | O | XX | O | O | XX | X | O |

* Assistance to in country training

1 Relative emphasis XXXX High XXX Medium XX Low X Very low O No attention

## Summary and conclusions

Five points have been introduced as being essential in an overall strategy for developing scientific manpower for root and tuber crop research and extension through training. These points have been advanced from the contention that the contributions made by international agricultural research centers through training to the developing world may in the long run exceed those of research and that national programs play the most important role in the transfer of technology process to reach farmers.

However, the plan of action must emerge from dialogue between national programs and the international centers. As development of national program capability is achieved and becomes productive, the direct responsibility for training diminishes for the centers while it increases for the national programs. It should be emphasized that this scheme will not have results and impact at the farmer level unless there is a policy decision made at the governmental level, and there is a commitment from national programs.

# Progress on Root and Tuber Improvement at IITA

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## Introduction

Root and tuber improvement work at IITA since 1971 has been to develop improved varieties and populations of cassava, sweet potato, yams, and cocoyams with high stable yield, resistance to major diseases and insect pests and nematodes, wide adaptability, good storage ability, and high consumer acceptance in the tropics.

Initial research and priority were directed towards stabilizing root crop production through varietal improvement by incorporating into locally adapted varieties the resistance to diseases and insect pests which cause severe damage to root and tuber crops in the tropics, particularly tropical Africa. Among the root and tuber crops, cassava had been given highest research priority followed by sweet potato, yams and cocoyams. However, yams are now given second priority.

## Constraints to production

In Africa, major biological constraints to stable production of cassava are diseases such as cassava mosaic (CMD) and bacterial blight (CBB) diseases, and more recently, insect pests such as cassava mealybug (CMB) and green spider mite (CGM), which were accidentally introduced from Latin America and are now causing severe damage.

For sweet potato in the tropics, weevils, nematodes and viruses are prevalent pests and diseases cause severe damage to the crop. Storage has also been a problem.

In yams, nematodes and tuber rots are serious during the pre- and post-harvest period causing extensive storage loss and reduction of quality and market value. Virus is also a problem. High production inputs for seed yams, such as staking and harvesting are required.

In cocoyams, blight complex has been serious in many countries and storage is another problem.

In addition to these constraints, traditional unimproved agronomic practices have seriously limited root and tuber production in the tropics.

This paper reports on approaches to overcome these constraints and on achievements made, particularly through genetic improvement, at IITA in the past 10 years.

Approaches to overcome constraints

Cassava: Local germplasm collected, evaluated and used as base material for breeding. Several thousand examples of exotic germplasm were introduced from outside, entirely in seed form for quarantine and phytosanitary reasons. Germplasm introduction was facilitated with less risk by this approach.

Both intra-specific and inter-specific crosses were made to obtain breeding source populations. Breeding populations have been improved through continuous, cyclic evaluation, selection and recombination using a half-sib family selection scheme. This also enabled incorporating many different genetic sources from many countries and institutions in Africa, Latin America, and Asia into a large breeding population with a large genetic variation of important agronomic characters. Seeds were planted directly and 100,000 seedlings have been raised and selected in the field each year. It has been most fortunate that the Institute is located at an ideal site for efficient screening of the breeding material for resistance to major diseases, insect pests and nematodes and with environmental conditions representing major root and tuber growing areas in tropical Africa. When environmental conditions in the field are not favorable for disease infection, artificial epiphytotic presence has been provided to magnify the differences between genotypes in the manifestation of the symptoms. The resistance is then re-confirmed in the laboratory by positive screening.

Dry matter content has been tested for each clone using a large drying oven from the preliminary yield trials stage. Consumer acceptance quality has been assessed at an advanced stage of breeding. A large number of genotypes have been screened for low cyanide content using the picrate leaf test method. The selections have been re-confirmed for low leaf and root cyanide content using Cooke's enzymatic assay method. Through continuous selection and recombination of the low cyanide genotypes, an improved low cyanide population with high yield potential and disease resistance has been developed from which many improved low cyanide clones have been selected. Recently an automated enzymatic assay method has been developed adopting Cooke's manual method. The method was used for more accurate testing of cyanide levels. With this method about 300 samples a day can be analyzed under better controlled conditions.

Sources of resistance to CMB and CGM have been identified and incorporated into susceptible but high yielding and disease resistant clones and populations. Results so far indicate that pubescence on young apical leaves is an important factor responsible for resistance to both insect pests. An antibiosis of resistance to CMB has also been reported.

All performance tests have been without fertilization at several locations with a wide range of environmental conditions, including high rainfall, sandy soil and dry savannah conditions under which cassava is grown.

The IITA improved breeding material has been sent to national programs in seed form for their evaluation and selection under local conditions.

Biological control of CMB at IITA has used several natural enemies introduced from Latin America where CMB originates.

Sweet potato: Germplasm has been introduced in seed form from many different countries in Africa, the Americas and Asia and evaluated for resistance to weevils and viruses and for other important agronomic characters. Sources of resistance

to insects and diseases have been identified and incorporated into breeding populations. The populations have been improved using a half-sib family selection scheme. The scheme is aimed at increasing population means, and retaining a high degree of genetic variability through continuous, cyclic evaluation, selection and recombination.

The short-range improvement program has focused on developing clones and populations with resistance to viruses, weevils and nematodes; the long-range program aims at developing improved populations with other important agronomic characters in addition to resistance to diseases, insect pests and nematodes. This two-pronged improvement approach is appropriate for IITA because it permits serving many national programs, providing them with genetically diverse and improved seed for selection under local conditions. In addition, the conventional intervarietal crossing program has also been used to meet specific needs.

The most promising clones have been tested without fertilization at several different locations covering a wide range of environmental conditions.

Tissue culture techniques have been introduced to produce disease-free material and to preserve germplasm in vitro. The most promising clones have been cultured in vitro and indexed for viruses for distribution to national programs.

Screening for large source potentials and sink capacities are being incorporated into breeding populations.

Recently, interspecific crosses were made to introduce resistance to diseases, pests and nematodes and other desirable characters into breeding populations.

Yams: White yams have been given highest priority among the economic yam species because of its relative importance in the region where IITA is situated.

Genetic improvement of yams previously was not possible because of the lack of knowledge about flowering, seed behavior and physiology. Now, techniques of hybridization, seed germination and establishment of seedlings have been developed. Techniques to obtain large tubers (1,000 to 1,200 g) from seeds and to increase multiplication ratio of tubers have been developed and applied for making up the planting material sufficient enough for subsequent clonal evaluation. Efforts are being made to obtain more seeds from *D. alata*.

Cocoyams: GA at the concentration of 1,500 ppm gave the best results of flower induction for both *Colocasia* and *Xanthosoma*. GA-promoted flowers have been hand-pollinated, resulting in about 2% of *Colocasia* and 38% of *Xanthosoma* inflorescenses setting viable seed. A large number of viable hybrid seeds have been produced, seedlings established and selections made. The hybrids have been evaluated for resistance to cocoyam blight and promising results are being obtained.

More than a hundred germplasm accessions of *Xanthosoma* have been introduced and evaluated. Cytogenetics and crossability of cocoyams have been studied, with encouraging results for developing future improvement strategies.

## Accomplishments

Cassava: The IITA improved high yielding and disease resistant varieties are popular and mass adopted by farmers in Nigeria. It is estimated that the varieties are now grown on more than 80,000 ha in Nigeria. They give farmers these advantages over local unimproved varieties: 50% to 300% higher yields, stable production due to resistance to CMB and CBB, better and quicker canopy development which speeds recovery from CMB and CGM attack with the onset of the rainy season, reduced weeding by one-third or more, and better processing quality. Demand by farmers for planting material of the IITA improved varieties is continuously high and expected to increase in the years ahead.

Among other national programs receiving improved cassava breeding material from IITA several have developed and released varieties in their countries. They include Sierra Leone, Zaire, Gabon, Tanzania, Seychelles, and Liberia.

Biological control of CMB has been successful using two natural enemies. They are being mass reared and distributed to national programs for release.

Sweet potato: Sources of resistance to African weevils, viruses and nematodes have been identified and incorporated into breeding populations. Clones with yields of about 20 tons/ha under no fertilization have been produced and some yielded up to 50 tons/ha under good soil conditions.

Countries that released varieties selected from IITA breeding material are Sierra Leone, Nigeria, Cameroon, Gabon, and Seychelles. Other countries receiving IITA material are also reporting promising results.

IITA-improved varieties indexed to be negative for viruses have been sent in vitro to more than 30 countries. A total of 600 germplasm accessions are preserved in vitro.

Yams: Breeding technologies for white and water yams have been sufficiently developed and populations with uniform and large tubers from seeds have been produced. Several white yam clones that can produce yields of 20 tons/ha without staking under no fertilization have been identified. Improved healthy seed yam production systems requiring less inputs have been developed.

Cocoyams: Breeding technologies have been developed. Sources of resistance to cocoyam blight complex have been identified and are being incorporated into breeding populations. Triploid *Colocasia* clones and a tetraploid *Xanthosoma* clone were identified.

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The Disease Disposition of Tuber Crops as Compared to other Annual Crops

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ABSTRACT

The Pathological Index (PI) is introduced as a measure for the overall disease incidence of a crop species. PI is calculated according to the formula:

$$PI = \frac{\text{No. of publications in Rev. Pl. Pathol.}}{\text{No. of publications in Pl. Breed. Abs.}} \times 100.$$

Similarly, partial PI values referring to fungal, bacterial, and virus disease incidence ($PI_F$, $PI_B$, $PI_V$) can be calculated.

The PI values of 45 annual crops have been determined, including 5 tuber crops. The overall disease incidence is high in yam, aroids, and potato, and moderate in cassava and sweet potato. Also, virus disease incidence is higher in the three former species. Cassava is unique in having relatively low $PI_F$ and high $PI_B$ values.

Tuber crops as a whole have a very high disease incidence as compared to cereals, medicinal fiber crops, and legumes. This is especially true with respect to bacterial and virus diseases. Vegetative propagation is accompanied by a higher disease incidence than propagation by true seed; this tendency is more pronounced with virus and bacterial than with fungal diseases.

Crops differ in their disposition to contract diseases and suffer from them. To express those differences quantitatively the term Pathological Index (PI) is introduced which is considered as an intrinsic character of a given crop species. This index is calculated according to formula 1:

$$PI = \frac{\text{No. of publications in Rev. Pl. Pathol.}}{\text{No. of publications in Pl. Breed. Abs.}} \times 100. \qquad (1)$$

Similarly, partial PI values, referring to fungal, bacterial and virus diseases ($PI_F$, $PI_B$, $PI_V$, respectively) can be calculated. As formula 2 indicates, PI is the sum of these partial indices.

$$PI = PI_F + PI_B + PI_V \qquad (2)$$

This pattern makes up the Pathological Profile of a crop.

Formula 1 is based on the number of phytopathological (in the case of partial indices of mycological, bacteriological and virological) publications dedicated to each crop as included in Review of Plant Pathology. This figure is divided by the number of publications reviewed in Plant Breeding Abstracts, in order to eliminate the influence of factors which are not related to phytopathology, such as the acreage of the crop, the attention it has received in research, and others.

## Results and Discussion

The PI values of 45 annual crops have been determined according to formula 1, in base of Review of Plant Pathology, vols. 55-59, and Plant Breeding Abstracts, vols. 46-50, corresponding to the years 1976 to 1980. The values obtained show a wide variation from 9.8 (foxtail millet, *Setaria italica*) to 157.7 (pineapple, *Ananas comosus*). Those of five tuber crops are shown in Table 1. In some crops, which include inter alia yams and aroids, the numerical base for the calculation of PI is very small; this permits only to establish certain trends in such cases.

As a rule, the $PI_F$ values are higher than those of $PI_V$ or $PI_B$, indicating that fungal diseases are more important in most crops than viruses or bacterioses. There are a few exceptions, however; one of them is cassava (Table 1).

## Agronomic Characters

The disease impact suffered by a species as expressed by its PI value may be influenced by various determinants. To identify these determinants, crops were grouped according to their agronomic characters, including intensity, climatic zone, type of propagation and plant parts harvested. The results of these comparisons can only be summarized here.

It could be demonstrated that the level of cropping intensity is positively correlated with the PI values; this is true for fungal, bacterial and virus diseases.

There are various factors responsible for this tendency. Firstly, in extensive agriculture many diseases can be tolerated, or pass even unnoticed, because under such circumstances the yield reductions produced do not justify major efforts in research and control. The margin of tolerance is much smaller in crops with high investments in capital and/or labor per unit area (Heitefuss, 1975).

In most of the intensively cultivated crops (fruits, vegetables, tobacco) product quality is of much more significance than in extensive crops like cereals or oil seeds. Therefore, diseases which affect quality, aspect, storage ability and commerciability have to be considered more in the former than in the latter species.

Finally, intensive agriculture is often associated with factors which tend to favor the development of epidemics: protected cultivation, irrigation and dense stands create a special microclimate favorable for many pathogens; a permanent occupation of the soil, extension of the growing season, overlapping cultures, small plots and the proximity of related species which share the same pathogens (e.g. solanaceae, cucurbitaceae) guarantee the presence of disease inoculum and vectors.

Table 1. Pathological Indices and number of pathogens recorded in tuber crops (in base of Review of Plant Pathology and Plant Breeding Abstracts, 1976-1980).

| | No. of publications 1976-1980 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P.B.A. | R.P.P. | | | | Pathological Indices | | | | No. of pathogens | | |
| Crop | | Total | Fungi | Bact. | Virus | PI | $PI_F$ | $PI_B$ | $PI_V$ | Fungi | Bact. | Virus |
| Aroids | 25 | 17 | 7 | 0 | 10 | 68.0 | 28.0 | 0.0 | 40.0 | 3 | 0 | 3 |
| Yams | 37 | 33 | 18 | 3 | 12 | 89.1 | 48.6 | 8.1 | 32.4 | 18 | 2 | 8 |
| Cassava | 198 | 92 | 28 | 34 | 30 | 46.5 | 14.1 | 17.2 | 15.2 | 19 | 2 | 8 |
| Sweet potato | 156 | 62 | 38 | 6 | 18 | 39.7 | 24.4 | 3.8 | 11.5 | 13 | 6 | 7 |
| Potato | 2,106 | 1,470 | 680 | 248 | 542 | 69.8 | 32.3 | 11.8 | 25.7 | 51 | 8 | 30 |



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When the crops are grouped according to the climatic zone they belong to (tropical, subtropical, warm temperate, cool temperate), the average disease impact is highest with the lower latitudes, decreasing towards the higher latitudes. This tendency is more pronounced with fungal and bacterial than with virus diseases.

To some degree, the temperature and humidity conditions of the tropics and subtropics might favor directly the development of many fungi and bacteria. Possibly of more importance for the abundance of inoculum and vectors is the year-round cultivation and/or presence of natural vegetation, in contrast to cool temperate and mediterranean zones, where cold or dry seasons interrupt the epidemic cycles. According to Levin (1975), in tropical climax communities the pressures of herbivores and pathogens are higher than in other communities; this might have its influence also on the crops cultivated in these regions.

A very important influence on the PI values is exerted by the kind of reproduction. The average PI of seed propagated species is much lower than that of vegetatively propagated ones. This is especially true for $PI_B$ and $PI_V$, and less so for $PI_F$. However, whereas all the asexually multiplied crops suffer considerably from virus diseases, some are nearly free from bacterial diseases, e.g. aroids, garlic, hops and strawberry. This indicates that vegetative reproduction is not necessarily associated with bacterial diseases.

The greater vulnerability of crops which are multiplied asexually can be explained in part by their genetic uniformity and their impossibility to adapt themselves to changing populations of pathogens. Another important factor is the transmissibility of many fungi, bacteria and especially viruses, via the planting material, as compared to the relatively small number of pathogens transmitted by true seed.

This has considerable epidemiological implications. Diseases of seed multiplied plants, in most cases, have their primary sources of inoculum outside the crop; therefore their spread is often delayed and plants become infected late in the season with less dramatic effects on yield. However, in the case of vegetatively transmitted diseases, the sources of inoculum are ideally distributed within the crop, which enables a rapid and efficient dissemination leading to early infections which considerably affect the yield. Moreover, late infections are of great significance because of the contamination of propagating material obtained from these plants.

Crop species were also arranged according to the plant parts harvested. The group of dry grains showed the lowest disease incidence; crops with subterranean products (roots, tubers, bulbs) and those where stems and leaves are utilized occupy an intermediate position, whereas crops with soft fruits have the highest PI values. Apparently, the more tender and delicate the organ, the more vulnerable it is to fungal and bacterial diseases.

The cereals are the least affected crops, with an average PI of 28.7, followed by pulses (38.9) and oil and fibre crops (39.0). The other groups, miscellaneous crops (58.5), tuber crops (62.6) and vegetables and fruits (67.3) show much higher PI values. These three groups are characterized by their sensibility to bacteria and viruses. Vegetables and fruits, in addition, are extremely vulnerable to fungal diseases.

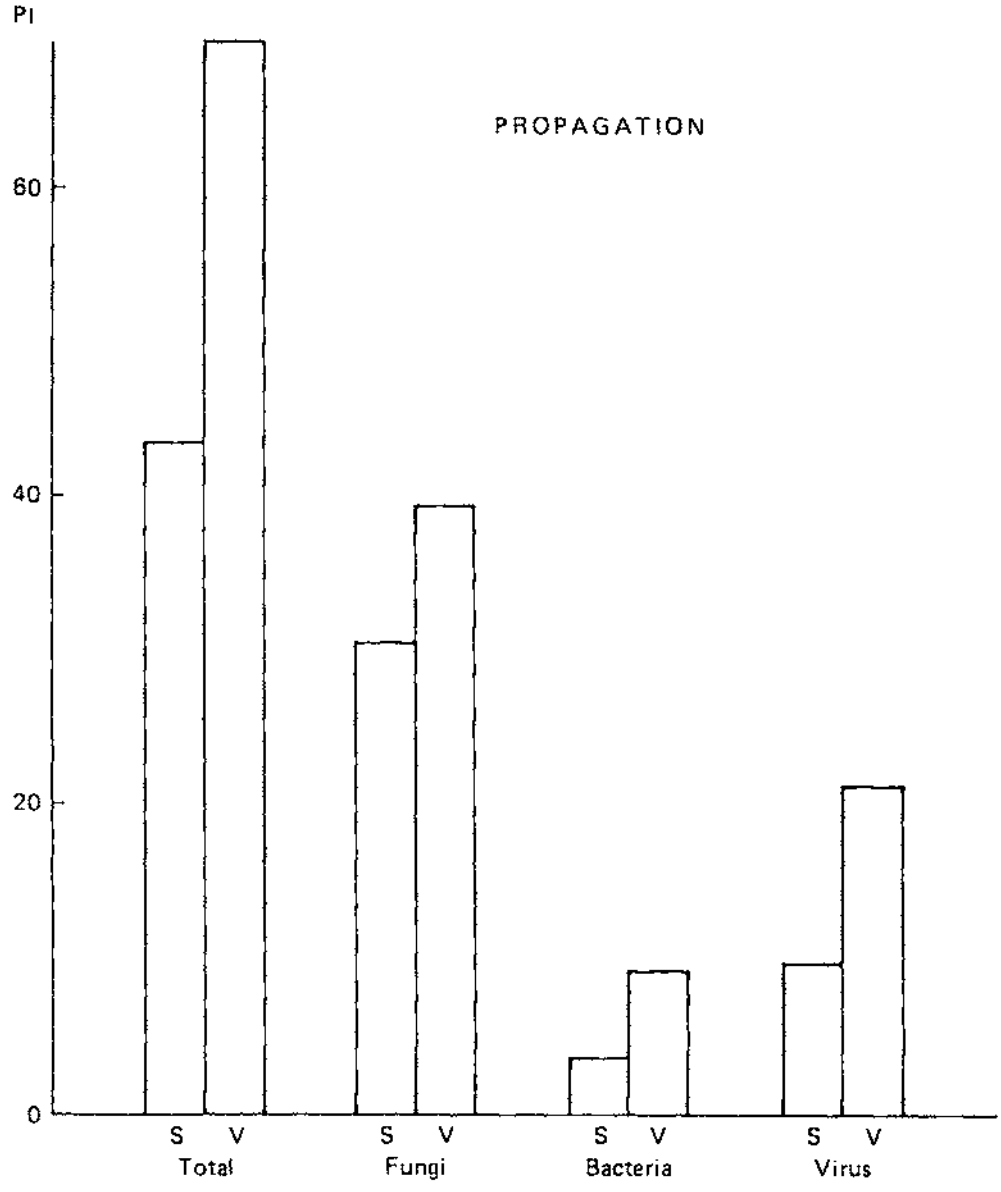


Figure 1. Average Pathological Indices of seed (S) and vegetatively (V) propagated crops.

It is evident that the differences in cropping intensity, climatic zone, propagation and plant parts harvested contribute to this pattern, as previously pointed out. With respect to tuber crops, the Study Group 4 of the International Symposium on Tropical Root Crops, in St. Augustine, Trinidad, identified four main factors responsible for the high disease impact in tropical tubers: the planting material of these vegetatively propagated species harbors viruses and other pathogens; the economic parts of the plants are exposed to the direct attack of soil pathogens; the wounds produced during harvesting provide avenues for infections which cause storage diseases; and the long growing season together with the humid tropical environment enhance the disease incidence (Martin et al., 1967).

Tuber Crops

Within the group of tuber crops, the highest PI values are found in yams, potato and aroids; cassava and sweet potato are less affected (Table 1). Also with respect to virus diseases, sweet potato and cassava have relatively low $PI_V$ values, those of potato, yams and aroids being considerably higher. The highest $PI_F$ is found in yams and the lowest in cassava, with intermediate values in sweet potato, aroids and potato. There are great differences also with respect to bacterial diseases, cassava being extremely vulnerable and sweet potato and aroids highly resistant to these pathogens. Bacteria are quite important also in potato (Table 1).

The marked differences in the Pathological Profiles are difficult to interpret. With the exception of potato, the tuber crops included here are predominantly of tropical regions. There are differences in cropping intensity, with the lowest level probably in cassava, an intermediate one in sweet potato and potato, and the highest level in yams and aroids. This factor may explain the Pathological Profiles of these species, at least partially.

From Table 1, it may be concluded that the number of pathogens recorded for each crop in the five volumes of Review of Plant Pathology indicated is of little significance in the PI values. Rather it reflects how much attention has been paid to each species. However, a closer look to the most important pathogens might be helpful to identify the main disease problems of each crop.

In aroids, Phytophthora colocasiae and dasheen mosaic virus are the most frequently mentioned disease agents, whereas none of the 28 pathogens cited for yams seems to play a dominant part. The most frequently named pathogen of sweet potato is Ceratocystis fimbriata, followed by the virus complex feathery mottle-russet crack-internal cork and Fusarium oxysporum.

The high incidence of bacterial diseases in cassava is due nearly exclusively to Xanthomonas manihotis which is the most important pathogen of this crop. The African mosaic virus complex is the next most important cassava disease.

The highest number of pathogens has been recorded for potato. By far the most important one is Phytophthora infestans, followed by Erwinia carotovora, virus X, virus Y, virus leafroll, Synchytrium endobioticum and Rhizoctonia solani.

The paramount importance of vegetative propagation for the high PI values of tuber crops is underlined by the fact that nearly all the pathogens mentioned are transmitted by the planting material. This should encourage the attempts to shift from vegetative to seed propagation, as has been initiated recently with potato (Accatino and Malagamba, 1982) and yams (Okoli, 1981).

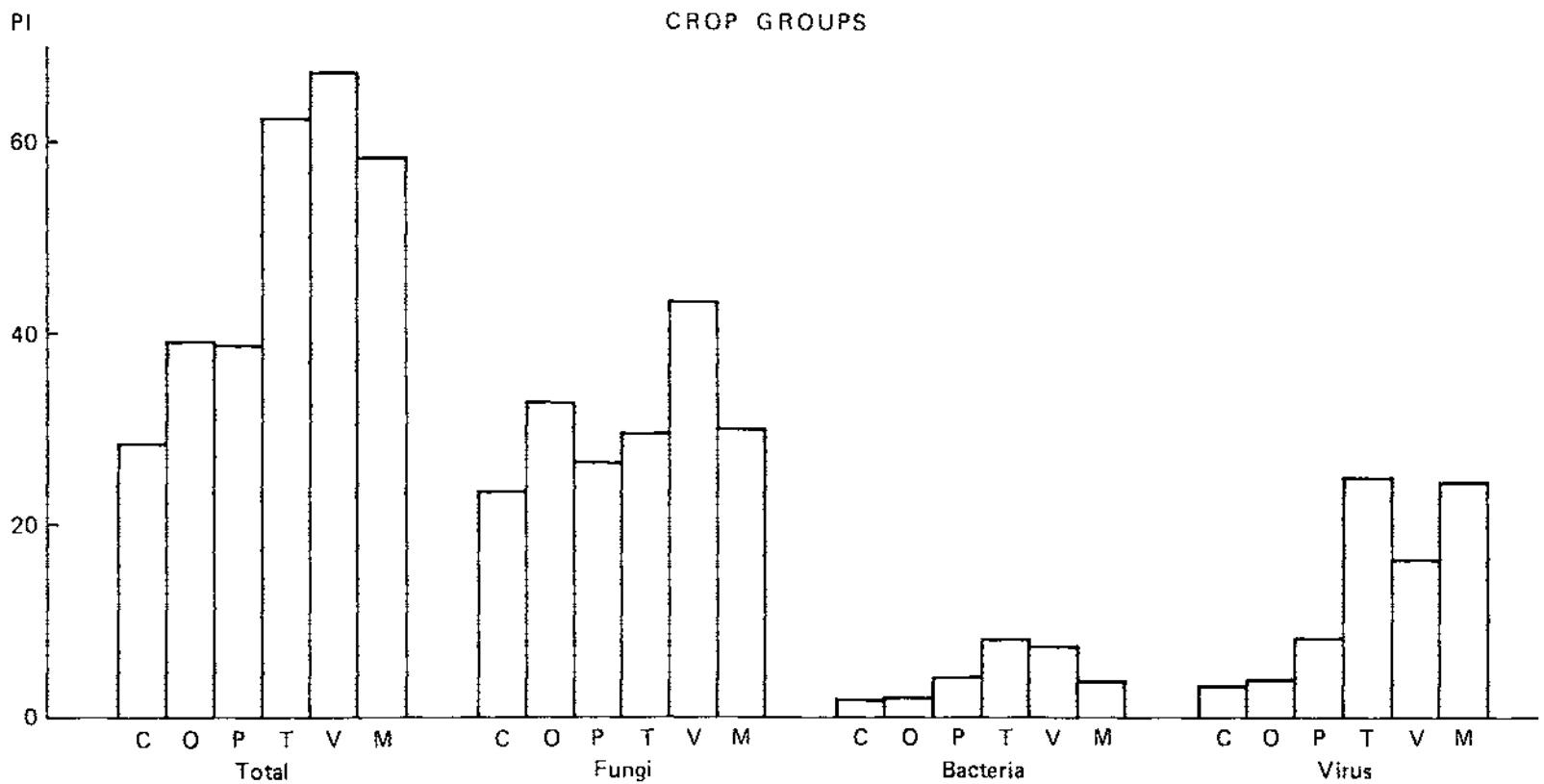


Figure 2. Average Pathological Indices of cereals (C), oil and fibre crops (O), pulses (P), tuber crops (T), vegetables and fruits (V) and miscellaneous crops (M).

## Conclusions

The Pathological Index and the Pathological Profile, introduced here, give a new insight into the disease problems of a species. This may pave the way towards a Comparative Pathology of crops, which can help to identify weak points of a crop species or crop group, and to develop a strategy in order to overcome these problems. In the case of tuber crops as a whole, the impact of diseases, as reflected in the high PI values, at least partly accounts for their inferior role in world agriculture as compared to cereals, which probably have a lower production potential than tubers, but are less affected by diseases.

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# The Potential for Producing Root and Tuber Crops from Seed

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## ABSTRACT

The physiological basis of yield of root and tuber crops will be discussed, based on a simple model for the cultivated potato *Solanum tuberosum*, from which a strategy for maximizing yield can be developed. The possible effects on the strategy of substituting true seed for normal methods of vegetative propagation will be discused.

## The physiological basis of yield with particular reference to S. tuberosum

The basic principle of crop production is the conversion of light energy into chemical energy in the process of photosynthesis. For this to take place, the raw materials of water, carbon-dioxide and about 13 mineral elements are needed, and a green crop canopy able to intercept radiation, part of which is fixed into chemical energy. Of these ingredients, the natural supply of nutrients is rarely adequate, but can be supplemented to make them unlimiting, so too can the supply of water, however, little can be done to increase the supply of carbon-dioxide. This leaves the utilization of light, which unless intercepted by the crop canopy, cannot be converted into chemical energy.

Monteith (1977) was able to show that in Britain, the total dry matter yields of crops, as disparate as barley, sugar beet, potatoes and apples, were closely and linearly related to the total amount of radiation intercepted by these crops. The efficiency with which light was converted into dry matter was approximately 1.4 g per MJ of intercepted radiation. Total dry matter yield is therefore a function of the total amount of radiation intercepted and the efficiency with which it is converted into dry matter. For economic yield, the analysis needs to be extended into the way dry matter is distributed between the various plant parts.

The first applications of this type of yield analysis on the potato crop was made by Scott and Wilcockson (1978), followed by a comprehensive review of this analytical approach, with its implications for growers, breeders and the potato industry, by Allen and Scott (1980). The relationship using potatoes and sugar beets, between total dry matter yield and the total amount of radiation intercepted by crops over the growing season, was report by Scott and Allen (1978). Both crops show exactly the same relationship between intercepted radiation and yield, fixing radiation with an efficiency of about 1.3 g dry matter per MJ intercepted radiation.

It would seem that, at least under temperate conditions, the major yield determining factor is the total quantity of radiation intercepted by crop canopies, and that the only major factor likely to affect the efficiency of the conversion is water stress. There is some evidence from unpublished data of Tostevin, referred to by Harris (1980), that efficiency may decline with the age of the crop, but the weight of evidence suggests that the conversion efficiency remains roughly the same over the length of the growing season. It is well known that leaf age affects the efficiency of photosynthesis (Leopold and Kriedemann, 1975), but the potato crop is an indeterminate crop and presumably whether or not efficiency declines with age will depend on the capacity of the crop to produce new leaves and therefore probably upon the average age of the leaves forming the crop canopy, although there has been little or no work on this aspect of growth in the potato crop.

It is also known that efficiency of conversion of light by individual leaves (Leopold and Kriedemann, 1975) is greatest at relatively low light intensities, but that for a full crop canopy efficiency does not decline until fairly high intensities owing to the geometrical arrangement of leaves. This will assume greater significance in tropical and sub-tropical latitudes as the intensity of radiation increases.

With regard to distribution of dry matter within the crop, the extreme plasticity of the crop has been ably demonstrated by Steward et al (1981) in response to changes in temperature and daylength. However, for the normal range of cultivars grown in the field under particular environments such plasticity is unlikely to be encountered. Allen and Scott (1980) were able to show that over the normal range of treatments likely to be given to potato crops in Britain, variation in the distribution of dry matter between tubers and the rest of the plant was likely to be small.

It would follow from the preceding comments upon the relationship between total dry matter yield and intercepted radiation and upon the distribution of dry matter, that there should be a close relationship between tuber dry matter yield and intercepted radiation. This is confirmed by data from Scott and Wilcockson (1978) and from a recent experiment at Reading (Blanco White, unpublished).

Based on this analysis it is possible to define a strategy for maximizing the yield of tubers grown in temperate conditions; this is simply to maximize the amount of radiation intercepted by the potato crop, consistent with economic constraints. This resolves itself into obtaining a leaf area index capable of intercepting most of the incident radiation as rapidly as possible and maintaining this for as long as possible or desirable. A leaf area index of 3 to 4 would seem adequate to intercept most of the incident radiation.

The "tools" available to the grower to implement the strategy can be broadly classified into three groups:

(a) selection of genotype
(b) manipulation of plants
    e.g. selection of tuber size, preplanting tuber treatments such as sprouting, selection of plant density and spatial arrangement.
(c) manipulation of the crop environment
    e.g. additional supplies of plant nutrients, supplementation of water supply.

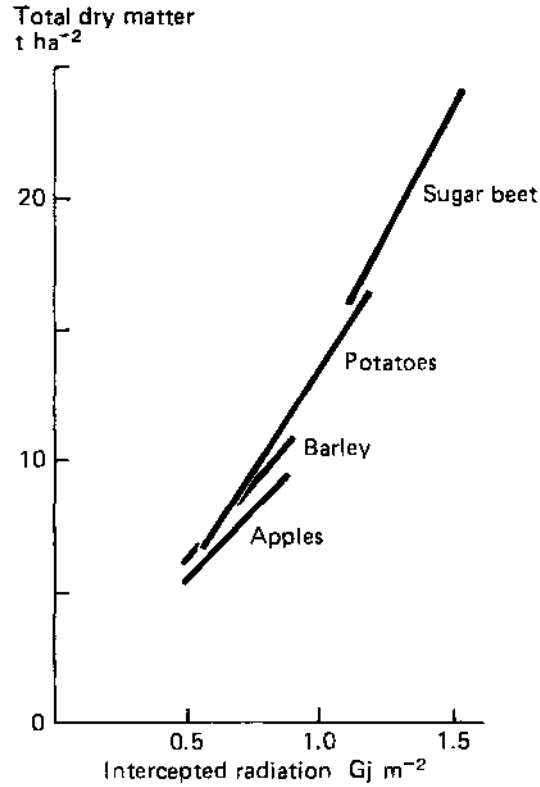


Figure 1. Relation between total drymatter yield at harvest and radiation intercepted by foliage throughout the growing season (Monteith 1977).

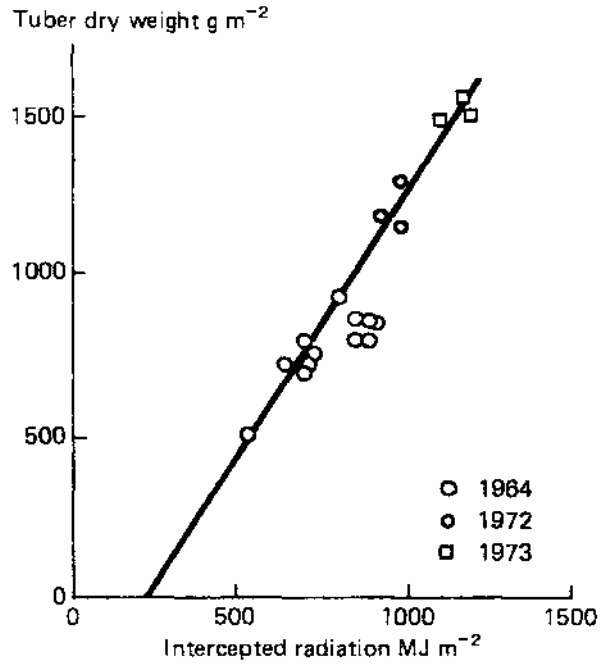


Figure 2. Tuber dry weight and intercepted radiation at Sutton Bonington (adapted from Scott and Wilcockson, 1978).

These tools may be considered to act in a positive way by increasing the amount of radiation intercepted, through effects on leaf growth, or they may operate through "negative" agencies, such as pests, diseases and weeds, which have a tendency to reduce the amount of radiation intercepted.

The grower, of course, has other matters to consider such as harvesting losses, losses during storage, and the quality of the product. A valuable feature of this type of analysis is that, given a knowledge of the radiation income and the pattern of crop growth, the potential yield of the crop can be readily calculated from the relationship between intercepted radiation and tuber yield. This makes it possible to estimate the scope for improvement under any particular set of environmental constraints.

An attractive feature of this type of analysis, particularly for agronomic research, is that the instrumentation needed to obtain estimates of intercepted radiation need only be minimal. In most of the work referred to the estimates have been made by placing solarimeters above and below the crop canopy, and their outputs measured by integrators over the growing season. However, it has recently been shown (Burstall and Harris, 1983) that there is an excellent correlation between the percent ground covered by leaves (viewed directly from above) and intercepted radiation. Simple inexpensive devices can be easily constructed to obtain these measurements. An instrument for measuring radiation receipts is the only other requirement. The height of the crop canopy will obviously affect the way such estimates are made.

Radiation interception and propagation of S. Tuberosum from seed

I am indebted to J. Shakya for the data used in this section, which were obtained from experiments carried out at Reading University in 1981 and 1982. In each year a growth analysis experiment was carried out in which the main variables were method of propagation and plant density. The percentage of incident radiation intercepted was measured directly in 1982, but in the following account it has been estimated from its relationship with leaf area index (1981) and with percentage ground covered by leaves (1982). Total incoming radiation was measured by a Kipp solarimeter. The total radiation intercepted by the crop canopy was calculated for each day from the time of crop emergence to the time of foliage death, or the final harvest.

In experiment 2 (1982) the methods of propagation compared were establishment from seed sown in the field, from seed planted in the greenhouse and subsequently transplanted, and from tuber eye plugs. Eye plugs were used in preference to whole tubers in order to establish comparable plant densities on a stem density scale. The tuber crop was the variety Désirée and the seed was derived from fruit collected from a crop established from tubers the previous year. The crop established from seed was genetically diverse, but this seemed to be a more noticeable feature in the tuber rather than foliage characters.

Tuber dry weights were plotted against intercepted radiation for each harvest of each of the three methods of propagation meaned over the density treatments. Intercepted radiation accounted for 97% of the variation in yield. Thus, in spite of the wide genetic diversity incorporated in the treatments and the widely different patterns of growth, tuber yield was accounted for by the same simple model.

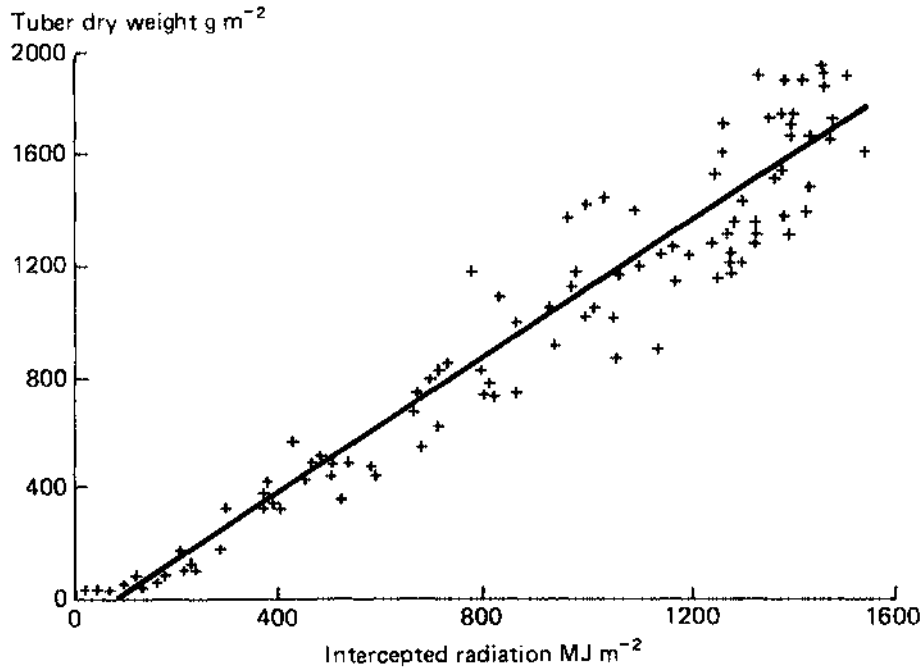


Figure 3. Relationship between accumulated tuber dry weight yield and accumulated intercepted radiation - University Farm Sonning, 1981. (S. Blanco White personal communication).

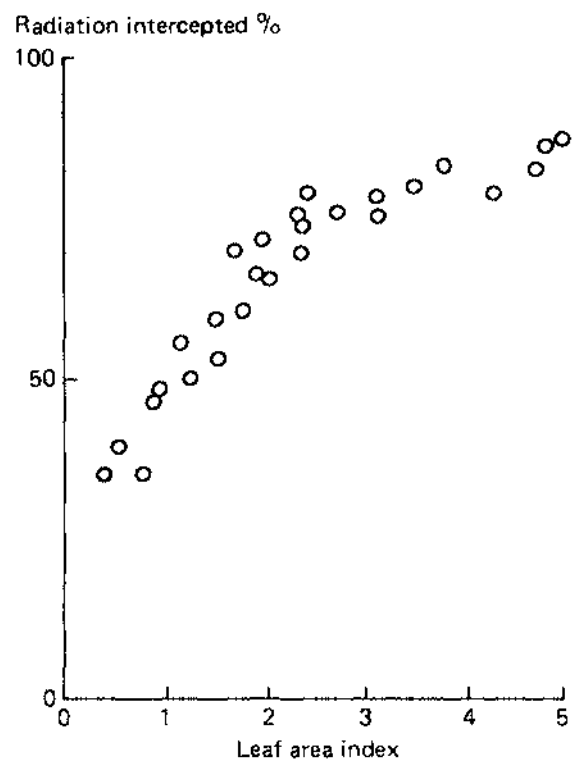


Figure 4. The relationship between leaf area index and total radiation intercepted. (Scott and Wilcockson, 1978).

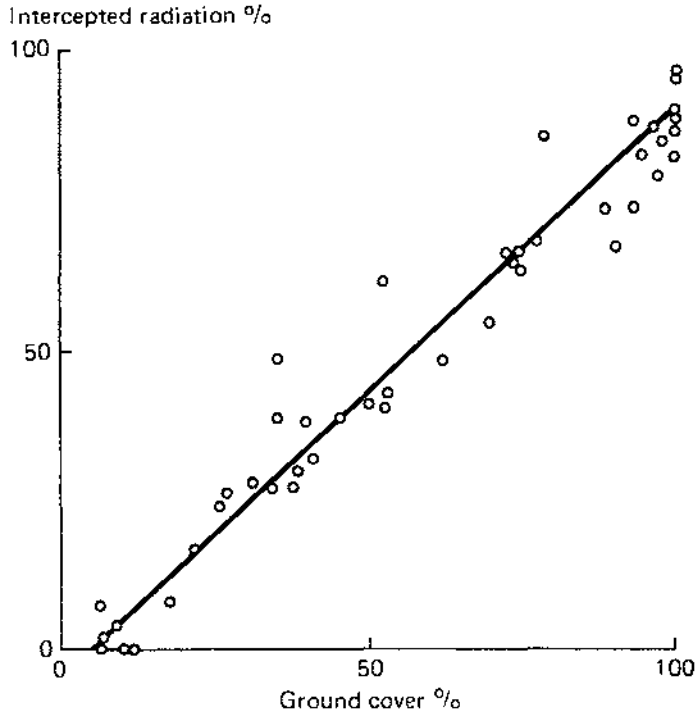


Figure 5. Relationship between percent ground cover and percent radiation interception (Burstall and Harris).

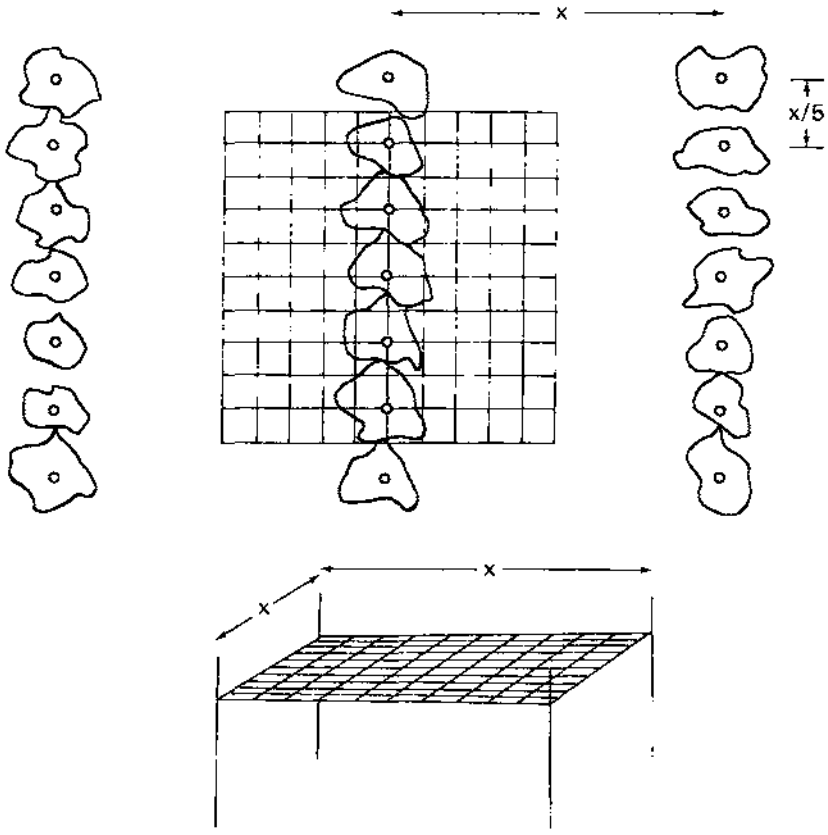


Figure 6. Simple grid for estimating crop cover.

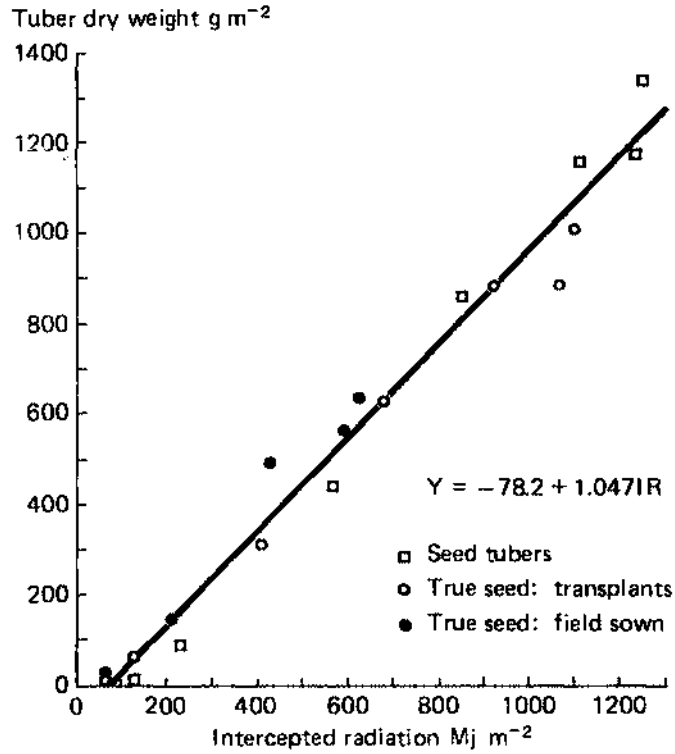


Figure 7. Relationship between intercepted radiation and tuber yield.

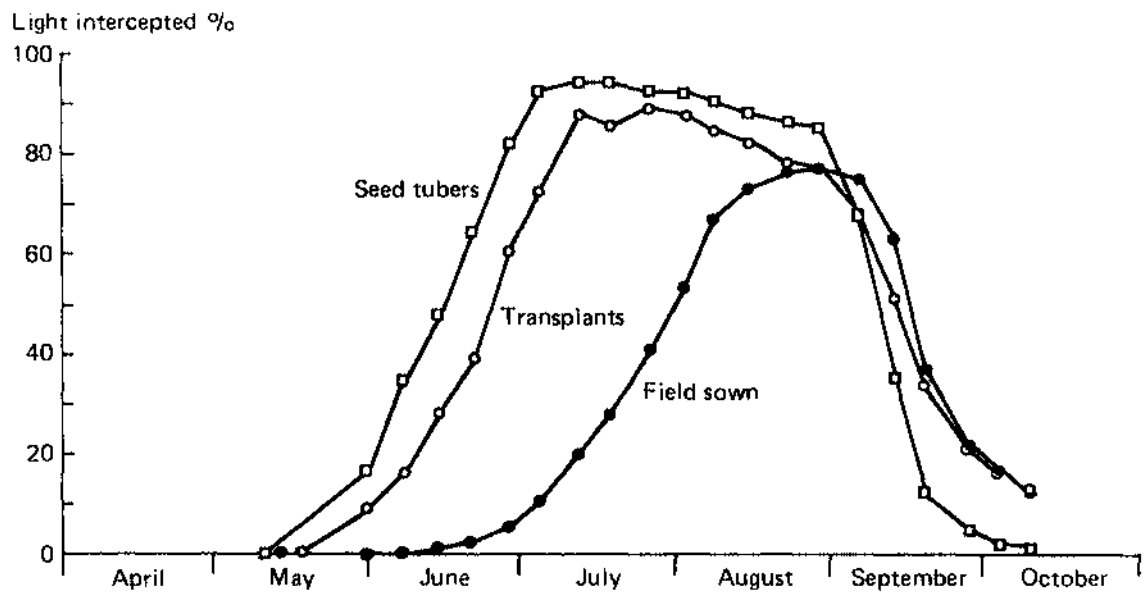


Figure 8. Method of propagating the potato crop and light interception, 1982, mean 4 densities. (Data of J. Shakya).

There were slight differences between the regressions for the three methods of propagation. These regressions together with the common regression are given in Table 1.

Table 1. Regression of tuber dry matter yield (y) (g $m^{-2}$) on intercepted radiation (IR) (MJ $m^2$) 1982 (each treatment is the mean of 4 densities)

| | Treatment | Regression |
|---|---|---|
| 1 | All methods of propagation | = - 78.2 + 1.047 IR |
| 2 | Field sown from true seed | = - 49.9 + 1.101 IR |
| 3 | Transplanted from true seed | = - 51.2 + 0.950 IR |
| 4 | Propagated from tuber eye plugs | = - 171.2 + 1.165 IR |

For crops propagated from seed, the amount of radiation intercepted before measurable tuber growth (45 and 54 MJ $m^{-2}$ for field sown and transplanted treatments respectively) was about one-third of the amount intercepted before the onset of tuber growth in the crop propagated from tubers (147 MJ $m^{-2}$). This is presumably a reflection of the greater chronological age of the seed propagated crops for any particular increment of radiation intercepted due to the slow development of the crop canopy.

It is immediately apparent that the slow development of the canopy from seed sown in the field offers severe limits to the potential of this particular treatment. On the other hand the pattern of light interception on the transplanted crop would suggest that this treatment has much more potential.

One way of increasing the interception of radiation, particularly in the initial stages of growth, is to increase plant density and adopt less rectangular planting patterns.

Before leaving these particular experiments attention is drawn to the patterns of light interception achieved by a transplanted crop and a crop propagated from whole tubers in experiment 1 carried out in 1981. In this experiment, the initial development of the canopy of the transplanted crop was set back by hail damage which occurred just after the crops had been transplanted into the field, and which did not affect the tuber propagated crop, however the latter showed severe leaf rolling from mid-July onwards and the crop rapidly senescenced. The crop propagated from seed completely escaped this condition. This potential effect on the incidence of tuber transmitted diseases is, of course, one of the advantages claimed for propagating the crop from true seed, and it affords an interesting demonstration of the effect that this particular method of manipulating the crop may have upon the realization of the strategy of maximizing radiation interception.

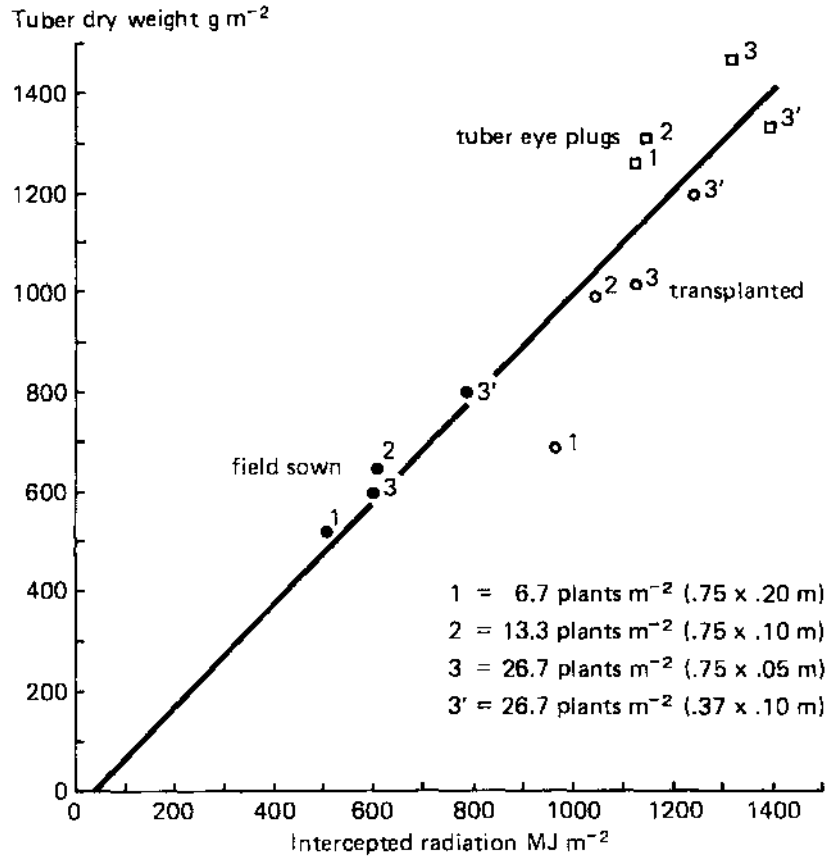


Figure 9 Effect of treatments on radiation intercepted and yield 1982.

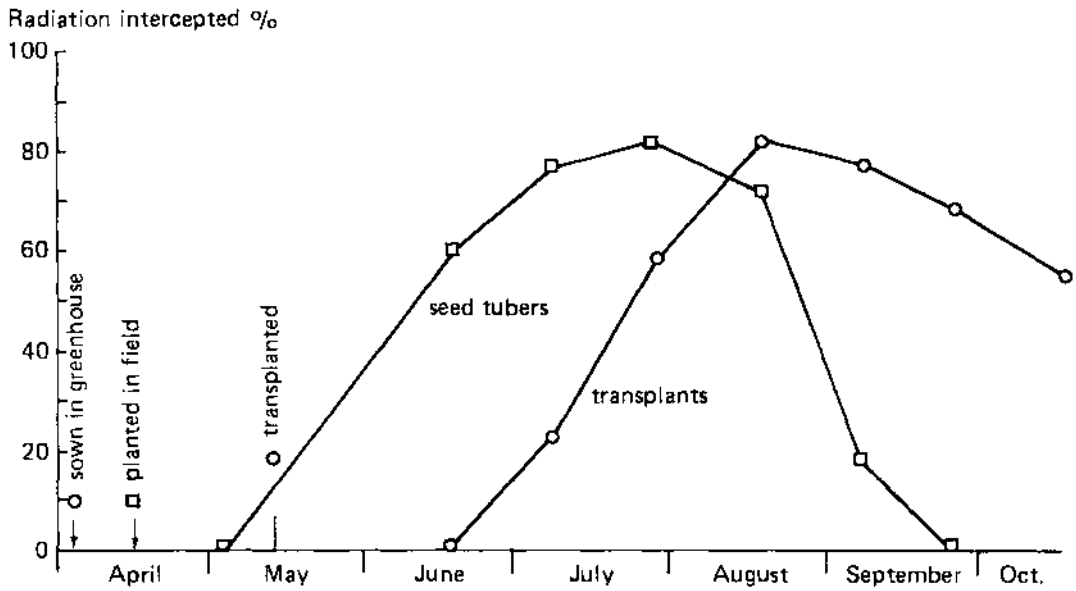


Figure 10 Percent radiation intercepted by crops propagated from tubers and seed 1981 mean 4 densities (J. Shakja).



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The type of analysis described, I believe is of considerable help in interpreting the results of treatments particularly where they depart so radically from normally accepted procedures, as is the case where normally vegetatively propagated crops are grown from seed. It not only assists in interpretation but it is of considerable help in planning further work. For example, in the case of our own experiments, it suggests that field sowing true seed is unlikely to give yields approaching those of conventionally propagated crops due to the excessive wastage of radiation resulting from the very slow canopy development. On the other hand, transplanting crops grown from true seed may only be marginally inferior to tuber propagated crops in the early part of the season and may under certain circumstances be superior in the latter part of the season. The initial poorer light interception may be overcome by earlier sowing of seeds for subsequent transplanting, if the shock due to delayed transplanting can be overcome by treatments such as the application of CCC, to curtail top growth and enhance early root development.

## The potential for producing tropical and sub-tropical root and tuber crops from seed

The apparent dearth of any literature on the production of the major tropical root crops from seed is interesting in that it suggests either that there is considerable potential for exploring this particular avenue, or that the difficulties of so doing are so formidable and well known that it offers an unlikely route for future development.

There can be no doubt that there are severe problems of flowering and seed production in all the tropical root crops (Simmonds, 1976; Wilson, 1977; Onwueme, 1978) which not only make any consideration of propagating these crops from seed a practical non-starter, but has also imposed a break on the progress of breeding new varieties. However, this need not necessarily be regarded as a permanent constraint either on breeding progress or on the possibility of ultimately being in a position to consider propagation from seed. Encouragement in this respect is given by research on pollination, seed set and germination in the white yam (*Dioscorea rotunda*) which has shown that these problems may be tackled successfully. Even more encouraging is the discovery that the low degree of flowering and high male to female ratio characteristic of plants produced by continuous vegetative propagation have been transformed to a much higher degree of flowering and a lower male to female ratio in second generation plants (Sadik, 1976). It has also been shown in sweet potato (Martin and Jones, 1971) that selection over six generations of open pollination increased the proportion of plants in flower, the number of flowers per plant and total seed production.

The use of growth regulators to promote flowering has been demonstrated in tannia (*Xanthosoma sagittifolium*) by McDavid and Alamu (1976), when applying gibberellic acid as foliar spray promoted flowering within 100 days when none were produced on the control plants. The same authors showed that soaking the setts in a solution of the same growth regulator before planting also promoted flowering (Alamu and McDavid, 1978).

The possibility that flowering may be restricted by pests and diseases has been demonstrated by Jones et al (1977) who found that certain insecticides gave dramatic increases in the number of seedlings per parent plant in the sweet potato.

The possibility therefore of developing new and more productive cultivars by sexual reproduction and of incorporating improved seed production capacity in such cultivars makes it perhaps worthwhile speculating on the potential advantages of propagating such crops from true seed.

It would, however, be potentially more productive if such speculations could be made in an agronomically orderly framework, and there are reviews of the physiological basis of tropical root/tuber crop production (Wilson, 1977; Loomis and Rapoport, 1976) on which such a framework may be built. These, however, like the model described above draw heavily on experiments with temperate root crops such as the potato and sugar beet. The merit perhaps of the model described here is its simplicity, and the fact that it can be tested with the minimal use of instrumentation and without complex growth analysis. It should be an invaluable aid, when considering questions of agronomic innovation, if this could be done in the light of clearly thought out and quantifiable physiological strategies.

Supposing that evidence collected in the way described suggested that there was a close relationship between intercepted radiation and the economic yield of a particular crop - what implications might this have for the production of that crop from true seed? Wilson (1977) has pointed out that if it is assumed that optimal light interception occurred at a leaf area index of 3, then a considerable proportion of the total time that tropical root crops are in the ground may be spent with indices of less than three (Table 2).

Table 2. Proportion of total crop time (%) spent with LAI less than 3.

| Crop | % total crop time |
|---|---|
| *Solanum* (tropical) | 40 |
| *Ipomoea* | 31 |
| *Xanthosoma* | 27 |
| *Dioscorea alata* | 50 |
| *Dioscorea esculenta* | 44 |
| *Dioscorea trifida* | 66 |

From Wilson, 1977

In terms of speeding up the interception of radiation, experience with *Solanum tuberosum*, outlined previously would seem to be distinctly discouraging, for the development of canopies capable of intercepting most of the incident radiation by seed propagated crops lagged far behind those of the vegetatively propagated counterpart, and especially where the seed was field sown. This is attributable both to the small amount of capital available for growth from seed compared with tubers, and to the climatic constraints which prohibited the early establishment from field sown seed because of the risk of frost damage. Earlier planting under protected conditions removed much of this adverse effect, and as outlined earlier, experiments are in hand which may make it possible to overcome this time lag completely - although obviously not without incurring extra costs.

This would suggest that in tropical root crops, similar strategies might be required to overcome similar problems, with seasonality of rainfall probably replacing the risk of frost as the most important environmental constraint.

However, the capacity to develop the crop off the field before planting could be a valuable property of seed propagation. It was shown clearly in Table 1 that the Dioscorea species are particularly slow to develop a crop canopy. Onwueme (1978) graphically describes the problem: "For the first 3 months or so after planting, the tuber is dormant and sprouting does not occur. Then for a further 1 to 2 months after emergence, the plant is almost exclusively made up of vine, the leaves remaining small and unexpanded." He points out that one way of speeding up early growth is to plant sprouted tubers; however, large losses of setts, both in moist and dry sprouting conditions is a severe drawback to the technique. With these problems in mind, it is possible to suggest that propagation from true seed might have something to offer. Seed grown in nurseries prior to the normal time of planting, where they could be watered and protected, could be ready to plant out and intercept radiation from the commencement of the growing season. Onwueme has pointed out that the foliage production from true seed may be sparse, but the possibility exists of solving this problem by early development away from the field, adjusting plant densities, and ultimately by improving early foliage development by breeding - in short by selecting a set of "tools" appropriate to this particular strategy.

Improving light interception in the early stages by appropriately managed seed propagation is, however, not the most obvious and immediately applicable way in which radiation interception might be improved to increase productivity. However, virus and other pathogens which are borne on the vegetative organs of propagation may cause serious reductions in the size of the leaf canopy and restrict the interception of radiation, propagation from seed may enable crops to be established which are free, at least initially free, from infection, and may escape or partially escape from the consequent reduction in canopy size. This possibility is illustrated in Figure 12 and Shakya (unpublished data) has shown that under these circumstances, yield of seed and tuber propagated crops were comparable. In this context it should not be overlooked that young seedlings may be particularly susceptible to infection by virus and other diseases, and will need adequate protection. This problem was experienced in some of our own experiments with seed propagation of potatoes in 1982. Whether or not this particular benefit of seed propagation will be attractive will depend upon the ease with which reasonably disease free stocks of vegetative propagules can be both maintained and obtained.

In addition to the possible effects of production from seed on the physiologically base strategy of production, this technique has other implications. It has often been pointed out that where the organ used to propagate the crop vegetatively is also the part of the plant which is consumed, then seed propagation has the obvious attraction of enabling the grower to utilize all the economic fraction of the crop, and to this extent some yield reduction due to seed propagation could be tolerated. Table 3 shows the low multiplication ratio of vegetatively propagated crops compared with seed crops.

These problems do not apply to cassava and sweet potatoes where propagation is by stem cuttings or from vines. Other considerations of no immediate relevance to the physiology of yield and vigorously canvassed as being of considerable practical importance to the production of potatoes from seed (Accatino and Malagamba, 1982) involve the relative ease and cheapness of storing, transporting and handling seed rather than vegetative material, and these considerations would apply equally well to the production of other vegetatively propagated crops.

Table 3. Ratio of fresh-weight yield to weight of planting material (multiplication ratio) for various crops.

| Crop | Approximate multiplication ratio |
|---|---|
| Guinea corn | 80 |
| Maize | 70 |
| Cowpea | 25 |
| Upland rice | 20 |
| Groundnut | 15 |
| Irish potato | 7 |
| Tannia | 5 |
| Taro | 5 |
| Yam | 5 |

Onwueme, 1978

In this paper I have attempted to give a broad outline of the potential and problems of propagating tropical root crops from seed. I have not dealt with the problems and benefits which may arise from incorporating propagation from seed into mixed cropping systems nor with possible effects on the quality - particularly with regard to size distribution of the edible products. These are important problems, but ones which need to be resolved locally.

The ideas put forward are based on studies of the potato crop, grown in Britain, by traditional vegetative methods and from seed, and it is clearly unwise to extrapolate uncritically such experience to crops and crop environments with greatly differing characteristics. It is also clear that, unlike the potato, a major obstacle for many tropical root crops is the difficulty of obtaining seed and this hurdle must be surmounted before any progress can be made. However, anyone advocating the possibility of producing potato crops from seed would, as little as 15 years ago, have been classified as an eccentric academic, and subsequent developments have made many agronomists reconsider the accepted techniques which have been developed over many generations. This experience would make it unwise to write-off the potential for using this technique for other vegetatively propagated crops.

The major point that I have tried to convey in this paper, and here I think our temperate experience may be valid to the tropics, is that it should be possible to make more rational conjectures concerning such questions as the potential value of the seed propagation of the tropical root crops if they were made in the context of physiologically soundly based production strategies. Such strategies could, in addition, suggest useful plant characters which could be incorporated into plant breeding objectives. It also seems to me that a case can be made for using the simplest acceptable physiological model available, and one which can be tested and applied without the need for sophisticated instrumentation. I hope that this paper has been able to make a reasonable case for such an approach.

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# The Origins and History of the International Society for Tropical Root Crops

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ABSTRACT

The historical process leading to the International Society for Tropical Root Crops (ISTRC) began in 1964, in Trinidad. A group within the University of the West Indies conceived the holding of a series of crop-oriented symposia, and in view of local relevance, "Tropical Root Crops" was selected as the first topic. This was accepted by the University early in 1965; the meeting, originally scheduled for April 1966, was actually held in April 1967. This Symposium brought together many hitherto isolated workers from many countries and was a great success. A strong feeling emerged that continuity must be established: a Continuing Committee was formed, with a sub-Committee to start the Newsletter, and an offer from the University of Hawaii to host a Symposium 3 years ahead, accepted.

This 2nd Symposium was held in August 1970; during it a Constitution was formally adopted, and ISTRC came into existence as a legal entity, the late Dr. M.L. Magoon being its first President. The 3rd Symposium was held at the International Institute for Tropical Agriculture (IITA) in Nigeria in December 1973, when the writer was elected President, and a commitment made by the Centro Internacional de Agricultura Tropical (CIAT), Colombia to host the 4th Symposium. The latter meeting took place in August 1976, and Dr. D.L. Plucknett elected President. Again, a commitment was made for the hosting of the 5th Symposium at Manila in the Philippines. This was realized in September 1979. All these three later Symposia, attracting different international participation, were also successful.

## Introduction

At the Manila Symposium in 1979, our President asked me to prepare a history of the Society, feeling that, 16 years on, there was need for a permanent record of what took place in those early days, especially for those who did not attend the earlier meetings. I was very pleased to accept, especially as I am the only person who, by good fortune, has attended all the Symposia held.

Events leading to the formation of ISTRC date back to the mid-1960's, a very different era from the present. Many tropical countries were only emerging from long periods of colonialist/imperialist domination, and tropical agricultural science was still greatly influenced by the socio-cultural hegemonism of the European/North American world. Its efforts were thus oriented largely towards

export cash crops, and food crops in general were largely neglected. Tropical root crops in particular, perceived as inherently alien by the expatriate or overseas-trained scientists and administrators, were even more neglected than other food crops. Only small cadres of indigenous scientists had emerged, many were still young and inexperienced; had received their scientific education in Europe or North America, largely unrelated to the problems of the tropics. Some useful work had been done, but depended on the enthusiasm of a few rare individuals, working in isolation. Research on root crops received little formal encouragement, and sometimes encountered substantial opposition. Much was never published, or appeared only in reports of limited circulation. Only two International Agricultural Research Institute (IARI's) existed, and neither had root crop interests.

It is therefore not surprising that the concept of an international meeting, or a permanent organization to unite tropical root crop workers, had not developed earlier. Mention should, however, be made of two earlier meetings. The Congres du manioc et des plantes feculentes tropicales des territoires de l'Union francais, was held in Marseille, France, in September 1949. Its delegates were all from the Francophone world and it was mainly limited to cassava. The Taro Conference of 1965 in Hawaii dealt with a single crop; and was attended only by delegates from the Pacific Basin and the USA, mainly Hawaii. Neither of these meetings led to on-going efforts to improve communications in the world of tropical root crops.

## Antecedants and the First Symposium, St. Augustine, Trinidad

The initiatives that led to the Society's formation were taken in the Caribbean, mainly Trinidad. In the early 1960's, the new University of the West Indies was establishing its identity, and the School of Agriculture particularly, inheriting the traditions of the former Imperial College of Tropical Agriculture dating back to 1921, was well placed to make its mark in the Caribbean. An informal group in the University, including Dr.J.A. Spence, Mr. P.H. Haynes and Dr. L.A. Wilson, conceived the holding of a series of scientific meetings, modelled on the Easter Schools of the University of Nottingham, but on an essentially Caribbean basis. Most fortunately, the theme "Tropical Root Crops" was selected for the first meeting, and accepted by the University in February 1965:

> "Because of the importance of the starchy roots and tubers as food in tropical countries and the emphasis placed by the University on relevant research, it was considered highly desirable that an attempt be made to collate existing information on these crops in order to identify gaps in our knowledge, make plans to fill these and also establish bases for practices aimed at economically expanding production and utilization"

and the meeting scheduled for April 1966. An Organizing Committee was set up and a circular letter was distributed widely, from which I quote:

> "A symposium on 'Tropical Root Crops' is being organized by the School of Agriculture of the University of the West Indies during the Easter recess of 1966. It will be held at St. Augustine and is scheduled for 27th March to 2nd April. The purpose of the symposium is to review existing knowledge of the common starchy 'roots' grown in the tropics for food and to define paths that may, with advantage, be followed in future investigations. The main emphasis will be on topics of basic importance to root crop production."

Because of the absence of certain key members of the Organizing Committee in 1966, and to give more time for publicity, the Symposium was finally held at St. Augustine, 2nd to 8th April, 1967. Participants numbered 157 from 30 countries, and 56 papers were read. There was, naturally, a preponderence of delegates from the Caribbean, but the Symposium was truly international. Participants were welcomed to Trinidad by the Hon L.M. Robinson, Minister of Agriculture, Lands and Fisheries, and to the University by the Pro-Vice-Chancellor, Dr. H.D. Huggins. The symposium was an unqualified success - not least perhaps on account of the generous, traditionally West Indian, hospitality that followed Dr. Huggins' timely reminder of the definition of a Symposium: "a convivial meeting for drinking and intellectual entertainment." There was an elegant sufficiency of both.

The Symposium took place at what can now be seen as one of the cruces of history; everywhere tropical root crop workers were realizing the importance of their crops, and the need for improved communication and recognition. It is, perhaps, no coincidence that the same year saw the publication of the nomothetic paper "Choice of food crops in relation to actual and potential production in the tropics" by de Vries, Ferweda and Flach, and my own definitive monograph on yams: almost for the first time, major contributions on tropical root crops were being made to the "respectable" scientific literature. The Plenary Session of the Symposium reflected the spirit of the age: in a long meeting, many ideas were enthusiastically protagonized. Eventually, it was unanimously decided that a similar Symposium should be held in a few years' time, and the location of Hawaii suggested; that a Newsletter should be established; that attempts should be made to establish a Root Crop Information Centre; and most important, that a Continuing Committee should be set up to ensure publication of the Proceedings - which eventually appeared in 1969--and to co-ordinate other matters of interest. During the next three years this Committee laid the foundations for the formation of ISTRC.

## The Second Symposium, Hawaii: Formal Constitution

The suggestion had been made at Trinidad, by Dr. E.E. Trujillo of the University of Hawaii, that a second Symposium could be hosted there, a few years on. This, in fact, came to pass, although unfortunately Dr. Trujillo was away from Hawaii at the time. However, his absence brought our retiring President, Dr. D.L. Plucknett, into a situation where he took over local arrangements for the Symposium, and having thus become involved in ISTRC's affairs, he has continued to influence and assist the Society in many different ways. The Symposium was held 23rd to 29th August, 1970, at the Ala Moana Hotel in Honolulu, although many facilities were arranged by Dr. Plucknett's Department of Agronomy of the University. It was smaller than that at Trinidad, perhaps because of the size of the Pacific Basin, from which many delegates were drawn, and the correspondingly high cost of air fares: while for delegates from other areas, Hawaii was very much on the "other side of the world," and the cost of attendance even higher. Nevertheless, 75 delegates were present, representing 25 countries, and a technically very useful meeting held. A feature of the Symposium was that, although most of the meetings were held in Honolulu, the group migrated for the last two days to the more relaxed surrounding of the island of Kauai. Here, delegates were released from the pressures of Honolulu, and were able to see the production of taro (*Colocasia* spp.) being conducted both in the traditional Polynesian system, and also with modern innovations. Other crops were discussed at the Symposium, but there was some concentration on taro, in view of its importance in the Pacific. The first volume of the Proceedings, containing the invited papers, was already published and was handed out to delegates on arrival.

Between Trinidad and Hawaii, it became clear in correspondence and meetings between members of the Continuing Committee, that there was need for some permanent form of association, and the concept of forming an International Society emerged. During this period, I drew up a first draft for a Constitution, which, after some modifications by others on the Continuing Committee, was presented to the Plenary Session at Hawaii. After lengthy debate, it was unanimously agreed that an International Society for Tropical Root Crops should be formed, and after some further modifications, the Constitution was formally accepted. Elections to the various offices were held: Dr. M.L. Magoon of the Central Tuber Crop Research Institute (CTCRI) in India, at that time the only specialist root crop institute in the world, became the Founder President. Thus was the Society formed. Even at the time, the Hawaii meeting was referred to as the "Second Symposium" - as though the Society had been formed retrospectively at Trinidad!

The Third Symposium, Ibadan, Nigeria: Consolidation

It was suggested by the President, Dr. Magoon, that the next Symposium should be held in India, but some difficulties developed and after a working visit by the Secretary, Mr. Haynes, to the newly-formed International Institute for Tropical Agriculture (IITA) at Ibadan, Nigeria, this latter location appeared more appropriate. After negotiations between officers of the Society and IITA Management, it was agreed that the 3rd Symposium should be held there. Nigeria, as the world's largest producer of yams, and third largest producer of cassava, and the most populous country in Africa, ensuring good attendance by local delegates, seemed a most suitable venue.

The Symposium was held at IITA, from 2nd to 9th December, 1973. It was attended by 125 delegates, 57 from within Nigeria, the others from 31 countries widely spread across the world: a truly international gathering. Many technically valuable papers were presented and discussed, and a major achievement was the establishment of contacts between African workers with those in Latin America, Asia, and elsewhere, often for the first time. Conceptual thinking about root crops was starting to undergo a radical change from that which had prevailed in the 1960's, when the Trinidad Symposium was being planned. A substantial program on cassava had been initiated, supported largely by the Canadian International Development Research Centre (IDRC), at the Centro Internacional de Agricultura Tropical (CIAT) and a related program, of especial relevance to African conditions, especially African mosaic, at IITA. This Institute also had global responsibility, within the network of IARI's for work on yams. Other funds were also becoming available for work on tropical root crops, and it was no longer so professionally "disreputable" to have interests in the field. It was against this background, and that of a high level of invited and presented papers, that a most successful Symposium was held, although it was unfortunate that the President was unable to attend. A number of participants were sponsored financially by the IDRC, and others by USAID.

For the first time, there was no doubt as to where the next Symposium would be: an offer came from IITA's Latin American counterpart, CIAT, early in the meeting, which was accepted with alacrity. The Plenary Session discussed the Constitution in considerable detail, and changes were made, notably the addition of a third position of Vice President, with especial responsibility for the coming Symposium (Dr. Alvarez-Luna, of CIAT, was naturally appointed), while it was also resolved that definite commitments to locations for coming Symposia would always be made in future. In Dr. Magoon's absence, I had the honour to be elected President for the next triennium. This Symposium served firmly to establish ISTRC

in the world of tropical agriculture. The only problem that arose was the long delay in the appearance of the Proceedings, which were published only after those of the 4th Symposium!

## The Fourth Symposium, Cali, Colombia

Much activity took place in the period between the Ibadan and Cali meetings: CIAT was rapidly building up its cassava program, which opened opportunities for many to visit CIAT, and to interact with the very competent local Organizing Committee.

When the meeting was held, 1st to 7th August, 1976, the excellent local arrangements made were immediately evident, even though, most unfortunately, Dr. Alvarez-Luna had recently left CIAT. The physical resources of CIAT - possibly architecturally the pleasantest research station in the world - made it possible for many participants to live on campus, and provided an excellent environment for both work and relaxation. Together with the many attractions of neighboring Cali, this went far to make the Symposium an interesting and enjoyable one: the closing reception and banquet, I recall, was one of the finest social occasions I have attended. Technically, the meeting was a great success, and most presentations were of a high standard, thanks to a careful editing policy adopted by the local committee. Attendance was the highest and most international of all the Symposia held so far, with 172 participants from 43 countries, although there was naturally a predominance (50) of Colombians. A number of the overseas participants were supported by IDRC and USAID and further most useful assistance was given by IDRC by providing professional editors who attended the Symposium, collected papers, edited them and published the Proceedings in record time - well inside a year from the Symposium.

Offers to host the next Symposium were received from both India and the Philippines (where a National Root Crop Research Centre had recently been established) and the Council recommended acceptance of the latter, which decision was ratified by the Plenary Session. Dr. D.L. Plucknett was elected as President.

## The Fifth Symposium, Manila, Philippines

For the second time, there had been no doubt as to where the Symposium was to be held, and there was the advantage that the active new Secretary was a Philippine national, and Director of the Philippine Root Crop Research and Training Centre (PRCRTC). The Centre being in a rather remote location in Leyte, and having somewhat limited facilities, the main part of the Symposium was held in Manila, at the Philippine Village Hotel, which provided good conference facilities, and accommodated all the delegates together. Valuable assistance in organization was provided by the Philippine Council for Agricultural and Resources Research (PCARR). The Symposium, held 17th to 21st September, 1979, was only slightly smaller than the 4th, with 129 participants from 38 countries, and again a strong editorial policy assured a high standard in papers presented. A feature of the Symposium was its association with a Workshop on Taro supported by the International Foundation for Science (IFS), primarily for its own grantees working on the crop in South East Asia and the Pacific Basin. This Workshop was actually held at PRCRTC but the delegates attended the main Symposium as well. The attendance was thus broadened, and a strong representation of taro workers ensured, while at the same time an interesting post-Symposium tour was provided for many delegates.

The Plenary Session went smoothly, with Dr. Plucknett re-elected as President, together with a balanced selection of Council members. Offers to host the next Symposium were received from India and the Centro Internacional de la Papa (CIP), Peru, and in view of the two former unsuccessful attempts to meet in India, the former was accepted. However, various problems at CTCRI would have rendered difficult the holding of a meeting there, and a new approach was made to CIP, who most kindly agreed, at a rather late date, to host the present meeting.

Other Activities

The main function of ISTRC has been to ensure that regular Symposia are held, and it has been the policy of successive Councils to hold Symposia in geographical locations spread widely about the tropical world, to gather as many workers as possible into the fold. It follows, therefore, that once a Symposium has been held in a particular region, there is unlikely to be another for many years to attract the same regional participants. After the 3rd Symposium in Nigeria, a number of people conceived the formation of an African Branch: many of these came together at a horticultural conference in Kumasi, Ghana the following year, and developed ideas further, eventually to crystallise after the (Nigerian) 1st National Seminar on Root and Tuber Crops held at the National Root Crop Research Institute (NRCRI), Umudike, 21st to 25th March, 1977. The Branch was formally constituted in June, 1978, the names of Dr. B.N. Okigbo and Dr. E.R. Terry being much concerned with its formation. A Regional Symposium was held 8th to 12th September, 1980 at Ibadan, and another meeting is scheduled for Douala, Cameroon in September 1983. There have also been suggestions since the 5th Symposium in Manila, that a South East Asia Branch might be formed, although formal steps have not been taken. Such regional Branches are welcome, as a way of extending the aims of the Society "to stimulate the efficient production and utilization of tropical root crops and to improve knowledge of these crops by dissemination of information." Although it is an entirely separate legal entity, it may be appropriate here to mention the Indian Society for Tropical Root Crops, which was founded by a former Director of CTCRI, Dr. N. Hrishi, and which is affiliated to ISTRC.

The other important activity of ISTRC is the publication of the Tropical Root and Tuber Crops Newsletter. The first issue appeared in January 1968, less than a year after the Trinidad Symposium, edited by Dr. J. León of the Instituto Interamericano de Ciencias Agrícolas (IICA). To quote from the Editorial:

> "During the International Symposium on Tropical Root Crops, held at the University of West Indies, St. Augustine, Trinidad, last April, it was agreed to establish a tropical root crops newsletter. Its main purpose is to facilitate communication among the persons working in genetics and breeding of these crops, as well as on allied fields."

Subsequently, the Newsletter broadened its scope to cover all aspects of tropical root crop studies. For many years, it was edited by Dr. Martin of the Mayaguez Institute of Tropical Agriculture, Puerto Rico, who thus performed a great service to ISTRC, while the last two issues were edited from the University of Hawaii. In all, 12 issues have appeared in the 16 years since Trinidad, the last in 1982, although the original aim was that it should be annual.

## Conclusion

The 16 years since Trinidad have seen a great change in tropical agriculture and root crops are by now far more generally accepted as important, and very substantial international and national funding is now being given, especially for work on cassava. Three IARI's; CIP, CIAT, and IITA have very substantial root crop programs, while in addition to India, Nigeria, Togo, Brazil and the Philippines now have specialized root crop institutes. Work in the area has proliferated in the greatly increased numbers of Universities and research institutes around the tropical world, although much still remains to be done. It is difficult to quantify how far these changes have been brought about by ISTRC's activities, but its function in creating a world community of tropical root crop workers, and the many contacts, collaborations and indeed personal friendships that have been formed at its Symposia, have surely played a major part.

| | 1970/1973 | 1973/1976 | 1976/1979 | 1979/1982 |
|---|---|---|---|---|
| President | M.L. Magoon (India) | D.G. Coursey (U.K.) | D.L. Plucknett (U.S.A.) | D.L. Plucknett (U.S.A.) |
| Vice-Presidents | D.G. Coursey (U.K.) | E. Alvarez-Luna (CIAT) | L. Degras (France) | N. Hrishi* (India) |
| | J. León (FAO) | P.H. Haynes (Trinidad) | H.D. Thurston (U.S.A.) | H.D. Thurston (U.S.A.) |
| | - | D.L. Plucknett (U.S.A.) | J. Madamba (Philippines) | L. Degras (France) |
| Past-President | - | - | D.G. Coursey (U.K.) | D.G. Coursey (U.K.) |
| Secretary | P.H. Haynes (Trinidad) | T.U. Ferguson (Trinidad) | M.R.Villanueva (Philippines) | M.R.Villanueva (Philippines) |
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| | F.W. Martin (Puerto Rico) | L. Degras (France) | L. Luján (Colombia) | F.D. Ghani (Malaysia) |
| | D.L. Plucknett (U.S.A.) | F.W. Martin (Puerto Rico) | B.N. Okigbo (Nigeria) | A. Montaldo (Venezuela) |
| | - | B.N. Okigbo (Nigeria) | L.A. Wilson (Trinidad) | E.R. Terry (IITA) |
| | - | L.A. Wilson (Trinidad) | - | T.U. Ferguson (Barbados) |
| | - | - | - | R.S. de la Peña (U.S.A.) |

*S. Sadik (CIP) after 1981.

Herbicidal Weed Control in Tannia Cocoyam (Xanthosoma sagittifolium)

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ABSTRACT

Sprouted corms of tannia (Xanthosoma sagittifolium) were grown at high density (1x0.5 m) with weeds controlled by a mixture of 4-5 kg/ha ametryne and 1 kg/ha paraquat, or by weeding with hand tools. The controls were an unweeded treatment at high density, and a hand-weeded treatment at the conventional spacing of 1x1 m.

Total yield (corms plus cormels) per hectare for the herbicide treatment was the same as for the hand-weeded treatment at the same high density, and higher than for the hand-weeded treatment at low density. Yet controlling the weeds by herbicide was only 46-55% as costly as control by hand.

## Introduction

The control of weeds in cocoyams is a major operation in the production cycle. In most countries, weeding is with hand tools about three times during the season. With increasing labor costs, hand-weeding has become expensive and uneconomical, and the search for effective chemical methods of weed control has intensified.

Onwueme and Fadayomi (1980) developed an effective weed control package for yams using herbicides (ametryne and paraquat) and planting at high density. This combination eliminated hand-weeding altogether and produced the crop at reduced cost.

These experiments were conducted to determine if the same strategies could be adopted in developing a weed control package for cocoyams. Moreover, since yams and cocoyams are often intercropped, it would be beneficial if the same herbicide combination could be found effective for both crops. The objective of this study was to evaluate cocoyams when the crop is grown at high density and weeds are controlled with ametryne and paraquat.

## Materials and Methods

Sprouted corms of tannia (Xanthosoma saggittifolium) each weighing about 250 g were planted 50 cm apart on ridges that were 1 m apart. Weeds were controlled with herbicides (Treatment A); or by hand weeding 2-4 times during the season (B); or the plot was left weedy throughout the season (C). An additional treatment (D)

used conventional wide spacing (i.e. low density) of 1x1 m with hand weeding. Herbicide application for treatment A in 1980 was a tank mix of ametryne (4 kg a.i./ha) plus paraquat (1 kg a.i/ha). In 1981, ametryne was at the rate of 5 kg a.i./ha, with paraquat at 1 kg a.i./ha. In each case, herbicides were applied 3 days prior to planting. Planting was in May each year, while harvesting occurred about 9 months later, after the plants had died back. Early in the season scarecrows were used to keep away birds that might dig up and consume freshly planted corms.

Field experimental layout was a randomized complete block design with 20 plants per plot in 1980; in 1981, 60 plants per plot for treatments A, B and C, and 30 plants for treatment D. The 1981 records included time required for various field operations and the heights of the plants at 5 months after planting.

## Results

### 1980 Experiment

Weed fresh weights at harvest were significantly higher for weedy control than for the herbicide treatment, indicating effectiveness of the herbicides (Table 1). No significant difference was noted in weed fresh weight of the herbicide treatment and the hand-weeded controls.

Table 1: Weed fresh weight at harvest (1980).

| Treatment | Weed weight (tons/ha) |
|---|---|
| Herbicide | 1.28 |
| Hand-weeded | 0.84 |
| Weedy | 7.66 |
| Hand-weeded, low density | 0.51 |
| LSD.05 = 3.39 | |

The corm, cormel and total yield for the experiment are in Table 2. Yield of the weedy treatment was significantly lower than of other treatments. This was true of corm, cormel and total yield. The corm and total yield for the herbicide treatment and the two hand-weeded controls did not differ significantly. However, the herbicide treatment produced a significantly higher cormel yield than the low density hand-weeded treatment.

Table 2: Cocoyam yields for 1980.

| | Yield/ha (kg) | | | Yield/stand (g) | | |
|---|---|---|---|---|---|---|
| Treatment | Corm | Cormel | Total | Corm | Cormel | Total |
| Herbicide | 7,693.3 | 10,810.0 | 18,503.3 | 384.7 | 540.5 | 925.2 |
| Hand-weeded | 7,606.6 | 9,565.0 | 17,171.6 | 380.3 | 478.3 | 858.6 |
| Weedy | 2,240.0 | 1,528.3 | 3,768.3 | 151.3 | 92.6 | 243.9 |
| Hand-weeded, low density | 5,615.8 | 6,491.7 | 12,107.5 | 576.3 | 665.5 | 1,241.8 |
| LSD.05 | 2,549.4 | 4,127.3 | 6,665.0 | 173.6 | 246.6 | 416.6 |

Corm, cormel and total yields per stand were significantly lower for the weedy control than for the other treatments (Table 2). Cormel and total yield per stand for the herbicide treatment and the two hand weeded treatments did not differ significantly. However, corm yield per stand was significantly higher for the low density hand-weeded control than for the herbicide treatment or the high density hand-weeded treatment.

1981 Experiment

Plant height measurement at 5 months after planting showed the mean heights for both herbicide treatment and low density hand-weeded control were the same (Table 3). This was significantly higher than the mean plant heights for the high density hand-weeded and the weedy treatments.

Table 3: Plant height at 5 months after planting (1981).

| Treatment | Mean plant height (cm) |
|---|---|
| Herbicide | 62.5 |
| Hand-weeded | 54.6 |
| Weedy | 51.1 |
| Hand-weeded, low density | 62.5 |
| LSD.05 = 5.7 | |

Time required per hectare for the two weedings in the hand-weeded control treatments are in Table 4. Weed control by herbicide cost only 55% and 46% of what it cost to control the weed by hand weeding in the high density and low density plots, respectively (Table 5).

Table 4: Weeding time per hectare (1981).

| Treatment | 1st weeding (man-hours)* | 2nd weeding (man-hours) | Total (man-hours) | Total (man-days)** |
|---|---|---|---|---|
| Hand weed, high density | 148.08 | 185.11 | 333.19 | 42 |
| Hand-weeded, low density | 166.40 | 231.29 | 398.08 | 50 |

*One man-hour: The continuous working of an able-bodied person for 1 hour.

**One man-day consists of 8 man-hours.

The results show corm, cormel and total yields/ha of the herbicide treatment were significantly higher than those of the low density hand weeded control

(Table 6). No significant differences were noted however between the high density hand-weeded treatment and the herbicide treatment for corm, cormel or total yield. The weedy control treatment recorded a lower corm, cormel and total yield than the other treatments except in the low density hand-weeded control where corm yield was not significantly different. Yield per stand is in Table 6. The corm, cormel and total yields per stand were significantly lower for the weedy control than for any of the other treatments except the corm yield of the high density hand-weeded treatment. Corm, cormel and total yields per stand were significantly higher for the hand-weeded treatment at the low density than at the high density. However, no significant differences were noted between low density hand-weeded treatment and herbicide treatment with respect to corm and total yield per stand.

Table 5: Comparative costs of weed control for the various treatments.

| | Cost/hectare (₦)* | | |
|---|---|---|---|
| Material/Operation | Herbicide | Hand-weed high density | Hand-weed low density |
| Herbicide (i) Ametryne | 70.00 | - | - |
| Herbicide (ii) Paraquat | 22.22 | - | - |
| Labor for spraying** | 4.61 | - | - |
| Use of knapsack sprayer | 10.00 | - | - |
| Labor for weeding** | - | 193.62 | 230.5 |
| Total | 106.83 | 193.62 | 230.50 |

*1₦ = 1.5 U.S. dollars.

**Labor cost was approximately ₦4.61 per man-day of 8 hrs.

Table 6: Cocoyam yields for 1981.

| | Yield/ha (kg) | | | Yield/stand (g) | | |
|---|---|---|---|---|---|---|
| Treatment | Corm | Cormel | Total | Corm | Cormel | Total |
| Herbicide | 3,816.7 | 3,904.7 | 7,721.4 | 272.5 | 276.6 | 549.1 |
| Hand-weeded | 3,483.3 | 3,603.1 | 7,086.4 | 231.3 | 234.3 | 465.6 |
| Weedy | 2,243.4 | 1,657.6 | 3,901.0 | 165.8 | 121.0 | 286.8 |
| Hand-weeded, low density | 2,788.2 | 2,831.9 | 5,620.1 | 352.3 | 356.3 | 708.6 |
| LSD.05 | 703.8 | 1,000.6 | 1,697.2 | 78.0 | 97.9 | 175.4 |

The generally low levels of yield in 1981 when compared with 1980 were probably due to the poorer soil used for the 1981 experiment.

## Discussion

Results indicate that herbicide weed control was possible in tannia without any yield reductions when compared with hand-weeded plots planted at high or low density. The herbicide treatment controlled weeds throughout the season, so no

supplemental weeding was required. Consequently, the cost of controlling weeds in the plot was reduced to a fraction of what it is in conventional practice.

Herbicide use to control weeds in cocoyams is not new. Diuron and atrazine at 1-2 kg/ha has been recommended for tannia (Kay, 1973; Kasasian, 1971) while diuron, atrazine, trifluralin, ametryne, or nitrofen have been recommended for taro (Pena et al, 1971). However, in tannia and upland taro, supplementary weeding is usually necessary because of decreasing leaf area and insufficient ground cover near the end of the season. Closer spacing in these experiments tended to maintain complete ground cover throughout the season and make supplementary weeding unnecessary.

As mentioned earlier, the ametryne with paraquat herbicide combination provided weed control in yams (Onwueme and Fadayomi, 1980). Its usefulness in cocoyams as well implies that it can be successfully used where yams and cocoyams are intercropped. In that case, plant yams first, apply herbicides 3-4 weeks later, and then plant cocoyams an additional few days later.

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Water Use and Efficiency in Lowland Taro Production

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ABSTRACT

Experiments were conducted to determine the effects of different rates of water flow and depth of flooding on the yield and yield components of lowland taro.

Using rates of water flow of 280,470 l/ha/day to 981,640 l/ha/day (30,000 gal/A/day to 105,000 gal/A/day), no significant differences were obtained in total corm and cormel yields of lowland taro, variety Lehua Maoli. Corm, marketable cormel and total yields averaged 32.3, 31.7, and 64.0 tons/ha, respectively. Water use efficiency calculated on the basis of liters water needed to produce a kilogram of taro corms was 800 l/kg for the lowest rate of water flow and 2,790 l/kg for the highest.

Yields of lowland taro decreased as depth of flooding increased from 0 cm to 20 cm. Highest yields were obtained from plots where water depth was maintained at 0 cm. Flooding to a depth of 16 and 20 cm drastically reduced marketable cormel yields causing a severe drop in total yield. Optimum depth of flooding in lowland taro appear to be 4 to 8 cm as this is sufficient to keep weeds under control without causing severe yield losses. Total yield at 0 cm depth was 28.5 tons/ha compared to 16.9 tons/ha at 20 cm depth of flooding.

Taro, Colocasia esculenta (L.) Schott, is a crop grown throughout the tropics and sub-tropics under a wide range of environmental and edaphic conditions. It is grown under extremes of water regimes, i.e. dryland or unflooded culture to waterlogged or flooded culture. Although majority of the approximately 760,000 ha of land used for taro production is under dryland or upland growing conditions (FAO, 1975), almost all of the taro in Hawaii is grown under waterlogged or flooded culture (Plucknett and de la Peña, 1971). Under flooded growing conditions, taro is assumed to use excessive amounts of water during its cropping period. Water used to flood the taro fields is allowed to flow continuously assuring low water temperature which helps to prevent development of corm diseases and also enhances the growth of the taro plant. Estimates on the actual amount of water needed to grow lowland taro has varied from farmer to farmer. Even water measurements done in taro farms vary considerably depending on the season when measurements are

taken. Watson (1970) estimated that the average water requirement of taro is 140,000 to 373,000 l/ha/day (15,000 to 40,000 gal/A/day) based on measurements made in taro fields of Oahu, Hawaii between 1962 and 1964.

In Hawaii, taro is a crop of major commercial importance. It was cultivated by the early Hawaiians who used taro as the source of "poi," the staple food which is prepared from boiled taro corms, mashed and pounded into a paste. Early records of Hawaiian agriculture report large acreages of taro in Hawaii, however, production over the last decade has declined considerably. In 1972, Hawaii produced about 4.1 million kg while in 1981, the production was only about 2.8 million kg, showing a decline of approximately 31% (Hawaii Agricultural Reporting Service, 1982). Much of the decline in Hawaiian taro production is attributed to the declining acreage used for taro. The decrease in acreage of taro is again attributed to the urban encroachment which is not only squeezing out the land used for taro but also drastically reducing the availability of water for lowland taro production.

Farmers in Hawaii, in their efforts to save the declining taro lands have gone to the extent of suing the government for water needed in taro production. To assess the water needs of taro growers, especially in Oahu, Hawaii where population is concentrated, experiments were conducted to determine the effects of different rates of water flow and depth of flooding on the growth and yields of lowland taro. The experiments on the rate of water flow were conducted in a commercial field in Hanapepe Valley, Kauai while the experiments on depth of flooding were conducted at the Kauai Branch Research Station, Kapaa, Kauai.

## Materials and Methods

### Experiment I - Water Flow Rate

This experiment was in Hanapepe Valley on the Island of Kauai in a commercial taro farmer's field. The soil is a typic Fluvaquents (U.S. Soil Taxonomy) or Eutric Gleysols (FAO/UNESCO) (Beinroth, Ikawa and Uehara, 1974) which is used for lowland taro production in Hawaii.

Using a replicated randomized complete block design, six rates of water flow were assigned in plots approximately 6x9 m in size. The rates of water flow used ranged from 280,470 l/ha/day (30,000 gal/A/day) to 981,640 l/ha/day (105,000 gal/A/day). Water flowing into each individually diked plot was provided through plastic pipes with individual control valves.

Taro, variety Lehua Maoli, the commercial lowland variety used in Hawaii, was planted with a 60x45 cm spacing, a recommended plant density for lowland taro (de la Pena, 1978). Except for different rates of water flow, all management practices including fertilization and weeding were uniformly applied. Fertilization and soil amendments consisted of a pre-plant application of hydrated lime (calcium hydroxide) at 500 kg/ha and urea, treble superphosphate and potassium chloride to provide rates equivalent to 100 kg/ha each of N, $P_2O_5$, and $K_2O$. A complete fertilizer mix (16-16-16) was applied 2 months after planting at 312.5 kg/ha. Urea was applied at 110 kg/ha 5 months after planting. Irrigation was stopped and the plots allowed to drain before each fertilizer application. Irrigation was resumed 5 to 7 days after application of fertilizers.

The crop was harvested 15 months after planting. Twenty hills were harvested from each plot for yield and yield component estimation.

Experiment 2 - Depth of Flooding

The depth of flooding experiment was performed in concrete tanks approximately 2 m wide, 3 m long and 1 m deep containing Kapaa Soil (Typic Gibbsiorthox). Six depths of flooding were assigned in a randomized complete block design replicated three times. Depths of flooding used ranged from 0 cm to 20 cm. Flooding was continuous except when fertilizers were applied during which time tanks were drained before the fertilizers were broadcast. Flooding was resumed 5 to 7 days after fertilizer applications. Basal fertilizer used was 16-16-16 at 110 kg/ha immediately before the last puddling operation. Three weeks after planting, the plots were inoculated with *Azolla filiculoides*, a floating fern capable of fixing atmospheric nitrogen, at 100 kg/ha fresh weight basis. At 3 and 6 months after planting, 50 kg/ha each of P and K were applied using treble superphosphate and muriate of potash.

Taro, variety Lehua Maoli was planted at 45x45 cm spacing. Water was applied to each tank via individual faucets and depths of flooding were controlled by varying the height of the outlet. The 0 cm depth of flooding received continuous water but it was allowed to drain without causing flooding above the soil surface making the soil completely saturated only. Amount of water going into each tank was approximately 280,000 l/ha/day.

The crop was harvested 14 months after planting. All of the plants were harvested from each tank and used for estimation of yield and yield components.

Results and Discussion

There is no significant effect of rate of water flow on growth and development of lowland taro. However, vegetative yield tended to increase with high water flow rates. Height of plants at harvest were highest at the highest rate of water flow with a difference of approximately 11% over the lowest rate used. Total leaf yield difference between the two rates was 16.9%. The total corm and cormel yields were not significantly affected (Table 1).

Based on water use efficiency or amount of water used calculated to produce 1 kg of taro corms, the value ranges from 800 l/kg to 2,790 l/kg for the lowest and highest water flow rates. Current use of water for lowland taro in some areas are almost unlimited. It is obvious from the results of the experiments that lowland taro can be produced with much less water. With judicious water control, there is great potential for expanded taro production, especially in Hawaii.

The depth of flooding in Kapaa Soil (Typic Gibbsiorthox) has a great effect on growth and consequently yield and maturity of lowland taro. Table 2 shows that shallow flooding or soil saturation enhances early growth and development and hastens maturity of Lehua Maoli. Deep flooding slowed growth and prevented early development of suckers. This resulted in greatly reduced cormel yields (Table 3). The significant yield difference between 0 cm flooding and 20 cm flooding is a result of the detrimental effect of deep flooding on cormel yields which are over 54% of total yields for 0 cm flooding and only 14% for the 20 cm flooding. The slight increase in corm yield of 14.5 t/ha compared to 13.0 t/ha did not compensate for the great difference in cormel yields between 20 cm and 0 cm flooding.

Table 1. Effects of water flow rates on yields of taro grown in Hanalei soil.

| Water flow l/ha/day | (gal/A/day) | Corm yield | | Marketable cormels | | Total | |
|---|---|---|---|---|---|---|---|
| | | mt/ha | t/A | mt/ha | t/A | mt/ha | t/A |
| 280,470 | (30,000) | 36.5 | (16.3) | 31.4 | (13.9) | 67.9 | (30.2) |
| 420,700 | (45,000) | 35.0 | (15.6) | 30.3 | (13.5) | 65.3 | (29.1) |
| 560,900 | (60,000) | 29.6 | (13.2) | 37.0 | (16.5) | 66.7 | (29.7) |
| 701,200 | (75,000) | 27.2 | (12.1) | 29.6 | (13.2) | 56.8 | (25.3) |
| 841,400 | (90,000) | 28.0 | (12.5) | 32.3 | (14.4) | 60.3 | (26.9) |
| 981,640 | (105,000) | 37.5 | (16.7) | 29.2 | (13.0) | 66.7 | (29.7) |
| Ave. | | 32.3 | (14.4) | 31.7 | (14.1) | 64.0 | (28.5) |

Location: Hanapepe Valley, Kauai

Age at harvest: 15 months

Table 2. Effects of depth of flooding on vegetative growth of taro.

| Water depth | | Height (cm) | | Leaf yields |
|---|---|---|---|---|
| cm | (in) | 6 MAP* | 14 MAP* | t/ha |
| 0 | (0) | 56.7 | 56.5 | 8.3 |
| 4 | (1.5) | 40.9 | 70.5 | 15.6 |
| 8 | (3.0) | 46.2 | 72.5 | 16.7 |
| 12 | (4.75) | 45.8 | 74.1 | 13.1 |
| 16 | (6.25) | 45.2 | 76.3 | 11.2 |
| 20 | (7.75) | 45.7 | 73.3 | 7.6 |

*MAP = months after planting.

Table 3. Yield components of taro grown in a Kapaa Soil at different depths of flooding.

| Water depth | | Yield components (t/ha) | | |
|---|---|---|---|---|
| cm | (in) | Corms | Cormels* | Total |
| 0 | (0) | 13.0 | 15.5 | 28.5 |
| 4 | (1.5) | 13.2 | 4.6 | 17.8 |
| 8 | (3.0) | 17.3 | 3.5 | 20.8 |
| 12 | (4.75) | 16.1 | 1.5 | 17.6 |
| 16 | (6.25) | 14.4 | 1.8 | 16.2 |
| 20 | (7.75) | 14.5 | 2.4 | 16.9 |

*Marketable cormels only.

In another experiment using Hanalei Soil, contrasting results were obtained (de la Peña and Melchor, 1982). Plants grown in Hanalei Soil performed better under flooded and highly reduced conditions. Continuously flooded taro in Hanalei Soil also grew better than plants which had been drained to a point where the soil started to crack. Addition of high rates of fertilizers, especially nitrogenous materials which is a customary practice among lowland taro farmers, proved detrimental. Excessive fertilizer in drained plants drastically reduced corm yields. There is also a strong relationship between over drying and application of high rates of lime and phosphorus with the occurrence of taro hard rot, a disease suspected to be physiological in nature.

The contrasting results obtained from drained and flooded soils of Hanalei and Kapaa Soils is speculated to be due to their contrasting chemical properties. Soil analysis data reveal that Kapaa Soil has extremely high free iron oxide and total iron contents compared to Hanalei Soil. Free iron oxide in Kapaa Soil is 33.9% compared to 8.9% for Hanalei Soil at 0 to 30 cm-depth (Soil Survey Staff, 1972).

In rice production, several researchers have shown that yields were better under soil moisture conditions of less than 100% saturation (Matsushima, 1976; Wang and Hagan, 1981). In a recent report from India, the beneficial effect of flooding was obtained from a Vertisol while soil saturation and soil water content below saturation gave better yields in an Alfisol (Dongale and Chavan, 1982). It is apparent from the present studies on water requirements of taro and rice that both crops' response to varying water regimes depend on the types of soils used.

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Effect of Some Intercrops on Taro

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SUMMARY

As the taro plant develops slowly during its early growth, it has the potential for intercropping during this period. The effects of six intercrops, longbean, cowpea, peanut, corn, okra and sweet potato on taro were studied.

All intercrops reduced taro yield and the extent of reduction varied with crops. Highest yield reduction, nearly 40%, was when okra was the intercrop. Corn, longbean, and cowpea reduced taro yield by about 16%, 20%, and 23%, respectively. The taro/longbean crop mixture gave the highest gross return, 50% above the non-intercropped taro treatment. Corn, cowpea and okra also increased the gross returns but less.

## Introduction

Although the edible aroids (family *Araceae*) are grown throughout the tropics and sub-tropics, they are of greatest importance in the Pacific region. Five species of aroids (*Colocasia*, *Xanthosoma*, *Cyrstosperma*, *Alocasia* and *Amorphophallus*) are grown for food in the region but taro (*Colocasia esculenta* var. *esculenta*) is by far the most important and a main staple food crop.

Traditionally taro in Fiji and elsewhere in the Pacific is grown under upland conditions in high rainfall areas in a mixed cropping system with long, medium, and short term crops. In Fiji long term crops generally are coconuts, cocoa and other tree crops, the medium term crops are banana and yagona (*Piper methysticum*), and the short term crops are other root crops and vegetables. A recent increasing tendency is to grow taro as a monocrop. The lastest two censuses of agriculture estimate that in Fiji in 1968 only about 25% of taro was grown as monocrop (Casley, 1969) but in 1978 over 50% was grown as monocrop (Rothfield and Kumar, 1980). Taro monocropping has assumed importance especially in near urban centres, where taro is grown largely as a commercial crop.

Onwueme (1981) has discussed merits of two situations in which taro is mixed with other crops. In one taro occupies lower levels of the canopy (when grown with taller crops) and in the other taro occupies the upper canopy layer (when low growing crops are planted between stands of taro). In traditional mixed cropping systems the former situation predominates and taro yields are generally lower due to shade conditions. Even in related *Xanthosoma* species, believed to be more shade tolerant than taro and often grown in shady conditions, it has been found that increasing light intensity increases yield (Rashid and Daunicht, 1979). The

possibility to intercrop taro with less effect on its yield appear better with the second situation described above.

The taro leaf area develops slowly from planting and peaks at about 5 to 6 months and then declines (Plucknett and de la Pena, 1971; Ezumah and Plucknett, 1973; Sivan, 1979). Leaf area development of three selected varieties under Fiji conditions shown in Table 1 indicate that for only a short period at mid-crop the leaf area is at about the optimum (LAI = 3) and for considerable periods early and late in growth of the crop when the leaf area is low it could be profitably intercropped.

Table 1. Leaf area duration (weeks) of main plant and suckers of three taro varieties in Fiji.

| | Leaf Area Index | | | | | | |
|---|---|---|---|---|---|---|---|
| Variety | <1 | >1<2 | >2<3 | >3 | <3>2 | <2>1 | <1 |
| Hawaii | 9 | 4 | 2 | 13 | 11 | 9 | 0 |
| Qawe ni Urau | 9 | 4 | 2 | 8 | 3 | 12 | 10 |
| Tausala ni Samoa | 9 | 7 | 4 | 0 | 6 | 12 | 10 |

Recent studies show that taro production as a commercial monocrop gives a low gross income of between F$1500 to F$2700 (Chandra and Sivan, 1981; Sivan, 1981). To investigate if income could be improved by intercropping early with short duration crops and to study effect of intercrops on taro, the trial discussed below was undertaken.

Experiment

The trial was on alluvial soil at Koronivia Research Station. Three leguminous crops, cowpea, longbean and peanut, and three other crops, corn, okra and sweet potato, all having good market potential in the area were selected for the study. Both taro and intercrops were planted the same day, taro 60 cm apart in the furrows 1 m apart (density 16,666 plants/ha) and intercrops were planted on the ridges formed between the furrows. Populations densities of cowpea, longbean, peanut, corn and okra were 33,332 plant/ha and sweet potato was same as that for taro. Including a non-intercropped taro treatment, seven treatments were replicated three times. From a gross plot area of 7.2x6 m, an inner area 6x4 m was used for taking yield and other records. The taro crop was fertilized with 100 kg N, 25 kg P and 100 kg K and the intercrops at half this rate.

Cowpea, longbean, corn and okra were harvested as green vegetables whereas the remaining two intercrops were harvested when fully mature. At 18 weeks after planting, when all intercrops were harvested, the leaf area indices of taro in various treatments were determined to measure the effect of the intercrops at this stage. Then taro plants were ridged-up and the crop was harvested 11 months after planting.

## Results and Discussion

Intercrops duration and leaf area indices of taro are in Table 2 while yields of taro and intercrops plus their gross value at the farm gate are in Table 3. To estimate gross value, current prices were used (also in the table).

Table 2. Crop duration of intercrops and the leaf area indices (LAI) of taro at 18 weeks in various treatments.

| Treatment | Intercrop duration (weeks) | LAI of Taro* |
|---|---|---|
| Taro (non-intercropped) | - | 1.33a |
| Taro/Peanut | 18 | 1.28a |
| Taro/Corn | 12 | 1.12a |
| Taro/Longbean | 11 | 1.08a |
| Taro/Cowpea | 11 | 1.02ab |
| Taro/Sweet potato | 18 | 0.52b |
| Taro/Okra | 18 | 0.51b |
| S.E. ± | - | 0.16 |

*Treatments with different letters in the column are significantly different (p = 0.05).

Table 3. Yield and gross value of taro and intercrops.

| | Yield (t/h) | | Gross Value (SF/ha)† | | |
|---|---|---|---|---|---|
| Treatment | Taro | Intercrop | Taro | Intercrop | Total |
| Taro | 18.2a* | - | 4,550 | - | 4,550 |
| Taro/Peanut | 15.8ab | 0.29 | 3,950 | 290 | 4,240 |
| Taro/Corn | 15.2b | 7.32 | 3,800 | 1,464 | 5,264 |
| Taro/Longbean | 14.5bc | 6.40 | 3,625 | 3,200 | 6,825 |
| Taro/Cowpea | 14.0bc | 3.26 | 3,500 | 1,630 | 5,130 |
| Taro/Sweet potato | 12.4cd | 1.54 | 3,100 | 385 | 3,485 |
| Taro/Okra | 11.1d | 7.25 | 2,775 | 2,175 | 4,950 |
| S.E. ± | 0.71 | - | - | - | - |

*Treatments with different letters in the column are significantly different (p = 0.05).

†Gross values of crops were estimated at current prices: taro and sweet potato 25c/kg; corn 20c/kg; okra 30c/kg; cowpea and longbean 50c/kg and peanut $1.00/kg.

With the exception of peanut, all intercrops significantly reduced taro yield. The peanut intercrop was severely affected by diseases resulting in low plant population and yield. Due to this the affect on taro yield may have been



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lessened. When this treatment is disregarded, other treatments show that the extent of reduction in taro yield was dependent upon the length of the period of competition between the taro and the intercrops. Corn, longbean and cowpea which were completely harvested by 12 weeks had less effect on taro yield than later sweet potato and okra harvested at 18 weeks. Leaf area indices of taro at 18 weeks also clearly support this. Okra and sweet potato drastically reduced the leaf area of taro while corn, longbean and cowpea had less and non-significant effect on the leaf area of taro.

Relatively small reduction of taro yield in the taro/corn mixture indicate that it is possible to intercrop taro with taller crops provided the intercrop is harvested by about 12 weeks. However, if taller crop of long duration (e.g. okra) is intercropped, then yield taro is severely reduced.

In taro grown under upland conditions, three phases in growth are recognized (Sivan, 1979). In the first phase, which lasts for 8 weeks, the plant develops slowly. In the second phase the plant accumulates dry matter rapidly reaching a peak at 22 to 24 weeks. During this phase there is also very rapid increase in the leaf area. In the third phase, from about 24 weeks onward, top growth and leaf area both decline but rapid corm growth continues until harvest at about 40 to 48 weeks. Because the taro plant develops slowly during the first 8 weeks, intercrops of short crop duration (less than 12 weeks) appear most suitable. These crops have much less effect and the taro plant recovers during the rapid growth phase. Long duration crops extend into and compete with taro during the rapid development phase and the plants are unable to recover sufficiently before rapid corm development takes over, hence the low yield.

When the total values of the crop mixtures are considered the taro/longbean combination gave the best return. It increased the gross returns by 50% compared to taro alone. The taro/corn, taro/cowpea and taro/okra combinations also increased returns but the increases were much smaller at about 18%, 15% and 11%, respectively. Okra as an intercrop that affects taro yield drastically may not be of interest to farmers who grow taro as the main crop.

The study shows that where taro is produced commercially as a monocrop on small size farms, gross returns can be considerably increased by intercropping with short duration crops.

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# The Potential of Taro in Some South Pacific Islands

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## ABSTRACT

The South Pacific has more than a thousand scattered islands, large and small. This paper presents potential uses of taro (Colocasia esculenta) in American Samoa, Western Samoa, the Cook Islands, Fiji, Papua New Guinea, The Solomon Islands, and Tonga. The development of taro silage and its use as animal feed, especially swine feed, is emphasized; and pig feeding trial data from recent University of Hawaii and American Samoa Government collaborative studies have been summarized in the paper. The potential of taro alcohol as a fuel for remote islands and the potential of taro starch as a raw material in cosmetics manufacturing are also discussed.

## Introduction

No single root crop can claim preeminence in the South Pacific. Cassava (Manihot esculenta), sweet potato (Ipomoea batatas), taro, yam (Dioscorea alata, D. esculenta), tannia (Xanthosoma sagittifolium), Cyrtosperma chamissonis, and Alocasia macrorrhiza (giant taro) are leading crops in one or more of the many islands. However, taro is one of the most common sources of staple carbohydrate and is also used extensively in ceremonial occasions (Yen in Ward and Proctor 1980, Chapter 9). It has attained considerable commercial importance as a fresh crop in many of large islands in the region, such as American and Western Samoa, Fiji, and others. Although taro is said to have originated in India and Asia (Chang, 1958; de la Pena, 1970; Plucknett, de la Pena, and Obrero, 1970), it can now be considered a native plant of the South Pacific islands.

Animal production, especially swine and poultry, makes a substantial contribution to the welfare and total productivity of the people of the South Pacific, although available statistics do not always show the full extent of this contribution. Pig production in particular has been totally integrated in the social and agricultural systems with strong ties to ceremonial uses in everyday life. (Quatermain in Ward and Proctor, 1980, p. 261).

Unfortunately, animal production in the South Pacific islands has been hampered by the high cost of imported feeds. Climatic characteristics that make

South Pacific islands ideal locations for taro production make them unsuitable for the production of feed grains or common forages, such as alfalfa (Steinke et al, 1983). However, taro yields large quantities of plant residues and, except for its acridity, is potentially an excellent source for locally-produced low-cost animal feeds. Actually, taro has been used as pig feed, but cooking was required to render the acridity inoffensive. With the current high cost of energy, this required process is no longer economically practical.

To illustrate importance of meat production in the South Pacific, 1980 American Samoa imports were $1,801,396 beef; $202,109 mutton; and $131,266 pork. Per capita, total fresh meat imports amounted to about $66 per annum (American Samoa Government, 1981). In addition, the government spends the equivalent of about one-third of its Agriculture Department's budget to subsidize swine feed to keep its pig farmers competitive.

The Asian Development Bank (ADB) surveyed South Pacific agriculture in 1979 covering Tonga, Western Samoa, Fiji, Papua New Guinea, the Solomon Islands, the Cook Islands, and Kiribati (Ward and Proctor, 1980). In Chapter 9 of South Pacific Agriculture Choices and Constraints, Yen indicated that per capita importation of rice and flour ranged from 30 to 52 kg per annum in these islands (except American Samoa). American Samoa's per capita importation of rice and flour was over $35 in 1980. Thus a potential exists for locally produced staple food to replace some imported rice and flour.

Availability and cost of energy are important to any developmental scheme and liquid fuels are an important component of the total energy consumed. Alternative liquid fuel sources must be carefully examined and developed, where economically feasible, to reduce the dependence of these islands on imported fuels. On large islands, wood may be a source for alternative energy (Watt in Ward and Proctor, 1980, Chapter 12), but on small islands, the conversion of taro into alcohol using solar distillation may already be economically feasible (Wang and Nagarajan, 1981). The ADB report has shown that fuel importation accounts for about 10% of total imports for these islands and American Samoa imported a total of $27,834,927 in diesel and gasoline fuels in 1980 (excluding aviation fuels). In Kiribati, the annual per capita fuel consumption is $42 and in the Solomon Islands, $143. There are potentials for taro alcohol to substitute for some of these imports.

## Utilization of Taro

There are three categories for taro usage: food and processed food for human consumption, animal feeds, and industrial uses.

### Food and Processed Food

Nutrient values indicate that the taro corm is an excellent source of carbohydrate but low in fat and protein which is of medium quality. Taro leaves do contain a much higher level of protein and are an excellent source of carotene and potassium. The leaves are high in calcium but the bioavailability of its calcium is currently uncertain due to the existence of anti-nutrient oxalic acid (Standal in Wang, 1983, Chapter 5).

Taro has been made into many commercial and experimental food products: flour, cereals, bread and cake, infant food, beverage powder, dried flakes, cooked slices and chips, frozen and canned products, extruded products, and pastes (including poi). Taro can be prepared into dehydrated forms to maintain stability

Table 1. Area, population and food importation pattern of selected South Pacific islands countries.

| South Pacific Island Country | Land Area[a] $km^2$ | Population[b] | Staple Importation[c], MT | | Importation of Food & Live Animal[c] | | Contribution of Agriculture to GDP[d,e] |
|---|---|---|---|---|---|---|---|
| | | | Rice | Flour | Imported US$1,000 | % of Total Import | |
| Cook islands | 240 | 18,126 | 190 | 800 | 3,805 | 21.3 (1977) | 16 (1976) |
| Fiji | 18,272 | 588,068 | 23,100 | 3,380 | 73,424 | 19.9 (1978) | 21 (1977) |
| Kiribati | 684 | 56,452 | 2,200 | 1,700 | 3,661 | 27.4 (1977) | 11 (1974) |
| Papua New Guinea | 462,243 | 2,828,600 | 70,000 | 22,000 | 90,928 | 21.1 (1976) | 33 (1977) |
| Solomon Islands | 28,530 | 197,708 | 3,200 | 2,800 | 5,808 | 16.3 (1978) | 15 (1972) |
| Tonga | 699 | 90,128 | 110 | 3,600 | 6,950 | 27.8 (1978) | 51 (1975) |
| Western Samoa | 2,935 | 151,983 | 1,200 | 4,300 | 12,052 | 28.0 (1977) | -- |
| American Samoa | 197 | 32,000[f] | | | | | |

[a]P.W. Hodgkinson, Population 1974, Statistical Bulletin of the South Pacific No. 7, Second Edition, South Pacific Commision, Noumea, 1977.

[b]R. Gerard Ward and Epeli Hau'ofa, "The Demographic and Dietary Contexts," Chapter 2 in South Pacific Agriculture Choices and Constraints, edited by R. Gerard Ward and Andrew Proctor, Asian Development Bank in association with the Australian National University Press, Camberra, Australia, 1980.

[c]Douglas E. Yen, "Food Crops," Chapter 9 in South Pacific Agriculture Choices and Constraints, 1980.

[d]Leslei V. Castle, "The Economic Context," Chapter 5 in South Pacific Agriculture Choices and Constraints, 1980.

[e]GDP = Gross Domestic Product.

[f]American Samoa Government, Statistical Bulletin, 1981.

and offer convenience and ease in preparation. It has been demonstrated that stable, intermediate products such as taro flour and dired slices could be prepared and further extruded into convenient, ready-to-use, stable forms such as rice, noodle, and macaroni. The key in wider usage of taro products will be price competitiveness (Moy and Nip in Wang, 1983, Chapter 10). It is unlikely that under current production schemes processed taro food items can become price competitive in the near future but the traditional usage of fresh taro can be expanded.

## The Potential of Taro as an Animal Feed

Animal industries have long been hampered in the wet tropics by the inability to produce locally-grown feeds. Imported feeds are simply too expensive and in most cases, unavailable.

In many tropical and subtropical areas, large acreages of agricultural lands are used for the production of products which yield vast quantities of both plant residues and processing by-products which are potential feed-stuffs for livestock. Taro is one of these products; however, it has not been widely used as an animal feed. The acrid principles have rendered fresh leaves, petioles and corms unacceptable for use as an animal feed without costly, high-energy processing. At least one case of cattle poisoning from consumption of the raw material has been documented. There are undocumented cases of use of taro leaves and stems as a pig feed, but these involved cooking the material for long periods of time. This strategy may have been acceptable earlier but with the current energy situation, it clearly is no longer acceptable (Tang in Wang, 1983, Chapter 6).

Based upon assessments of the potential of taro as an animal feed and the need for some degree of processing for storage and to neutralize the acridity, the silage process was determined to be the process most likely to achieve the goals. The high moisture content of the taro tops (up to 92%) and the environmental conditions under which it is grown make it difficult to field-dry taro tops, therefore suggesting that ensiling this product may have some potential for animal feed.

Upland taro can be harvested as forage and the best harvest interval seems to be 12 weeks with relatively heavy application of nitrogen fertilizers. Ensiling taro is a relatively simple process and a number of feed materials can be ensiled with taro tops. The fermentation process generally reaches stability and the silage should be ready to be used by the tenth day. Lactic acid levels would indicate the capability for prolonged storage.

A joint collaborative feeding trial with swine was conducted in American Samoa under an agreement between the University of Hawaii and the American Samoa Government Department of Agriculture. Financial support for the project came from the Western Regional Office of the U.S. Department of Agriculture.

Satisfactory performance can be obtained when gilts are fed varying amounts of taro silage. This seems to indicate that taro silage potentially can be utilized in pig production in the humid tropics without adverse effects.

An initial report (University of Hawaii, 1982) on dryland Bun-Long taro indicates that with soil moisture stress maintained at the 20 millibars level and a cutting interval of 12 weeks, an annual yield of about 5 MT/ha of dry matter can be harvested from taro tops. With bagasse mulching, 8 to 10 MT/ha of dry matter

may be potentially available annually. An additional 5 to 10 MT/ha of dry matter may be derived from corms. These data are preliminary and more conclusive information will become available in 1983. The reason that they are discussed here is to give some preliminary indications of what potentials dryland taro crops may have as a feed crop.

## Potential Industrial Used

### Cosmetics

Rice starch has been commonly used in cosmetic dusting preparations such as face powders and other colored powders some of which are dispensed through various aerosol systems. Rice starch is regarded as the finest commonly available starch with a size of about 5 micrometers mean diameter. Considering that taro starch varies from 3.5 to 5 micrometers with higher gelation temperatures than rice starch (Bun-Long at 71°C vs rice at 64°C), one may speculate that taro starch can compete with rice starch in the cosmetic field where unit price is not much of a problem but small particle sizes and the efficiency with which color can be added to the particles may be important (Griffin and Wang in Wang, 1983, Chapter 12).

### Fuel Alcohol

Many developing countries could reduce their dependence on imported oil considerably by replacing part of their petroleum requirement with alcohol produced from sugar or starch-containing crops. Taro would serve perfectly well as a raw material for alcohol production provided that local economies favor such production.

Roughly, the starch-to-alcohol conversion ratio has been identified as 1.76 kg of starch to 1 liter of alcohol.

The cost of alcohol production from cassava has been estimated at $0.15/liter or $0.57/gallon in 1978 dollars (Milfont, 1978; Phillips, 1978). As a first approximation, alcohol production cost from taro should be similar. As a comparison, the estimated costs of ethanol production from corn is $0.43/gallon and from sugarcane it is $0.57/gallon (Brown, 1980). The processing costs, of course, will vary with plant efficiency, fuel cost, and others. The starch-to-alcohol conversion process requires a substantial amount of energy, particularly in the distillation process, and where the energy comes from is clearly an important consideration. Sugarcane, because of the bagasse, brings with itself a large percentage of the required processing energy in the form of fuel for steam production. Taro, because of the high feed value of its leaves, may have an equally good overall energy balance if multiple uses of the entire plant are considered and a majority of the heat requirements for distillation could come from both solar and methane gas generated from animal waste.

Wang and Nagarajan (1981) have given the design parameters for a 43-hectare integrated fresh taro/swine/alcohol production system and estimated operational parameters of such an integrated system. The values used by Wang and Nagarajan were only best estimates that are subject to revisions to meet local conditions, and were used to illustrate how such a system could be designed and evaluated, and to show that such systems could be potentially economically feasible.

Summary

Taro (Colocasia esculenta) is an important plant in many South Pacific islands. There are sufficient existing data to indicate that taro silage, whether made of tops only or made of the entire taro plant, can be an effective substitute for a substantial portion of the commercial swine feed currently in wide use in these islands. Since pork production is important in these islands, and since taro prices tend to fluctuate widely following the annual production pattern of taro, an integrated taro/swine production system for small farmers in these islands has the potential of bringing significant economic benefits to the small farmers and consumers in these developing areas by stabilizing taro and pork prices and by directly increasing farm income through utilization of currently wasted plant materials.

The development of integrated taro/swine/alcohol production in some remote islands where fuel cost is high is a possibility that needs to be further explored. Production of alcohol is a well established technology; nevertheless, the technology is not currently available in many of the islands where the economic potential may exist.

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# Morphological and Anatomical Changes of the Keladi Cina (*Colocasia esculenta*) Plant in the Vegetative and Flowering Stages

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## ABSTRACT

The crop cycle of the *C. esculenta* plant varies from 4 to 12 months depending on the cultivar. After planting, there is a period of rapid vegetative growth followed by a decline. During the period of decline there is an increase in the size of the undergrown corm.

Flowering in the Malaysian cultivars of *C. esculenta* is rare; it occurs only in a few cultivars. In the growth cycle of the plants without inflorescence, the apical meristem produces only foliar primordia which develop into leaves. In a flowering plant, the pattern is interrupted by the emergence of the floral primordia. Morphological and histological changes in the plant and meristem were observed.


## Introduction

The importance of inducing flowering and seed production in taro (*Colocasia esculenta*) has only recently gained full interest and support (Volin, 1976; Alamu and McDavid, 1978; Wilson, 1979; Strauss and Arditti, 1979; Ghani, 1981). It is now possible to project seed production with improved and higher yielding cultivars of *C. esculenta*. Despite this, however, a gap exists in knowledge of processes and changes leading to flowering, during flowering and transition from the vegetative to floral stage.

The very source of such information at morphological level is the apical meristem of the plant. The apical meristem and its development contributes to plant expression which is observed as its vegetative leaf, time of initiation, number of leaves produced, rate of leaf production and likewise for the time, number and rate of inflorescences produced. The close and strong relationship between these two factors (the vegetative and flowering processes) is undoubtedly also linked to other factors such as leaf area index, net photosynthetic rate, senescence, tuber initiation and yield.

The positive relationship between leaf area and yield has been shown to be consistent (Purewal and Dargan, 1957; Enyi, 1967a; 1967b; 1977; Bourke and Perry, 1976; Ezumah and Plucknett, 1977; Abit and Alferez, 1980). This has stimulated the need for knowledge on the growth and development aspects in taro.

## Materials and Methods

A uniform population of more than 600 plants was raised in field plots. The 7.2 m square plots each contained eight raised rows with 12 plants/rows. Spatial arrangement was 90x60 cm. The plants were under dryland cultivation and were watered twice daily.

Twenty randomly sampled plants were available for dissection each 14 days. Ten samples were fixed 70% FAA solutions (Formalin Acetic Alcohol = 90:5:5) and embedded for sectioning after the green foliar leaves and non-chlorophyllous leaves were removed.

The delicate tissues near the meristem in a number of specimens were damaged and lost, hence the final total were utilized of 10-15 per sample of successfully dissected growing points.

Hardening of tissues in preserved specimens prevented successful dissection of the primordia and apical meristem, resulting in loss of samples for weeks 6, 22, and 30.

Alongside this study, the plant population was used for a separate experiment on growth, the result contributing to the study of the apical meristem.

## Results

### Composition of the growing plant

Mature *C. esculenta* (cv. Keladi Cina) plants are composed of green foliar leaves, non-chlorophyllous leaves, the primordial leaves and the growing apex. Each structure is ensheathed within the preceding structure and is contained within the youngest of the exposed, green, foliar leaves. The leaves are spirally arranged on the corm.

In the first weeks after planting, a small leaf was produced and within it were leaf primordia and the apical meristem.

By the third week, the first foliar green leaf, a rolled expanding leaf and non-chlorophyllous leaves were distinguishable. After the third week, all plants consisted of the full complement of foliar structures. The apex was surrounded by recently initiated primordia. This constant pattern ensued until the 44th week in non-flowering plants.

In a flowering plant the pattern was interrupted. The terminal apex produced the inflorescence primordium and a lateral apex from the axil of the youngest leaf was the vegetative apex.

### Production of foliar structures

Changes in the total number of foliar structures at different stages in the growth cycle were due to rate of leaf primordial production and leaf longevity. The number of expanded green leaves on a plant which must have been largely influenced by rates of senescence as well as expansion, contributed to the fluctuation in the total since the rest of the structures remained fairly constant as in 8 to 14 weeks, 24 to 28 weeks, 38 to 40 weeks and 42 to 44 weeks (Table 1).

At 16 weeks the maximum leaf number was achieved and this was followed by a decline until harvest at 44 weeks.

Corm initiation

Corm initiation was detected about week 16 and flowering occurred between weeks 18 to 21. These events appeared to have some correlation with leaf area. When corm initiation occurred there was an increase in living foliage area and leaf number up to 7 leaves but when flowering occurred there was a gradual decline to 6 and 5 leaves. This was correlated to the morphological and cellular changes observed at the apex.

Further work to establish a causal connection of the observed changes with leaf senescence rates is underway.

Table 1. Number of foliar structures of Keladi Cina plants at different stages.

| Age of plant (weeks) | Expanded green leaves | Green rolled leaves | Non chlorophyllous leaves | Primordium | Total |
|---|---|---|---|---|---|
| 2 | 1 | - | 2 | 1 | 4 |
| 3 | 2 | 1 | 2 | 1 | 6 |
| 4 | 2 | 1 | 3 | 3 | 9 |
| 6 | 3 | - | - | - | - |
| 8 | 3 | 2 | 2 | 3 | 10 |
| 10 | 4 | 2 | 2 | 3 | 11 |
| 12 | 5 | 2 | 2 | 3 | 12 |
| 14 | 5 | 2 | 3 | 3 | 13 |
| 16 | 7 | 4 | 3 | 3 | 17 |
| 18 | 6 | 4 | 2 | 3 | 15 |
| 20 | 5 | 3 | 3 | 3 | 14 |
| 22 | - | - | - | - | - |
| 24 | 5 | 2 | 3 | 3 | 13 |
| 28 | 4 | 2 | 3 | 3 | 12 |
| 30 | - | - | - | - | - |
| 32 | 3 | 2 | 4 | 3 | 12 |
| 34 | 3 | 1 | 3 | 3 | 10 |
| 36 | - | - | - | - | - |
| 38 | 3 | 1 | 2 | 3 | 9 |
| 40 | 2 | 1 | 2 | 3 | 8 |
| 42 | 2 | 1 | 1 | 3 | 7 |
| 44 | 2 | 0 | 2 | 3 | 7 |

Histological Studies of the Apical Meristem

Materials and Methods

Whole plants were dissected carefully to remove foliar structures one by one down to the apical dome on the meristem. Meristem tips were used for slide preparation as were leaves, petioles, corms. For histological preparations, paraffin

embedding methods described by Johansen (1940), Sass (1958), and Gray (1962) were used. Sectioning of paraffin blocks was on a MSE sledge microtome at 10 μ thickness and Spencer Rotary Microtome (Model 820). Sections were stained with Safranin and Fast Green.

## Results

### The vegetative apex

The vegetative apex surface consisted of a layer of flattened cells, the tunica. The corpus region as such was not clearly distinguishable in longitudinal sections. It appeared as a transition between two rows of tunica cells and lower meristem region. Both tunica and corpus cells appear similar in size with large nuclei. At an older stage, meristematic activity in central corpus cells raised the apex to form a flattened dome. Periclinal divisions in the apical dome resulted in formation of leaf primordia. Subsequently, rapid division and elongation of cells resulted in further growth of leaf primordia. Each new leaf primordium was inserted within the previous one. A total of 32 to 34 leaves were produced in one crop cycle.

In plants producing inflorescences, there were changes at the apical meristem. Precise trigger for transition from vegetative to floral apex remains unknown for taro.

### The floral apex

A distinct change in size and shape of the floral apex was noted. The vegetative apex was low and flattened, the floral apex consisted of a broad raised dome which became narrow and unusually elongated as it grew upwards. This was followed by differentiation which resulted in a double dome and a single primordium. The double dome structure consisted of differentiating terminal floral apex (spathe and spadix) and subtending foliar primordium.

### The morphology of the floral apex

The flowering plant carries normal foliage green leaves (vegetative) and the cluster of inflorescences. The cluster of inflorescences arise in the axil of the youngest leaf. Spiral arrangement and ensheathing leaf bases result in a number of protective hood-like structures over inflorescence primordia. Average number of colorless inflorescence primordia was 3 to 4 and between each primordium was a "membranous sheath" structure. The terminal inflorescence apex and lateral floral primordia were displaced by the lateral vegetative apex.

Promotion of new leaves ceases when the growing point becomes reproductive and it would seem that the longevity of the last formed leaves is increased at this time. Subsequently, a lateral apex becomes activated and leaf production resumes from such a single growing point and this continues until full corm growth is attained at the end of the growth cycle.

## Conclusion

The studies revealed the growth and developmental behavior of the growing meristem as a vegetative apex and its adjustment to accommodate the floral process over a "short" period before it reversed to become a vegetative apex.

## Acknowledgements

This research is part of a larger study on the flowering growth and corm initiation in local keladi (C. esculenta) cultivars by the author. Thanks goes to the International Foundation for Science, Sweden, for funding this project and to University Kebangsaan Malaysia for use of facilities. The author personally thanks Prof. W.W. Schwabe for his advice and En. Abu Hassan Basir for his technical assistance.

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Anatomy and Histochemistry of Taro Seed

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ABSTRACT

This study reports findings on seed anatomy and histochemistry in taro (Colocasia esculenta). Perhaps because taro is propagated vegetatively, little information is available regarding taro sexual propagules (seeds). Major significance of this study is the first time observation of internal seed structure in taro and the identification of an aleurone layer.

Seeds were fixed in 5% glutaraldehyde and post-fixed in 2% osmium tetroxide and subsequently embedded in epoxy resin. One micrometer thick sections were cut on an ultramicrotome and were subjected to various histochemical stains.

A uniseriate aleurone layer which is rich in protein bodies is clearly differentiated as the outermost layer of the endosperm. A starchy endosperm underlies the aleurone layer. In addition to protein bodies, the aleurone layer contains starch granules and lipid bodies. The cotyledon is rich in lipid, but also contains numerous starch granules.

## Introduction

In contrast to abundant information on seed anatomy and histochemistry of numerous plant families, especially the Poaceae (Buttrose, 1963; Evers, 1970; Jones, 1971), few studies have been of seed structure in the Araceae, especially the important tuber crop taro, Colocasia esculenta. One reason may be difficulty of preparative techniques in embedding and sectioning of the small seed, especially if paraffin embedding is employed. Another reason may be that taro is generally propagated by asexual means, thus bypassing the sexual propagules (seeds). Development of seed handling techniques and establishment of breeding programs for taro (Jackson and Pelomo, 1980; Strauss et al., 1979 and Shaw 1975, 1982), however, necessitates an understanding of seed structure and physiology.

This study reports findings on seed anatomy and histochemistry in taro, with special reference to the previously undescribed aleurone layer.

## Materials and Methods

Dry, ungerminated seed of taro, Colocasia esculenta were obtained from Dr. G.V.H. Jackson, Ministry of Agriculture and Home Affairs, Solomon Islands, and fixed in 5% glutaraldehyde in a 0.05 M cacodylate buffer, pH 6.8, for 6 hours,

followed by post-fixation overnight at 4 C in 2% $OsO_4$. Prior to fixation an incision was made in the testa to aid in infiltration of fixative solutions. Following dehydration in an acetone series, seeds were infiltrated and embedded in Spurr's low viscosity epoxy resin (Spurr, 1969). For light microscopy, thick sections, 1-2 um, were cut with glass knives on an LKB Ultratome III, mounted on glass slides, and stained by the following standard histochemical procedures.

1. Lipids and starch: Sudan black B (Bronner, 1975).
2. Water insoluble polysaccharides: Periodic acid-Schiff's (PAS) reaction (Jensen, 1962).
3. Proteins: Bromophenol blue (Chapman, 1975).

## Results and Discussion

The embryo is small in comparison to size of the seed, and consists of a hypocotyl-root axis and a single bilobed cotyledon (Figure 1) which is epigeal. It is rich in lipid and starch as determined by the PAS reaction and Sudan black B staining. Following emergence from the seed coat, the cotyledon becomes green and photosynthetic. The embryo comprises approximately one-third the volume of the seed and the endosperm approximately two-thirds. It is situated at the micropylar end and is surrounded by starch-filled endosperm except at the root tip. The testa or seed coat is a multilayered structure which contains numerous pockets of calcium oxylate crystals (Figure 2).

The uniseriate aleurone layer is the outermost layer of the endosperm and consists of large cuboidal aleurone cells which have thin cell walls (Figures 2, 3). The thin walls appear to be in contrast to the thick aleurone walls in wheat (Morrison, Kuo and O'Brien, 1975) and barley (Taiz and Jones, 1973). Wheat aleurone cell walls exhibit autofluorescence because of presence of ferulic acid in the walls. Taro aleurone cell walls, however, were not autofluorescent. The aleurone layer is in direct contact with the embryo only at the lower portion of the hypocotyl-root axis where it extends along the lateral edge of the hypocotyl-root axis. A second type of aleurone cell, or modified aleurone, is continuous over the root axis of the embryo (Figure 1). This modified aleurone consists of rectangularly shaped cells. In Poaceae, aleurone transfer cells have been described in this region (Esau, 1977). An electron microscopic study is in progress which will clarify if this modified aleurone is indeed a transfer cell layer. As determined with the periodic acid-Schiff's reaction (Figure 3), the aleurone cells contain starch granules. The sub-aleurone endosperm is filled with large starch granules (Figure 3). Protein bodies, which stain with bromophenol blue, are dispersed throughout the cytoplasm of the aleurone cells (Figure 4).

Taro seed provides an opportunity to investigate the structure and physiology of seed germination in a monocotyledonous, but non-grass family (Araceae). Particular interest is in answering several questions. Do the protein-storing aleurone cells of taro synthesize and release amylases as well as other hydrolases in response to gibberellic acid? Is the primary function of the tissue to mobilize the total food reserves of the endosperm for the growing embryo during germination? Answers to these questions are currently being explored along with an ultrastructural analysis of the aleurone and other seed tissues.

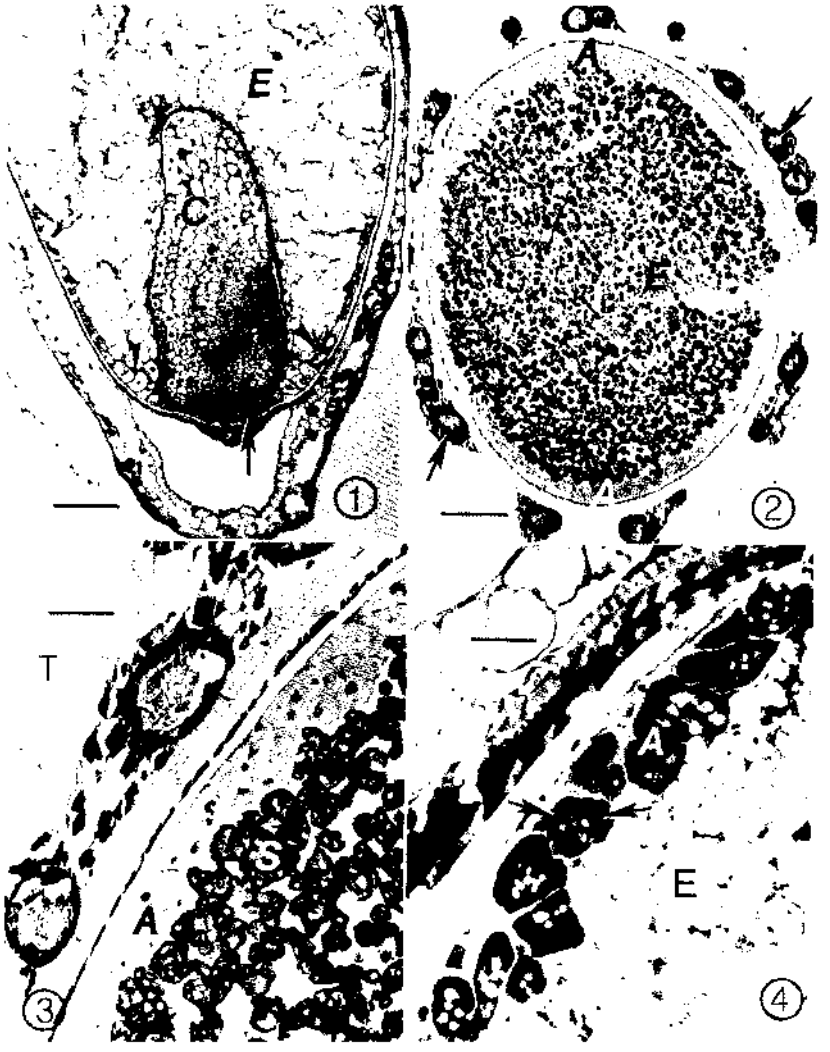


Figure 1. Longitudinal section through taro seed. Smaller arrow indicates aleurone layer adjacent to the hypocotyl-root axis. Longer arrow indicates modified aleurone layer. Toluidine blue staining. C = cotyledon; E = endosperm. Scale bar = 100 um. x 125.

Figure 2. Transverse section through taro seed illustrating differentiation of endosperm into an outer uniseriate layer, the aleurone layer (A), and the underlying starchy endosperm (E). Starch granules appear red (dark in this micrograph) after reaction with the periodic acid-Schiff's reagent. Pockets of crystals are evident (arrows) in the seed coat. PAS staining. Scale bar = 100 um. x 125.

Figure 3. PAS reaction of aleurone (A) and starchy endosperm. Starch granules (small arrows) are evident in the aleurone layer. Larger starch granules (S) fill the starchy endosperm. T = testa. Scale bar = 25 um. X 500.

Figure 4. Bromophenol blue staining of aleurone (A). The cytoplasm contains dark staining protein bodies (arrows). Starch granules appear clear against the dark background. Starchy endosperm (E) contains no protein bodies. Scale bar = 25 um. X 500.

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Anatomy and Histochemistry of Taro, Colocasia esculenta (L.) Schott, Leaves

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ABSTRACT

Taro (Colocasia esculenta) leaves are composed of a multi-layered palisade and air-filled spongy mesophyll. Vascular traces are encircled by a ring of vacuolate cells which may extend to the upper and lower epidermis. Abaxial and adaxial stomata are present, with the former being more numerous. Subsidiary cells appear to be of the para-mesoperigenous type and guard cells are sunken with plastids that display few membranes, but prominent starch inclusions. The epidermal cells are highly vacuolate with prominent protrusions or extensions on the exposed surfaces. Despite the presence of the bundle sheath, no conclusive evidence exists to indicate taro is capable of carbon fixation by a C4 pathway. In light of other morphological and histochemical features of the leaf this appears even more unlikely.

## Introduction

Few reports are available about structure of taro leaves (Strauss, in press; Strauss and Scheirer, submitted). Most current information comprises generalized morphological descriptions rather than detailed microscopic studies. One early paper discussed structure and distribution of stomata in the Colocasia leaf (Yarbrough, 1934). However, data are based on a single leaf of an apparently ornamental plant. No comprehensive study of edible cultivars has been reported. Another early study details morphology of abaxial epidermal outgrowths of the leaf blade (Guengen, 1908). This phenomenon is relatively rare and the authors only know of a single cultivar in which it occurs. A report on genetic variability in taro included several morphologic characters of leaves and concluded that while some appeared to be heavily influenced by environment others were under more direct genetic control (Arditti et al., 1980; Strauss, et al., 1980). Specifically, foliar dimensions appeared strongly influenced by the environment.

This study elucidates structure of the taro leaf to provide a basis for future physiological studies. Further, understanding anatomy of normal leaves aids in gaining better knowledge of pathogenesis effects on taro.

## Materials and Methods

Plant material was obtained from Drs. M. Pearson, University of Papua New Guinea, and R.S. de la Peña, University of Hawaii, Kauai Branch Station, and maintained under greenhouse conditions, in the ground, at the Burlington Botanical Research Facility of Northeastern University, Woburn, Massachusetts. Selected

plants were also cultured in environmental chambers under 16 h photoperiods at 28° to 30°C and with 70% relative humidity.

Replicas of the leaf surface were made by application of a solution of acetone and clear nail polish (1:1) to the surface of the leaf. The resulting film was cleansed of particulates by gentle heating in 3M HCl. Data were gathered from a minimum of 30 separate areas for each leaf.

Portions of leaves were fixed for 24 h in 3% glutaraldehyde in Hepes buffer, pH 6.8, at 4 C. Postfixation was for 60 min. in 2 percent osmium tetroxide in buffer. Tissues were then dehydrated in an acetone series and embedded for electron microscopy (Spurr, 1969). Three micron sections were stained by Sudan black (Bronner, 1975) or periodic acid Schiff's methods (Lillie, 1965) and examined using light microscopy. Thin sections were stained with uranyl acetate (Hayat, 1972) and lead citrate (Venable and Coggleshall, 1964) and examined on a Zeiss EM 9S electron microscope.

## Results and Discussion

A typical taro leaf blade can be divided into two general areas, the large veins and the intercostal lamina, the latter being the area between the major veins. On the adaxial (upper) surface stomata are distributed over the intercostal and veinal areas while on the abaxial (lower) surface stomata are absent from the regions of epidermis overlying the veins. This confirms earlier reports of stomatal distribution on the undersurface of the taro leaf (Yarbrough, 1934). The epidermis often appears papillate on the abaxial surface (Figures 1, 2).

The major and lateral veins are composed of several bundles underlying a palisade layer and radially distributed bundles of collenchyma (Figure 3). Interspersed through the tissue of these veins are numerous vascular bundles as well as rings of large, vacuolate cells apparently composing an aerenchyma tissue. Stomates were not present on abaxial surfaces of these veins, but were found over the loosely packed palisade tissue of the adaxial surface. Similar morphology has been found in the petiole. Such morphology in taro has previously been suggested as an adaptation to flooded conditions of growth (Onwueme, 1978).

The small, minor veins of the intercostal regions are composed of a single vascular strand surrounded by a single layer of vacuolate bundle sheath cells, the latter often extending to the epidermal surfaces (Figure 2). Within the vein a duct-like cell can often be noted (Figure 2). This cell is articulated, contains dark staining material and resembles a laticifer (Figure 4; Esau, 1969). Stomata occur on both surfaces (Figure 2). They are paracytic in form and have been tentatively classed as para-mesoperigenous, though this requires ontogenetic study for confirmation (Fryns-Claessens and Van Cotthem, 1973; Stebbins and Khush, 1961).

Adaxial stomata overlie substomatal chambers in the palisade tissue, while abaxial ones open directly into the spaces of the spongy mesophyll (Figure 2). Plastids of the guard cells contain prominent starch grains and few internal membranes. They do not apppear to be photosynthetic (Figure 5). Such a situation has been noted in orchids of the genus Paphiopedilum (Nelson and Mayo, 1975; Rutter and Willmer, 1979).

The palisade layer of the leaf is composed of one to three layers of elongate cells situated below the adaxial epidermis (Figure 2). Occasional densely stain-

ing cells are noted in the palisade tissue which are, in form, similar to the other cells of this region. Transverse sections reveal these cells to be somewhat regularly distributed in the palisade tissue (Figure 6). They are similar to the tanniferous cells found in the palisade tissue of Dioscorea (Ayensu, 1972). Elucidation of their exact nature requires further study.

Cells in the spongy layer are organized to form approximately rectangular air spaces (Figure 2, Strauss, in press). Raphide idioblasts, as previously reported for Colocasia are noted in the spongy mesophyll (Figure 7), as are the smaller druses of calcium oxalate, similar to those reported to occur in the corm (Sakai and Hansen, 1968; Sunell and Healey, 1979).

Of several cultivars of taro examined all showed a greater density of stomata on the upper and lower leaf surfaces than previously reported (Table 1). As noted earlier, stomata are greater in number on the abaxial surfaces (Yarbrough, 1934). However, the ratio of abaxial to adaxial stomata is considerably lower for the cultivars examined than a similar ratio calculated from data in the earlier study. Since that study utilized an ornamental plant we suggest our results to be more representative of the true condition for the edible cultivars of taro. Examination of several leaves, of similar developmental age, in C. esculenta cv 'Bun

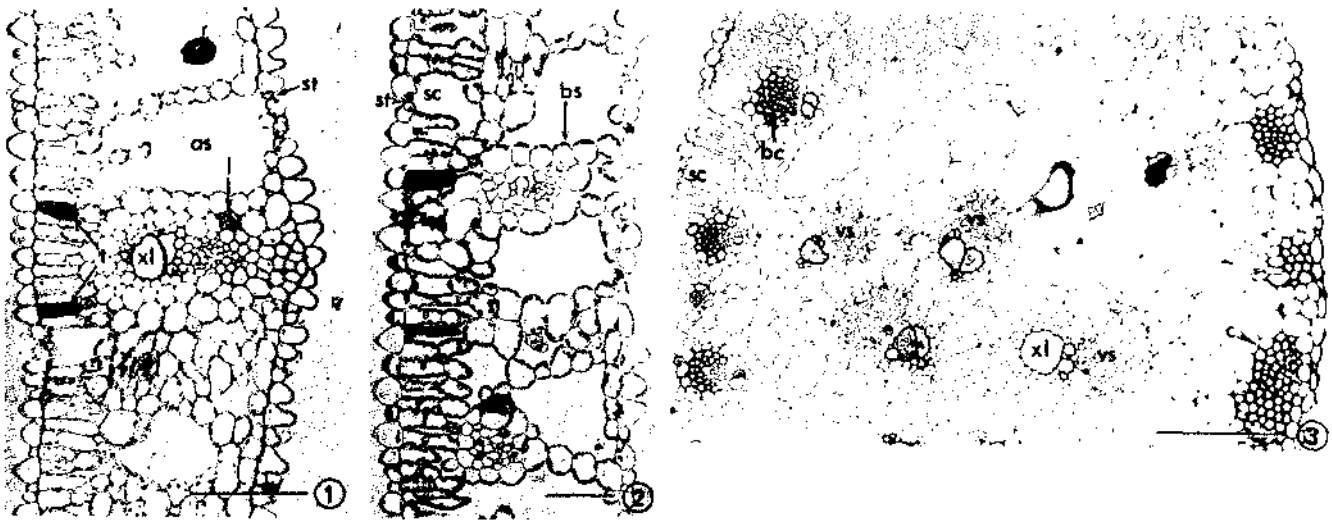


Figure 1. Transverse section of leaf blade of Colocasia esculenta cv Bun long showing minor vein and papillate abaxial epidermal cells; st, stomata; r, raphide idioblast; as, air space; xl, xylem lacuna; l, laticifers; t, tanin cell. Bar = 100 microns.

Figure 2. Transverse section of intercostal lamina from Colocasia esculenta cv K268 with minor vein and bundle sheath; bs, bundle sheath; sc, substomatal chamber; st, stomate. Bar = 50 microns.

Figure 3. Transverse section of major vein from leaf of Colocasia esculenta cv Bun long. Note adaxial palisade parenchyma, collenchyma bundles and vascular strands; bc, bundle collenchyma; c, abaxial collenchyma bundle; sc, substomatal chamber; vs, vascular strand; xl, xylem lacuna. Bar = 200 microns.

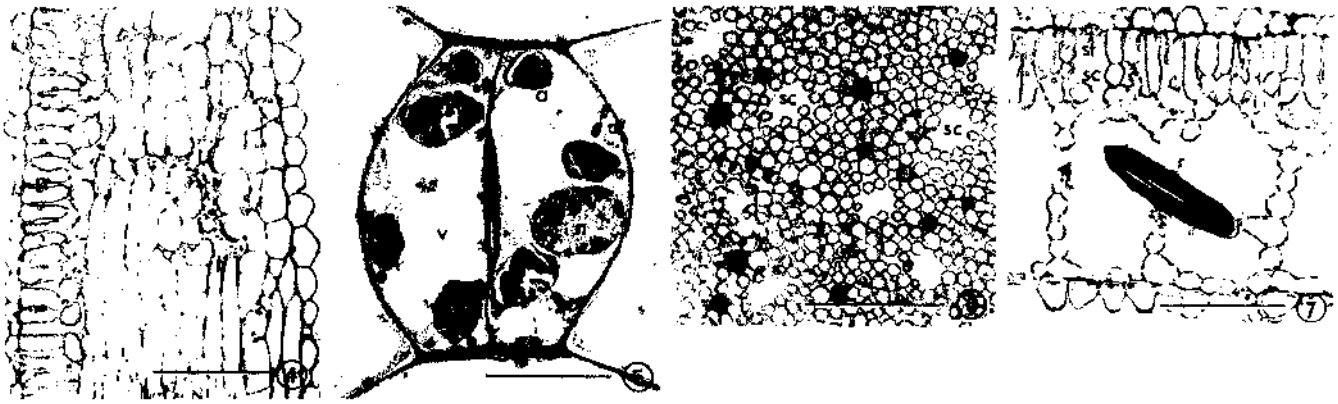


Figure 4. Longitudinal section of laticifer in minor vein of Colocasia esculenta cv Bun long; l, laticifer; p, palisade parenchyma. Bar = 100 microns.

Figure 5. Paradermal section through adaxial stomate of Colocasia esculenta cv Bun long; a, amyloplast; n, nucleus; v, vacuole; n, nucleus. Bar = 10 microns.

Figure 6. Paradermal section through palisade layer of Colocasia esculenta cv K268 lamina showing tannin cells and substomatal chambers; sc, substomatal chamber; t, tanin cell. Bar = 100 microns.

Figure 7. Transverse section of lamina of Colocasia esculenta cv Bun long showing raphide idioblast; r, raphide idioblast; sc, substomatal chamber; st, stomate. Bar = 100 microns.

long' revealed considerable variation in stomatal density. Ratio of abaxial to adaxial stomata, however, was similar to the values for other cultivars studied (Table 2). Distribution of stomata in leaves and stomatal density are, no doubt, strongly influenced by the environment.

When compared histochemically, the concentration of starch in guard cells is seen as an intense PAS reaction. Subsidiary cells display lower stain intensity but appear to contain higher levels of PAS positive material (presumably carbohydrate) than the surrounding epidermal tissue. With respect to lipids, the guard cells are the only epidermal cells showing a positive Sudan reaction. This may reflect the higher level of cytoplasmic membrane and lesser vacuolar size in these cells than in other epidermal cells. As might be expected, palisade parenchyma has higher levels of carbohydrate and lipid than spongy mesophyll when analyzed histochemically. This is commensurate with the expected higher level of photosynthetic activity in these cells.

The general organization of the taro leaf into distinct palisade and spongy mesophyll, with large air spaces, suggests carbon fixation occurs by a C3 pathway. Further, the bundle sheath lacks the characteristic chlorenchyma and general

Table 1. Distribution of stomata on adaxial, upper, and abaxial, lower, leaf surfaces for several cultivars of taro, *Colocasia esculenta*, compared to an earlier report.

| Cultivar | Stomata, mm-2 Adaxial (A) | Abaxial (B) | B/A |
|---|---|---|---|
| 'Akado' | 98 ± 14 | 134 ± 29 | 1.4 |
| 'Bun long' | 121 ± 16 | 166 ± 10 | 1.4 |
| 'Lehua maoli' | 133 ± 14 | 165 ± 23 | 1.2 |
| 'Red moi' | 147 ± 27 | 191 ± 16 | 1.3 |
| *Colocasia antiquorum* (Yarbrough, 1934) | 50 | 116 | 2.32 |

Table 2. Comparison of stomatal densities from several plants of taro, *Colocasia esculenta* (L.) Schott cv 'Bun long'. All samples taken from the second fully expanded leaf on each plant.

| Plant | Stomata, mm-2 Adaxial (A) | Abaxial (B) | B/A |
|---|---|---|---|
| I | 134 ± 22 | 167 ± 26 | 1.2 |
| II | 133 ± 17 | 178 ± 17 | 1.3 |
| III | 191 ± 26 | 293 ± 22 | 1.5 |
| IIIa | 116 ± 20 | 152 ± 17 | 1.3 |
| IV | 162 ± 31 | 195 ± 20 | 1.2 |

morphology typical of such cells in the C4 plant (Bidwell, 1979; Brown, 1975; Laetsch, 1974). Electron microscope studies have not detected a peripheral reticulum, typical of C4 chloroplasts (Stein and Strauss, unpublished; Laetsch, 1974). Finally, histochemical evidence points to accumulation of carbohydrates in the palisade tissues, suggesting that formation of these compounds is not restricted to the bundle sheath. Thus, it seems unlikely that taro is capable of carbon fixation by a C4 pathway.

Acknowledgements

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Flowering Behavior in *Colocasia gigantea* Hook. f.

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ABSTRACT

The process of anthesis, stigma receptivity, pollen shed, pollen fertility, and some genetic characteristics were studied in *Colocasia gigantea* Hook. f., a related species of taro (*Colocasia esculenta* (L.) Schott).

Anthesis began between 8:00 p.m. and 1:00 a.m. followed, after several hours, by the secretion of mucous in the stigmas, which was taken as evidence of receptivity. Stigmas became receptive some hours earlier than pollen shedding. Pollen was shed about 27 to 32 hours after anthesis.

The pollen fertility recorded was more than 90%. Each fruit contained 30 to 90 seeds with an average of 500 to 900 fruits in each inflorescence. Seed germination was 76% to 100%, with epigeous germination. This high fertility may be of use in breeding within the genus *Colocasia*.

# Salt Tolerant Tissue of Taro: Selection and Constituents

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## ABSTRACT

A salt-tolerant tissue was selected from callus of *Colocasia esculenta* var. *antiquorum* initiated on solid Knop's medium by subculturing for 4 years on modified Linsmaier-Skoog medium containing 100-700 milliosmoles (10%-70%) artificial seawater. Plantlets were initiated by transferring the tissue to TIBA-containing solid medium.

Cell wall thickness, cell size, chloroplast size and structure, and starch grains are affected by the concentration of seawater. The same is true for levels of inorganics, calcium oxalate, chlorophyll, protein, and secondary and quarternary alkaloids. These changes may be related to salinity tolerance and adaptation.

## Introduction

A number of workers have successfully applied contemporary tissue culture techniques to taro (Hartman, 1974; Mapes and Cable, 1972; for a review see Arditti and Strauss, 1979). However, response to in vitro conditions is genotype specific (Jackson, Ball and Arditti, 1977). Of those cultivars reported to produce callus from shoot tip explants, most have low percentages of regeneration and the callus is not easily maintained (Jackson, Ball and Arditti, 1977; Nyman, Gonzales and Arditti, 1981).

Callus of a cultivar of *Colocasia esculenta* var. *antiquorum* name UCI Runner is one of the least recalcitrant genotypes. Shoot tip explants from this cultivar produce a callus which undergoes a rapid, but reversible transition to a stable differentiated growth form we have termed "calloid" (Nyman, Gonzales and Arditti, 1981; Nyman, Gonzales and Arditti, in press a) and b). The transition from callus to calloid appears to represent a prerequisite physiological event necessary for organogenesis. Unlike most taro calli, calloid masses are stable, fast growing and organogenetically active. These characteristics allow for the selection of salt tolerant tissues and plantlets (Nyman, Gonzales, and Arditti, 1981).

The purpose of this study was to: (1) assess the effects of growth regulating substances and media components on organogenesis from calloid tissues, and (2) determine the effects of seawater on differentiation and organogenesis from calloid. Since there is some evidence to suggest that the calloid stage may occur prior to shoot formation from rice (Inoue and Maeda, 1980; Maeda, 1980a and b) and

sugarcane callus (Krishnamurthi, 1977), this information may be useful in developing more direct methods for plantlet production from calli of other monocots.

## Materials and Methods

### Tissue culture

Callus cultures were produced by previously described methods from shoot tip explants of a cultivar of Colocasia esculenta var antiquorum named UCI Runner (Arditti and Strauss, 1979; Jackson, Ball and Arditti, 1977). Once initiated, callus was transferred to solid or liquid Linsmaier-Skoog medium containing 0.1 mg/l napthaleneacetic acid (NAA) and 0.1 mg/l adenine-N-benzyl-9-tetrahydro-2H-pyran-2-yl (SD8339-Shell Development Co., Modesto CA., 95252, USA) or 1.0 mg/l dimethylaminopurine (6-DMAP). Tissues were subcultured on the maintenance medium every 2 to 4 months under conditions described earlier (Nyman, Gonzales, and Arditti, in press a).

Salt tolerance was selected for by transferring tissues to successively higher concentrations of an artificial seawater mix added to the culture medium (Nyman, Gonzales, and Arditti, in press b; Nyman, Gonzales and Arditti, 1981). The components and methods for preparing the artificial seawater (ASW) are available in the literature (Cavanaugh, 1964; Nyman, Gonzales, and Arditti, 1981). To obtain plantlets, tissues were transferred to media containing substitutions of the the hormones present in the LS maintenance medium and the cultures were observed daily. The growth regulating substances used in the experiments included: kinetin (K), benzylaminopurine (BAP), adenine-N-benzyl-9-tetrahydro-2H-pyran-2-yl (SD8339), 6-dymethylaminopurine (6-DMAP), napthaleneacetic acid (NAA), indoleacetic acid (IAA), 2, 4, 5-trichloroacetic acid (2, 4, 5-T), gibberrellic acid (GAA), 2, 4, 5-tri-iodobenzoic acid (TIBA) and aminocyclopropane-1-carboxylic acid (ACCP). Some of these compounds were also tested on whole plantlets in an attempt to enhance shoot and/or root development (Table 2). As well, dilution of components in the LS medium and alternate media were tested for their effects on plantlet development (Tables 1 and 2).

In attempts to further enhance plantlet development, equimolar substitutions of fructuose, raffinose, galactose, and sorbitol were made for sucrose in the LS medium. Anticontaminants singly and in combinations were also tested for their effects on calloid differentiation. These included benlate, Nystatin, Penicillin G, Gentamycin, sodium omadine, Kanamycin sulfate, Vancomycin, and Amphotericin B.

### Microscopy

Plant material for scanning electron microscopy was cut into 1 $mm^3$ pieces and fixed for 14 to 18 hours in 4% glutaraldehyde in 0.1M sodium cacodylate buffer at pH 7.2. After a slow ethanol dehydration (10% increments for 20 to 30 minutes at each concentration), and a similarly slow infiltration with freon, the tissue was dried in a Bomar 900 EX critical point dryer. The material was then mounted and coated with gold for 3 minutes in a Hummer 2 Sputter coater. Observations were made with an Hitachi S-500 scanning electron microscope at 5 KV.

To stabilize tissues taken from samples grown in seawater media, sucrose was added to the fixation solution. A concentration of 0.63M sucrose was empirically found suitable for tissues grown on 70% ASW. Concentrations of sucrose necessary to stabilize tissues from other levels of ASW were calculated mathematically (i.e. 0.09M sucrose/10% ASW, 0.18M sucrose/20% ASW).

## Results

### Plantlet differentiation from calloid

After 32 weeks, plantlets differentiated from calloid grown on group IIa maintenance media (Figure 1, Table 1). However, most of these had developed root primordia visible only with the use of light and scanning electron microscopes (Figure 2). The first formed leaves were linear in appearance (Figure 2) and plantlets did not grow vigorously. As well as generating plantlets, calloid tissues produced various types of abnormal leaf and shoot-like structures, and protocorm-like bodies (Figures 3 and 4).

Calloid could not be maintained on media lacking either an auxin or a cytokinin or both. High levels of auxin were damaging to the calloid leading to necrosis and death (Table 1). Although GAA added to IIa media at low concentrations enhanced growth, it did not affect either the rate or amount of plantlet differentiation.

Tri-iodobenzoic acid (TIBA) added at 1 mg/l to media without hormones caused a stimulation of plantlet production and a corresponding decrease in the numbers of abnormal structures (Figure 5, Table 1). Further, plantlets were produced in a much shorter period (2 to 4 weeks) and grew more vigorously than those on other media (Table 1). In the presence of K, TIBA did not stimulate normal plantlet production, but calloid grew as a light green mass of tiny compressed shoots (Figure 6).

### Development of individual plantlets

Plantlets produced from calloid cultures appeared variable in: (1) appearance of their shoot systems, (2) degree of root formation, and (3) rate of growth. However, some characteristics of their development were uniformly affected by changes in media composition (Table 2). Growth of individual plantlets was supported by half strength and full strength media without exogenous hormones, including LS, Murashige-Skoog (MS) and soil extract (SE). Full strength media favored development of plantlets with relatively large spatulate leaves and thick petioles (Figure 7). Shoots were less well developed on half strength media, but roots were formed at a faster rate (Figure 8).

In presence of K and/or NAA, shoots developed more slowly than on media without hormones, producing higher numbers of linear leaves (Table 2). The addition of the auxin 2, 4, 5-T caused either severe retardation of shoot growth or plantlet death. Plantlets grown in the presence of the ethylene precursor, ACCP at concentrations between 0.1 to 1.0 mg/l were not visibly different from those on hormone-free medium. At a concentration of 10 mg/l, ACCP was lethal to plantlets. The addition of 1 mg/l TIBA both with and without K did not appear to affect individual plantlet development (Table 2).

### Effects of artificial seawater on calloid and plantlets

Calloids were established and grew well in concentrations of ASW from 100 to 700 milliosmoles (10% to 70%). Although no differences in gross morphology were noted in calloid tissues, optimum plantlet production occurred at 40% to 50% ASW on group IIa media (Table 1). Plantlets differentiated after approximately 32 weeks of growth for all seawater concentrations, and were produced on both solid and liquid media. Development was more rapid on solid medium.

Table 1. Maintenance and media for differentiation of plantlets from calloid cultures.

| Use | Basal medium @ | State of medium | Growth regulators (mg/l) cytokinin# | auxin* | gibberellin** | other*** | Results |
|---|---|---|---|---|---|---|---|
| Maintenance of calloid (Group I) | LS | Solid | 0 | 0 | 0 | 0 | Necrosis and death often occurred within the first month of culture |
| Maintenance of calloid (Group IIa) | LS | Solid | 1.0 BAP | 0.1 NAA | 0 | 0 | Calloid healthy and grew well--plantlet differentiation after 32 weeks, few roots, shoots superficially like seedlings, but first formed leaves linear and plantlets very small--some abnormal growth |
| | LS | Solid | 1.0 SD8339 | 0.1 NAA | 0 | 0 | |
| | LS | Solid | 1.0 6-DMAP | 0.1 NAA | 0 | 0 | |
| | LS | Solid | 1.0 K | 0.1 NAA | 0 | 0 | |
| | LS | Solid | 1.0 SD8339 | 0.1 NAA | 0.1 GAA | 0 | Calloid appeared dark green and grew well, but plantlet differentiation was similar to media IIa without GAA |
| | LS | Solid | 1.0 SD8339 | 0.5 NAA | 0.1 GAA | 0 | |
| | LS | Solid | 0.2 BAP | 0 | 0 | 0 | Necrosis and death |
| | LS | Solid | 0 | 0.2 NAA | 0 | 0 | Necrosis and death |
| Maintenance of calloid (Group IIb) | LS | Solid and liquid | 10.0 BAP | 0 NAA | 0 | 0 | Chlorosis and poor growth rate |
| | LS | Solid and liquid | 10.0 BAP | 2.0 IAA | 0 | 0 | Chlorosis and poor growth rate |
| | LS | Solid and liquid | 10.0 BAP | 0 | 0 | 0.1 ACCP | Chlorosis and poor growth rate--some death |
| | LS | Solid and liquid | 10.0 BAP | 0 | 0 | 1.0 ACCP | Chlorosis and poor growth rate--some death |
| Maintenance of calloid and stimulation of vigorous plantlet growth (Group III) | LS | Solid | 0 | 0 | 0 | 1.0 TIBA | Stimulation of plantlet development after 2 to 4 weeks in culture--plantlets larger with more normal looking spatulate leaves more numerous plantlets with visible roots |
| | LS | Solid | 0 | 0 | 0 | 50 to 100 TIBA | Necrosis and death |
| | LS | Solid | 1.0 K | 0 | 0 | 1.0 TIBA | Light-green color --many small compressed plantlets with linear leaves, rapid calloid growth |

@ For composition of media, see Arditti and Strauss, 1979; LS-Linsmaier-Skoog medium
# BAP-benzylaminopurine, SD8339- adenine-N-benzyl-9-tetrahydro-2H-pyran-2-yl 6-DMAP-6-dimethylaminopurine
*IAA- indoleacetic, NAA- napthaleneacetic acid
**GAA- gibberellic acid
***ACCP- aminocyclopropane-1-carboxylic acid, TIBA- 2, 4, 5-tri-iodobenzoic acid

Note: Other concentrations of cytokinins and auxins used in media IIa, but since these do not significantly affect growth rate of calloid or plantlets, they are not listed separately. Concentrations of 0.1 mg/l have been tested for all cytokinins with 0.1 mg/l NAA.

Table 2. Maintenance and media for plantlets derived from calloid cultures

| Use | Basal medium @ | State of medium | Growth regulators (mg/l) cytokinin# | auxin* | gibberellin** | other*** | Results |
|---|---|---|---|---|---|---|---|
| Maintenance of small plantlets without added hormones (Group I) | ½ strength LS, MS, and SE | Solid | 0 | 0 | 0 | 0 | Most plantlets developed shoot systems superficially resembling seedling shoots, leaves were spatulate in appearance some developed visible roots after 1 to 3 months |
| | full strength LS, MS, and SE (with and without Nuchar) | Solid | 0 | 0 | 0 | 0 | Full strength media favoured shoot development, ½ strength root development |
| Maintenance of small plantlets and root stimulation (Group II) | full strength LS, MS and SE | Solid | 0.6 K | 6.0 NAA | 0 | 0 | Vegetative growth of shoots is slightly reduced over group I- leaves appeared more linear in shape, slight promotion of root growth |
| | | | 1.0 K | 2.0 NAA | 0 | 0 | |
| | | | 3.0 K | 2.0 NAA | 0 | 0 | Other concentrations yield similar results as above |
| | full strength LS | Solid & liquid | 1.0 K | 1.0 NAA | 0 | 0.1 ACCP | Reduced shoot growth--compared to group I leaves linear |
| | | | 0 | 1.0 NAA | 0 | 0.1 ACCP | Plantlets similar to group I |
| | | | 0 | 0 | 0 | 1.0 ACCP | Plantlets similar to group I |
| | | | 0 | 0 | 0 | 10.0 ACCP | Necrosis and rapid plantlet death |
| | | | 0 | 0.2 2,4, 5-T | 0 | 0 | Reduced growth rate of shoots and roots- some necrosis and death |
| Maintenance of small plantlets (Group III) | ½ strength LS | Solid | 0 | 0 | 0 | 1.0 TIBA | Similar growth to group 1 |
| | ½ strength LS | Solid | 1.0 K | 0 | 0 | 1.0 TIBA | Similar growth to group 1 |
| | ½ strength LS with nuchar | Solid | 1.0 K | 0 | 0 | 1.0 TIBA | Similar growth to group 1 |
| | ½ strength LS with nuchar | Solid | 0 | 0 | 0 | 1.0 TIBA | Similar growth to group 1 |

@For composition of media, see Arditti and Strauss, 1979; LS- Linsmaier-Skoog medium; MS- Murashige-Skoog medium; SE- soil extract medium.

# K-kinetin

* NAA- napthaleneacetic acid, 2, 4, 5-T - 2, 4, 5- trichloroacetic acid

**GAA- gibberellic acid

***ACCP- aminocyclopropane-1-carboxylic acid, TIBA- 2, 4, 5-tri-iodobenzoic acid

Plantlet production was stimulated on LS medium by the addition of 1 mg/l TIBA (Table 1). Rate of plantlet production was much improved on this medium, and differentiation of the first visible plantlets occurred after 2 to 6 weeks. Although this enhancement of plantlet production was noted on all seawater concentrations, plantlets produced on 60% and 70% ASW were often smaller and grew less vigorously than those on 50% and below.

Observations of 32-week-old calloids made under the SEM show protocorm-like bodies (Figure 4), abnormal shoot and leaf-like structures (Figure 3), as well as normal-looking plantlets were produced on all seawater concentrations. Most calloid masses had at least some differentiated stomata on regions other than leaf primordia (Figure 9). However, development of large calloid surfaces with high numbers of stomata was more common on tissue grown in liquid rather than on solid cultures. Numbers of stomata were highest on calloids grown in 40% ASW liquid cultures.

Regions with a tumor-like appearance were found on calloid masses at all ASW concentrations (Figure 10). Variations in the structure of these occurred both within and between cultures. However, all appeared to result from two or more growth centers existing in close proximity.

## Discussion

Some calloids grown on standard LS maintenance medium with 1.0 mg/l DMAP and 0.1 mg/l NAA develop plantlets after 4 to 6 months (Nyman and Arditti, in press b). More commonly, however, 32 weeks were required before calloid cultures produced significant numbers of normal-looking plantlets under these conditions.

In the present study, observations of calloid from LS maintenance medium under the SEM, revealed abnormal leaf-like and shoot-like growth reminiscent of structural abnormalities associated with lateral buds exposed to artificially high auxin/cytokinin ratios (Nyman and Cutter, 1981). Among such effects are development of shoots with decreased or missing leaf primordia, and reduction in mature leaf size. Occurrence of linear leaf-like structures arising from calloid tissues and plantlets and the observed protocorm-like bodies may be growth forms representative of an imbalance in the auxin/cytokinin levels. The tumor-like structures may be caused by a number of meristems arising in close proximity which become stunted and do not produce normal sequences of leaf primordia.

Calloid characteristics indicative of supraoptimal auxin concentrations could not have been observed without high resolution microscopy studies. These observations led to experimental use of four different media containing TIBA, a known antiauxin. The results with low concentrations of TIBA were consistent with theoretical considerations in that normal plant development indicative of optimal auxin concentration was favored over abnormal growth. There results indicate that structural observations can be used in the formulation of new media.

Root development was favored by half strength media, whereas full strength media were better suited for shoot development. Good root development on a two-fold dilution of basal medium has also been reported for Douglas fir plantlets regenerated from cotyledons (Cheng, 1979). Growth effects of media components may vary depending on a number of factors (Dougall, 1981). Thus, it is possible that dilution effects may be due to reduced levels of one or more components or general osmotic effects.

Figure 1. Plantlets differentiating from calloid after 32 weeks in culture and placed on Linsmaier-Skoog medium without added hormones. The calloid from which the plantlets were produced had been maintained on Linsmaier-Skoog medium with 1 mg/l 6-dimethylaminopurine and 0.1 mg/l napthaleneacetic acid. x 5.

Figure 2. Scanning electron micrograph of a single plantlet produced from calloid grown on Linsmaier-Skoog medium with 1 mg/l 6-dimethylaminopurine and 0.1 mg/l napthaleneacetic acid. Note the linear appearance of the first formed leaves (L) and the small root primordia (R). x 19.

Figure 3. Scanning electron micrograph of a leaf-like structure produced by a 32 week old callodi growing on the same medium as Figure 2. x 160.

Figure 4. Scanning electron micrograph of protocorm-like (P) in a young calloid (∿ 12 weeks old) growing on the same medium as Figure 2. x 200.

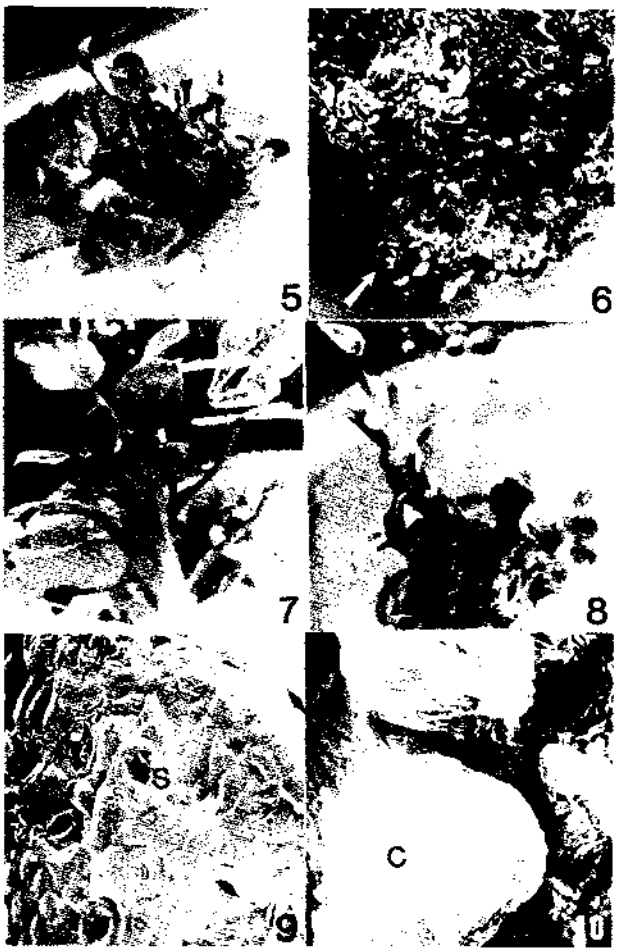


Figure 5. Differentiating plantlets from a calloid culture growing for 4 weeks on Linsmaier-Skoog medium in the presence of 1 mg/l tri-iodobenzoic acid. x 4.

Figure 6. Calloid growing for 4 weeks on Linsmaier-Skoog medium in the presence of 1 mg/l tri-iodobenzoic acid and 1 mg/l kinetin. Note the numerous tiny compressed plantlets (arrow). x 4.

Figure 7. Individual plantlet growing on full strength Linsmaier-Skoog medium for 2 weeks, transferred from a culture similar to the one shown in Figure 5. x 4.

Figure 8. Individual plantlet growing in half strength Linsmaier-Skoog medium for 2 weeks, transferred from a culture similar to the one shown in Figure 5. x 4.

Figure 9. Scanning electron micrograph of the surface of a calloid from Linsmaier-Skoog medium with 1.0 mg/l dimethylamilnopurine and 0.1 mg/l napthaleneacetic acid, and 100 milliosmoles (10%) artificial seawater. Note the abundant stomata (S). x 400.

Figure 10. Tumor-like region on a calloid surface from Linsmaier-Skoog medium with 1.0 mg/l dimethylaminopurine and 0.1 mg/l napthaleneacetic acid, and 300 milliosmoles (30%) artificial seawater. Note the closely spaced growth centers (C).x 60.

The concentrations and chemical nature of auxins and cytokinins as well as the addition of ACCP to culture media affected plantlets and calloid differently. NAA was more effective than IAA in media used to support the calloid, possibly due to its stability. Calloid growth in the present of the four cytokinins tested was equivalent suggesting that all are equally effective. In the absence of either an auxin or a cytokinin calloids became necrotic and died. This indicates that requirements of calloid are for a balanced auxin-cytokinin ratio. The effect of TIBA may be to support a favorable auxin/cytokinin balance in the tissue. This view is supported by observations that normal plantlet development is inhibited when TIBA IS added in the presence of exogenous kinetin. Further if TIBA affects auxin levels, then it is reasonable to assume that endogenous auxin/cytokinin levels are not optimal. All hormone effects observed were clearly independent of ASW concentration.

At this point, it is difficult to determine whether the adaptation to ASW is genotypic or phenotypic. However a number of general characteristics should be noted: (1) cumulative growth on all concentrations (except for 60% ASW) was comparable; (2) in the initial cultures, higher numbers of plantlets with a normal appearance formed on 40% ASW; (3) calcium oxalate content, chlorophyll, protein and secondary alkaloid levels in ASW cultures were higher than those on standard medium (Nyman, Gonzales, and Arditti, 1981), and (4) cell wall thickness, cell size, chloroplast size and structure, numbers and size of starch grains appear to vary with ASW concentration (unpublished results). A great deal of variation was also noted in plantlet characteristics. This variation was independent of medium and therefore appears to be somaclonal (Larkin and Scowcroft, 1981). If so, the basis of adaptation to ASW cultures may be genetic and the strategy for production of salt tolerant cultivars might include the screening of somaclonal variants.

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# Breeding Strategies for Controlling Diseases of Taro in Solomon Islands

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## ABSTRACT

Progress towards breeding taro resistant to four severe diseases is described. Resistance to Phytophthora leaf blight was found in a wild taro from Thailand and appears to be monogenic and dominant. A backcross program to incorporate resistance to local cultivars has begun. Different reaction to dual infection by taro large and small bacilliform viruses exists in local cultivars. When those that are resistant buy low yielding ("female") were crossed with others that have high yields and are susceptible ("male") all the progeny died. Resistance is now sought from selfed and intercrosses $F_1$ plants derived from further 'male' x 'female' crosses. The only cultivar resistant to a corm and root rot caused by the nematode Hirschmanniella miticausa is low yielding and corms and leaves are acrid when cooked. Crosses have been made between this cultivar and those with more favoured taste and higher yields. The possibility of combining the breeding programs is discussed.

## Introduction

Fundamental to improvement of subsistence agriculture based on root crop staples is providing growers with cultivars of superior agronomic characteristics. Selection among local, established cultivars often fails to reveal those with desired traits. Mass importation of germplasm from other countries, as vegetative propagating material, is hazardous and, in most countries, prohibited by plant quarantine regulations. Breeding programs based on selective, controlled importation of cultivars offers a better approach. In recent years this has been demonstrated at international institutes where breeding programs have been established to tackle problems of cassava, sweet potato and certain yams.

Taro, a forth major root crop of tropical countries, has received relatively little attention. In most tropical regions it is the least important of the root crops. However, in the South Pacific taro often dominates the subsistence economy. But in some countries of the region the crop is becoming difficult to grow.

In Melanesia, especially, a number of pests have jeopardized continued large-scale cultivation of the crop and threaten adjacent countries of the South Pacific. Of particular importance are Phytophthora leaf blight, taro large and small bacilliform virus diseases and a corm rot disease caused by the nematode

Hirschmanniella miticausa. Breeding programs have been started to produce plants with resistance.

In 1976, preliminary investigations began to define breeding techniques and to determine strategies for disease control. This work, supported by the International Foundation for Science, was summarized at the IFS-sponsored meeting on Taro and Cocoyam in 1979 (Jackson and Pelomo, 1980). Since then FAO/UNDP Root Crops Development Project for the Pacific Countries has assigned a plant breeder to assist the project. This paper describes progress to date.

## Taro Leaf Blight

Taro leaf blight, a serious disease of taro caused by the fungus Phytophthora colocasiae occurs in many countries of South East Asia and the Pacific (Trujillo, 1967; Plucknett et al, 1970). In the South Pacific region it is in Papua New Guinea (Shaw, 1963), and Solomon Islands where it is considered to be the most important disease of taro (Barrau, 1958). Reductions in corm yield of 40% to 60% have been reported (Jackson et al., 1980). The fungus also causes a serious postharvest corm decay (Jackson and Gollifer, 1975).

Breeding for resistance to the disease began in 1979. Seed collected from a wild taro in Bangkok, Thailand and grown in Solomon Islands to have seedlings free of virus for use in transmission studies, produced plants that were immune to leaf blight. With the use of gibberellic acid (Alumu and McDavid, 1978) local cultivars were induced to flower and were crossed with the naturally flowering Bangkok variety (Jackson and Pelomo, 1980). The progeny (F1) were both resistant to leaf blight and, like the Bangkok variety, suckers were formed on runners. This initial success stimulated development of a backcross program using Solomon Islands cultivars as recurrent parents. The local cultivars used in the first crosses were not selected for particular agronomic merit but because they flowered at the same time as the Bangkok variety. Subsequently, two popular local cultivars were chosen as recurrent parents. Both have good taste. One (cv. Akalomamale) has only moderate corm yield but is resistant to a virus disease, whereas the other (cv. Luma'abu) is high yielding but dies from virus infection. Progeny from the first backcross segregated into an equal number of leaf blight resistant and susceptible plants, and in addition, half the progeny produced runners. This suggests that both leaf blight resistance and the method of sucker production are controlled by single, dominant, genes (Table 1).

Having established the mode of inheritance of leaf blight resistance it was then necessary to develop a method of testing the reaction of seedlings to leaf blight before field planting. The following procedures have been established: 3 to 4 months-old seedlings are sprayed with a dense suspension of zoospores induced to develop from sporangia, collected in distilled water, from taro leaves with lesions of P. colocasiae or from the surface of 10-day-old cultures of the fungus growing on lima bean agar, by refrigerating the sporangial suspension to c. 6°C for a minimum of 4 h and subsequently leaving the suspension in shallow trays for 2h at ambient temperatures (20° to 25°C). The two methods of collecting the spores are necessary because of insufficient quantities of naturally produced sporangia during periods of low rainfall, which frequently occur on the Guadalcanal Plains. After spraying, plants are held at high humidities for 72 h until lesions develop. Initial tests showed good correlation between disease reaction of seedlings, artificially inoculated in this manner, and that which occurred when they were transplanted to the field and subjected to natural epiphytotics of leaf blight. Thus about half the number of plants of each generation are discarded at

seedling stage; thus, the limited area of irrigated land available at the research station is saved for assessment of yield and other important agronomic characteristics. Such assessment is required for leaf blight resistant plants of second backcross generation which have recently been field planted, but this work is hindered by plants, sprayed with gibberellic acid, invariably produce small corms. Because of this, plants must first be grown to maturity, without gibberellic acid treatment, to select those that are high yielding as parents for future generations.

## Virus Diseases

Two bacilliform shaped virus particles of different size are associated with diseases known locally in Solomon Islands as alomae and bobone (Gollifer and Brown, 1972; James et al., 1973; Kenten and Woods, 1973). The diseases are also found in Papua New Guinea (Shaw et al., 1979), and one or the other particles occur in several countries in the South Pacific (Jackson, 1980). Taro in Solomon Islands is categorized by growers into two groups on the basis of susceptibility to infection by the two particles. One group, containing the so called "male" taro, is generally tall and high yielding. Infection of these plants by both particles causes alomae, a lethal disease. Infection by either large or the small bacilliform virus alone results in less serious diseases, causing mild mosaics and minor leaf distortions, from which plants eventually recover. The other group contains taro which are short and low yielding. These are known as "female" taro. They are resistant to alomae, but infection by the large bacilliform virus causes bobone. This is not lethal and plants eventually recover but corm yields are reduced (Gollifer et al., 1978).

The possibility that high yields and resistance to alomae could be combined was tested by making crosses between the "male" and the "female" cultivars. From three crosses in 1978 about 120 seedlings were planted at Dala Farm on Malaita, where the virus diseases are endemic. Contrary to expectations, disease spread among the seedlings was slow, although the block was infected with vectors of the virus particles, *Tarophagus proserpina* and *Planococcus pacificus*. Eventually the majority of plants developed symptoms similar to alomae and became stunted with severely chlorotic, distorted leaves, but took many weeks to die. These $F_1$ plants were either more susceptible to bobone or more resistant to alomae than their parents. After 13 months all but 26 had died. These survivors were retested and during three subsequent replantings all died from virus disease. To confirm the susceptibility of the $F_1$ plants a further 15 crosses between "male" and "female" cultivars were made in 1980, from which about 900 seedlings were planted on Malaita in early 1981. As occurred in the first planting, disease spread was initially slow, but after 12 months only 222 healthy plants remained. Three suckers from each were replanted and infested with large populations of the two insect vectors. Within 6 months most plants were dead.

These results indicate that resistance to alomae may be a recessive trait. Therefore, to increase desirable homozygosity, selfing, sib-mating and intercrossing among the $F_1$ plants of "male" and "female" crosses is now required. To achieve this the few survivors from the second plantings on Malaita, together with other seedlings raised from "male" and "female" crosses have been planted at the Dodo Creek Research Station on Guadalcanal.

Table 1. Number and percentage of plants forming runners and resistant to Phytophthora leaf blight in the first backcross generation.

| Pedigree | *Total No. of plants | No. of plants with runners | % runners | Total No. of plants | No. of plants resistant to Phytophthora leaf blight | % resistant |
|---|---|---|---|---|---|---|
| (Tafaibeu x Bangkok) x Akalomamale | 55 | 28 | 50.91 | 40 | 16 | 40.00 |
| (Bangkok x Bobolo) x Oga | 57 | 27 | 47.37 | 9 | 5 | 55.55 |
| (Bangkok x Bobolo) x Akalomamale | 48 | 22 | 45.83 | 33 | 15 | 45.45 |
| (Kareto x Bangkok) x Akalomamale | 77 | 37 | 48.05 | 138 | 66 | 47.83 |

*The two sets of data, for runners production and leaf blight resistance, recorded on different batches of plants.

For each cross, $X^2$ tests confirmed a 1:1 ratio of plants with and without runners and resistant and susceptible to leaf blight (P = 0.01).

## Nematode Corm Rot

A corm and root rot disease caused by a nematode (Bridge et al., in press) is newly reported from two provinces of Solomon Islands (Mortimer et al., 1981). The disease also occurs in Papua New Guinea (J. Bridge, Rothamsted Experimental Station, personal communication). In both places infection renders the corms inedible. The disease is of particular interest in that it attacks taro grown under dryland cultivation, on rainfed mountain slopes, and also those grown in swamp pits, on low lying atolls. In the swamp pits the disease is devastating and in one locality taro cultivation has been almost entirely abandoned.

One cultivar has been found with resistance to the disease. This taro, often found in streams and swamps on all islands, is used only when other foods are scarce. The corms are usually very small and acrid when cooked. Crosses between this taro and cultivars that are high yielding have more acceptable taste. Several hundred seedlings have been grown from these crosses and will soon be planted in swamp pits where the nematode is present. A few seedlings from each of the crosses will be planted at the research station. These will be used to develop the program further if $F_1$ plants do not have acceptable corm size and resistance to the disease.

## Discussion

Preliminary results show that breeding programs offer solutions to four serious diseases of taro in Solomon Islands. The results are particularly important because no other control methods are appropriate to subsistence agriculture in the country. For the virus and nematode programs it is too early to be confident that plants will be produced with disease resistance and high yields. The next generation of plants derived by selfing progeny of "male" and "female" crosses should indicate if the breeding strategy to obtain alomae resistance is correct.

More immediate success is likely from leaf blight program where resistance from the Bangkok variety is being transfered to local cultivars. Seed from these crosses was fortunately viable. Problems were anticipated because taro in Asia has greater variability in chromosome number than that of the Pacific (Yen and Wheeler, 1968) and hybridization between cultivars might have produced non-viable seed (Abraham, 1970).

Search for alternative sources of resistance will always be important to the leaf blight program. Breakdown of resistance to *Phytophthora* disease in other crops is well documented (Vander Plank, 1963; Wheeler, 1969). It will pose a constant threat to the durability of the resistance in taro produced from this breeding program, especially as this resistance is governed by a single, dominant, gene. Not only is taro from India important but also that in collections elsewhere.

Although treatment of plants with gibberellic acid is vital to promote flowering, its use on field-grown taro produces abnormally tall plants with small corms. This means that at each generation agronomic assessment and the production of seed takes 12 to 15 months. To reduce time between generations to one crop cycle, concentrations of gibberellic acid, lower than the routinely used rate of 250 ppm, will be tested. One, or at most two, large influorescences are required. At present several are produced which are small and contain a high proportion of

sterile flowers. Failure to reduce the time between generations will seriously delay the programs and any subsequent attempt to combine them.

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Promotion of Flowering, Seed Production and Seedling Screening in Minor Edible Aroids

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ABSTRACT

In the Pacific, Colocasia is clearly the most important of the edible aroids and Xanthosoma is spreading rapidly and widely. The less well known Alocasia macrorrhiza and Cyrtosperma chamissonis have more restricted distributions and are considered minor crops in the region as a whole. They are, however, staple foods on some islands, Alocasia being frequently cultivated in Samoa and Tonga and Cyrtosperma on atolls and low coralline islands where few other crops survive.

Germplasm collections of Alocasia and Cyrtosperma have been assembled at Alafua and a genetic improvement program initiated. Studies related to the promotion of flowering with gibberellic acid, hand pollination, seed germination and seedling rearing are discussed.

In the Pacific region the edible aroids, Colocasia esculenta (L.) Schott, Xanthosoma sagittifolium (L.) Schott, Alocasia macrorrhiza (L.) Schott, and Cyrtosperma chamissonis (Schott) Merr. are cultivated. Of these, Colocasia (taro, talo) is the most important within the region as a whole. It is an ancient crop which has prestigious as well as economic value. In comparison, Xanthosoma (cocoyam, talo palagi) is relatively new to the region, having been introduced during the last century. Nonetheless, it has spread rapidly and widely because its high yields and disease, shade and drought tolerance often make it easier and more profitable to grow than Colocasia.

Alocasia (giant taro, ta'amu, kape) and Cyrtosperma (giant swamp taro, pula'a pulaka, babai) are less well known and have more restricted distribution in the region. However, they are dominant or co-dominant cultivated staples on some islands. Alocasia is frequently cultivated and marketed in Western Samoa, Tonga, the Wallis Islands, and Tuvalu and in Tonga it is socially and ceremonially important. To a lesser extent it is cultivated in American Samoa, Papua New Guinea, Vanuatu, Solomon Islands, New Caledonia and other parts of French Polynesia (Barrau, 1958, 1961; Plucknett, 1970; Fa'anunu, 1977; Mauala, 1977; Merrick, 1977; Thaman, 1977, 1981; Bourke, 1979; personal observations).

Cyrtosperma is the most important aroid on the resource-poor atolls and low coralline islands of Kirabati, Tuvalu, Tokelau, Papua New Guinea, Solomon Islands and Micronesia where it is grown in natural swamps or in large, manmade swamp pits dug down through sand and coral-limestone rock to the fresh water lens. It is

also cultivated as a supplementary and reserve food in the Cook Islands, in poorly drained areas of the Rewa River Delta, Fiji, in high island fresh water swamps of Papua New Guinea and in the coastal swamps of the Solomon Islands. In Western Samoa wild stands are infrequently harvested; only during times of food shortages (Catala, 1957; Barrau, 1958, 1961; Plucknett, 1970, 1977; Small, 1972; Wall and Hansell, 1976; Hadley, 1977; Bourke, 1979; Thaman, 1981; personal observations).

Traditionally, both Alocasia and Cyrtosperma are vegetatively propagated using head setts or suckers. In the Pacific some cultivars of Alocasia flower naturally, generally after at least one year's growth, but naturally-set seed has not been found. Viable seeds have, however, been collected in Australia (D.E. Shaw, personal communication) and in the Philippines (W.J. Cable, personal observation). Natural flowering occurs in many cultivars of Cyrtosperma, naturally-set seed is frequently found and farmers occasionally rear volunteer seedlings (Catala, 1957; Small, 1972; personal observations). Nonetheless, to facilitate the genetic improvement of these two aroids, techniques are required for promoting early, uniform and abundant flowering in all cultivars and for controlled hand pollination, seed germination and seedling rearing.

It is now well documented that gibberellins promote flowering in several aroids including Colocasia and Xanthosoma and techniques for pollinating and growing seedling populations have now been perfected for these two genera (McDavid and Alamu, 1976; IITA, 1977; Alamu and McDavid, 1978a, 1978b, 1978c; Cable, 1979; Jackson and Pelomo, 1980; Wilson, 1980a, 1980b, 1980c, 1981). The present study was initiated to adapt these techniques to Alocasia and Cyrtosperma. Two portions of the study, promotion of flowering in Alocasia and flowering, fruiting and seed germination in Cyrtosperma, will be discussed in this paper.

## Materials and Methods

### Promotion of Flowering of Alocasia

Seventeen accessions of Alocasia have been collected from Western Samoa and established at Alafua. From this collection two clones, Ta'amu Toga and Ta'amu Niu Kini, were selected for their contrasting propensity to flower naturally. Ta'amu Toga frequently flowers about one year after planting whereas Ta'amu Niu Kini does not flower naturally even when left undisturbed for 2 or more years. Plants were grown in the field from vegetative propagules planted at Alafua on 27 April at a spacing of 1.5x1.5 m. To insure vigorous growth, plants were fertilized one month after planting with 50, 11 and 80 kg/ha N, P and K respectively and 2 and 3 months after planting with 100, 22 and 40 kg/ha N, P and K respectively. A randomized complete block design with three replications, three plants to a plot, was used.

Plants were treated with aqueous solutions of technical grade gibberellic acid (GA, 75% potassium salt, ICN) at the concentrations of 750 and 1500 ppm or with a water control of 0 ppm GA. These were applied with surfactant (0.25% v/v Agral LN, ICI) as foliar sprays using a hand sprayer. Plants were treated once when they reached the 3 to 6 leaf stage, about 2 months after planting. Approximately 60 ml of solution was applied to each plant, covering all leaves to runoff and filling the cup formed by the petiole bases. Observations on flowering were recorded at two-day intervals beginning from the appearance of the first inflorescence and continuing until about 6 months after planting when most, but not all, plants had finished flowering.

## Flowering, Fruiting and Seed Germination of Cyrtosperma

Twelve accessions of Cyrtosperma have been collected from Western Samoa and planted at Alafua. Although preliminary trials indicated that flowering can be promoted with 1000 ppm GA, adequate numbers of inflorescences were not available from the collection and therefore inflorescences and fruit clusters were collected from wild stands at five locations within the country. Seeds were extracted either by (1) removing seeds from fresh, mature fruits; (2) removing seeds from fresh, mature fruits and fermenting them overnight in small quantities of water; or (3) fermenting the entire fruit cluster for several days before washing out the seeds.

Since earlier observations indicated that dry seeds germinated poorly, a trial was designed to determine the effects of drying on percentage and rate of germination. Treatments consisted of (1) no drying, fresh seeds planted immediately after extraction, (2) drying and storing for 1 to 23 days, and (3) drying for 1 day, coating with melted candle wax, storing for 1 to 35 days and removing wax by scraping immediately before planting. All seeds were extracted by fermenting entire fruit clusters. Drying and storage were at ambient conditions (24-30°C, high RH) and seeds were sown in convered Petri dishes containing thin layers of steam sterilized soil and maintained at ambient conditions. Twenty-five seeds per treatment were planted and the trial was repeated five times whenever sufficient mature fruits were available. Germination data were recorded daily for 30 days after sowing. Seedlings were transplanted to pots in the greenhouse when cotyledons were fully expanded.

## Results and Discussion

### Promotion of Flowering in Alocasia

None of the water-treated control plants of Ta'amu Niu Kini and only one of the nine control Ta'amu Toga plants flowered during the 6 months experiment. In contrast, the percentage of plants flowering in the GA treatments ranged from 67% to 100% (Table 1). In Ta'amu Toga 750 ppm GA resulted in a higher percentage of plants flowering although this difference was not significant and in Ta'amu Niu Kini the percentage of plants flowering was not affected by GA concentration. Likewise, the mean number of normal inflorescences produced was higher in Ta'amu Toga plants treated with 750 ppm GA although the difference was not significant and in Ta'amu Niu Kini there was no difference between GA concentrations (Table 2) although the 1500 ppm treatment tended to produce weaker inflorescences. Ta'amu Toga yielded more inflorescences than Ta'amu Niu Kini.

Generally, GA-treated plants flowered earlier than water-treated controls but no consistent differences in number of days from treatment to appearance of the first normal inflorescence were observed between GA concentrations or between clones (Table 3).

In both clones GA-treated plants had shorter petioles and smaller leaf blades and some leaf deformities were observed. In Ta'amu Niu Kini, GA increased suckering so that flowering plants produced leaves and inflorescences simultaneously but, in contrast, most GA-treated plants of Ta'amu Toga terminated in floral buds and new leaves were not available to support developing fruits.

Both 1500 and 750 ppm GA gave satisfactory results in terms of time to flowering, percentage of plants flowering and number of inflorescences. In one clone tested 750 ppm gave better results and in both clones 750 ppm produced more



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Table 1. Effects of GA on percent plants flowering in *Alocasia*.

| GA Conc. (ppm) | Ta'amu Toga | Ta'amu Niu Kini | Mean ($\overline{T}$) |
|---|---|---|---|
| | Plants flowering (%) | | |
| Water control | 11 | 0 | 6 |
| 750 | 100 | 67 | 84 |
| 1500 | 89 | 67 | 78 |
| Mean (GA treatment only) | 94 | 67 | |
| Mean ($\overline{C1}$) = | 67 | 45 | |
| LSD ($\overline{X}$) P = 0.05 | 44 | LSD ($\overline{T}$) P = 0.05 | 31 |
| P = 0.01 | 63 | P = 0.01 | 45 |
| CV (%) | 77.0 | LSD ($\overline{C1}$) P = 0.05 | 26 |
| | | P = 0.01 | 36 |

Table 2. Effects of GA on number of inflorescences produced in *Alocasia*.

| GA Conc. (ppm) | Ta'amu Toga | Ta'amu Niu Kini | Mean ($\overline{T}$) |
|---|---|---|---|
| | Inflorescences/plant | | |
| Water control | 0.7 | 0.0 | 0.4 |
| 750 | 5.7 | 3.3 | 4.5 |
| 1500 | 4.2 | 3.9 | 4.0 |
| Mean (GA treatment only) | 5.0 | 3.6 | |
| Mean ($\overline{C1}$) = | 3.5 | 2.4 | |
| LSD ($\overline{X}$) P = 0.05 | 1.8 | LSD ($\overline{T}$) P = 0.05 | 1.2 |
| P = 0.01 | 2.5 | P = 0.01 | 1.8 |
| CV (%) | 72.8 | LSD ($\overline{C1}$) P = 0.05 | 1.0 |
| | | P = 0.01 | 1.4 |

Table 3. Effects of GA on days to first normal inflorescence of *Alocasia* from time of application.

| GA Conc. (ppm) | Ta'amu Toga | Ta'amu Niu Kini | Mean ($\overline{T}$) |
|---|---|---|---|
| | Days | | |
| Water control | 119 | NF* | - |
| 750 | 94 | 103 | 99 |
| 1500 | 100 | 98 | 99 |
| Mean (GA treatments only) | 97 | 101 | |
| *No flowers produced | | | |
| No significant differences between 750 + 1500 ppm GA | | | |
| CV (%) | 7 | | |

vigorous inflorescences and is therefore more suitable for breeding purposes. Concentrations lower than 750 ppm should be tested on T'amu Toga to find a treatment which does not reduce leaf production so drastically.

## Flowering, Fruiting and Seed Germination in Cyrtosperma

The inflorescence of Cyrtosperma consists of a large spadix, often 20 to 25 cm long, covered by an open spathe. In contrast to most edible aroids which are monoecious, the flowers of Cyrtosperma are hermaphroditic and distributed uniformly over the entire length of the spadix. Pollen shed begins at the apex of the spadix and progresses through the mid-section to the base. The fruiting head is a cluster of densely packed berries, yellow to orange-red when mature, each containing one to several large seeds measuring 5 to 10 mm in diameter. In 28 fruit clusters collected from five locations in Western Samoa the number of seeds/berry ranged from 1 to 4 with a mean of 2.4 and the number of seeds/fruit head ranged from 9 to 253 with a mean of 108. Most berries were located on the basal one-third to one-half of the spadix and on the side not enclosed by the spathe, suggesting that inflorescences are protogynous and rain pollinated. In western Samoa berries were rarely observed near the apex of the spadix, however in Kiribati, berries have been commonly found along the entire length of the spadix suggesting that insects or wind do transfer pollen between inflorescences in some locations.

Fruiting heads harvested when berries were fully developed but still green were successfully ripened by placing the cut end of the peduncle in water and storing until berries softened and turned yellow or orange-red. Generally seeds from less-than-fully developed berries were, however, too immature to germinate, even after post-harvest ripening.

All three methods of seed extraction resulted in good seed germination, but those two methods involving fermentation, either of the seeds or of the entire fruit cluster, were the most satisfactory since they removed the gelatinous coating encasing each seed.

Germination of fresh seeds planted without drying immediately after extraction ranged from 12% to 84%. Germination percentages were reduced by half or more after 2 or 3 days of drying and storage and all viability was lost after 5 to 8 days of drying and storage. Waxed seeds which were stored one and 2 days before sowing had lower percentage germination compared to unwaxed seeds stored for the same period, but waxing did tend to reduce somewhat the rate of decline in viability when seeds were stored for 4 to 7 days. Nonetheless, all viability was lost with longer storage.

Fresh seeds and seed dried for one day began germinating 6 to 15 days after sowing compared to 13 to 22 days for seeds dried and stored 2 to 7 days and 20 to 32 days for waxed seeds. Drying and waxing presumably delayed imbibition.

Establishment of seedlings in the greenhouse was good although growth was slow in the coral sand/soil potting mixture used. Plants are presently being maintained until they are large enough to screen for tolerance to salinity.

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# Food Quality and Chemical Composition

Evidence of Proteolytic Enzyme Activity in Taro, Calocasia esculenta (L.) Schott

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ABSTRACT

A substrate for the assay of proteolytic activity, Azocoll, was used to demonstrate presence of protease in taro. Using 10 g samples of taro corms and 100 mg of Azocoll in 10 ml 0.05 m tris-HCl buffer incubated for 30 min at 37°C, differences in degree of proteolytic enzyme activity in some taro cultivars were detected. Due to relative speed and ease of the procedure, its development as a possible chemical method in quantification of proteolytic enzyme activity in taro and other aroids is suggested.

## Introduction

The acrid or itchy principle found in members of the family Araceae has attracted attention of various workers (Walter and Khanna, 1972; Tang and Sakai, 1983; Sakai, 1979). Various theories have been advanced to explain this property of the aroids (Tang and Sakai, 1983; Walter and Khanna, 1972, Middendorf, 1982). Among the speculations on the possible cause of aroid acridity is the presence of proteolytic enzyme such as dumbcain in Dieffenbachia (Walter and Khanna, 1972). The presence of calcium oxalate crystals, especially in the genera Colocasia and Xanthosoma have been well documented (Sunell and Healey, 1979; Sakai, 1979) and implicated as playing a role in the acridity of these crops (Sakai, 1979; Middendorf, 1982).

Following the lead of Walter and Khanna (1972) and the proteolytic nature of some snake venoms, a substrate, Azocoll, was used to determine the presence of protease(s) in some taro cultivars at the University of Hawaii germplasm collection in the Island of Kauai.

## Materials and Methods

The following procedure was used for this work:

Reagents. Azocoll (Calbiochem) used without purification.
Tris-HCl, 0.05 m, pH 9.0

Procedure. Place 10 g sliced taro corm in a beaker containing 10 ml Tris-HCl buffer. Add 100 mg Azocoll and incubate at 37°C for 30 minutes. Filter off solid components and read absorbance of filtrate at 520 nm in a colorimeter. Run blanks with each determination to account for pigment, starch and other interferences.

## Results and Discussion

Using the procedure described, absorbance of six taro cultivars was obtained:

| Cultivars | A at 520 nm |
|---|---|
| Aa'aa | 0.92 |
| Apuwai | 0.86 |
| Bun-long | 0.43 |
| Kalpao | 0.42 |
| Lehua Maoli | 0.79 |
| Miyako | 0.52 |

All taro samples gave positive reaction to Azocoll indicating the presence of proteolytic enzyme(s). A listing of the cultivars used in the experiment based on known and alleged level of acridity follows closely the absorbance values of the samples. Bun-long is currently used in making taro chips in Hawaii due to its low level of acridity compared to Apuwai and Lehua Maoli which are used for making "poi," the Hawaiian staple food. Lehua Maoli and Apuwai can also be made into taro chips, but the corms must be boiled or steamed prior to slicing and frying into taro chips. Miyako is a dasheen cultivar grown for vegetable and of moderate acridity. The cultivar Aa'aa is more acrid than any of the materials used (Anderson, 1983). The acridity level of the cultivars based on current uses is:

Bun-long, Kalpao < Miyako < Apuwai, Lehua Maoli < Aa'aa.

The coincidence of the above listing to the absorbance obtained with Azocoll tends to add support to the possible role of proteolytic enzyme(s) in the acridity of taro and other aroids. Taro corm samples boiled for 30 minutes gave negative reaction to the substrate confirming the enzymic nature of the principle being investigated. For want of a name, "taroin" is suggested to refer to the protease in taro, *Colocasia esculenta* (L.) Schott until further investigation has elucidated its nature and other characteristics. The method needs to be further investigated to confirm the role of the enzyme in the acridity of taro. If this role of "taroin" can be confirmed, the method can be used as a rapid and simple technique for determination of acridity levels of taro and possibly the other aroids.

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Starch Distribution in Cocoyam (Xanthosoma spp.) Corms and Cormels

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This paper reports results from a project that contributes to a cooperative program between the Institute of Food and Agricultural Sciences of the University of Florida and the Gas Research Inst., entitled "Methane from Biomass and Waste."

ABSTRACT

Starch concentration, percent dry weight and specific gravity determinations were made on Xanthosoma caracu, X. atrovirens and X. violaceum. X. atrovirens had highest starch concentration in both corms and cormels with 35.1% and 46.2% starch, respectively. In all cases cormels were higher in starch than corms. Variation in starch concentration within corms and cormels was less than that between species and the corms and cormels. Specific gravity of corms and cormels explained 89% and 72% of variability in starch concentration; thus, high specific gravity can be used as a selection parameter for high starch content.

Cocoyam is an important staple crop in several lowland tropical areas, including southern Florida where production of X. caracu is estimated as much as 2,000 ha. In the Araceae family, this crop, like its relatives, is well adapted to moist soils and partial shade. Nonetheless, some cultivars can be successfully grown in full sun. Even though it is grown for its starch-filled cormels, little is known of the variation in starch content.

## Materials and Methods

Three cocoyam species Xanthosoma caracu, X. atrovirens and X. violaceum were selected for starch evaluation. Field grown 12-month-old plants were harvested and cleaned prior to analysis. The plants were divided into main corm and cormels. Each corm was divided into upper, middle, and lower one-third section. The cormels were also divided into thirds, proximal to the main corm, central and distal from the main corm. Specific gravity measurements were made on each section. A cross section disk of 10 g was taken from each part for dry weight determination. For starch determination, a second cross section disk was taken and divided into four 100 mg wedges as sub-samples. Starch determination was made through enzymatic hydrolysis of starch to glucose followed by glucose quantification (Dekker and Richards, 1971; O'Hair, 1981). To measure the variation in lateral starch distribution a standard 9 mm cork bore was used to take a sample from the central section of both the corm and cormel of each species. The bore was positioned to pass through the center of the storage organ. The extracted core sample was divided into 7 sequential, 100 mg pieces (Table 1) and analyzed for starch concentration as before. Statistical analysis of the data was done through least squares regression with general linear models.

Table 1. Lateral distribution of starch concentration (%) according to species and storage organ.

| Storage organ | Sequential section | Relative location | Species | | |
|---|---|---|---|---|---|
| | | | caracu | violaceum | atrovirens |
| Corm | 1 | Outer edge | 6.3 | 4.1 | 15.3 |
| | 2 | | 14.2 | 11.0 | 30.9 |
| | 3 | | 16.0 | 11.7 | 38.7 |
| | 4 | | 17.0 | 10.7 | 39.9 |
| | 5 | | 14.0 | 10.9 | 34.9 |
| | 6 | | 14.7 | 10.5 | 23.9 |
| | 7 | Center | 11.8 | 9.5 | 26.9 |
| Cormel | 1 | Outer edge | 25.7 | 17.4 | 52.3 |
| | 2 | | 33.0 | 23.4 | 53.1 |
| | 3 | | 24.4 | 24.0 | 46.4 |
| | 4 | Center | 27.6 | 23.9 | 51.7 |
| | 5 | | 29.2 | 24.9 | 53.1 |
| | 6 | | 31.9 | 23.5 | 56.7 |
| | 7 | Outer edge | 33.5 | 18.4 | 57.5 |

## Results and Discussion

Overall, cormels were significantly higher in starch concentration, percent dry weight and specific gravity than the corms (Table 2). The greater difference in starch concentration in comparison to the dry weight is attributed to the age of the tissue sampled. Corms probably were higher in fiber content than the cormels. In the corm, the starch concentration ranged from a low of 7.2% in the lower section of *X. violaceum* to a high of 49.6% in the lower section of *X. atrovirens* (Table 3). In the cormels, the starch concentration ranged from a low of 20.9% in the proximal (closest one-third to the corm) section of *X. violaceum* to a high of 52.4% in the central one-third section of *X. atrovirens*. In both corms and cormels, *X. atrovirens* was significantly higher in starch than *X. violaceum* and *X. caracu*. The dry weights ranged from a low of 16.4% in the lower corm section of *X. caracu* to a high of 53.4% in the central cormel section of *X. atrovirens*. In all cases the cormels were higher in percent dry weight than the corms. All parts tested had less than 1% glucose.

Table 2. Starch, dry weight and specific gravity of *Xanthosoma*, excluding differences between species.

| Storage organ | Starch(%) | Dry weight(%) | Specific gravity |
|---|---|---|---|
| Cormel | 31.9a* | 38.8a | 1.0565a |
| Corm | 19.9b | 29.2b | 1.0260b |

*Mean separation in columns by Duncan's multiple range test, 5% level.

Table 3. Storage organ starch, glucose and dry weight comparisons in Xanthosoma.

| Species | Storage organ | Section | Starch(%) | Glucose(%) | Dry weight(%) |
|---|---|---|---|---|---|
| caracu | Corm | Upper | 12.4 | 0.0 | 17.2 |
| | | Central | 14.4 | 0.0 | 18.0 |
| | | Lower | 13.5 | 0.0 | 16.4 |
| | Cormel | Distal | 21.7 | 0.0 | 21.2 |
| | | Central | 24.9 | 0.0 | 25.8 |
| | | Proximal | 22.0 | 0.0 | 22.6 |
| violaceum | Corm | Upper | 13.3 | 0.0 | 25.7 |
| | | Central | 11.3 | 0.0 | 34.1 |
| | | Lower | 7.2 | 0.4 | 45.7 |
| | Cormel | Distal | 32.3 | 0.2 | 43.6 |
| | | Central | 25.2 | 0.0 | 52.4 |
| | | Proximal | 20.9 | 0.0 | 44.8 |
| atrovirens | Corm | Upper | 22.6 | 0.9 | 25.7 |
| | | Central | 33.2 | 0.5 | 34.1 |
| | | Lower | 49.6 | 0.2 | 52.7 |
| | Cormel | Distal | 44.0 | 0.2 | 44.6 |
| | | Central | 52.4 | 0.0 | 53.4 |
| | | Proximal | 42.4 | 0.6 | 44.8 |

Excluding differences between the species and plant part tested, 84% of the variability in starch concentration was explained by the differences in dry weight and specific gravity ($Y = -296.29 + 0.25\ X1 + 300.89\ X2$; where Y = percent starch, X1 = percent dry weight and X2 = specific gravity). When only the specific gravity is considered, 80% of the variability in starch is explained ($Y = -300.31 + 341.94\ X1$; where Y = percent starch and X1 = specific gravity). Only 35% of the variation in starch concentration was explained when the dry weight value alone was used.

When evaluations were separated between the corms and cormels, 89% of starch variability in corms and 72% in cormels was explained by differences in specific gravity alone ($Y_{corm} = -459.20 + 466.78\ X1$ and $Y_{cormel} = -241.65 + 258.77\ X1$; where Y = percent starch and X1 = specific gravity). This indicates that specific gravity readings can be substituted for actual starch measurement when large numbers of corms and cormels are to be screened for starch content.

In both corms and cormels, X. atrovirens had a significantly higher starch concentration than the other two species (Table 4). The upper portion of the corm had significantly less starch than the lower section, while the distal section of the cormel was significantly higher in starch concentration than the proximal section (Table 5). This suggests that corm and cormel starch concentrations may be related. These results also indicate that starches are not evenly distributed within corms and cormels.

The core sample taken through the central part of the corms and cormels revealed that the outside edge and center of corms tend to have a lower starch concentration than the parts in between (Table 1). This did not appear to be so

Table 4. Starch concentration (%) of Xanthosoma storage organs.

| Species | Corm | Cormel |
|---|---|---|
| atrovirens | 35.1a* | 46.2a |
| caracu | 13.4b | 26.2b |
| violaceum | 10.6b | 22.9b |

*Mean separation in columns by Duncan's multiple range test, 5% level.

Table 5. Starch distribution within corms and cormels of Xanthosoma.

| Storage organ | Section | Starch (%) |
|---|---|---|
| Corm | Lower | 23.4a* |
| | Central | 19.6ab |
| | Upper | 16.1b |
| Cormel | Central | 34.2a |
| | Distal | 32.7a |
| | Proximal | 28.4b |

*Mean separation within storage organs by Duncan's multiple range test, 5% level.

in X. atrovirens cormels. In this case, no specific trends were detected. The outside edge of the X. violaceum cormel tended to have a lower starch concentration than the parts in between. However, variation did not appear to be major in any case.

Major differences in starch concentration are attributed to genetic variation. Since all species can be crossed to produce fertile progeny (Volin and Beale, 1981), it should be possible to breed and select for high starch. Screening and selection could be facilitated by using specific gravity as a reflection of starch concentration.

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Variability in Taro, Colocasia esculenta Starches: Size, Gelation, and Amylose Content

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## ABSTRACT

Starch of a large number of taro cultivars was examined. Mean particle sizes were determined by laser light scattering. Additional data on gelation temperature and amylose content were also assayed.

Initial results indicated segregation into two distinct size classes. However, the larger sample size reveals a normal distribution for starch particle size. Gelation temperatures and amylose contents also vary about a generalized mean. Deviation from the mean is greatest for amylose content. There is no correlation between particle size and gelation temperature or amylose content. When morphological similar cultivars are compared the variation seen is less than that in the whole sample. Suggesting possible usefulness of these in characteristics assaying relatedness of closely allied cultivars. Although not of taxonomic significance, results here indicate that breeding taro to produce particular starch qualities should be possible for industrial application.

## Introduction

The application of taro, Colocasia esculenta, starch to industrial purposes, specifically plastics manufacture, has been discussed in previous reports (Griffin, 1979, 1982). Taro starch has been suggested as a suitable filler for production of LPDE carrier-bag films. Further applications for plant starches have been investigated in areas where the special technical characteristics derived from them make their use desirable. These include coatings and stiffening agents for plastics. Melt rheology of certain polymers can also be modified to enable processing by techniques not otherwise possible (Griffin, 1982).

Two problems are the general unavailability of commercial quantities of taro starch and the relatively poor knowledge of the characteristics of such starches. Early studies indicated that taro starch was generally of small particle size and had a relatively high gelation temperature (Goering and Dehaas, 1972; Griffin, 1979, 1982). Study of gelation, particle size and amylose content for taro starch of a few cultivars further suggested that taro starches might be useful in the

resolution of taxonomic questions in taro. Specifically the distinction between the botanical varieties of taro (for review see Plucknett, in press).

This study intends to determine the degree to which such physical data concerning taro starches can be utilized in botanical classification systems. Additionally, the extent of variability of several physical characters of taro are surveyed in anticipation that such information will be useful in development of cultivars with starches of industrial significance.

## Materials and Methods

Plant material was supplied by Dr. R. S. de la Peña from the University of Hawaii, Kauai Branch Station germplasm collection (KBS). Additional samples were from taro cultivars supplied by Dr. G. V. H. Jackson, Ministry of Agriculture and Home Affairs, Solomon Islands (SI).

Starch was prepared either from fresh corms or air dried material by procedures described elsewhere (Strauss and Griffin, in preparation). Analysis of particle size by laser light scattering as well as gelation temperature and amylose content was assayed by methods described in a report currently being prepared for publication (Strauss and Griffin, in preparation).

## Results and Discussion

Data for particle size, amylose content and gelation temperature of the corm starches of taro used in this study are being reported separately (Strauss and Griffin, in press). Examination of the results for ranges reveals maximum particle size in of 5.1 um and minimum size of 1.79 um. Amylose contents were as high as 43% for several cultivars and as low as 3% for one. For gelation temperatures the range was from 75°C in two cultivars examined to 68° for several others (Table 1).

Table 1. Range of mean and standard deviations for particle size, amylose content and gelation temperature of starch from cultivars of taro, *Colocasia esculenta*. n = number of cultivars examined.

| Physical character | Max. value | Min. value | mean | s.d. | n |
|---|---|---|---|---|---|
| Particle size, microns | 5.10 | 1.79 | 3.34 | 0.56 | 107 |
| Amylose content, percent | 43 | 3 | 24.04 | 7.41 | 108 |
| Gelation temperature, C | 75 | 68 | 70.6 | 3.4 | 108 |

Calculation of standard deviations for data from all cultivars reflects the fact that most cultivars have values for particle size, gelation and amylose content which cluster about a single mean value. This is in contrast to earlier speculations that two or more distinct groups existed for each of these parameters

(Griffin, 1982). Deviation from the mean is greatest for amylose where the standard deviation is nearly 31% of the mean value (Table 1).

When amylose or gelation temperature are compared to starch particle size the resultant plot appears to demonstrate weak correlation of these characters with starch grain size (Figures 1 and 2). However, a one-sided F test indicates no significant correlation. Deviation from the regression line suggests little reliability in predicting any one of these characters from values for another (Figures 1 and 2). This would imply that breeding for particular starch characters, independent of others should be possible. Values for amylose, gelation and particle size are not strongly dependent on each other.

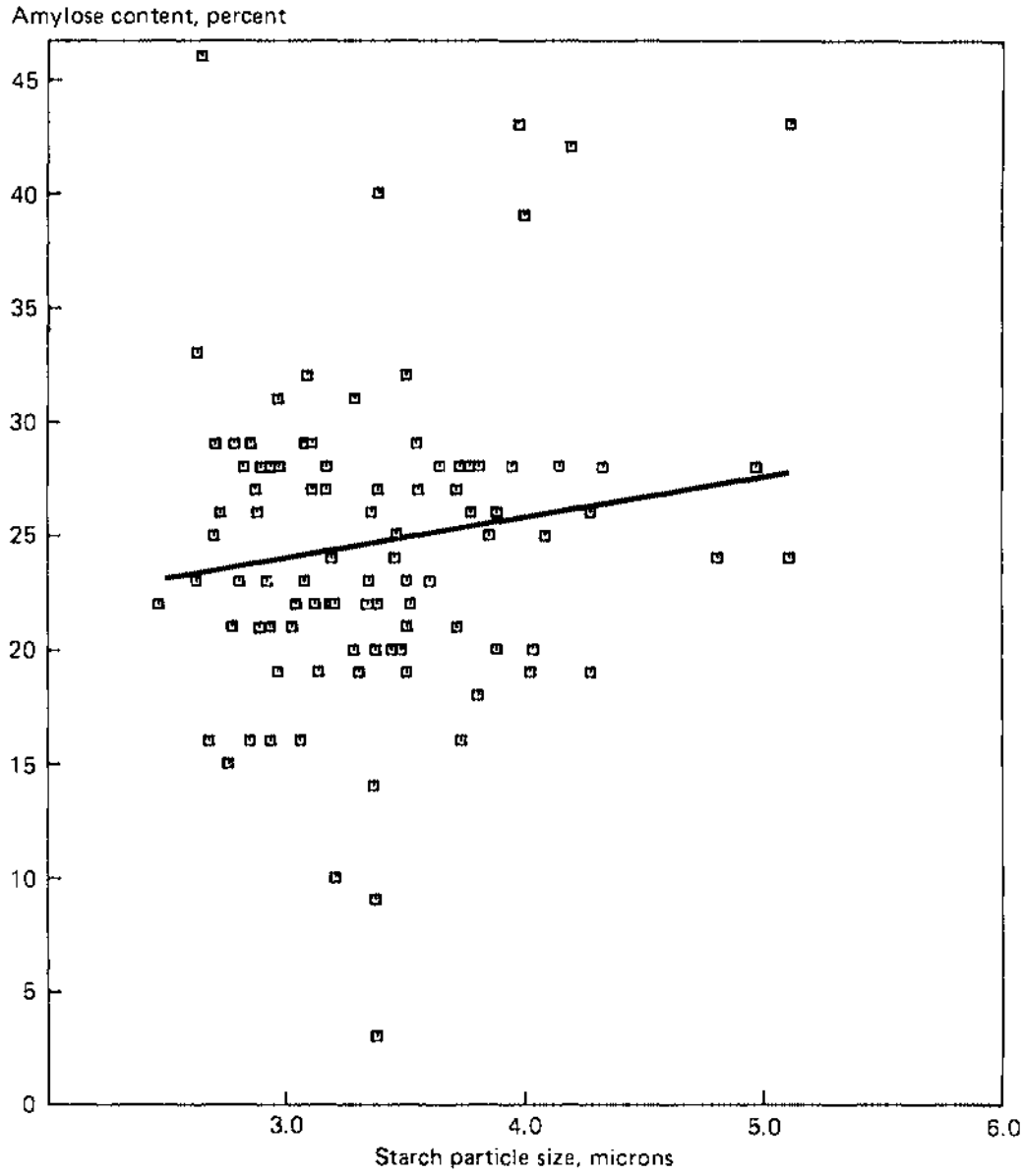


Figure 1. Illustration of the relationship of starch particle size and amylose content for several cultivars of taro, Colocasia esculenta. Regression equation: Y = 18.690 + 1.777X; Coeff. of determination: 0.0202[illegible]; F: 2.1064, one-sided test; 1, 102 degrees of freedom; n = 104.

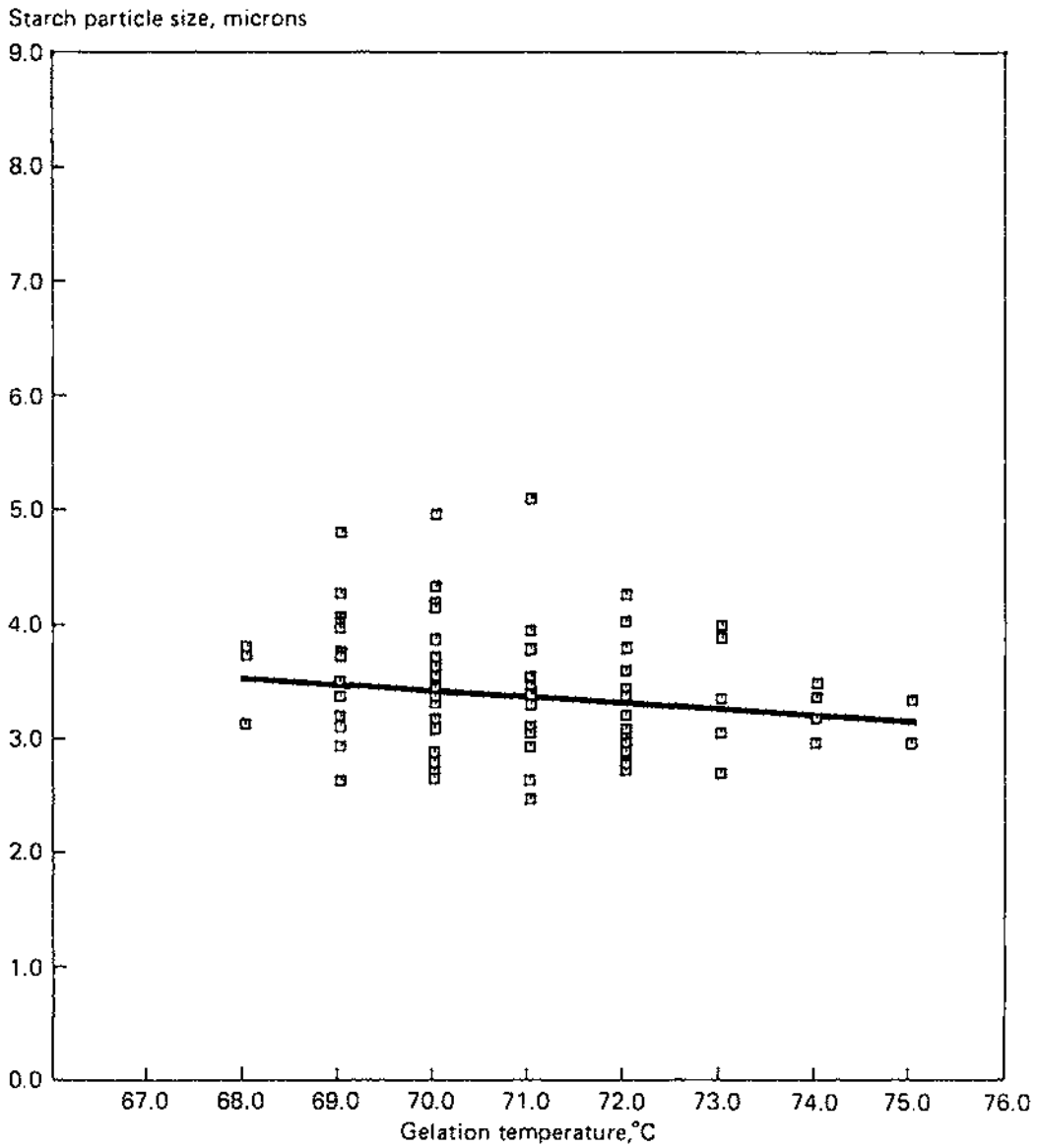


Figure 2. Relationship of particle size to gelation temperature for starches of taro, Colocasia esculenta. Regression equation: Y = 72.355 - 0.455X; Coeff. of determination: 0.023695; F: 2.4027, one-sided test; 1, 99 degrees of freedom; n = 101.

Comparing the parameters studied in two large, morphologically similar groups revealed a close similarity for some of the characters (Table 2). In the cv 'lauloa' group particle size showed little variation from the mean of 2.92 um while in the cv 'mana' group data had a standard deviation greater than that found in the sum of all samples tested. For amylose the cv 'lauloa' group showed lesser and the cv 'mana' group greater deviation from the mean than in the whole sample. Gelation temperatures for both groups varied less than the range seen in the sum of all samples studied (Tables 1 and 2).

Table 2. Comparison of physical characteristics of starch from two groups of taro, Colocasia esculenta from the University of Hawaii, Kauai Branch Station (KBS).

| Cultivar | Particle size, um | Amylose, percent | Gelation, C |
|---|---|---|---|
| Lauloa dala | 2.96 | 28 | 72 |
| Lauloa keokeo | 2.96 | 31 | 74 |
| Lauloa palakea-eleele | 2.80 | 23 | 70 |
| Lauloa palakea-keokeo | 2.89 | 21 | 72 |
| Lauloa palakea-papamu | 2.85 | 29 | 72 |
| Lauloa palakea-ula | 3.06 | 16 | 72 |
| mean | 2.92 | 24.7 | 72 |
| s.d | 0.09 | 5.7 | 1.3 |
| Mana eleele | 3.45 | 24 | 70 |
| Mana kea mata | 5.10 | 24 | 71 |
| Mana keokeo | 3.18 | 22 | 70 |
| Mana lauloa | 3.48 | 20 | 69 |
| Mana okoa | 4.80 | 24 | 69 |
| Mana piko | 4.03 | 20 | 69 |
| Mana ulaula | 5.10 | 43 | 71 |
| Mana uliuli | 3.94 | 28 | 71 |
| mean | 4.10 | 25.6 | 70 |
| s.d. | 0.77 | 7.5 | 0.93 |

It seems unlikely that the physical characteristics of starch in taro will, by themselves, be able to taxonomically separate taro cultivars or the botanical varieties. Our separate comparison of C. esculenta var antiquorum and C. esculenta var esculenta (Purseglove, 1972) plants revealed little unusual between the two cultivars which could serve to separate them on the basis of starch characters (Strauss and Griffin, in preparation). It is also evident that while some groups of taro can be inferred to be more closely related, on the basis of similarities in starch properties, plants cannot confidently be placed in those cultivars on the basis of such information alone. However, such information could be useful in determining the degree of relatedness of closely allied cultivars.

Weak relationships between particle size and the other characters investigated is of significance in the development of specialized cultivars for specific industrial application. Knowledge of the inheritance of these characters would aid breeding efforts to produce cultivars with specific starch qualities. Data demonstrate that, with respect to starch, the genetic base for breeding programs is varied and wide ranging. This has also been shown to be true for other structural and chemical characters in taro (Arditti, et al., 1980; Strauss, et al., 1980). A study of seedling starches of taro is still necessary to determine the mode of inheritance and the degree to which certain of these characters can be easily manipulated.

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## Dry Matter Distribution and Root Proliferation in Taro

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ABSTRACT

The proportion of dry matter in tops, corms and roots of the taro plants (*Colocasia esculenta* (L.) Schott) studied ranged from 44-72, 20-48 and 4-7 percent, respectively.

Spatial distribution of roots was investigated by carefully collecting roots to a depth of 25 cm at distances of 0-20 cm from the plant ($S_1$), 20-end of canopy ($S_2$) and 15 cm beyond $S_2$($S_3$).

The root density in the $S_1$, $S_2$ and $S_3$ soil samples ranged from 126-582, 20-48 and 2-11 $\mu g/cm^3$, respectively.

## Studies on Coleus Starch

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ABSTRACT

Coleus starch was isolated by standard procedures and its properties were studied. The granule size varies from 5 to 20, with majority between 8 to 16. The gelatinization temperature range is 65° to 85°C. Viscocity of a 2% solution is 37 sec (Redwood No. 1) at 75°C, which increases to 56 sec on cooling to room temperature and remains steady afterwards. The solution is translucent and of acceptable clarity. The solution stability is around 72 hr. The total amylose content is 33%, of which soluble amylose is 12.8%. The swelling volume is 25 cc/g of starch. The reducing value in terms of ferricyanide number is 2.74. The results are discussed in comparison with other tuber crop starches.

# Studies on Root-Rot Disease of Cocoyam (*Xanthosoma sagittifolium*) in Cameroon caused by *Pythium myriotylum*. Some Aspects of Epidemiology and Control Measures

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## ABSTRACT

Root-rot disease caused by *Pythium myriotylum* is the major constraint of cocoyam cultivation in Cameroon. Epidemiological studies led to the following conclusions: disease evolution is influenced by rainfall and temperature; disease is propagated by soil and planting material; high population density favors the disease evolution, while low population density slows it.

Root-rot disease can be controlled with Ridomil (diméthyl phenyllalaminate de methyl), a systemic fungicide. Aliette (ethyl-phosphite d'aluminium) has a negative effect.


## Introduction

Cocoyam or macabo (*Xanthosoma sagittifolium*) is one of the most important root and tuber crops (19) grown in Cameroon. A root-rot disease called "APOLLO" by farmers in the major growing area (4, 19, 22, 23, 24) is a limiting factor of macabo production. This disease, caused by *Pythium myriotylum* (22, 23, 24), was noticed 12 to 15 years ago. *Pythium* spp. are among the more important pathogens and considerable research has been done on their identification, mode of spread and control (3, 8, 12, 13, 14, 15, 16, 17, 25). Generally soil moisture, water logged soil conditions, high soil temperature and high planting density favour development of *Pythium* diseases (1, 7, 11, 16). *P. myriotylum* has been reported to cause root-rot of several grasses, vegetables (8, 9, 11, 18, 20, 25) and cocoyam in Papua New Guinea (McGregor pers. com., 1980). In all cases, disease spread is either through infested soil or infested planting material. Recently a number of fungicides for controlling *Pythium* spp. and *Phytophthora* spp. diseases became available (6, 27).

In Cameroon, macabo is a staple food in the forest area. The Cameroon National Root Crops Improvement Program (C.N.R.C.I.P.) has put more emphasis on the study of cocoyam root-rot for 4 years. This paper presents results of studies on mode of spread of the disease, in space and time, effect of planting density on disease evolution, and some control measures, using two systemic fungicides (Ridomil and Aliette). Results of studies on the symptomatology and etiology of this disease were presented elsewhere (24).

## Materials and Methods

Site: All experiments were at Nyombe (80 meters) during the rainy season from the middle of March to the end of November and in volcanic soil. Main crops grown in the area are bananas and pineapple.

Studies on the epidemology of the disease were in 1979, 1980, and 1981. The same cultivar (white) of cocoyam was used each time. For all experiments described below: planting time--15 through 30 March; observations on disease symptoms--June until October; harvest time--end of December.

### Investigations on the mode of spread of root-rot

The development of the disease was studied on 625 $m^2$ plots (planting density--10,000 plant/ha), with the following treatments: (a) infested planting material--infested soil; (b) infested planting material--uninfested soil; (c) healthy planting material--infested soil; healthy planting material--uninfested soil. Disease symptoms were scored as described below.

### Evolution of disease in space and time

These studies were in 1979, 1980, and 1981 on experimental (2,500, 1,600, 1,600 $m^2$) plots, respectively. In 1979 apparently healthy corms were used on a plot previously planted with bananas then fallow one year; in 1980 the same type of planting material was used on a plot previously cropped with sweet potato; in 1981, diseased planting material was used on a plot previously cropped with bananas then fallow one year. Planting density was 10,000 plants/ha.

Disease symptoms were rated on each plant using a 0-4 scale, (0 = no symptoms (0%); 1 = yellowing of 1 to 2 leaves (25%); 2 = yellowing of 3 to 4 leaves (50%); 3 = yellowing of 5 to 6 leaves (75%) and 4 = yellowing of all leaves (100%). These were observed every 2 weeks from the end of May until middle of October. Disease incidence and infection were evaluated at each observation.

### Effect of close spacing on disease development

High planting density provided favorable conditions for a fast spread of root-rot of cocoyam. In 1980 and 1981 experiments compared the effect of different population densities on the development of the disease on corms and cormels yields. Planting densities tested (plants/ha): A (10,000); B (6,700); C (4,500); D (3,400) and E (2,500); plot size: 64 $m^2$; four replications for each treatment; completely randomized block design; disease symptoms were rated as above.

### Effect of fungicides on the development of disease

Planting material: Natural infested corms were used.

Chemicals: Two fungicides were tested: N-[2-6 dimethylphenyl[-N-[2 methoxyacetyl]-alanine methyl esterl] (ridomil) and [Phosethyl-al] (Aliette) formulated as 25% a.i. and 80% a.i. wettable powder, respectively. All concentrations are given as active ingredient (a.i.).

Experimental procedure: In 1981 fungicides at different concentrations were applied by soil drenching 1 $m^2$ away from macabo plant; concentrations tested: control (A) = infested corms; ridomil (B) = 20 g/20 l water/plant in four ap-

plications (8-4-4-4); 3, 4, 5 and 6 months after planting; ridomil (C) = 10 g/10 l water/plant in four applications (4-2-2-2) as above; Aliette (D) = 32 g/32 l water/plant and (E) = 16 g/16 l water/plant in 4 applications (8-8-8-8) and (4-4-4-4) respectively as above. Plot size 16 $m^2$; planting density = 10,000 plants/ha. Five treatments with 4 replications, completely randomized block design. Disease symptoms were rated as above, and yields of corms and cormels evaluated at harvest.

## Results

### Mode of spread of root-rot

In all cases observed root-rot was spread either by infested soil or infested planting material. Plants from infested corms planted in infested soil developed poorly and remained dwarfed throughout their vegetative cycle. Those from either infested soil with healthy corms or from infested corms with pathogen-free soil developed in most of the cases a yellowing form of the disease (22).

### Disease evolution in space and time

Disease spread in foci that develop at the same time in the plot. Most of foci started from water logged sites in the field. Mapping of the disease showed that the rate of the spread is relatively fast. Foci can expand 6 to 8 m a week. In addition, secondary foci developed. Because the spread of the disease is from many foci, it is not always easy to establish the rate of the spread.

Observations on disease evolution showed that the development of root-rot, which usually starts in the middle of June is slow at the beginning then becomes rapid from July until end of August (Table 1 and Figure 1). The disease development curve can be divided in two parts. The first part, from middle of July to end of August, might correspond with the multiplication of pathogen while root surface which can be infected is still adequate. Mean temperature, relative humidity (26°C and 89% respectively) and rainfall (1,800-2,500 mm, July-September) are optimum at the time, in Nyombe, for maximum development of *P. myriotylum* (Nzietchueng, in preparation). The second part from end of August until middle of October might correspond at a time where root surface which can be attacked by the fungus is reduced. A stabilized phase follows where there is mixture of yellowing of leaves caused by disease and those related to the normal senescence of the plant.

### Effect of planting density on disease development

The relatively high planting densities provide favorable conditions for a fast spread of root-rot. Experiments in 1980 and 1981 led to the conclusion that low population densities slow disease development (Table 2). At the end of August while disease incidence was greater than 75% in A and B, it was less or equal to 50% in C, D and E. Treatments C and D yielded more corms and cormels than A and B (Table 2).

Table 1. Course of cocoyam root-rot.

| Years | Dates<br>Observations | 15/06 | 30/06 | 15/07 | 30/07 | 15/08 | 30/08 | 15/09 | 30/09 | 15/10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1979 | % diseased plants | 2.8 | 13.5 | 32.2 | 51.8 | 80.6 | 95.6 | 96.6 | 96.6 | 98.1 |
| | Infection index | 0.1 | 0.4 | 1.2 | 2.0 | 3.2 | 3.9 | 3.9 | 3.9 | 4.0 |
| 1980 | % diseased plants | 13.2 | 19.2 | 26.2 | 56.4 | 72.0 | 92.1 | 95.5 | 95.6 | - |
| | Infection index | 0.4 | 0.8 | 1.0 | 2.2 | 2.9 | 3.7 | 3.9 | 3.9 | - |
| 1981 | % diseased plants* | - | 45.0 | 70.0 | 80.0 | 93.8 | 93.8 | 93.8 | 96.0 | 96.0 |
| | Infection index | - | 1.8 | 2.8 | 3.2 | 3.8 | 3.8 | 3.8 | 3.9 | 3.9 |

*Infested planting material was used.

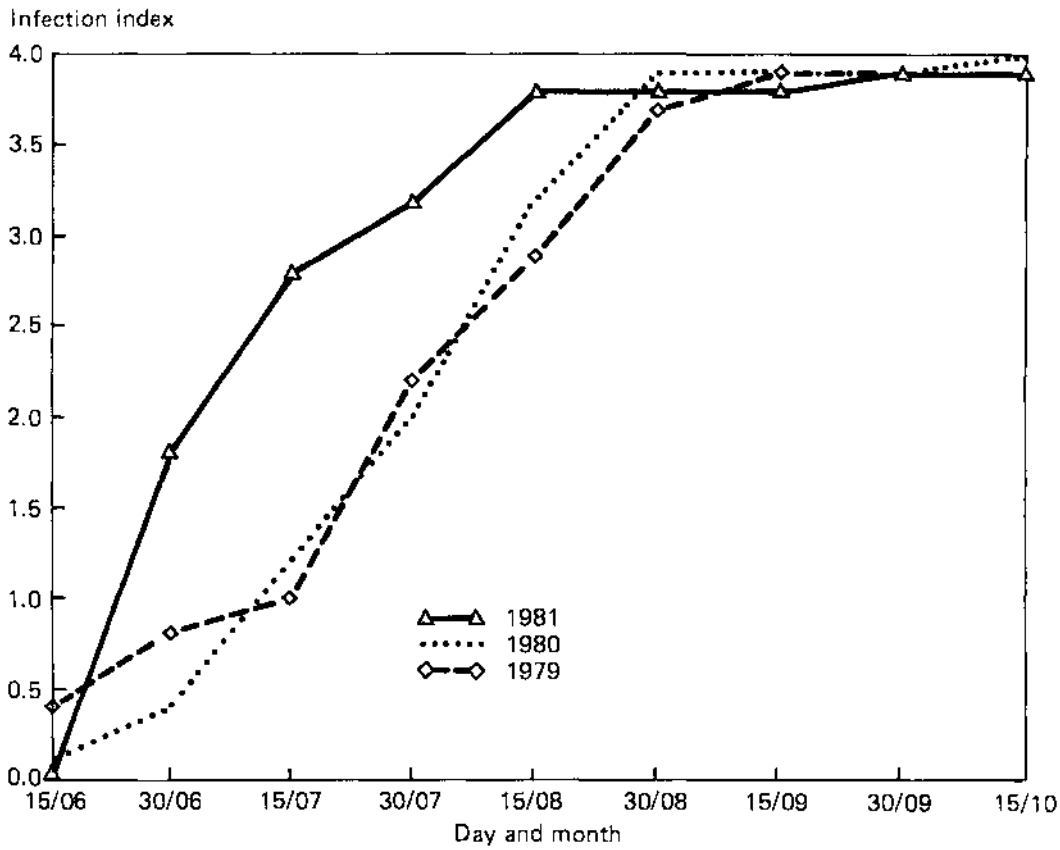


Figure 1. Course of cocoyam root-rot.

Table 2. Effect of planting density on disease development and cormel yield (1981).

| Treatments | Planting density | Disease scores (end of August) | Cormels yield/plant (kg) | Yield ton/ha |
|---|---|---|---|---|
| A | 10,000 plants/ha | (1)92.7<br>(2) 3.7 | 0.95 b | 9.5 |
| B | 6,700 | (1)92.5<br>(2) 3.7 | 1.3 bc | 8.6 |
| C | 4,500 | (1)40.1<br>(2) 1.6 | 2.5 a | 11.1 |
| D | 3,400 | (1)45.0<br>(2) 1.8 | 2.8 a | 9.3 |
| E | 2,500 | (1)50.0<br>(2) 2.0 | 1.9 ac | 5.0 |

(1)% diseased plants.

(2)Infection index; figures followed by same letter are not significantly different (P = 0.05).

## Effect of Metalaxyl and Aliette on disease development and cormels yields

Metalaxyl showed a positive effect in controlling disease evolution at 10 g a.i./plant. At 20 g a.i./plant, phytotoxicity was noticed. There was also a significant effect (P = 0.05) of Metalaxyl on cormels yield at harvest (Table 3). Aliette at concentrations tested did not show a positive effect in controlling root-rot (Table 3).

## Discussion

Cocoyam root-rot disease as all *Pythium* spp. diseases is propagated through infested soil and diseased planting material. Disease development is favoured by water logged conditions, high temperature and high rainfall. Close plant spacing enhances disease spread while low planting density slows it.

Metalaxyl was effective for controlling root-rot disease of cocoyam. Previous studies in 1979 and 1980 (19, 23), testing Ridomil at 9 g a.i./$m^2$/plant show less effectiveness than 10 g a.i./plant in 1981. Effectiveness of Ridomil only at a so high concentration (soil drenching 10 a.i./$m^2$/plant), indicates possible biodegradation in the soil by microorganisms, or a strong leaching. Metalaxyl used at 1 000 mg/pot as soil drench inhibited completely the sporulation of *Phytophthora infestans* (6, 27). Bakala and Trocme (4) reported that the non effectiveness of metalaxyl for controlling black pod of cocoa (*P. palmivora*) in Barong-Bikang (Sout Province - Cameroon) is due to the high rainfall; fungicide is washed off after spraying. The same is true in the case of cocoyam root-rot in Nyombe (same ecological zone). Although it is possible to increase cormel yields by more than 100% (Table 3), metalaxyl cannot be used at farmers level. Aliette used either at 32 g (a.i.) or at 16 g a.i./plant did not show a positive effect. To reduce disease incidence it is advised to use disease-free material and low planting density. Some degree of control of *Pythium* diseases through resistant culti-

vars has been reported for beans (2) and a number of other plants (21). More emphasis has been put on this aspect in the control of root-rot disease of cocoyam in Cameroon (Nzietchueng in preparation).

Table 3. Effect of Metalaxyl and Aliette on cocoyam root-rot (1981).

| Treatments | Planting Density | Disease Scores (end August) | Cormel yield ton/ha |
|---|---|---|---|
| A | 10,000 plants/ha | (1)92.5<br>(2) 3.7 | 4.7 a |
| B | -1- | (1)10.0<br>(2) 0.4 | 5.6 a |
| C | -1- | (1) 7.5<br>(2) 0.3 | 10.1 b |
| D | -1- | (1)87.5<br>(2) 3.5 | 2.9 a |
| E | -1- | (1)85.0<br>(2) 3.4 | 5.0 a |

(1)% diseased plants

(2)Infection index; figures followed by same letter are not significantly different ($P$ = 0.05).

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Rhabdovirus Infection of Taro, Colocasia esculenta (L.) Schott, from Papua New Guinea: Comparison of Symptomatic and Asymptomatic Material

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ABSTRACT

Samples of symptomatic and asymptomatic leaves of taro, Colocasia esculenta (L) Schott, from Papua New Guinea, were fixed, embedded and sectioned for electron microscopy. Symptomatic material showed marked bobone disease virus (BDV) symptoms.

Cells of infected, symptomatic tissue contained inclusions, of virions and viroplasm. The cytoplasm appeared granular and contained large numbers of polyribosomes. The chloroplasts had reduced membrane contents and increased amounts of starch. General anatomy of the leaf was altered with an increase in cell number and decrease in size of the palisade cells.

In similar samples from the same plant at a later, asymptomatic, time no cellular evidence of viral infection could be detected. The cytoplasm contained fewer polyribosomes and plastids, less starch and more extensive granal membranes. Leaves had palisade anatomy like that in uninfected material.

## Introduction

Taro, Colocasia esculenta, has been shown to be affected by three different viruses (Jackson and Pelomo, 1980; Jackson and Firman, 1982; Shaw, Jackson and Plumb, 1979). Dasheen Mosaic Virus, a long flexous rod, has been assigned to the potato Y virus group. (Zettler, et al, 1970; Kenten and Woods, 1973). The other two viruses are bacilliform particles, associated with the "alomae" and "bobone" diseases of taro in the Solomon Islands (Jackson and Firman, 1982; Gollifer and Brown, 1972; Kenten and Woods, 1973). The larger of these bacilliform particles is restricted to the Solomon Islands and Papua New Guinea (Jackson, 1978; Jackson and Firman, 1982; Shaw, et al., 1979), and is considered to be a rhabdovirus (Francki and Randles, 1980; James, Kenten and Woods, 1973; Shaw, et al., 1979). The smaller particle, similar to cocoa swollen shoot virus, appears to be distributed throughout many taro growing areas (Jackson and Firman, 1982; James, et al., 1973; Shaw, et al., 1979).

Few papers have been published regarding the nature of the bacilliform particles of taro. Classification of the large particle is based primarily on evidence from a single study (James, et al., 1973; Kenten and Woods, 1973). Instability and difficulty of isolation have even further hampered efforts to purify the rhabdoviral particle (James, et al., 1973). Little information is

available regarding localization of these viruses in infected material. The passage of time has only served to accentuate the need for better understanding and control of these diseases (Jackson and Firman, 1982). This is a preliminary report of efforts to determine the distribution of the viruses of taro in infected material and the effects of these viruses on normal structure. Work has been primarily concerned with the rhabdovirus, recently designated Bobone Disease Virus (BDV) (Francki and Randles, 1980; Francki, Kitajima and Peters, 1981).

## Materials and Methods

Samples of taro displaying symptoms of viral infection were received from Papua New Guinea. These plants were maintained in an environmental chamber under 16 h photoperiods at 28° to 30°C and 70 to 90% relative humidity. Alternately, plants were placed in 21 plastic pots at the Burlington Botanical Research Station, Woburn, Massachusetts. Ambient light in the greenhouse was supplemented with Sylvania Gro-lux fluoroescent lights to produce continuous light conditions.

Portions of leaves, from symptomatic and asymptomatic plants, were fixed in glutaraldehyde, post fixed in osmium, embedded and examined under the electron microscope by procedures described elsewhere in this volume (Stein, Strauss and Scheirer). Three to five micron sections were afixed to glass slides, stained with toluidine blue (Richardson, Jarret and Finke, 1960) and examined using a bright field Olympus Light Microscope.

## Results and Discussion

Several cellular differences are notable between symptomatic and asymptomatic leaves (Table 1). One difficulty in interpreting the results as BDV effects is that nearly all cells containing the rhabdovirus virions also contain the flexous rods of Dasheen Mosaic Virus (DMV) (Figure 1). In these regions of virus production prominent polyribosomes are evident. Viroplasms, like those associated with other plant rhabdoviruses (Francki and Randles, 1980) have also been noted occasionally, but only in symptomatic material (Table 1).

Table 1. Summary of cellular differences noted in symptomatic and asymptomatic *Colocasia esculenta* var *esculenta* cv K268 plants infected with dasheen mosaic virus (DMV) and bobone disease virus (BDV).

| | General Appearance | |
|---|---|---|
| Structure | Symptomatic Plants | Asymptomatic Plants |
| Virion | present | absent |
| Viroplasm | present | absent |
| Polyribosomes | numerous | few |
| Chloroplasts | | |
| membranes | reduced | grana/stroma |
| | grana | structure typical |
| Starch | abundant | few grains |

Figure 1. Cytoplasm of leaf mesophyll cell from infected, symptomatic taro, Colocasia esculenta var esculenta cv K268. Note bacilliform particles of Bobone Disease Virus (BDV) (small arrows), flexous rods of Dasheen Mosaic Virus (DMV) (large arrows), and polyribosomes (p). Bar = 1 micron.

Figure 2. Transverse section through palisade parenchyma from infected, symptomatic taro, Colocasia esculenta var esculenta cv K268. Chloroplasts (arrow) contain considerable starch (s). Bar = 5 microns.

Figure 3. Transverse section through palisade parenchyma from infected, asymptomatic taro, Colocasia esculenta var esculenta cv K268. Chloroplasts (arrows) contain little starch and numerous membranes n, nuclei. Bar = 5 microns.

Figure 4. Transverse section of leaf from infected, asymptomatic taro, Colocasia esculenta var esculenta cv K268. Note rectangular air spaces (as), prominent bundle sheath (bs), and palisade (p). Bar = 50 microns.

Figure 5. Transverse section of leaf from infected, symptomatic taro, Colocasia esculenta var esculenta cv K268. Palisade (p) cells are more numerous and of a smaller average length. Note lack of a distinct bundle sheath. There are still large air spaces (as) in the leaf. Bar = 50 microns.

Chloroplasts in the palisade parenchyma of symptomatic plants often contain fewer internal membranes and usually display considerable starch accumulation, when compared (Figures 2 and 3) to the same plant during an asymptomatic period. Thus though the virus appears to be restricted to the cytoplasm, it has profound effect on chloroplast biochemistry. One review reports virus particles being noted as budding from the nucleus (Francki, et al., 1981). We have been unable to confirm this in material from Papua New Guinea.

Examination of distribution and morphology of cell types in the leaf reveals a profound effect on cells of the palisade parenchyma and bundle sheath (Figures 4 and 5). In the former, cells appear to have undergone multiple division, as their numbers are increased and average size decreased. The normally distinct bundle sheath is poorly visible in the symptomatic plant. This is consistent with findings that all of these cells contain virus in the symptomatic plant. It is not clear, though, where the virus (or its genetic material) is during an asymptomatic period.

This preliminary report points up the need for considerable further study of this virus. Little success is evident in isolating virus particles. However, the dense number of polyribosomes suggests that it might be possible to use these in a cell-free protein synthetic system to produce viral proteins for antisera production. Feasibility of such an approach remains to be determined. Distribution of this virus is needed to understand its development and survival in taro germplasm.

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# Germination and Storage Behavior of Seed of *Colocasia gigantea* Hook. f.

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## ABSTRACT

A study was carried out on germination behavior and viability during desiccation and storage of seeds of *Colocasia gigantea* Hook. f.

Seed germination at room temperature was poor, but rapid and uniform germination could be induced by subjecting fully imbibed seeds to a heat treatment of 40°C for a minimum of 24 hours.

Desiccation of fresh seeds did not affect viability. Seeds dried to moisture content were stored at temperatures of 28°, 10°, and -20°C in sealed plastic bags. Seeds stored at 10° and -20°C for one year showed no significant decline in germination, while seeds stored at 28°C showed a rapid decline in viability after three months of storage under tropical climatic conditions.

# Propagation and Tissue Culture

Effect of Presence of the Terminal Bud, and Size and Type of Sectioning of the Corm on Propagation of New Cocoyam

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ABSTRACT

Among factors which affect establishment of taro and cocoyam crops, the quality of planting material is of prime importance. During the period January and March, 1982, in Turrialba, Costa Rica, management of planting material was evaluated under greenhouse conditions. Weight of seed, corm, methods of corm sectioning, and presence or absence of terminal bud were studied. Number of buds, leaf area, and petiole length were determined at 60 days.

In both species, bud number was increased by increasing weight of the seed corm and by eliminating the terminal bud. Use of large corms with a terminal bud increased the leaf area and petiole length. When cocoyam corms were sectioned transversely, apical sections tended to produce larger leaf area than basal section. Longitudinal sectioning produced no differences. In taro, transverse sectioning produced no differences in leaf area while longitudinal sectioning affected this parameter. In neither species was petiole length significantly affected by type of corm sectioning.

## Introduction

New cocoyam and taro are promising crops for the humid tropics, having high food production potential.

Establishment of these crops is affected by various factors, including nature of planting material. In *Xanthosoma sagittifolium*, larger seed corms result in higher yields and a larger leaf area index (Enyi, 1976b). This result has been related directly to the diameter of the bud which produces the plant (Spence, 1970). In taro, no differences have been observed in yield using small seed corms, weighing 41, 30, and 17 grams (Da Silva, 1971). Some yield factors such as leaf area index, number of tillers per plant, number of leaves per plant, mean weight per plant, leaf area, were significantly greater in plants from larger seed corms. This leads to the conclusion that two factors were responsible for the low production from smaller seed pieces: high mortality and low yield per plant (Bourke and Perry, 1976). In the case of transversely sectioned cocoyam corms, tip sections containing the terminal bud were superior to other sections in terms of rate of germination, rate of leaf area development, corm yield, and mean weight of lateral and principal corms (Vasquez and Torres, 1974). More rapid germination

of upper sections is perhaps due to lower dormancy levels in the younger sections (Enyi, 1976a).

The objective of this study is to determine the influence of handling propagation material of cocoyam and taro on growth and development.

## Materials and Methods

Seed pieces of cocoyam and taro were evaluated under greenhouse conditions at Turrialba, Costa Rica, between January and March, 1983. Three different sizes (800, 200 and 100 g) were used in cocoyam and seven sizes (800, 200-300, 150-199, 75-100, 50-74, 25-49, and smaller than 25 g) were used in taro, each with and without terminal bud.

In the 800 and 200 g cocoyam corms and in the 800 g taro corms, different types of sectioning were: transverse in three sections (apical, medial, and basal) and two types of longitudinal sectioning (in halves or quarters). Seed corms were planted in black polyethylene bags containing three liters of soil in a completely randomized design. Sixty days after planting shoot number, leaf area and length of the longest petiole were measured.

## Results and Discussion

### Cocoyam (*Xanthosoma sagittifolium*)

Leaf area at 60 days was greater ($P = 0.01$) in plants produced from large (800 g) seed corms than from smaller (200 g) seed corms. Presence or absence of terminal bud did not affect leaf development significantly in any corm class (Figure 1) although leaf area tended to be somewhat greater in plants produced from corms from terminal buds. The greater leaf area in plants from larger seed corms without terminal buds is perhaps due to greater number of sub-terminal buds in the larger corms once apical dominance is removed as well as to larger bud size which Spence (1970) maintained regulates the development of leaf area.

Petiole length in plants from large corms was significantly superior ($P = 0.01$) to that in plants from corms of smaller weight. Petiole length in plants produced from corms with a terminal bud showed a tendency to be greater than in those from corms without a terminal bud although this difference did not attain statistical significance. This difference tended to decrease as corm size increased.

Shoot number was greater in seed corms without a terminal bud. Elimination of the terminal bud should remove the effect of apical dominance permitting development of sub-terminal buds. Increase in shoot number is greater in larger corms since they have a greater number of sub-terminal buds (Figure 2).

Trends noted in leaf development and petiole length as affected by presence or absence of a terminal bud possibly decrease with age as the corms without a terminal bud produce a greater number of shoots once apical dominance is eliminated. In corms without a terminal bud, shoot production from the sub-terminal buds is slower than in corms with terminal buds, but this difference may be compensated for by greater leaf area development proceeding from a greater number of shoots after 60 days.

In the two types of sectioning studied, transverse and longitudinal, no differences were observed for the parameters studied. In the case of transverse sectioning, the apical section showed significantly greater leaf area than the other sections (P = 0.05). There was no difference between medial and basal sections. No differences were observed between types of longitudinal sectioning (Figure 3).

Number of shoots per plant was smaller for the terminal transverse section and for the whole corm due to dominance exercised by the terminal bud (Table 1). The difference between number of buds in the terminal transverse section and the whole corm with respect to the other sections (medial, basal, half longitudinal and quarter longitudinal) is greater in corms of larger size, possibly due to the effect of a greater number of sub-terminal buds in the large corms, which are ready to sprout as soon as apical dominance is removed.

Table 1. Number of shoots per plant of cocoyam (*Xanthosoma sagittifolium*) and taro (*Colocasia esculenta*) at 60 days as affected by corm weight and type of corm sectioning.

| Treatments Corm Weight (g) | Type of Section | Cocoyam $\bar{X}$ | Cocoyam S | Taro $\bar{X}$ | Taro S |
|---|---|---|---|---|---|
| | apical | 1.20 | 0.44 | 1.00 | 0.00 |
| | medial | 5.25 | 0.43 | 3.22 | 0.67 |
| | basal | 4.00 | 3.16 | 2.56 | 1.42 |
| | half longitudinal | 3.80 | 1.92 | 1.92 | 0.90 |
| | quarter longitudinal | 2.33 | 0.82 | 1.83 | 0.58 |
| | whole corm | 1.66 | 0.58 | 1.00 | 0.00 |
| 200 g | apical | 1.08 | 0.29 | | |
| | medial | 1.27 | 0.46 | | |
| | basal | 1.29 | 0.47 | | |
| | half longitudinal | 1.53 | 0.64 | | |
| | quarter longitudinal | 1.13 | 0.35 | | |
| | whole corm | 1.00 | 0.00 | | |

In the case of corms weighing 800 g, the medial transverse section produces a greater number of shoots, possibly by combined effect of the absence of apical dominance and the greater number of buds in this section, which are in a state of intermediate dormancy as compared with buds in the apical (terminal) and basal sections. The basal section has a greater number of buds than the apical section, yet fewer than the median section, due to elimination of apical dominance and a greater degree of bud dormancy. The half and quarter sections in the longitudinal cut have a greater number of shoots than the treatments having a terminal bud (terminal section of the transverse cut and the whole corm) but fewer than the medial and basal sections of the transverse cut. When the corm is sectioned longitudinally, functioning of the terminal bud is virtually eliminated although a partial apical dominance effect persists; furthermore, in the longitudinal sectioning, area of the cortex where buds are located is narrow, leaving a lesser number of subterminal buds which sprout first and acquire dominance over the remaining buds.

Taro (Colocasia esculenta)

Leaf area development and petiole length was greater (P = 0.01) in higher weight corms. Principal corms (weighing 800 g) produced a greater leaf area and petiole length than secondary (75-300 g) and tertiary (less than 50 g) corms; secondary corms were superior to tertiary corms (Figure 4).

There was no difference with regard to leaf area and petiole length for principal corms with or without terminal buds while for secondary and tertiary corms, those with terminal buds were significantly superior in terms of these parameters. It is possible that with age, these differences will diminish, since total leaf area from a larger number of shoots per plant may compensate for slower sprouting observed in corms without a terminal bud. In tertiary corms, leaf area and petiole length are directly related to corm size, attaining statistical significance at the 1% level.

Shoot number at 60 days was greater in corms without a terminal bud, due to the absence of apical dominance (Figure 5). In the case of transversely sectioned corms, the terminal section maintains the dominance of the terminal bud, the medial section triples the shoot number with respect to the terminal section, followed by the basal section with a smaller number of shoots than the medial sections but greater number than the terminal section.

The half quarter longitudinal sections produced a greater number of shoots than the terminal transverse section but fewer than the medial and basal transverse sections (Table 1). This result is similar to that observed with cocoyam.

Leaf area and petiole length were greater for whole corms than for sectioned corms (significant at p = 0.05). Among types of transverse sections, there was no difference in leaf area for the terminal section with respect to the medial and basal sections, but the medial and basal did differ significantly at the 1% level. In longitudinal sectioning, half sections produced significantly (P = 0.05) greater leaf area than the quarter sections. Different types of sectioning produced no significant differences in petiole length.

Conclusions

1. Taro and cocoyams showed similar effects of corm size and sectioning on leaf area, petiole length and shoot number.

2. Most vigorous plant development was obtained with propagating material of largest size.

3. Propagating material with terminal buds develops sprouts more rapidly. Delay in initial development of planting material without terminal buds is compensated for by a greater number of shoots.

4. It is possible to use corm sectioning to increase quantity of seed pieces and obtain a greater uniformity in the planting.

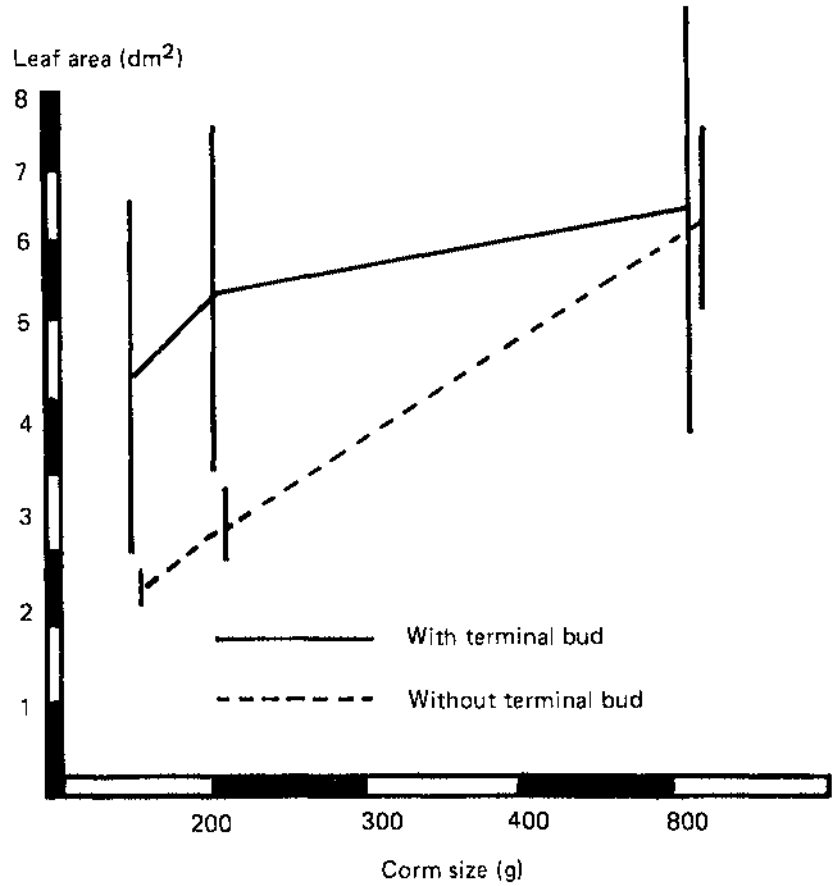


Figure 1. Variation of leaf area of cocoyam (Xanthosoma sagittifolium) at 60 days in relation to size and seed corm with and without terminal bud.

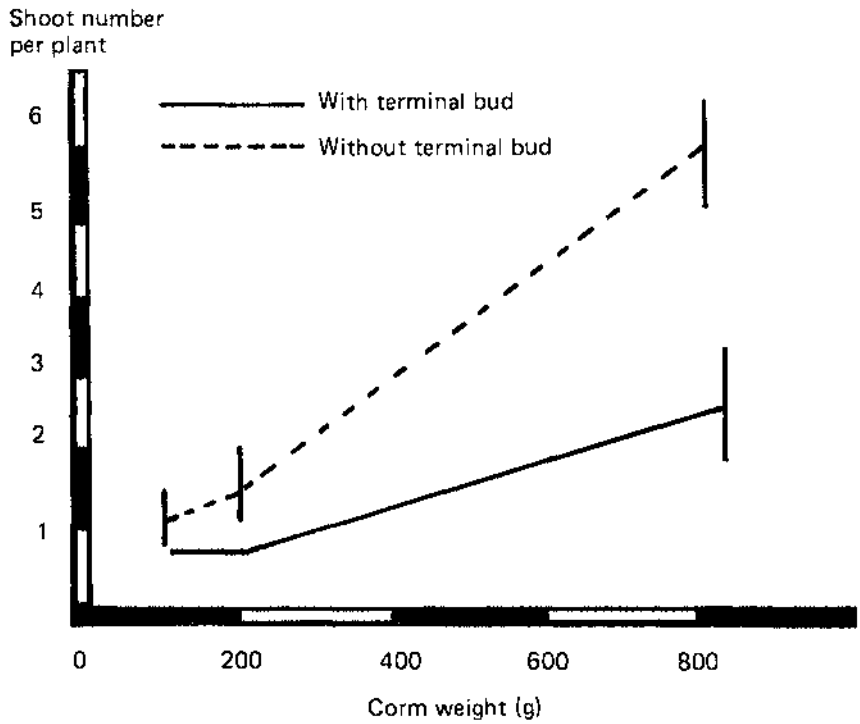


Figure 2. Number of shoots of cocoyam (Xanthosoma sagittifolium) at 60 days, as affected by weight of seed corm, with and without terminal bud.

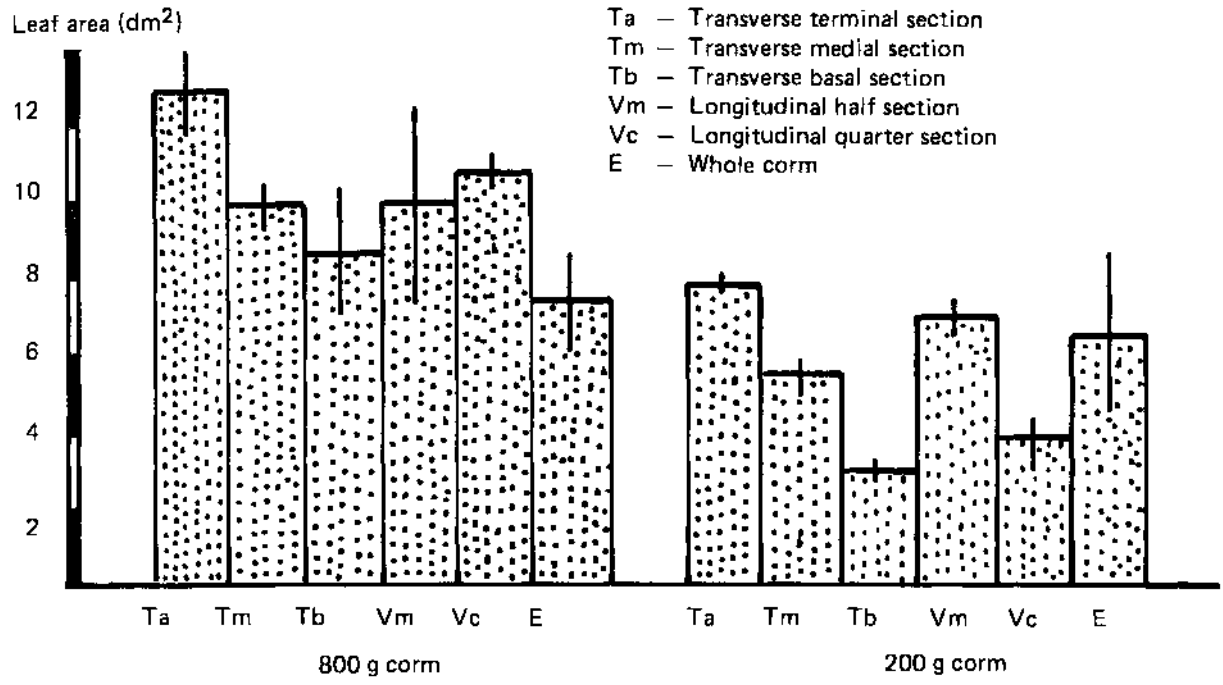


Figure 3. Leaf area ($dm^2$) in cocoyam plants (Xanthosoma sagittifolium) as affected by size and method of sectioning of seed corm.

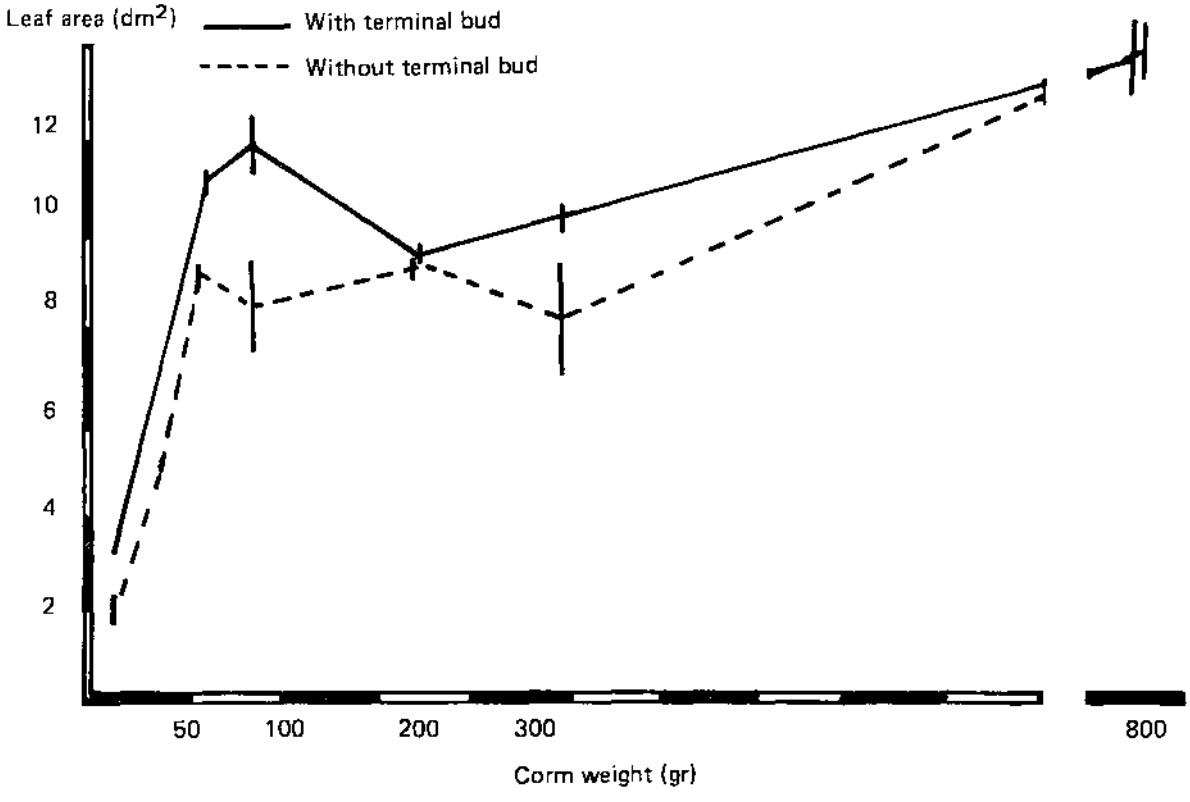


Figure 4. Variation in leaf area of Taro (Colocasia esculenta) as affected by weight of seed corm, with and without terminal bud.

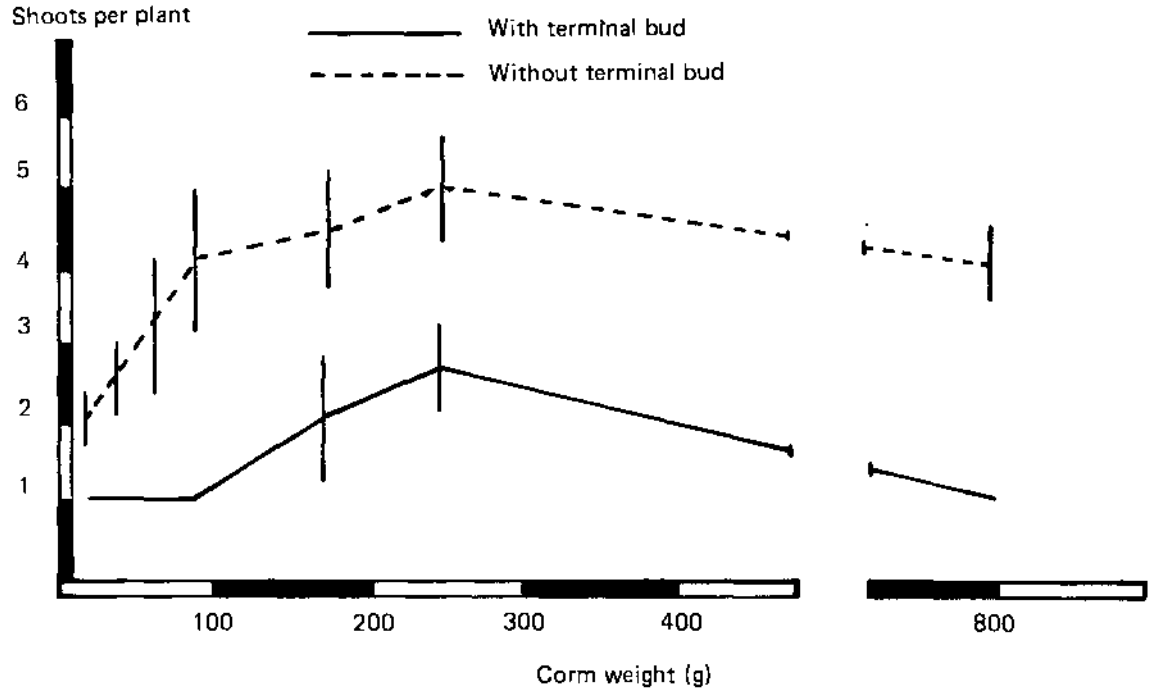


Figure 5. Number of shoots of Taro (Colocasia esculenta) as affected by weight of seed corm with or without terminal bud.

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# The Potential of Cassava in Optimizing Small-Farm Productivity in Liberia

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## ABSTRACT

Cassava is second to rice as the most important food crop in Liberia. Although rice is the staple food, farmers face many problems in achieving high yield and profit. Cassava needs less inputs and investments and gives more yield and economic return, plus its productivity in terms of calories per unit land per unit time is significantly higher than rice and other staple food crops.

Because of the importance of cassava optimizing small-farm productivity in Liberia, a cassava program was initiated at the Central Agricultural Research Institute of the Ministry of Agriculture in 1979 to increase the quantity and to improve the quality of the crop. The program is also motivating the farmers 1) to grow more cassava in their farms, 2) to increase their farm productivity to be self-sufficient in food, and 3) to increase their standard of living. The progress of the program and the importance of cassava and its potential in small-farm productivity in Liberia are discussed in the paper.

Cassava (*Manihot esculenta* Crantz) is the seventh largest produced staple food in the world (FAO, 1969). It is grown throughout tropical regions and consumed as primary, secondary or supplementary staple. Products from cassava roots, such as industrial starch (including derivatives) and livestock feed, are used increasingly within and outside the tropical belt. World production is about 100 million tons annually from 10 million hectares. Africa produces about 40 million tons from about 5 million hectares (FAO, 1971).

In Liberia, cassava is second to rice as the most important food crop with total annual production of 250,000 tons from an estimated 63,158 hectares of land. It provides Liberia with more than 25% of daily calorie intake. In addition, the leaves supply much needed protein and vitamins in diets of both urban and rural populations.

Cassava has increased in importance as a basal food. One reason is its ability to fill the "hungry gap" especially when rice becomes unavailable. Cassava has been cultivated in Liberia for many years, virtually no attention has been given to improvement of this crop. In view of increasing population demands, high yielding cassava -- even under adverse conditions -- is of major importance. Desirable yield features should encourage the spread of cassava cultivation in Liberia. Future development of cassava in Liberia can significantly contribute to both the economy and improvement of human life and animal production.

## Research for Improvement

Realizing the importance and potential of cassava as an energy food during food crises, a cassava improvement program was initiated at the Central Agricultural Research Institute (CARI) of the Ministry of Agriculture in 1979 in close collaboration with the International Institute of Tropical Agricultural (IITA), Ibadan, Nigeria. Recently, financial assistance from the International Development Research Center (IDRC), Ottawa, Canada, has began to operate the program for 3 years.

The program's main objective is to evolve high yielding, good quality, disease and pest resistant/tolerant varieties together with improved cultural practices for high production.

CARI cassava research is at a preliminary stage. However, progress has been made since collaboration with IITA:

Germplasm. Local germplasm materials of cassava were collected nation-wide. Fifty-one accessions were collected and a live germplasm bank established at CARI. Accessions are being evaluated against introduced varieties from IITA. Most local types are disease- and insect- susceptible and have low yield potential. The germplasm bank will be maintained for future plant breeding work.

Varietal improvement. Thousands of cassava genotypes were introduced to CARI from the IITA breeding program for establishment, evaluation and screening. Clonal, preliminary, advanced and uniform yield trials were established with hundreds of high yielding, disease-free cassava clones for selection. This year multi-locational trials were established with three CARI-selected clones at eight locations in three priority counties of Liberia's total of nine counties. Final selection will follow studies under different ecological conditions for adaptation to a wide range of environments before release to farmers. The other six counties will be covered in the future. Results of studies with these three selected clones are in Table 1. Thorough agronomical research (time of planting, time of harvesting for both tuber and leaf, methods of planting, fertilizer use, relations, intercropping) will continually develop sound economical recommendations for farmers in various ecological conditions.

Table 1. Comparison of selected CARI cassava clones against a local check.

| | Diseases and Pests | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Clones | CMD | CBB | ANTH | LS | GH | RSM | Yield metric tons/ha | Quality |
| CARICASS 1 | 1 | 1 | 1 | - | 0 | 0 | 63.7 | Excellent |
| CARICASS 2 | 1 | 1 | 1 | - | 0 | 0 | 51.3 | Very good |
| CARICASS 3 | 1 | 1 | 1 | - | 0 | 0 | 47.3 | Good |
| Local check | 4 | 2 | 1 | + | 0 | 0 | 20.1 | Very good |

CMD - cassava mosaic disease; CBB - cassava bacterial blight; ANTH - cassava anthracnose; LS - cercospora leaf spot; GH - grasshoppers; RSM - red spider mite.

Rapid multiplication unit. Establishment of a rapid multiplication unit for cassava has been proposed for CARI. Cassava plants nearing final selection would be multiplied and planting materials distributed to multi-locational trials and to farmers. Each year thousands of cassava genotypes would be introduced to CARI for screening and selection.

## Potential Impact

Cassava contributes significantly to the world food supply, being the staple food of about 200 million people in the tropics (Coursey and Haynes, 1970).

Cassava contributes to Liberia's food supply as primary, secondary or supplementary human food, as livestock feed, and as cassava starch or flour incorporated by food industries into products for human consumption.

Cassava's productivity in terms of calories per unit land per unit time is significantly higher than rice and other staple food crops (Vries et al., 1967). Cassava can produce 250 x $10^3$ calories/ha/day as compared to 176 x $10^3$ for rice, 110 x $10^3$ for wheat, 200 x $10^3$ for maize, and 114 x $10^3$ for sorghum (Coursey and Haynes, 1970). Grain crops subjected to intensive improvement have nearly reached limits of their genetic potential for yield whereas tropical root development is virtually untouched leaving substantial room for improvement (Coursey and Haynes, 1970).

In Liberia cassava can be planted any time. This permits greater flexibility in farmers work schedule. Harvesting may be delayed for several weeks without serious changes in the composition and quality of roots. This flexibility enables farmers to attend the main crop (rice) and use their spare time on cassava. Because cassava roots left in the ground without harvesting for several weeks or months do not spoil, local farmers usually retain cassava plants in the field as security against famine and other unforeseen food shortages.

In some areas of the country a few roots from a single plant are harvested to meet the family's current need while remaining roots are left intact for future use. This admirable suitability of cassava as a subsistence crop is a main reason for its popularity in Liberia.

The comparatively low cost of cassava production is evident in its being one of the cheapest foods in most growing areas. This is attributed to several factors such as low labor requirement, easy cultivation, high productivity, and low investment.

Cassava is valued for at least three outstanding ecological adaptations: drought tolerance, ability to grow in sub-optimal soils, and aggressiveness towards weeds and insect pests. Some cassava varieties grow in regions with as little as 500 mm of annual rainfall; other varieties are adapted to regions with 5,000 mm rain.

Cassava plants need sufficient moisture only in early stages for establishment. Reserves of carbohydrate in the roots enable plants to survive and quickly resume growth when moisture becomes available.

Flexibility of the crop with respect to its moisture needs, enables farmers to raise successful crops of cassava in regions with low annual rainfall inadequate to support cultivation of many cereals. It is considered a safe "risk" crop

in areas with erratic rainfall distribution and danger of drought. In some areas, total productivity of land is maximized by raising a crop of cassava after the main rice crop when scanty rain is insufficient for a second cereal crop. This rugged quality of cassava gives it a competitive superiority over cereals and promotes the productive use of agricultural niches presently unsuitable for cereal cultivation (Appan et al., 1970).

It is said that cassava can grow in depleted soils where even many weeds will not grow. However, as in the case of drought tolerance, the eco-physiology of this adaptation has not been adequately investigated. Cassava roots penetrate deeper and tap nutrients from lower soil strata inaccessible to many cultivated annuals (Jones, 1959). Cassava cultivars are capable of growing on soils ranging from a stiff marine clay with a pH of 8 or 9 to sands and loose laterites with a pH of 5 to 5.5 (Rogers, 1965). Ability to grow in sub-optimal soils offers cassava a competitive advantage over other staple food crops. Perhaps this is the most significant aspect in evaluating the importance of this crop in indigenous food production systems.

Cassava does well against weeds if the proper variety is used and adequate soil water and nutrients are available. Within 3 to 4 months after planting, the crop puts up a dense canopy of foliage and weeds are shaded out.

The crop also has potential in food value. It is rich in calories but deficient in protein, fat, and some vitamins and minerals. Cassava roots contain varying concentrations of carbohydrates, lipids, proteins, minerals, vitamins, and water. Their composition is similar to other tropical starchy roots. An estimated average composition of cassava is 60-65% water, 30-35% carbohydrate, 0.2-0.6% ether extract, 1.2% crude protein, and relatively low content of minerals and vitamins (Jones, 1959).

Cassava leaves are high in protein, crude protein ranging from 20.6 to 36% dry weight basis. Seventy-five percent of the crude protein is reportedly true protein and its feeding value is high (Veen, 1938). Cassava leaf protein is as superior as soybean protein (Rogers and Milner, 1963). Possibilities exist of extracting protein from cassava leaves for use as food supplement (Singh, 1964). Fresh cavassa leaves contain appreciable quantities of ascorbic acid, but once picked they lose it fairly rapidly at tropical temperatures. Fresh leaves contain about 352.2 mg/100 gm of ascorbic acid (Raymond et al., 1941). Juice extracted from cooked leaves and vacuum concentrated contain upwards of 2,000 mg ascorbic acid per 100 gm. Leaves also contain carotene, 9746-11136 u/100 gm in fresh leaves and 7172 u/100 gm after cooking. Vitamin A, Vitamin $B_1$ and Vitamin $B_1$ are also present in addition to ascorbic acid (Van Veen, 1938).

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Cassava Cultivators and their cultivars. (Preliminary results of case studies in the Sierra region of the Dominican Republic)

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ABSTRACT

Cassava cultivators in the sierra region of the Dominican Republic have been selecting varieties on the basis of tolerance to degraded soils, length of production cycle, and market preferences. Given prevailing ecological conditions, cassava cannot be kept indefinitely in the ground, but must be harvested within two to three years to prevent root deterioration . The "piggy bank function" of cassava does not appear to exist anymore to the extent previously suggested in the literature.

The preliminary results of agro-sociological case studies on cassava cultivators are presented, to be confirmed by ongoing research.

## Introduction

Why do peasant cultivators grow different varieties of cassava? The question first struck me in the Dominican Republic while preparing a research project on field problems in cassava cultivation as perceived by the growers.*

Biosystematic researchers and anthropologists agree on the great proliferation of cassava varieties in the western hemisphere. Rogers & Appan (1973) using an exhaustive taxonomic classification arrived at surprising numbers of varieties. This confirms anthropological field research, particularly ethno-botanical studies. Berlin & Berlin (1977) in recent work among Aguaruna cultivators of northern Peru, report that 30 varieties are being grown at one particular time. They note, however, that about 100 varieties are known among the Aguaruna, possibly even as many as 200 (Berlin & Berlin, 1977: 11; 25).

In previous research in the Dominican Republic, I had noted the amazing amount of knowledge regarding varietal characteristics among peasant farmers (Box, 1979).

*The question was also raised by Dr. James Cock, of CIAT's cassava team, while the author was preparing the field research in the Dominican Republic. The present paper is a partial response to his question.

Lacking was methodology to find out why cultivators grow these varieties. Although highly refined botanical methods exist for distinguishing cassava cultivars, and a fairly well developed technique emerges from anthropological studies on ethnobotany (Berlin, Breedlove & Raven, 1973), this is to no avail when one has to give a fairly rapid answer to the question. One complaint of biological scientists against anthropologists is that their work may be interesting, but gives too much information on too little, and too late (for a response see Brady et al., 1982). I intended to develop a technique to give a rapid, approximate answer to biological scientists who could then decide if they wished to investigate the matter further with refined methods.

## Methods and Techniques

The variety-study formed part of a larger agro-sociological research on cassava cultivators in the Dominican Republic. This was aimed at the question: what are appropriate agro-sociological methods and techniques for identifying cultivation problems which are both felt by farmers and considered fit for study by agricultural researchers? In other words, we were not interested in establishing a list of all problems felt by the farmers and not in doing a general sociological survey on the social structures they are part of. Finally, we did not test technology because almost no scientifically derived technology has been adopted by cassava cultivators in the Dominican Republic (Box, 1982: 9).

The research team's interest was exactly in this lack of adoption. Could it be that the new technology did not provide solutions to the cultivator's problems?

In preparing the research we found several things, from actual experience, and from conversations with colleagues in agricultural research institutes** we worked with:

1. If you want to know about problems in cassava cultivation, do not start out asking for them because you are likely to receive fairly general, standard answers which are hardly relevant to the biological scientist charged with studying them;
2. Varietal selection has been a dominant mode of solving cultivation problems among cassava growers;
3. A historical approach to varietal selection may provide clues to reasons for changes in the cultivation system and may thereby indicate significant problems producers faced and face.
4. The capacity to articulate reasons for changes in the past is not equally distributed among the population of cultivators. Some growers are more aware of these reasons than others. Therefore it is better to start an investigation with those, who through experience and reflection are regarded as knowledgeable by their peers.

Starting from the premise that agricultural scientists play a key role in the process of problem solving we began by asking them what they considered to be the problems facing cassava cultivators. This gave us a first indication of significant problems and of the geographical area they were associated with.

With this knowledge we went to the particular regions and identified farmers' organizations and extension agencies which were locally operative. We repeated

**CIAT, CENDA (Centro de Desarrollo Agropecuario, Zona Norte) and ISA (Instituto Superior de Agricultura); the latter two are in Santiago, República Dominicana

the same questions and got another list of problems. We also asked them to bring us into contact with cassava cultivators respected by their fellow-growers for their knowledge and experience. These should be people who were known to have engaged in systematic observation of changes in the cultivation-system, if possible generated by themselves. We called these people "experimenters," not because they engaged in scientific trials, but because they did the thing coming closest to it among common cultivators.

Locating "experimenters" was no problem. In each community a number of growers are regarded as more informed. The existence of farmer organizations like unions, cooperatives or clubs facilitates the process considerably. A preliminary conclusion and hypothesis for further testing is that the degree of integration of knowledge on experiences with a particular crop in a particular area, is correlated with the degree of formal organization among its cultivators.

If this hypothesis is validated, the resulting proposition has definite implications for the organization of agricultural research. For this would mean that through a judicious selection of informants in organized communities, agricultural researchers could become aware of cultivators' problems. For communities of growers with less social organization, other methods would be needed.

Each prospective informant was visited and was asked a few questions on his knowledge and experience in cassava cultivation. If we found that he could rapidly indicate selected characteristics of both past and present varieties, or had engaged in the types of experiments mentioned, and had the opportunity to partake in a time consuming interview, he was selected. As part of the second visit, a number of questions were asked on past and present varieties grown, reasons for changeovers in terms of advantages and disadvantages of each variety, and finally a resumé in terms of characteristics judged relevant in the selection of current varieties.

These interviews were coupled with field observation and soil analysis. The whole process took about a day per informant. On the whole, some 40 case studies were done following this recipee; 18 cases were in the Sierra region and the following preliminary conclusions are based on their analysis.

## Preliminary results

On the basis of the 18 case studies, plus about a dozen complementary interviews on an ad hoc basis (in places where no case study was done), a list of 103 labels *** could be drawn. But to how many varieties do these labels refer? Some varieties are known under more names. But one name may also refer to quite distinct varieties. If one asks a farmer what varieties he is cultivating, he may give a generic classification in terms of the most general type of cassava: bitter, sweet or somewhere in between. This may be followed after some urging by a general color indication: black, white, yellow or in some cases red. These refer to rootskin color, the color of the pulp (before or after cooking) or the color of the foliage or trunk. In other cases a proper name might be mentioned like Facundo, Ricardo or Zenón. Or reference is made to a particular quality, characteristic or special trait of the plant, the tubers or the location it came from. Qualities like size (Chiquita, Mediana or Grande), stem or trunk color (Palote

***Label: local name for particular variety.

colorado), leaf color (Hoja de rosa), new-leaf color (Cogollo morado), color of the extracted pulp-juice (Agua de coco), or color of the cooked tubers (Yema de huevo). Proper names may be given (like Corocitera, derived from a village called Corocito, Maguera from neighbouring Magua, or Jobera from a site called Los Jobos), or combinations of any number of these with previous traits (Sanjuanera grande). Finally a number of general qualities might be referred to, such as the fact that the variety produces sweet tubers in some periods, but bitter at other times (Agriadulce, Amarga dulce), that the leaves may be so poisonous as to kill a cow eating them (Ahoga vaca, Matavaca), or that the taste of the roots is so good that you want more (Damemás). Now comes the difficult step. Finding out what labels belong to what varieties, on the basis of cultivators' knowledge. Using the characteristics, as well as available synonyms, we arrived at a preliminary classification. In it, the 104 labels are redistributed over 63 potential varieties. "Potential" because a definitive classification can only be made after detailed botanical work. Such work will probably reduce the number of past and present varieties to less than 60, but in excess of about 20 varieties currently available in the CENDA collection (Personal communication, M. Rodríguez, 1981).

Several things must be noted. First, labels may be poor indicators but consensus among cultivators in a particular region exists. Second, the same label may be used for varieties with quite different characteristics, such as in the case of Machetazo. It is a common label associated with sweet varieties having a yellowish pulp. Third, even varieties which appear to be well identified with one name on which consensus exists among cultivators, do have local variations which maybe only some farmers recognize.

Why more varieties?

The question as to the multiplicity of varieties may be broken down into two:

a) Why do cultivators grow different varieties over time, i.e. why do they change from one variety to the other (or, from one type of varieties to another type);
b) Why do they grow different varieties at one given time?

Let us first look at the data of cultivators of whom we have enough information to answer both questions (Table 1). The number of known varieties among these informants varied between 6 and 21, with an average of about 14. This means that 14 varieties could be described on the basis of own experience. On the whole, informants had more sweet than bitter varieties. They knew an average of about 5 bitter varieties, against 9 sweet ones and cultivated actually an average of 2 bitter against 4 sweet varieties.

This general observation is confirmed by the number of known varieties where 28 bitter varieties are mentioned against 35 sweet ones.

So at least for this group of cassava cultivators it is clear that they do grow more than one variety and that they have experience with about twice the number they actually cultivate.

Why have they changed from one variety to another? It is yet too early to make any definitive statements but on the basis of the case studies we can select those varieties which were grown in the past but not in the present ("historical varieties"), those grown in the past which continue to be cultivated in the

Table 1. Different varieties grown by selected informants in the Central Sierra region (Monción) of the Dominican Republic (1982).

| N° Informant | Community | Number of Varieties Grown: Past[1] Bitter[3] | Past[1] Sweet | Present[2] Bitter | Present[2] Sweet | All |
|---|---|---|---|---|---|---|
| S 2 | Jicomé | - | 6 | - | 4 | 6 |
| S 4 | Dejao-Arr. | 5 | 13 | - | 4 | 18 |
| S 6 | Pamarejo | 5 | 4 | 3 | 2 | 9 |
| S 7 | Monción | 3 | 6 | 1 | 2 | 9 |
| S 8 | Palmarejo | 4 | 7 | 2 | 3 | 11 |
| S 10 | Veladero | 6 | 9 | 1 | 2 | 15 |
| S 11 | Veladero | 6 | 8 | 2 | 3 | 14 |
| S 12 | Meseta | 4 | 9 | 3 | 6 | 13 |
| S 13 | Rodeo | 6 | 15 | 2 | 8 | 21 |
| S 14 | Gurabo | 4 | 9 | 1 | 4 | 13 |
| S 15 | Corocito | 5 | 8 | 3 | 6 | 13 |
| S 16 | Jicomé | 5 | 14 | 3 | 5 | 19 |
| S 17 | Dajao-Arr. | 6 | 14 | 2 | 3 | 20 |
| S 18 | Cacique | 5 | 8 | 2 | 3 | 13 |
| Averages | | 4.9 | 9.3 | 2.1 | 3.9 | 13.9 |

[1]Includes varieties grown by others on the farm, but of which informant has sufficient knowledge to describe.
[2]Includes all varieties currently grown, including ones for experiments.
[3]Includes bitter-sweet varieties (which are almost not cultivated in 1982, due to the disappearance of the pigs which fed on them).

present ("classical varieties"), those grown actually and are of recent origin ("newcomers") and those grown in the recent past, but the cultivation of which was discontinued ("drop-outs") (see Figure 1).

Figure 1. Classification of varieties according as to whether or not they are actually cultivated vs. whether or not they were introduced.

| | | Actually cultivated? Yes | No |
|---|---|---|---|
| Recently | Yes | "Newcomers" | "Drop-outs" |
| Introduced? | No | "Classics" | "Historicals" |

This diagram can only be made for particular cultivators. It is hard to generalize, since a variety which is a recent introduction for one, is a "classic" for someone else. In the Sierra situation, no general patterns for the spread of varieties could be recognized. So generalization remains rather hazardous, as far as specific varieties is concerned. It becomes somewhat easier if we abstract from varieties and classify by traits or qualities (which may or may not be as-

sociated with a given variety under given conditions). If we elaborate the data accordingly, Table 2 emerges.

Table 2. Classification of varietal traits according to actual cultivation, vs. recency of introduction by positive (+) and negative (-) points.

| | Actually Cultivated ? | |
|---|---|---|
| | Yes | No |
| Recently introduced ? | | |
| Yes | + yields higher<br>+ short cycle<br>+ tolerates poor soils<br>+ starch content[0]<br>+ market value<br>- taste<br>- tolerance to delayed harvest<br><br>e.g. Facundo[0]<br>Damemas | + yields<br>+ cycle shorter<br>+ taste<br>- tolerance poor soils<br>- market value<br>- resistance root rot<br>- availability planting material<br>- degeneration plant material<br><br>e.g. Agua de coco[0]<br>Tres meses |
| No | + acceptable yields<br>+ taste<br>+ tolerance to delayed harvest<br>- cycle (long)<br>- tolerance poor soils<br>± market preferences[1]<br><br>e.g. Media carga[0]<br>Amarilla grande | + taste<br>+ tolerance to delayed harvest<br>- tolerance to poor soils<br>- cycle<br>- market value/preferences<br>- availability planting material<br>- degenerating plant material<br><br>e.g. Veinte reales[0]<br>Lula |

[0]) Refers to bitter varieties.

[1]) For bitter varieties: "bitterness", "color", "starch content", "color of final product after baking".

Facundo is the typical case of variety which was recently adopted by farmers producting bitter cassava for local factories, which make casabe or flatbreads of it. The market for casabe increased considerably over the past 10 years and so did the cultivation of the Facundo variety which the factories prefer for its starch content, stable HCN level (or toxicity) and tuber shape and size. It withstands the generally degraded soils farmers are obliged to use, has a shorter cycle than the 2 or 3 years which generally are needed for other varieties, and its planting material is available and trustworthy.

But like some other varieties which are recently introduced it has one negative point. According to certain farmers it is more susceptible to root rot when left in the ground. A variety like Media carga yields less and has a longer cycle, but would be more tolerant of delayed harvest.

This means that certain farmers stick to some of the "classics" because they reduce the risk of cropless due to root rot. The effect of this strategy is not yet known. If root rot is caused by poor drainage of the soil it attacks both types of varieties.

On the whole, our informants indicated that given the conditions of depleted soils or rapidly depleting soils, cassava cannot be kept indefinitely in the ground. Only few informants indicated that under certain conditions the harvest could be delayed after 2 or 3 years. In the case of bitter cassava, either root rot or drastic reduction of starch content was reported. Sweet varieties suffered from the same problems, plus increasing bitterness in taste.

## Conclusions

Using a modified ethnoclassificatory approach to cultivar identification, using both cultivators and researchers as judges in an iterative process, the author could distinguish 60 cultivars on the basis of preliminary results. This suggests a far greater diversity of cultivars than could be expected on the basis of existing collections or reports.

A succession of cultivars is established over the past 50 years, suggesting continuous search for plants which are well adapted to prevalent cultivation conditions and market preferences. This suggests, in turn, a far greater amount of cultivator experimentation with cassava than has hitherto been acknowledged. Cassava cultivators can hardly be defined as traditional farmers in this respect: they innovate whenever conditions permit.

The primary characteristics cultivators appear to have selected contemporary cultivars on, are their capacity to grow on soils with declining fertility, yielding marketable roots in ever shorter production cycles. The main problem faced with selected cultivars is root rot, even on relatively well drained hill lands.

Under these conditions the so called "piggy bank function" of cassava cultivation does not appear to exist anymore.

Cassava cannot be kept indefinitely in the ground, but must be harvested in time to prevent substantial harvest losses.

Sociologists and economic anthropologists can assist such research by clarifying the rationale for the existing cultivation system and by indicating the changes currently taking place.

This is not an exclusive contribution of the social sciences.

Agronomists with a broad view of the cultivation system could generate the same questions. If they are trained adequately, they may come up with comparable answers. But in teams which force agronomists to be quite specialized, the social scientist contributes by generating a link between existing farmer knowledge and research establishments.

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Community Organization Through Cassava Production: Towards a Mobilization of the South African Peasantry

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ABSTRACT

Technology developed at the international agricultural research centers can be regarded as successful only when adopted in the production situation. A rural development program geared to the application of CIAT cassava technology in peasant farming systems in South Africa is examined.

A brief history of land allocation and the colonization of Zuzuland is presented. An analysis of the tribal authority system, used by the British and adopted by the central government of South Africa as a form of control, shows this system to be a hindrance to development.

The manner in which the cassava development program is being conducted aims at not only improving agricultural production but also at acting as a catalyst for organizational development. A considerable degree of organization has been achieved in the 18 months during which the project has been running. The strategy adopted in this project--community organization through physical programs--could be applied with other crops and in other parts of the world.

The rationale behind establishment and financing of the international agricultural research centres was and still is that research would ultimately benefit farmers of the Third World. Technology developed and information generated at these centres is of benefit only when actually applied. Likewise new crop varieties justify the expense incurred in their development only when they prove themselves in the production situation.

The centres, however, do not, and possibly cannot, accept responsibility for the implementation of improved technology and must therefore at times experience the frustration of having developed varieties and techniques which are not being adopted. National institutions have the responsibility of "selling" the methods to farmers who are generally regarded as conservative.

This paper examines a rural development program in South Africa which is geared precisely to applying such technology, i.e., CIAT cassava production techniques, to the advantage of peasant farmers. It also examines the power structure in a neo-colonial situation and suggests that it is the powerlessness of peasant communities, rather than peasant conservatism, that is the basis of underdevelopment.

While the analysis is of the situation in a particular region of South Africa there are sure to be many parallels which can be drawn with peasant communities elsewhere in the world and hopefully a contribution will be made to the orientation of other development programs.

## Location of the Project

The Mpukunyoni Development Project is in Zululand in the province of Natal with the Mpukunyoni area itself covering around 700 sq km between latitudes 28° S and 28.5° S. It has a seasonal subtropical climate with an average annual rainfall of under 800 mm in the west increasing to 1,000 mm in the east.

The boundaries of the Mpukunyoni area were first defined by the Zululand Lands Delimitation Commission of 1902-4 set up by the British Government to define tribal boundaries in Zululand and to set aside land for purchase. This move followed the military defeat of the Zulus in 1879 and the annexation of Zululand to the British colony of Natal in 1897.

In negotiating with the Zulu chiefs the commissioners assured them that they would have the right to bid for the land that would be set aside for purchase. When the delimitation was completed, however, only white settlers were allowed to occupy this land with the Zulus being confined to the occupation of the tribal areas defined by the commissioners. Natal joined the Union of South Africa in 1910 and this racial division of land was re-inforced by the Lands Acts of 1912 and 1936 and persists to this day.

## The Tribal Authority System

When the British colonized Natal and Zululand they were faced with the task of administering and controlling a large indigenous population with only a handful of British officials. This they accomplished by co-opting the existing system of tribal chiefs and headmen. The 1878 and 1891 Codes of Natal Native Law placed the power to appoint and remove chiefs in the hands of the Governor of the Colony of Natal who then became the "Supreme Chief." The Zulu chiefs then became minor deputies of the governor.

Since the formation of the Union of South Africa in 1910 and subsequently the Republic of South Africa in 1961, the co-option of the chiefs has been reinforced. The Native Administration Act of 1927, the 1967 Natal Code of Bantu Law, and the 1974 KwaZulu Chiefs' and Headmen's Act have all made the chiefs responsible to central authority rather than to their own people. Just as this system was used by the British to colonize Natal and other parts of the world, so has it been used by the minority South African Government to control and manipulate a vast black rural population.

While an examination of the functioning of the tribal authority system shows it to be a mechanism for control it is in fact clouded by the myth of representation. The chiefs used to be the representatives of the people prior to colonization and are still perceived as such by many development agents and aid sources. Thus rural development projects and development aid are channeled through the chiefs and their deputies.

Without representative organizations with whom development agents can discuss projects, many schemes fail and the benefits in others are appropriated by a small group of powerful individuals. Existing inequalities in rural societies are rein-

forced and little progress is made towards physical or organizational development. The lack of equality in local structures is likely to be a problem in many developing societies and in fact research in Pakistan shows a positive association between greater equality of social power distribution and the adoption of agricultural innovations (Freeman et al., 1982).

It is therefore within a historical framework of colonial manipulation of Zulu society and within the present day inequalities of the South African system that the Mpukunyoni Development Project has to operate.

Mpukunyoni Development Project

The Mpukunyoni Development Project, which started at the beginning of 1981, is financed by the Anglo American Corporation of South Africa and co-ordinated by the Centre for Research and Documentation of the University of Zululand. The starting point of the project is the provision of assistance on credit to peasant farmers to produce cassava for industrial processing. African Products Ltd., a subsidiary of the Anglo American Corporation, guarantees a market for cassava produced by Mpukunyoni farmers and plans to establish a starch extraction plant in the vicinity.

A total of 60 growers established cassava fields in the 1981/82 planting season (October to February) and a program is under way to include more than 100 new growers in the current 1982/83 planting season. A shortage of planting material limited plantings to one-half hectare per grower initially with the intention to expand individual holdings when top growth is ready for propagation.

While cassava is the chief physical component of the project, considerable assistance is also being given to the Mpukunyoni community in provision of domestic water supplies and in cultivation of other crops such as cotton, sweet potatoes, citrus, and vegetables. Research and development work is geared towards meeting as broad a range of needs as possible.

The activities of the project must however be seen within the underlying philosophy of the project which can best be described as "community organization through physical programs" and specifically "community organization through cassava production." Account is taken of the shortcomings of the tribal authority system and the lack of representative structures described above and the project is implemented in a manner designed to contribute towards remedying this situation.

Allocation of cassava planting material and other benefits of the project are spread as widely as possible to include many people in the initial phases of the project. This promotes the development of organizations representing large numbers of rural people, and is in fact the opposite of the "demonstration" strategy which assumes that if one works with a select group of individuals these individuals will pass on technological skills to others.

Access to technology and information can be used by an elite to reinforce their positions of power and to appropriate disproportionate amounts of aid. The project therefore deals with farmers associations rather than individuals and encourages steps towards the democratic functioning of these associations. The concept of constitutions which protect members rights has been introduced and much effort is put into membership education not only on technological matters but also on organizational procedure.

Thus a physical program such as the promotion of cassava production becomes a vehicle around which peasant farmers mobilize in order to form representative associations which not only co-ordinate their agricultural activities but also represent the interests of their members on a broader level.

## Cassava as a Catalyst

Organization does not take place in a vacuum and for a farmers association to go from strength to strength the activities of that association must meet with success. Cassava as a pivot for organization appears to be well suited to the Mpukunyoni area. It is an area of erratic rainfall where the standard subsistence and cash crops (largely maize and cotton) often fail completely. Cassava has already proved its drought tolerance and initial research indicates that the variety M Saf 2 can be expected to produce 24 tons of fresh root per hectare per annum on a commercial basis (Daphne, 1980).

Cassava production techniques follow closely the recommendations and technology developed at CIAT. The selection and dipping of planting stakes is done to ensure crop hygiene while a stringent eradication program was conducted at the end of 1979 to ensure that cassava bacterial blight (identified in South Africa in 1978) did not enter the production area. The same care in distribution of planting material is exercised to keep cassava mosaic virus out of the production area while a longer term breeding program has been initiated to produce resistant varieties.

Appropriate technology such as the CIAT-developed harvester blade is used to ensure a balance between an efficiently run operation and the demand for work in the Mpukunyoni area. While much assistance with operations is provided by African Products, Ltd., at this stage the intention is that peasant farmers and their associations will completely control their own cassava production within a short period of time.

## Impact of the Project

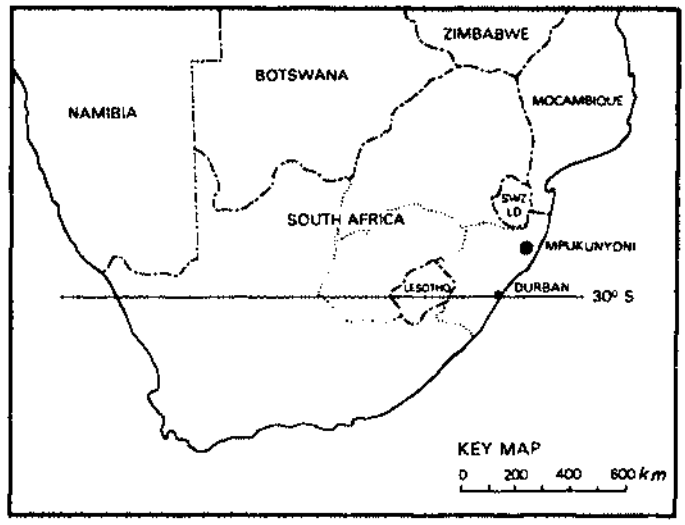
In terms of the initial aim of the project, to promote community organization, considerable success has been achieved. The Mpukunyoni Cassava Growers Association was formed on April 14, 1982 and a constitution was adopted on June 23. The cassava program and also the general increase in agricultural and organizational activity in the area has led to the formation of an association representing cotton growers and also to the formation of 12 localized farmers associations dealing in general agriculture. On September 29, representatives from the various associations came together to form the Mpukunyoni Farmers Union representing over 1,000 households in the area.

This body while not directly challenging the tribal authority system, has the potential to provide an alternative system of representation. Agricultural and other developments will have a forum for discussion and aid can be channeled through elected office bearers thus ensuring a more equitable distribution of benefits.

While the socio-political process described here refers to a specific project in South Africa it is believed that this particular philosophy of development has application in many other parts of the developing world. Peasant societies are often poor because they do not have effective local structures for voicing

opinions and demands. For similar reasons development aid often seems not to reach the people who really require it.

Thus although the Mpukunyoni Development Project is confined to a small corner of the globe we are hoping to contribute towards a model of development which can be adapted to the benefit of the rural poor elsewhere.




Location of Mpukunyoni area within southern Africa.

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Yield Components as Influenced by Methods of Planting Cassava Cuttings

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ABSTRACT

A field experiment investigated, through monthly samplings, the influence of vertical and horizontal planting methods on the expression of total biological yield components of cassava.

Horizontal planting effected a greater production of roots per plant but yielded as many tubers as did vertical planting. In turn, vertical planting outyielded horizontal planting with respect to dry matter of roots, tubers, leaves, and stems.

In small farming systems where no mechanization is involved, vertical planting could be used to obtain greater yields.

The choice of cassava planting positions (vertical, horizontal, and inclined) varies according to continents, countries and within a country, according to regions (Lorenzi et al., 1981; Ezumah and Okigbo, 1981; Sinthuprama, 1981). Scientists justify adoption of a given planting position according to variety, soil characteristics, and climate. Among other reasons, Toro and Atlee (1981) found vertical planting (VP) to be generally recommended because of better and more uniform distribution of roots and consequent better anchorage that eliminates lodging. In a study published by A.C.C.T. (1981), the horizontal planting (HP) position was favored because of greater fertilizer use efficiency leading to higher yields. In large scale cassava production systems, horizontal and inclined (IP) positions are preferred because of ease of machinery usage in harvesting operations. In traditional cultivation practices, choice of a planting position is made on the grounds of old habits. To improve yields then, new but simple and efficient cultivation changes must be introduced.

In the Ivory Coast, cassava is produced mainly by small farmers in the southern part of the country where rainfall is high. HP and IP positions are common, rarely the vertical (VP). An experiment involving a high yielding variety studied, through a stepwise approach, the makeup of yield components from planting to harvest using VP and IP positions to choose the most favorable method that could be recommended to small farmers.

## Materials and Methods

A field experiment from March 1981 to April 1982 use a high yielding variety CB (from People's Republic of Congo) on the ORSTOM farm where soil is sandy. *Pueraria phaseloides* had been growing on the field the previous 2 years.

Soil amendments consisted of: dolomitic stone 1,000 kg/ha, nemagon (a nematicide fumigant) 100 l/ha, and no fertilizer N P K applied. Cassava stem cuttings 25 cm long were VP and HP on the flat.

In VP, two-thirds of the total length of cuttings were placed in the soil. HP cuttings were placed flat 5 cm under the soil.

Planting density varied from 0.5x1 m to 1.5x2 m according to sampling dates and stages of growth. Such precautions were taken to minimize neighbouring root systems interpenetration and to facilitate root sampling. Vertical and horizontal lines alternated on the field. Samplings were at month intervals and consisted of digging up the whole root system in such a way that each and every root was accounted for. Ten plants/planting position were sampled each time and parameters such as total production of leaves, roots and tubers; plant height and dry matter were measured.

## Results and Discussion

Roots, tuber and leaf production on the one hand, and root, tuber leaf and stem dry matter on the other hand, are discussed in this paper.

### Total Root Production (Figure 1)

Root production totaled about 50 roots at 1 month after planting (MAP) in VP while HP had only produced 30 roots. However, VP reached maximum root production (55 roots) at 2 MAP while HP reached maximum (75 roots) one month later with a margin of 36% over VP. Subsequently, root number decreased steadily to stabilize at 25 for VP and 33 for HP from 10 MAP up to harvest time. However, total root loss was greater in HP (-43 roots) than in VP (-30 roots).

### Tuber Production (number of bulking roots) (Figure 2)

Root bulking began 2 MAP which agrees with the reports of Cours (1951). Maximum number of bulking roots (17) was reached at 5 MAP in VP and 7 MAP in HP.

This number decreased to 14 bulking roots in both cases at harvest time. This represents 56% in VP and 42% in HP of total roots retained at harvest time. It appears that in VP position, number of tubers is maximized although total root production is less than that attained in HP.

The decrease in bulking root number from 17 to 14 roots, shows that not all the bulking roots become tubers. This fact is supported by field observations.

### Leaf Production (Figure 3)

Leaf production at monthly intervals increased gradually in HP.

In VP an early large increase (from 10 to 90 leaves/month) was maintained through the 5th month. Afterwards, leaf production rate increased gradually up to harvest time. In any case, leaf production rate was maximum in the latter part of the growing season, that is, from 8 to 12 MAP for VP and from 10 to 12 MAP for HP. VP produced more leaves than did HP on both monthly and yearly basis.

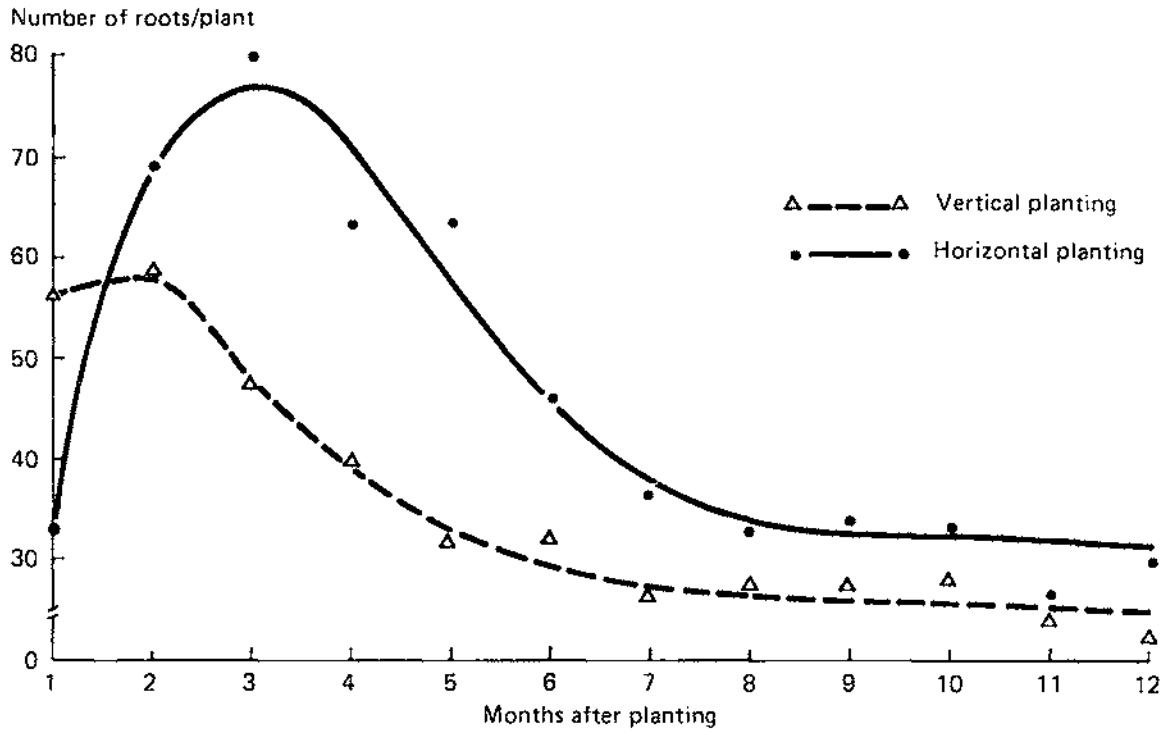


Figure 1. Influence of planting position on root production.

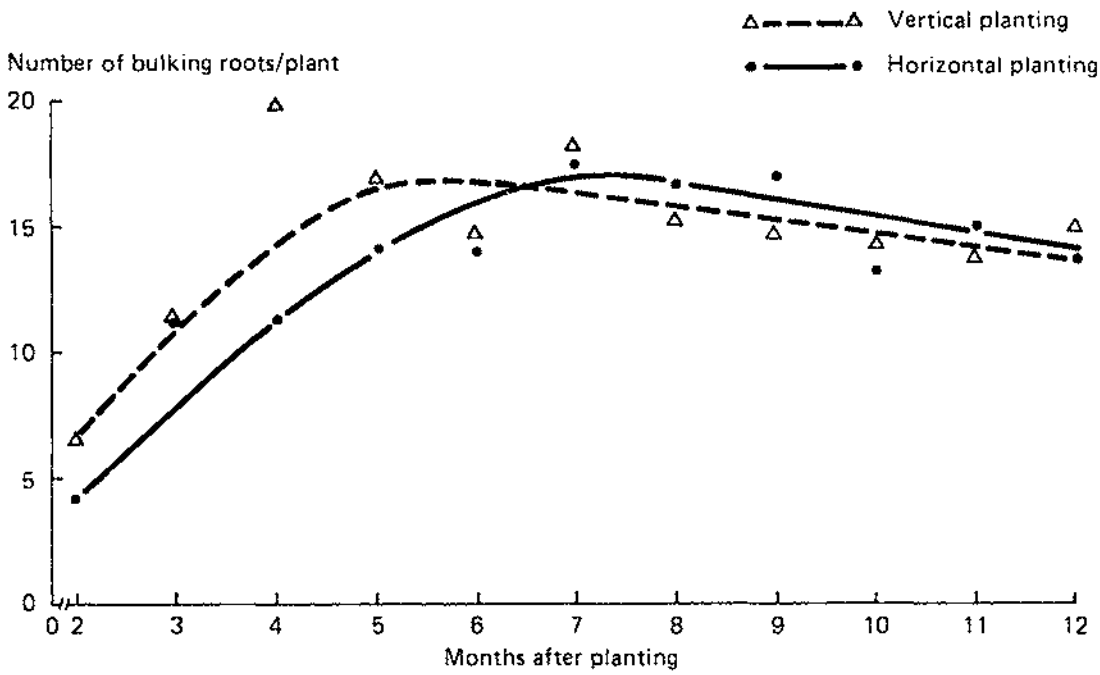


Figure 2. Influence of planting position on number of bulking roots.

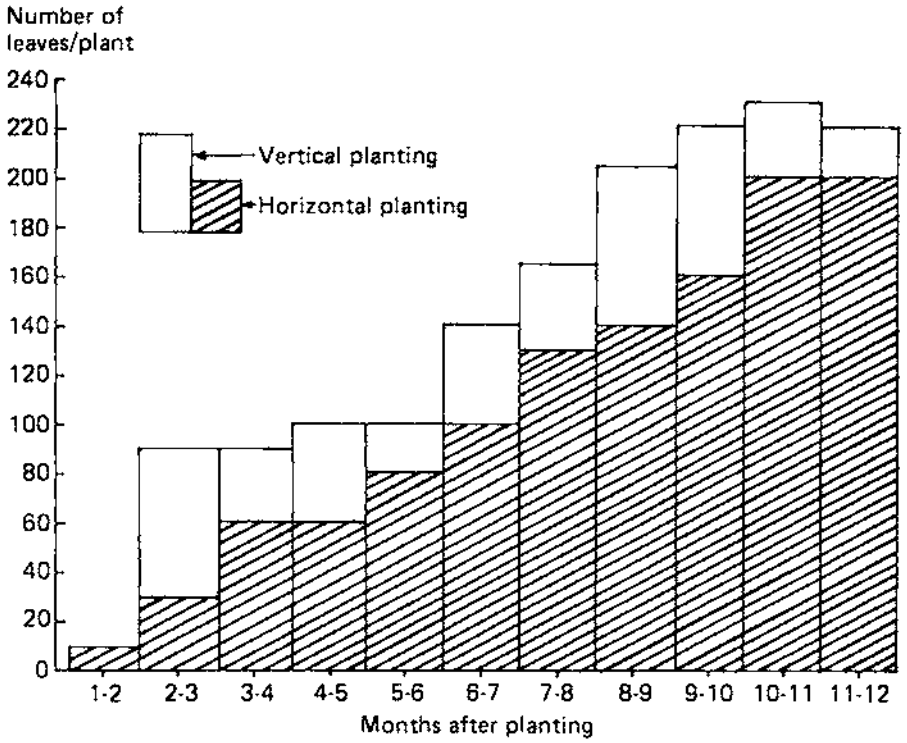


Figure 3. Influence of planting position on leaf production at monthly intervals.

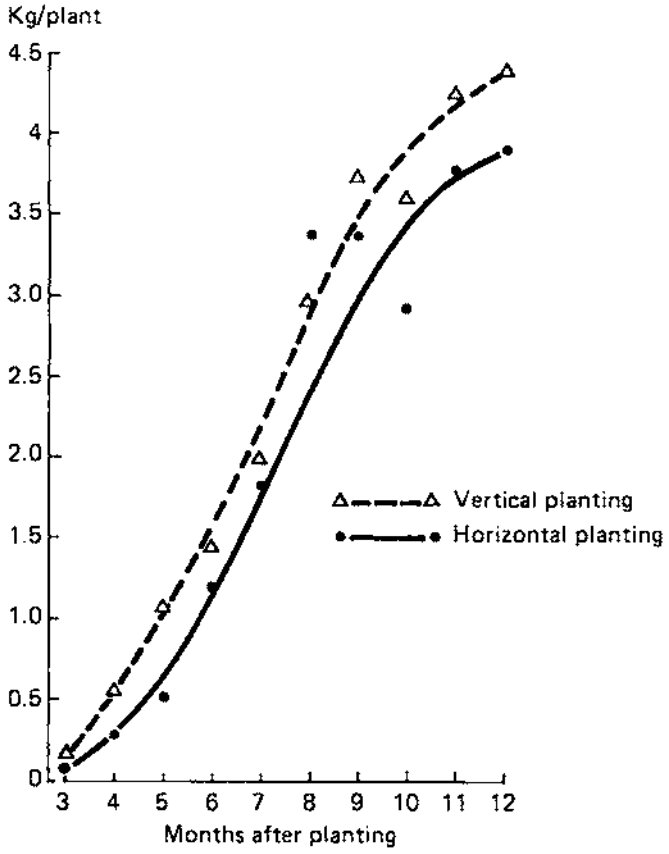


Figure 4. Influence of planting position on tuber dry weight.

Dry Matter in Tubers (Figure 4)

Dry matter accumulation in tubers followed the same pattern in both planting positions but VP accumulated more dry matter than did HP over the whole period of the growth cycle. The difference in dry matter accumulated further widened as harvest time approached. For example, at 12 MAP, the difference between VP and HP was 0.5 kg/plant, that is, 1.7 kg fresh weight/plant. Assuming a population of 3,333 plants/ha, this difference amounts to 5.7 t/ha in favor of VP.

Dry Matter in Stems (Figure 5)

Dry matter accumulation in stems was slow from 1 to 3 MAP but increased at a higher rate over the remaining months. The difference in dry matter between VP and HP increased as time went on. A difference of about 20% in favor of VP was recorded from 10 to 12 MAP.

Dry Matter in Leaves (Figure 6)

Dry matter in leaves increased sharply up to 5 MAP, reached a maximum between 5 and 7 MAP, then decreased. Throughout the growth cycle, VP effected a relatively higher amount of dry matter than did HP. At 5 MAP when dry matter accumulation was maximum, VP had a margin of 17% over HP.

The seeming discordance between dry matter accumulation pattern and that of leaf production could be attributed to maximum leaf retention, bigger leaf size and perhaps minimum migration rate of photosynthates from the leaves to the bulking roots during the earlier months (1 to 6 MAP) of plant growth. During the latter part of the growth cycle, photosynthates migrate massively from leaves to tubers (Williams, 1974).

It can be concluded from results of this experiment that VP is more advantageous than HP in terms of yields, and could be recommended to small farmers. However, these results cannot be extrapolated to other varieties.

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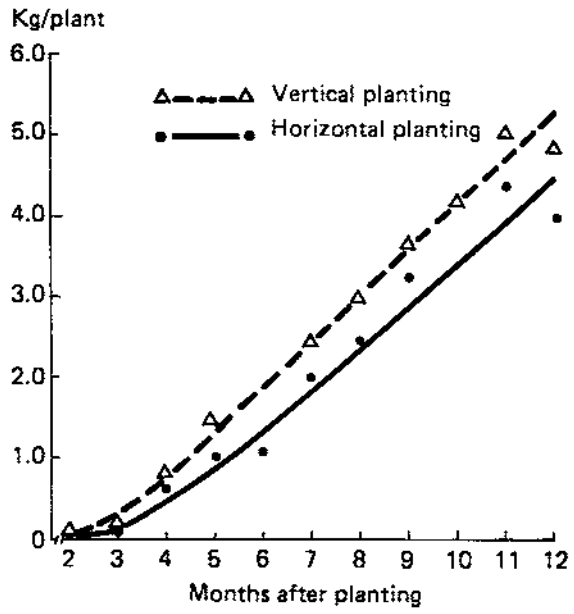


Figure 5. Influence of planting position on stem dry weight.

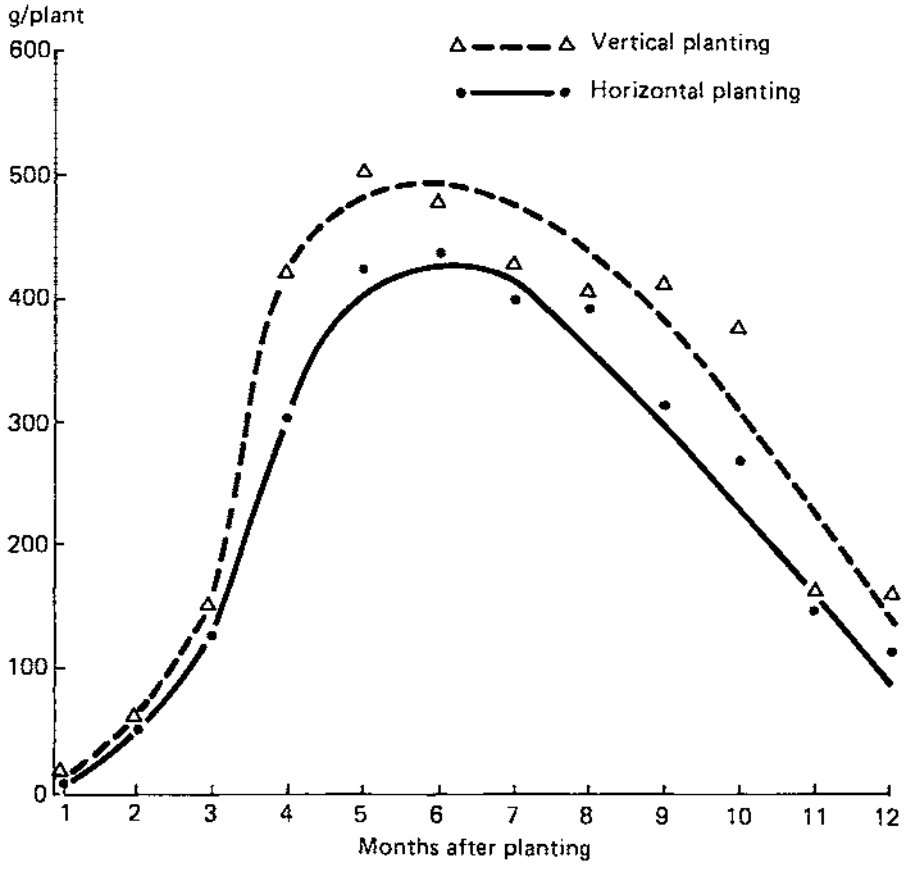


Figure 6. Influence of planting position on leaf dry weight.

# The Agronomy of Mukibat Cassava

Authors: B. Guritno, Sitompul, and Soetono, Brawijaya University, Malang, Indonesia, and G.H. de Bruijn, Agricultural University, Netherlands.

## SUMMARY

The Mukibat system of cassava production in Indonesia can lead to significant yield increases as compared to ordinary cassava. Preparation of graft combinations is time consuming, but once prepared, they can be reused for repeated planting. Mukibat cassava can be planted like ordinary cassava; digging planting holes, as often practices, can be omitted. For pure stand conditions, plant density of about 8,000 plants/ha was found to be optimal. Nitrogen fertilization increases yield significantly up to a level of 100 kg N/ha. No significant response to P and K was found. High root yield is obtained after a growth period of 12 to 15 months. Mukibat cassava has a somewhat higher HCN content than ordinary cassava.

## Introduction

In Indonesia cassava has an important role as a staple food, particularly for low income groups. One possibility to increase cassava production in Indonesia is using the Mukibat system. This system was developed in 1952 by a farmer named Mukibat, and it is based on grafting or budding of a scion of *Manihot glaziovii* onto a stock of *M. esculenta*. Surveys indicated that the system leads to a considerably higher yield than conventional cassava cultivation (de Bruijn and Dharmaputra, 1974). Farmers consider the system as laborious while generally the taste of Mukibat cassava is slightly bitter due to presumably higher HCN content.

Realizing the high potential of the Mukibat system, research started in 1973 at the Faculty of Agriculture, Brawijaya University, with the support from the International Development Research Centre (IDRC), Ottawa, Canada. Additional support was by the Indonesian Institute of Sciences (LIPI) which acted as a counterpart for research projects funded by foreign countries. Results of the experiments have been reported periodically in the form of Progress Reports (I to X).

## Planting material preparation

The preparation of planting material for Mukibat cassava cultivation entails more skill and time than that for conventional cassava cultivation. For large scale introduction of the Mukibat system, this poses a serious handicap. The results of our research, however, indicate that this impediment can be reduced. For this purpose, the grafts should be made in such a way that they can be reused several times. Planting material can be used repeatedly up to the fourth genera-

tion without significant yield reduction (Table 1). With respect to this, the stock section is lengthened by 5-10 cm.

Table 1. Influence of the reused grafts on the dry root yield (t/ha).

| Grafting material | Experimental site (ecological type) | | | |
|---|---|---|---|---|
| | T. agung (dry) | Pagak (moderate) | Muneng (dry) | Lumajang (wet) |
| First original grafting | 16.3 | 11.8 | 18.1 | 12.0 |
| Second reused grafting | 21.0 | 17.0 | 17.8 | 12.5 |
| Third reused grafting | 22.4 | 17.1 | 16.9 | 12.0 |
| Fourth reused grafting | 25.1 | 22.9 | 17.6 | 11.8 |

Progress Report VI, 1979.

Basically two methods have been developed to prepare planting materials for Mukibat cassava cultivation. These are the grafting and budding methods. Obviously the grafting method is easier to apply and it also leads to better results.

With this method one person can make about 200 graftings per day. To strengthen the connection section and to facilitate the grafting work, a thin piece of bamboo is put in the pith of both scion and stock and then bound with binding material such as plastic fibers.

Stock and scion material selection

All varieties in East Java ever tested could be used for the intended grafting. However, some varieties showed inconsistent response and high yielding varieties may not necessarily be high yielding when planted in the Mukibat system and vice versa. Some varieties considered to be most suitable for both Mukibat cassava cultivation as well as for conventional cassava cultivation are listed in Table 2. Faroka variety appears to be most suitable and better adapted to a wide range of environments.

For scion material, two types of *M. glaziovii* are available, the so called "black" and "white" types. Both are equally good, yet the black type may indeed be superior over the white type in a given environment. The scion material is usually taken from original *M. glaziovii* plants but material from Mukibat plants is also good (Table 3).

Planting method

In most cases farmers plant Mukibat cassava in large deep holes prepared some months prior to planting. The diameter varies from 0.5 to 1.5 m and depth from 0.1 to 1.0 m, depending on soil conditions and local customs. Experiments indicate, however, that Mukibat cassava can be planted in the usual way as ordinary cassava (Table 4) with land prepared by hoeing or plowing with or without making ridges.

Table 2. Varieties used for the Mukibat and ordinary cassava cultivation at three experimental sites.

| System | Experimental site (ecological type) | | | |
|---|---|---|---|---|
| | Pagak (moderate) | | Muneng (dry) | Lamajang (wet) |
| Ordinary | 1. Faroka<br>2. Muneng 257<br>3. Soma | 4. Ketan<br>5. Ngganing | 1. Muara<br>2. Pandesi<br>3. 259-D-GM-42 | 1. Faroka<br>2. Muara |
| Mukibat | 1. Faroka<br>2. Ngganing<br>3. Soma | 4. Mentega<br>5. Ketan<br>6. Muneng 257 | 1. Pandesi<br>2. Faroka<br>3. Muara<br>4. Ngganing | 1. Faroka<br>2. Ndoro<br>3. 257/B/Va<br>4. Ngganing<br>5. Valenca |

Progress Report III, 1974/75.

Table 3. Influence of the origin of M. glaziovii material on the fresh root yield (t/ha).

| Experimental site (climate) | Variety | Scion material origin | |
|---|---|---|---|
| | | Original M. glaziovii | Mukibat M. glaziovii |
| Pagak (moderate) | Faroka | 34.7 | 37.4 |
| | Ndoro | 26.8 | 28.5 |
| Muneng (dry) | Faroka | 44.8 | 40.2 |
| | Gading | 38.5 | 42.7 |

Progress Report III, 1974/75.

Table 4. Effect of different land preparation on the fresh root yield (t/ha).

| Land preparation | Var. at Pagak | | Var. at Muneng | |
|---|---|---|---|---|
| | Faroka | Ndoro | Faroka | Gading |
| Like ordinary cassava* | 25.6 | 25.0 | 43.8 | 34.6 |
| Holes: 0.3 m deep | 35.5 | 20.3 | 45.3 | 33.4 |
| 0.5 m deep | 24.2 | 21.7 | 41.2 | 36.4 |

*Land is prepared for planting by hoeing evenly.
Progress Report III, 1974/75.

## Plant density and spacing

Planting density is one of the most important factors to be considered to obtain high yields. Farmers of East Java may adopt a spacing of 1.5 to 3.0 m x 1.5 to 3.0 m, but the most common spacing is 2.0 x 2.0 m. However, Dharmaputra and de Bruijn (1976) suggested that the 2.0 x 2.0 m spacing is too wide to allow optimal yield.

Several spacing experiments have been conducted, but results varied considerably depending on the variety, on environment as well as on the quality of grafted planting material. Experiments with the high yielding Faroka variety indicated that the higher the plant density (up to 15,000 plants per hectare), the higher the root yield. On the other hand, it was found that yield increases over densities of 8,000 plants/ha were not significant. Based on this experience we consider a plant density of 8,000 plants/ha (spacing 1.25 x 1.00 m) being suitable.

## Fertilizer application

The application of fertilizer in Mukibat cassava cultivation seems to be determined by the variety used, soil condition and soil nutrient levels in particular. In our research, mainly nitrogen fertilizer was considered, as nitrogen is also the only nutrient applied in conventional cassava cultivation in East Java. In several experiments no significant response of Pork fertilization occurred. This was probably due to the relatively good phosphate and potassium status of the soils at the experimental sites. Additionally Mukibat cassava responded less to application of organic matter, such as farm manure and organic wastes.

Optimum nitrogenous fertilizer application for Mukibat cassava in East Java was determined to be about 100 kg N/ha. The estimated result for the N optimum application using regression analysis lies between 75 and 145 kg N/ha (Progress Report IX, 1980). In other areas the situation is different and subject to further studies. An experiment in Lampung, South Sumatera, indicated a response to potassium and phosphate fertilizer in conventional cassava cultivation.

## Time of harvest

Harvest time for cassava is commonly based on how the ontogenetic drift of dry matter accumulation into tuberous root sink against time, and another consideration is root yield quality.

In general farmers' practice, Mukibat cassava is harvested at 8 to 18 months old, depending on variety and particularly on local customs and the need for food. Our experiments indicated highest accumulation of dry matter in the root sink is reached at 12 to 15 months after planting (Dhapmaputra and de Bruijn, 1976). The same trend was found in other experiments.

Therefore, we suggest that harvest at 8 months is too early for good root yield. In the other hand, after about 15 months quality decreases as the roots begin to become woody and the taste deteriorates. Our tentative conclusion for the best harvest time is at 12 to 15 months after planting.

## Cyanogenic glucosides

Cyanogenic glucocides usually expressed in HCN content, frequently pose a problem if cassava is used as food for human consumption or animal feed. For adults the lethal dosage is reported to vary between 50-60 mgs or 0.5-3.5 mgs/kg body weight.

Mukibat cassava has a relatively higher HCN content than conventional cassava. Experimental results show that HCN content of Mukibat cassava varied from about 50 to 200 mgs/kg fresh root depending on factors like fertilizer use, plant variety and plant density or spacing. Nitrogenous fertilization increased the HCN content, while phosphate and potassium applications tended to reduce HCN content. There is also an indication that the wider the spacing the higher the HCN content.

## Conclusion

The Mukibat system of cassava cultivation is superior compared to the conventional cassava cultivation and most suitable for smallholders. Experiments showed that the disadvantages of the system, related to labour-input, could be minimized. A set of crop and soil management practices has been developed which is suitable for smallholders, permitting high yield and good quality.

For large scale cultivation in mechanized estates, the Mukibat system is less suitable. However, in transmigration areas with large numbers of smallholders concentrated and organized, the Mukibat system may be applied as well.

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Nitrogen and Potassium Responses of Two Cassava Varieties Grown on an Alfisol in Southern Nigeria

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## ABSTRACT

A fertilizer trial on an Alagba soil series (Oxic Paleustalf) at Ikenne in the forest zone of southwestern Nigeria for three consecutive croppings to determine responses of cassava varieties TMS 30555 and TMS 30572 to N and K.

Nitrogen application increased plant top yield and N percentage in leaves with no significant effect on tuber yield. Potassium application significantly increased plant top yield, leaf K percentage and tuber yield. Potassium response was observed in the second year of continuous cassava cropping with variety TMS 30555 and in the third year with variety TMS 30572. Variety TMS 30572 appears to be more effective in utilizing soil K. Potassium response can be expected on this Alagba soil series when IN Am. Acetate extractable soil K test level is $\leq$ 0.15 me/100g soil. The cassava crop also responded to K application when the K level of the index leaf blade is $\leq$ 0.1% K.

## Introduction

Cassava is widely grown in the humid region of West Africa on diverse soil types. A relatively large acreage is grown on Alfisols derived from sedimentary parent materials. These soils are known to have low nutrient status and particularly low potassium reserve (Juo and Grimme, 1980). Potassium deficiency usually develops in these soils 3 to 4 years following land clearing from secondary bush fallow with intensive cropping (Kang, 1980). In the traditional bush fallow system cassava is usually planted as the last crop during the cropping cycle and yields are often low - in the order of 6 to 8 tons/ha. This low yield is in part attributable to low soil nutrient status resulting from depletion by preceeding crops.

To meet the increasing demand for this staple food, various agencies in the area attempt to boost cassava production. Investigations to determine the N, P and K responses particularly of high yielding varieties (Amon and Adetunji, 1973; Ofori, 1973; Takyi, 1974; Obigbesan and Fayemi, 1976; Obigbesan, 1977, Kang et al., 1980) show that N and K responses are more common than response to P. Results of fertilizer trials in southwestern Nigeria between 1960-1965 also showed that K response was common on the acid sandy Ultisols (J.E. Okeke, unpublished report). However, with increasing interest for establishing large commercial production units in the region, data on the nutrient requirement for continuous

production is not available. To meet this need, several long term fertilizer management studies were undertaken in southern Nigeria. This paper reports results of N and K fertilizer trials on an Alfisol for three cropping seasons.

## Materials and Methods

The field trial was at Ikenne (6°50'N and 3°41'E) in the forest zone of southwestern Nigeria from 1978 to 1981. Following land clearing from secondary regrowth, the experimental site was cropped once with upland rice prior to the experiment. The soil, an Alagba soil series, is a clayey, kaolinitic, isohyperthermic member of the Oxic Paleustalf, derived from sandy sedimentary materials. The surface soil has a sandy loam texture and the following chemical properties at the start of the experiment: pH (in 1:1 soil:water ratio), 5.9; organic C, 1.30%, total N, 0.17%, ECEC, 4.23 me/100g; IN $NH_4$-acetate extractable Ca, Mg and K of 2.57, 1.40 and 0.23 me/100g respectively; extractable Bray P-1, 8.9 ppm P.

The experiment used a split plot design with four replications. Two cassava varieties, TMS 30555 and TMS 30572, were the main plot treatments. Six sub-plot treatments consisted of a control and combinations of three levels each of N and K fertilizer treatments (see Table 1). Nitrogen (calcium ammonium nitrate), half applied at 4 weeks after planting (WAP) and the remainder at 4 months after planting (MAP). Potassium (muriate of potash) was applied at planting. Phosphorus (single superphosphate) was also applied to all treatments at the rate of 30 kg P/ha per crop. Cassava was planted at 1x1 m spacing. Harvested plot size was 30 $m^2$. At harvest tuber subsamples were taken and dried at 65°C to estimate dry tuber yields.

To determine plant nutrient status, leaf blade samples were collected from the first mature leaves at about 4 MAP. After drying and grinding in stainless steel mill, the plant samples were wet digested and analysed for P, K, Ca, Mg, Mn and Zn contents. Nitrogen was determined from a separate subsample using the micro Kjedahl method.

## Results and Discussion

### Growth and Yield

Variety TMS 30572 showed better growth than variety TMS 30555. Distinct differences in growth due to fertilizer treatments were only observed in the third crop. Plants from the no fertilizer and no N treatments were slightly chlorotic. Plants from the no K treatments were also chlorotic with shorter plants and smaller leaves. Severe bacterial blight infestation was obvious with both varieties in the no K treatment. Odurukwe and Arene (1980) also reported reduction in severity of bacterial blight infestation with K application.

Yield of the 1978-1979 crop is not presented. Due to too early harvesting at 11 MAP, tuber yield was low, below 5 tons fresh tuber/ha. There was no significant differences in tuber yield between the various treatments. The plants from the control and no N treatments showed higher tuber yield than those receiving N. In thus appears that N application delayed tuber bulking, a similar observation was also reported by Kang and Wilson (1980).

Table 1. Effect of nitrogen and potassium application on fresh tuber yield of cassava varieties TMS 30555 and TMS 30572 grown on Alfisol (Oxic paleustalf) at Ikenne.

| Fertilizer N | Treatment K | 1980 TMS 30555 | 1980 TMS 30572 | 1980 Mean | 1981 TMS 30555 | 1981 TMS 30572 | 1981 Mean |
|---|---|---|---|---|---|---|---|
| (kg/ha) | | (tons/ha) | | | | | |
| 0 | 0 | 19.5 | 19.5 | 19.5 | 17.6 | 15.1 | 16.4 |
| 0 | 120 | 21.5 | 21.1 | 21.2 | 23.3 | 19.6 | 21.5 |
| 60 | 120 | 23.3 | 25.4 | 24.4 | 18.2 | 17.3 | 17.8 |
| 120 | 120 | 21.4 | 21.8 | 21.6 | 19.4 | 19.8 | 19.6 |
| 120 | 0 | 18.3 | 21.9 | 20.1 | 13.5 | 13.9 | 13.7 |
| 120 | 60 | 21.6 | 23.1 | 22.4 | 20.9 | 21.7 | 21.3 |
| Mean | | 20.9 | 22.1 | | 18.8 | 17.9 | |
| LSD .05 (I) | | 3.1 | | | 1.5 | | |
| (II) | | 3.1 | | | 3.6 | | |
| (III) | | 4.1 | | | 5.1 | | |
| (IV) | | 4.4 | | | 4.9 | | |

(I) Between variety means.
(II) Between fertilizer treatment means.
(III) Between fertilizer treatments within variety.
(IV) Between fertilizer treatments among varieties.

Tuber yields from the 1980 and 1981 harvests are in Table 1. Harvested at 13 MAP, relatively high fresh tuber yields were obtained above 18 tons/ha with K application. The yield in 1981 was slightly lower. There were no significant differences in fresh tuber yield between the two varieties. In 1980 the control treatment showed slightly lower yield than the fertilized treatments. Highest yield was observed with combined application of 60 kg N/ha and 120 kg K/ha. Variety TMS 30555 showed a significant response to K application in this year.

The 1981 yield showed the same trend as that observed in 1980. Yield of the control was significantly lower than from the combined N and K treatments. In contrast to the 1980 result where application of 60 kg N/ha increased yield, in 1981 N application depressed yield particularly of variety TMS 30555. This yield depression is probably related to the higher degree of bacterial blight infestation in this variety with N application. A significant response to application of 60 kg K/ha was observed with both varieties in this year.

The dry tuber yield from the 1981 harvest is in Table 2. Dry tuber yield showed the same trend as of fresh tuber yield. The dry tuber percentage of variety TMS 30555 was slightly higher (38.1%) than that of variety TMS 30572 (36.1%). The lowest percentage was observed with variety TMS 30572 with no K application (32.8%).

Table 3 shows the plant top yield from the 1980 harvest. Variety TMS 30572 was significantly higher in plant top yield than variety TMS 30555. Plant yield also increased significantly with N and K applications, with variety TMS 30572 showing higher yield response.

Table 2. Effect of nitrogen and potassium application on dry tuber yield on cassava varieties TMS 30555 and TMS 30572 grown on Alfisol (Oxic paleustalf) at Ikenne in 1981.

| Fertilizer N | Treatment K | Variety TMS 30555 | Variety TMS 30572 | Mean |
|---|---|---|---|---|
| (kg/ha) | | (tons/ha) | | |
| 0 | 0 | 6.7 | 5.4 | 6.1 |
| 0 | 120 | 9.0 | 6.5 | 7.8 |
| 60 | 120 | 6.8 | 6.4 | 6.6 |
| 120 | 120 | 7.2 | 7.1 | 7.2 |
| 120 | 0 | 5.1 | 4.6 | 4.9 |
| 120 | 60 | 8.2 | 8.0 | 8.1 |
| Mean | | 7.2 | 6.3 | |
| LSD .05 (I) | | 1.1 | | |
| (II) | | 1.7 | | |
| (III) | | 2.4 | | |
| (IV) | | 2.4 | | |

(I) Between variety means.
(II) Between fertilizer treatment means.
(III) Between fertilizer treatments within variety.
(IV) Between fertilizer treatments among varieties.

Table 3. Effect of nitrogen and potassium application of fresh top yield of cassava varieties TMS 30555 and TMS 30572 grown on Alfisol (Oxic paleustalf) at Ikenne, harvested in 1980.

| Fertilizer N | Treatment K | Variety TMS 30555 | Variety TMS 30572 | Mean |
|---|---|---|---|---|
| (kg/ha) | | (tons/ha) | | |
| 0 | 0 | 19.0 | 25.9 | 22.5 |
| 0 | 120 | 22.6 | 26.1 | 24.4 |
| 60 | 120 | 24.6 | 31.0 | 27.8 |
| 120 | 120 | 29.5 | 36.2 | 32.9 |
| 120 | 0 | 19.6 | 28.1 | 23.9 |
| 120 | 60 | 24.8 | 33.4 | 29.1 |
| Mean | | 23.4 | 30.1 | |
| LSD .05 (I) | | 4.3 | | |
| (II) | | 5.8 | | |
| (III) | | 8.1 | | |
| (IV) | | 8.5 | | |

(I) Between variety means.
(II) Between fertilizer treatment means.
(III) Between fertilizer treatments within variety.
(IV) Between fertilizer treatments among varieties.

There appears to be little relationship between plant top yield (Table 3) and tuber yield (Table 1) with N application. The increased top yield with N application had little effect on tuber yield. However, application of K significantly increased top and tuber yields. The plant top yield of variety TMS 30555 was more affected by K application than that of variety TMS 30572.

## Soil Potassium Status

The soil potassium status showed a sharp decline from its original value of 0.23 me at the initiation of the experiment with continuous cassava cropping. As in Table 4, the decline was more pronounced in the no K than in the control treatment. Considering the surface soil K data sampled at 1 MAP in relation to the fresh tuber yield for the 1979-1980 and 1980-1981 croppings, it appears that K response can be expected on this soil type when the IN Am. Acetate extractable soil K test value is below 0.15 me. Obigbesan (1977) also observed K response on tuber yield in similar soil with test value of 0.12 me K. However, no K response was observed on soils derived from basement complex rocks which have soil K test values ranging from 0.15 to 0.08 me, probably due to the higher K reserve in these soils.

Table 4. Extractable (IN ammonium acetate) potassium levels in surface soil of Oxic paleustalf at Ikenne as affected by nitrogen and potassium applications.

| Fertilizer N (kg/ha) | Treatment K | Year 1979* | 1980* (me/100g) | 1981** |
|---|---|---|---|---|
| 0 | 0 | 0.15 | 0.12 | 0.10 |
| 0 | 120 | 0.21 | 0.17 | 0.12 |
| 60 | 120 | 0.21 | 0.18 | 0.11 |
| 120 | 120 | 0.18 | 0.16 | 0.11 |
| 120 | 0 | 0.12 | 0.09 | 0.09 |
| 120 | 60 | 0.17 | 0.13 | 0.11 |

*Sampled one month after planting.

**Sampled at harvest.

## Plant Nutrient Status

The nutrient status of the index leaves from the 1980-1981 cropping is in Table 5. Little differences is noted in the mean N status between the two varieties. However, variety TMS 30572 showed higher K percentage. There was a pronounced increase in N percentage with N application. Decreasing N status with increasing K application was probably due to a dilution effect, since K application increased top growth (Table 3). It is interesting to note that the N percentage was near or below the critical value of 4.5% N given by Asher et al. (1980). Yet, there was no significant effect of N application on tuber yield of variety TMS 30572, and even negative effects on tuber yield of variety TMS 30572 and on tuber yield of variety TMS 30555 (Table 1). The K leaf status with no K application was near to

the critical value of 1% K given by Asher et al., (1980). There appears to be little difference in the leaf P, Ca, Mg, Mn and Zn percentages between the two varieties. Nitrogen and K applications also have no significant effect on the status of the other nutrients.

Table 5. Nutrient composition of cassava index leaves as affected by nitrogen and potassium application.

| Treatment N (kg/ha) | K | N | P | K (%) | Ca | Mg | Mn (ppm) | Zn |
|---|---|---|---|---|---|---|---|---|
| | | | | Variety 30555 | | | | |
| 0 | 0 | 4.43 | 0.37 | 1.17 | 1.45 | 0.76 | 176 | 30 |
| 0 | 120 | 3.60 | 0.35 | 1.26 | 1.38 | 0.75 | 176 | 34 |
| 60 | 120 | 4.03 | 0.37 | 1.39 | 1.38 | 0.67 | 168 | 34 |
| 120 | 120 | 4.14 | 0.37 | 1.42 | 1.62 | 0.72 | 195 | 41 |
| 120 | 0 | 4.94 | 0.36 | 0.99 | 1.55 | 0.80 | 157 | 39 |
| 120 | 60 | 4.77 | 0.37 | 1.32 | 1.44 | 0.71 | 153 | 33 |
| Mean | | 4.32 | 0.37 | 1.26 | 1.47 | 0.73 | 170 | 35 |
| | | | | Variety 30572 | | | | |
| 0 | 0 | 4.13 | 0.37 | 1.37 | 1.38 | 0.67 | 195 | 41 |
| 0 | 120 | 3.73 | 0.35 | 1.50 | 1.35 | 0.61 | 202 | 38 |
| 60 | 120 | 4.01 | 0.38 | 1.61 | 1.45 | 0.72 | 228 | 41 |
| 120 | 120 | 4.28 | 0.38 | 1.55 | 1.39 | 0.65 | 206 | 41 |
| 120 | 0 | 4.85 | 0.36 | 0.15 | 1.34 | 0.69 | 191 | 34 |
| 120 | 60 | 4.83 | 0.38 | 1.32 | 1.52 | 1.67 | 191 | 41 |
| Mean | | 4.30 | 0.37 | 1.42 | 1.40 | 0.66 | 202 | 39 |
| LSD .05 (I) | | 0.17 | 0.02 | 0.21 | 0.22 | 0.06 | 18 | 6 |
| (II) | | 0.47 | 0.03 | 0.29 | 0.27 | 0.10 | 38 | 11 |

(I) Between variety means.
(II) Between fertilizer treatments among varieties.

Results of the present trial showed the importance of K application for continuous cassava production on this Alfisol derived from sandy sedimentary materials. Even with three consecutive cassava croppings, N application only affected plant top yield (Table 3) and leaf N status (Table 5), but had no significant effect on tuber yield. It is to be expected that with subsequent croppings N application will be needed. However, in this soil with low K reserve (Juo and Grimme, 1980), K response was already obtained in the second cassava cropping with variety TMS 30555 (Table 1). Variety TMS 30572, which has a more robust growth, appears to be more effective in utilizing soil K and only showed K response in the third cropping year. A maintenance dressing of K at the rate of 60 kg K/ha is thus recommended early in the cropping cycle for continuous cassava production on this soil type. A response of the cassava crop to K application can be expected in this soil when the IN Ammonium acetate extractable K is $\leq$ 0.15 me in the surface soil.

Although some investigators have observed positive correlation between cassava tuber yield and total plant top yield (Ngongi et al., 1976), data presented only support such relationship with K application but not with N application.

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# The Effects of Waste-Gas Flares on the Surrounding Cassava Plantations in the Niger Delta Regions of Nigeria

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## ABSTRACT

The retardation of tuber yield of *Manihot esculenta* Crantz due to waste-gas flares, which has been frequently observed by local farmers, is described. Cassava tubers decreased in length and in weight as the distance from the flares decreased. Such decreases were also correlated with decreases in the content of starch and ascorbic acid (vitamic C) in the tubers. In addition, the amino acid and total sugar contents of the tubers increased with decreasing distance from the flares. The high levels of amino acids and sugar in tubers closer to the flares suggest reduced synthesis, or increased degradation of tuber proteins and insoluble carbohydrates, respetively. Of all the environmental factors examined, only soil temperature increased as the distance from the flares decreased.

It is concluded that the waste-gas flares, most probably through their effect on the surrounding soil temperature, reduce the quantity and quality of tuber yield on cassava plantations.

## Introduction

Development of the oil industry in Nigeria dates back to the 1950's. Since that time, this industry has played a dominant role in the general economic development of Nigeria. All the oil is produced in the Niger Delta region of Nigeria, from both inland and offshore oil fields. Despite tremendous benefits that Nigeria has derived from the oil industry in terms of improvement in quality of life and enhancement of the rate of economic development, serious attendant disadvantages have arisen from development of this industry. One problem is environmental pollution.

Environmental pollution associated with the oil industry is a consequence of either:

(a) the discharge of oil and oil products into the environment from the oil fields, or from the extensive network of pipelines through which oil is transported between the production wells and the terminals from where it is exported or transported to the points at which it is distributed for consumption. Such discharges have been referred to as oil spills, or,

(b) burning in the atmosphere of waste gases which accumulate as a result of activities in the production fields and the refineries. Burning these gases produces what are commonly referred to a waste-gas flares.

The present report deals with effects of these waste-gas flares on performance of crops in farmland vegetation in the vicinity. There is no doubt that pollution associated with these flares can affect man and his environment in many ways. Isichei and Sanford were the first to demonstrate in 1976 that the growth of plants was generally surpressed, and that the flowering process in certain species of plants was retarded by these gas flares. They also found that the flares diminished the value of agricultural productivity. Similar observations have been made by others workers on okro plants and palm trees, but the retarding effects were not clearly defined and characterized.

In the studies now being reported, the major physical environmental factors that are affected by the gas flares have been characterized and the extent of retardation of growth and yield of farmland vegetation has been fully defined. Changes in quantities of certain nutrient constituents of cassava was also determined.

## Materials and Methods

Physical Environmental Factors. Temperature, moisture, and intensity of illumination of atmosphere and soil were measured at various distances from the gas flares.

Temperature measurements. Atmospheric temperatures were measured by exposing the mercury ends of thermometers to air for 2 minutes. An average was obtained from simultaneous readings with three different thermometers. Soil temperatures were measured by dipping the mercury end of the thermometer into the soil for 2 minutes and taking an average from simultaneous readings of three different thermometers.

Moisture determinations. Soil moisture was measured by drying soil samples, obtained at specific distances from the flares, to constant weight and determining the percentage water content. The atmospheric humidity was determined by means of a wet-bulb hygrometer. An average of three readings was also taken for both atmospheric and soil moisture.

Light intensity was taken at vegetation levels with a photometer.

Physical Measurement of Plants. Whole plants, leaves or tubers were used, as appropriate.

In the case of cassava (*Manihot utilissima* Pohl.) tubers, the length of each tuber and its diameter at the thickest point were measured. Each tuber was weighed fresh soon after harvest, and later dried in a Gallenkamp oven at 90°C to constant weight, and the dry weight was recorded. Measurements in respect of height, diameter, fresh weight and dry weight were carried out in quintuplicate.

Chemical Analysis. Changes in quantities of certain nutrient constituents, with increasing distance from the gas flares, were studied in cassava tubers. Three major nutrients obtainable from plants were considered: carbohydrates, amino acids, and ascorbic acid.

Carbohydrates. The starch and total sugar contents of cassava tubers were determined.

Starch. Starch content of the tubers was determined by the direct acid hydrolysis method in which starch is hydrolysed into sugar by means of hydrochloric acid, and the sugar produced is determined as dextrose by the Lane and Eynon (1923) procedure.

Total sugar. Total sugar content of tubers was estimated by the anthrone colorimetric procedure (Clark, 1964).

Amino acid. Amino acids were quantitatively estimated by method described by Balogun (1971).

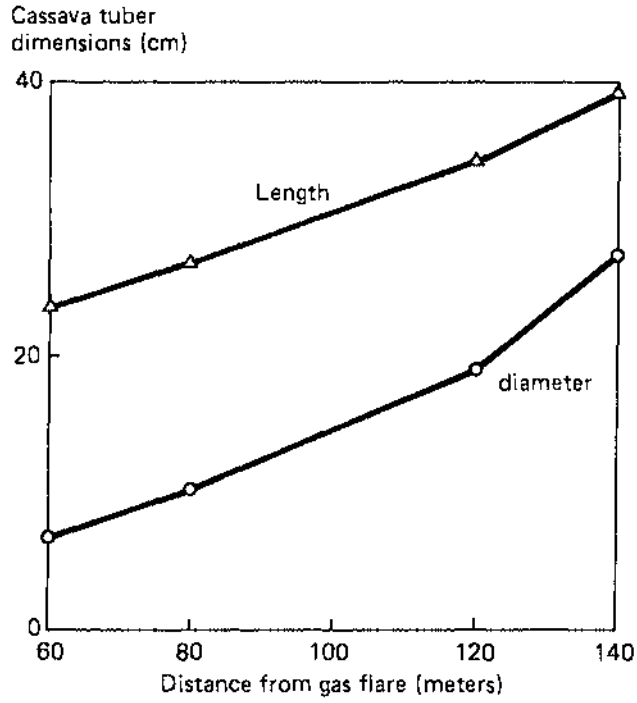
Ascorbic acid. The ascorbic acid concentration in each sample was determined by comparing optical density values with a standard curve for pure ascorbic acid.

## Discussion

Results of the present studies confirm observations of previous workers that growth of farm crops is retarded by waste-gas flares. Such retardation of growth, measured as decreases in the dimensions of cassava tubers, corresponds with decreases in the levels of certain nutrient constituents, such as starch and ascorbic acid (Vitamim C). It is thus clear that, in addition to causing an overall retardation of the growth of plants, waste-gas flares also reduce the nutritional quality of the crop harvest. Since the only physical environmental factor that was found to increase as the distance from the flares decreased is soil temperature, it is concluded that the gas flares exert their effects, at least in part, through their effect on the temperature of the surrounding soil. Such heat-induced retardation of growth in plants has been frequently reported (Oswueme and Lawanson, 1973).

The following uncaptioned charts show trends in cassava tuber dimensions, weight, starch content, abscorbic acid content, amino acids contents, and total sugars as distance changed from crop to gas flare. Figure 7 shows the changes in temperature.

Figure 1.



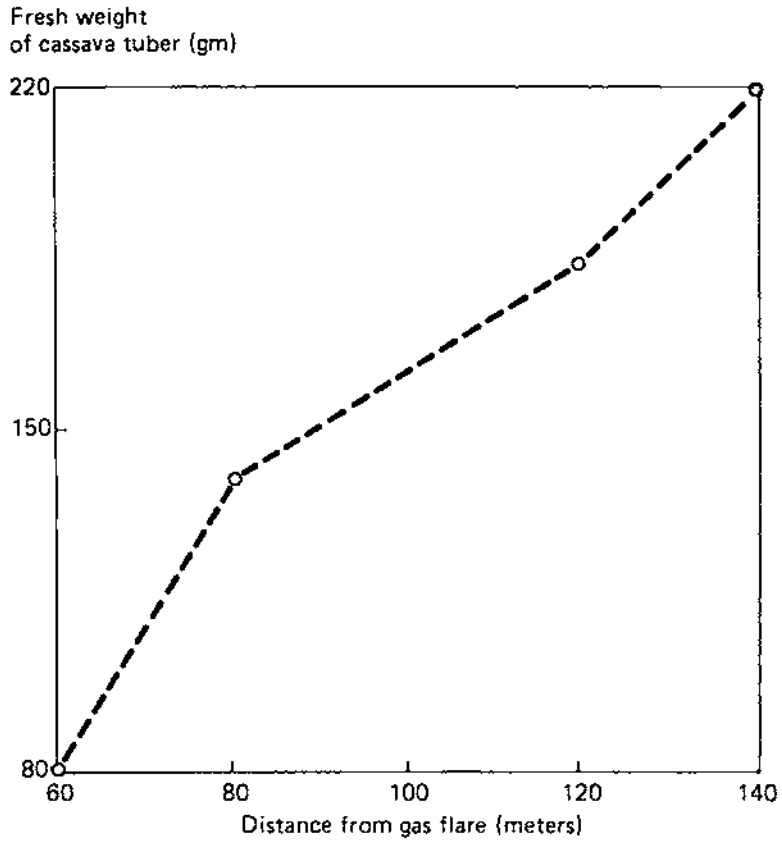



Figure 2.

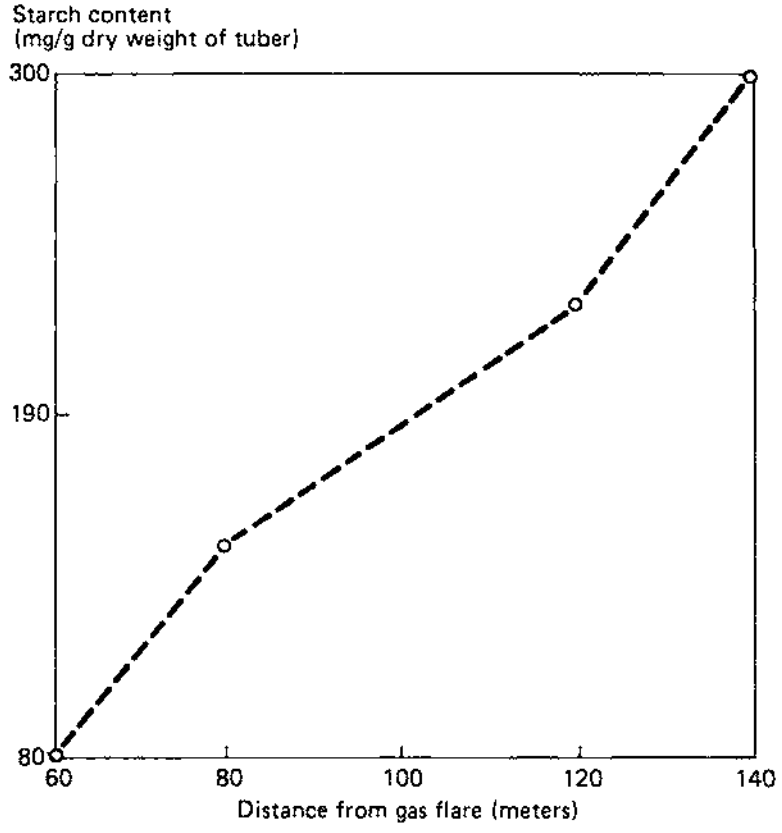



Figure 3.

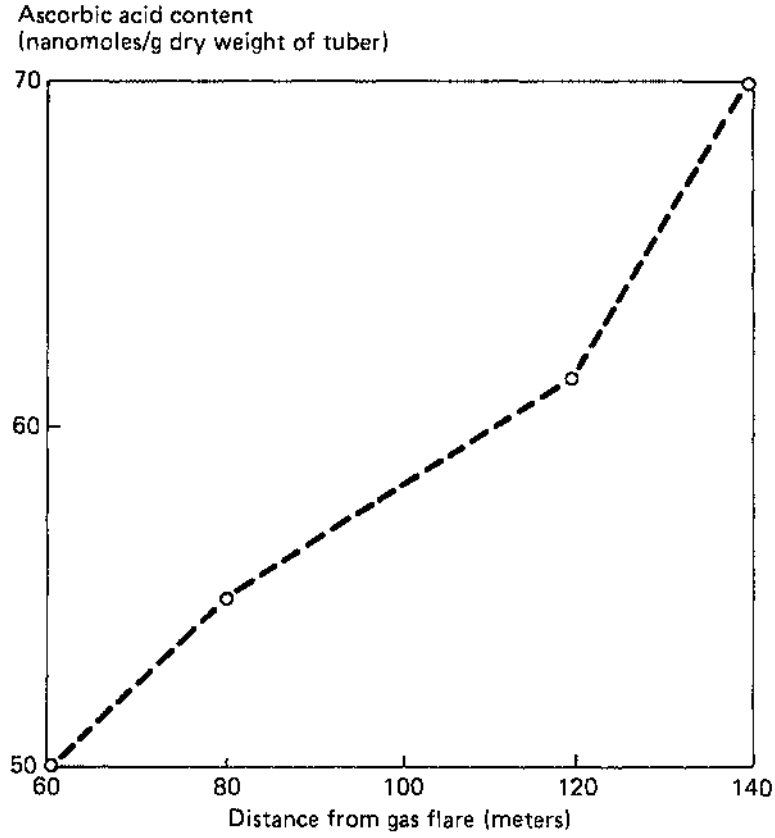



Figure 4.

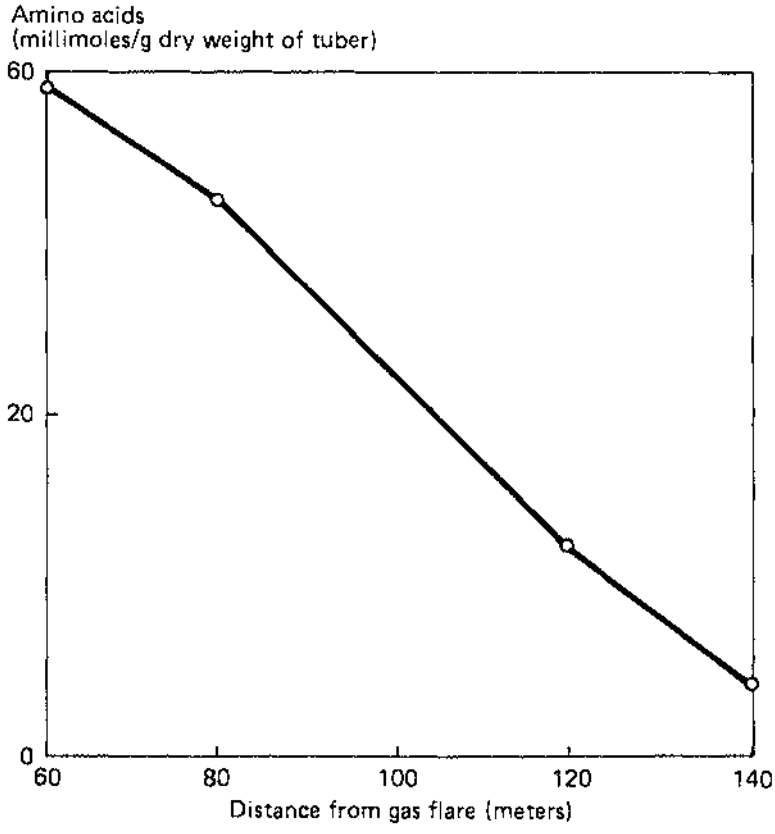



Figure 5.

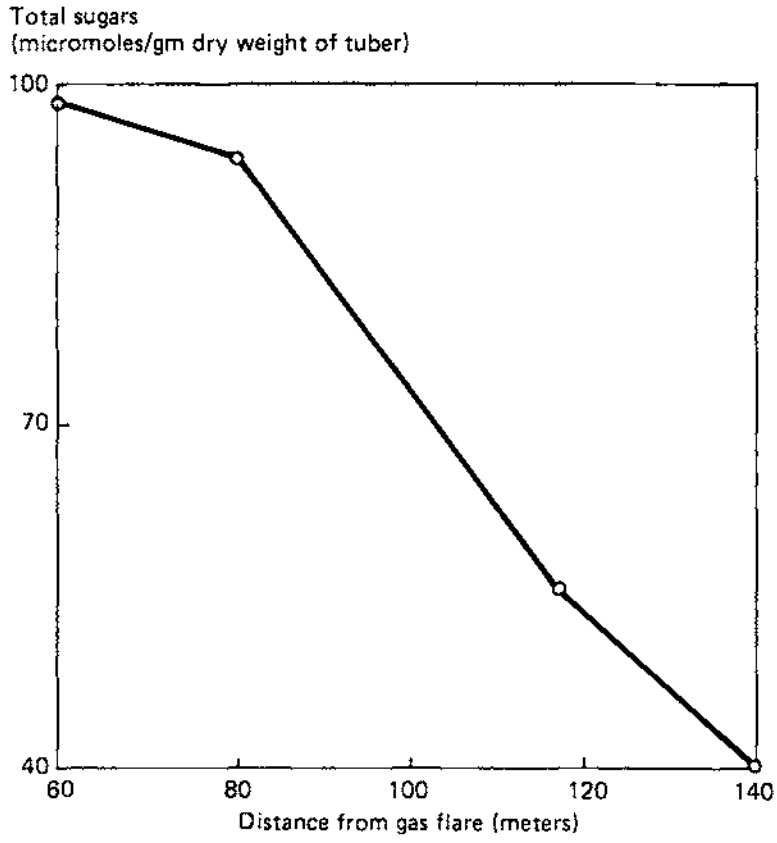



Figure 6.

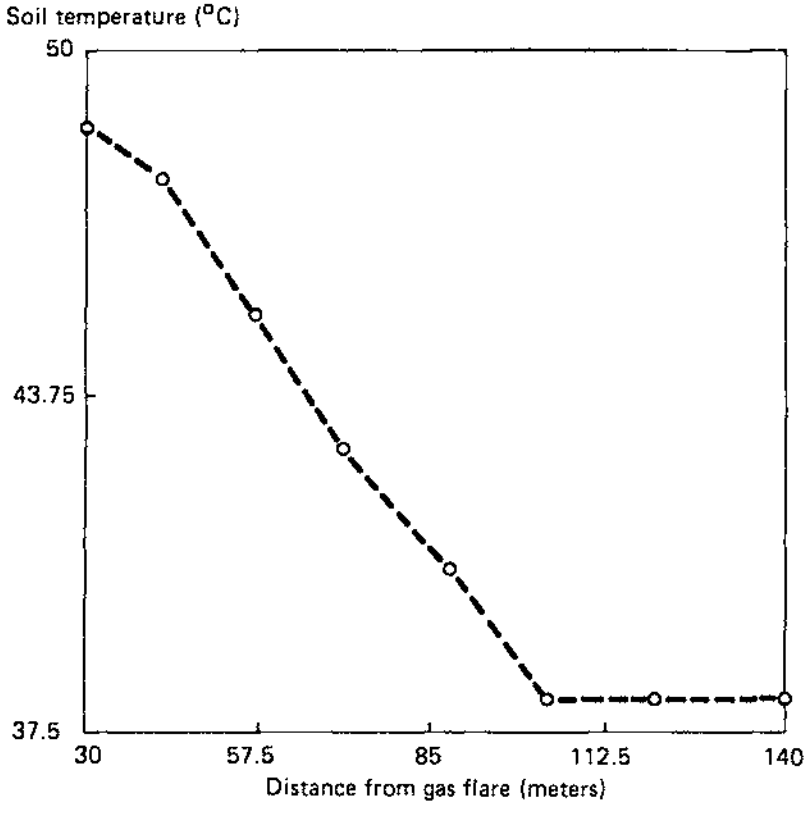



Figure 7.

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# The Production of Planting Material in Cassava: Some Agronomic Implications

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## ABSTRACT

In traditional cultivation systems obtaining cassava planting material is an integral part of the production process. With advent of new technology and larger plantations, however, root and stake production may occur separately. Identification of agronomic practices specifically suited for stake production is therefore desirable.

Stakes of different ages are usually obtained within the same plant, more mature stakes showing more vigorous sprouting but young stakes frequently giving higher yields. High planting densities increase total number of primary and secondary stems/ha thus increasing total stakes number/ha although average stake weight may decrease. High natural soil fertility or fertilization on poor soils can increase stake production significantly. In early growth stages, cassava is highly sensitive to weed competition which can reduce top growth drastically. Good, timely weed control is therefore essential to produce large numbers of good quality stakes per plant.

## Introduction

In traditional cropping systems, obtaining vegetative material for planting cassava has been an integral part of the production process. The relative ease with which cassava is propagated from stem cuttings has probably been one of the reasons why no specific cassava stake production technology has yet been developed. On the other hand, poor stake production practices and the resulting low-quality planting material are frequent reasons for low productivity in cassava. While application of sound stake production practices is important for both small and large producer, it may become necessary for the latter to separate more and more stake from root production in response to specific requirements of large plantations where quantity, uniformity, quality and continuity of supply must be assured. In this paper, several agronomic practices are discussed in relation to production of cassava planting material, providing a starting point for the development of a specific stake production technology.

## Materials and Methods

Characteristics of the experimental sites. Trials were at CIAT-Palmira and Quilichao stations in the Cauca Valley of Colombia, South America, at ICA (Instituto Colombiano Agropecuario) - Carimagua in the eastern plains and at ICA-Caribia

and "La Idea" farm on the Colombian north coast. The CIAT-Palmira Station, located at 1,000 m.a.s.l., has annual rainfall of 1,025 mm in bimodal distribution, 23.7°C annual temperature and 72% mean annual relative humidity. The soil is a vertic calcustoll (mollisol) with a silty clay texture, pH 6.0, organic matter 4.2% and a generally high base status and fertility. Elevation of Quilichao is 1,035 m.a.s.l., annual precipitation is 1,590 mm, annual mean temperature is 23.6°C and annual mean relative humidity 69%. The soil is a typic dystropept (Inceptisol) with a clayey texture, pH 4.1, organic matter 6.3% and low P and base status but high P fixing capacity and high aluminum and manganese saturation. Carimagua, at 200 m.a.s.l., has annual rainfall of 2,094 mm and an annual mean temperature of 26.5°C. The soil is a typic haplustox (oxisol) with clayey texture, pH 4.5, organic matter 2.5% and very low P and base status, but high aluminum saturation. Climatic characteristics of the north coast sites Caribia and La Idea are an elevation of 30 and 10 m.a.s.l., and respective annual mean temperatures of 27.5°C and 27.2°C, annual rainfall of 1,393 and 1,606 mm, and mean annual relative humidity of 84% and 86%. The soil at Caribia is an unclassified entisol with sandy loam texture, pH 6.0, organic matter 1.6%, high available P but intermediate to low base status. At La Idea, the soil is an unclassified entisol of sandy texture, pH 6.3, organic matter 0.9% and low P and base status.

Experiment 1: The effect of the age of stakes within the plant on a subsequent crop.

At CIAT-Palmira, 12-months-old cassava, variety M Mex 11, an erect growing, late branching, medium vigor cultivar, was chosen to harvest stakes of 20 cm length from the lower, middle and upper portion of the primary stem, as well as from the first branches (secondary stem), immediately above the first ramification. Stakes were then planted in a preirrigated field on ridges in a 0.8x1.2 m arrangement. A fertilization of 100, 44 and 166 kg/ha of N, P and K was given at planting. The sprouting process was monitored and final sprouting percentage determined. Root numbers, sizes, and weights were measured at final harvest, 11 months after planting.

Experiment 2: Influence of planting densities on the production of stakes in cassava.

Fresh planting material of variety M Ven 77, an erect growing, late branching, medium vigor variety was produced at CIAT-Palmira and sent to ICA-Carimagua to plant plots with equivalents of 5, 10, 20 and 40 x $10^3$ plants/ha on ridges of 0.5 m distance. Before planting, 1 t/ha of dolomitic lime was incorporated with land preparation and 100, 88, 166 and 10 kg/ha of N, P, K and Zn were applied at planting. The number of primary stems per plant as well as the number and fresh weight of stakes was assessed 12 months after planting. To be counted as a stake, cuttings had to fulfill the following requirements: Length approximately 20 cm, a ratio of pith diameter to total diameter between 1:2 and 1:3 (to ensure adequate maturity) and a bud-number not below five.

Experiment 3: The effect of N fertilization on stake production on a soil low in organic matter and available N.

Variety M Col 22 was grown at ICA-Caribia showing an erect growth habit and intermediate vigor under the given temperature conditions. Planting was on ridges in a 1.8x0.6 m arrangement. The trial received a standard fertilization of 83 kg K/ha, and 10 kg Zn/ha together with levels of 0, 50, 100, 150 and 300 kg N/ha.

At the age of 10 months, plants were harvested and total top and root fresh weights as well as stake number and fresh weights were recorded. Stake selection criteria were those given for Experiment 2.

Experiment 4: The effect of weed control efficiency on stake production in cassava.

The local variety "Secundina" and a CIAT hybrid, CM 342-170 were grown at "La Idea" farm on the Colombian north coast. For "Secundina," the traditional spacing of 1.2x1 m was used whereas the hybrid was grown at 1x1 m, both cultivars being grown on the flat. Differential weed control levels during early growth were established by using chemicals and doses differing in their weed control effectiveness. The treatments were manual control as necessary, oxifluorfen at rates of 4, 2 and 1 liter/ha (commercial product), Diuron plus Alachlor in mixture at 1 kg and 2 lt/ha, Oxadiazon at 2 liters/ha and no control (weedy check). Weed control percentage was assesses visually at 10-day intervals. Ten months after planting, plants were harvested and total top and root fresh weight as well as stake number and stake fresh weight was recorded. Stake selection criteria were those given for Experiment 2.

## Results

The age of the plant and stems. When the age of a cassava plant in relation to stake production is considered, two aspects are important: the age of the plant *per se* as determined by the number of days from planting and the age of the stems within the plant.

Up to the present, no specific research has been conducted with regard to influence of plant age *per se* on stake production but it appears logical that as plant age increases, top growth also increases, and with it the amount of stems from which planting material may be obtained. Furthermore, cassava as a perennial is unlikely to have a clearly defined optimum or maximum age for stake production. Although in plants of advanced age, primary stems may be too lignified to be used as planting material, there will always be stems of a superior order which fulfill the requirements of adequate maturity. The influence of plant age on the relationship between total and useful top growth with regard to planting material is not known nor is there information on "earliness" of varieties to produce stakes in relation to genotypes and edaphoclimatic influences.

On the other hand, some information is available on effect of stakes obtained from stems of different age within the plant. Stems resulting from initial sprouts of the planting piece are called primary stems and represent the oldest tissue of the plant whereas secondary, tertiary, etc., stems resulting from the branching process are formed later and represent younger tissue. In Experiment 1, the effect of stakes from primary and secondary stems on sprouting and yield was compared. There was considerable difference in speed of sprouting among stakes of different ages. Stakes from middle and lower part of the primary stems (i.e. the older stakes) sprouting much faster and more vigorously than stakes from the upper portion of primary stems and from secondary stems, i.e. the younger stakes (Figure 1). While no differences existed between the four groups of stakes with regard to percent final stand at harvest, plant height or total top fresh weight, there was a large difference between commercial root weights, stakes from the secondary stems (the youngest stakes) giving a significantly greater commercial root yield than the oldest stakes (Table 1). The same tendency was observed with regard to

total root yield, however, differences among treatments were statistically non-significant.

Table 1. Effect of stake age within the plant on sprouting, growth and root yield of a subsequent crop.

| Stake age and origin | Final sprouting (%) | Plant height at harvest (cm) | Total fresh weight | | |
|---|---|---|---|---|---|
| | | | Total tops (t/ha) | Total roots (t/ha) | Commercial roots (t/ha) |
| Very old lower part primary stem | 100 a* | 234 a | 34.3 a | 15.9 a | 11.2 b |
| Old middle part primary stem | 100 a | 239 a | 32.3 a | 16.7 a | 12.0 ab |
| Intermediate upper part primary stem | 100 a | 241 a | 32.9 a | 17.5 a | 12.3 ab |
| Young lower part secondary stem | 100 a | 240 a | 32.9 a | 21.3 a | 16.9 a |

*Means in the same column followed by the same letter are not significantly different at P = 0.05, according to Duncan's multiple range test.

These data for an erect growing, late branching variety corroborate earlier findings showing that in less erect, earlier branching varieties, younger stakes (middle and upper portion of plant) also give greater yields (CIAT, 1979).

The effect of planting density. During early growth, cassava plants tend to not interfere with each other, even at greater than normal planting densities. The number of sprouts/plant which form the primary stems, is therefore almost not affected by planting density, as results from Experiment 2 show. This, however, leads to a greater number of primary stems per unit area at higher planting densities and to increased competition among these stems at later growth stages. As a result, individual stems stay thinner and a lower production of stakes/plant with adequate size, maturity and bud number is obtained (Figure 2a). On the other hand, higher planting densities increase the total number of plants per unit area sufficiently to more than compensate for the decrease in number of stakes per plant. In the end, higher planting densities do increase the total amount of stakes produced per unit area, mean stake fresh weight being somewhat adversely affected (Figure 2b). Similar experiences with the use of increased planting densities for the production of quality planting material in cassava have been reported from India (Mohankumar et al, 1980).

Influence of N on stake production. In Experiment 3, there was a large influence of N fertilization on total top fresh weight of plants. As expected, increased N levels promoted formation of stems and foliage which almost doubled in weight comparing the 300 with the zero N level (Table 3). However, stake number per plant was only slightly increased up to 150 kg N/ha and showed a decline at 300 kg N/ha.

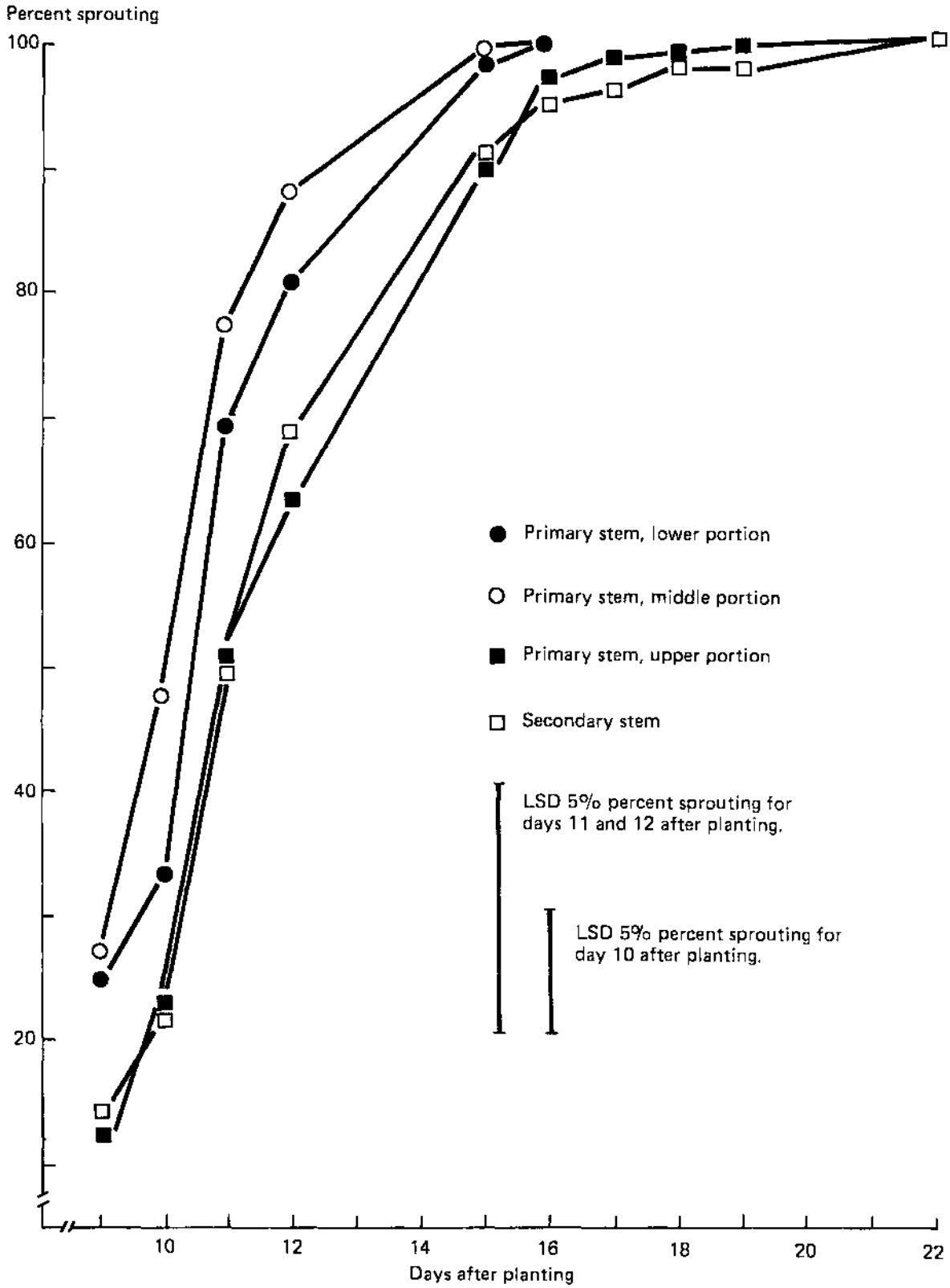


Figure 1. Effect of stake origin within the plant on the sprouting process in cv. M Mex 11. CIAT-Palmira, 1981.

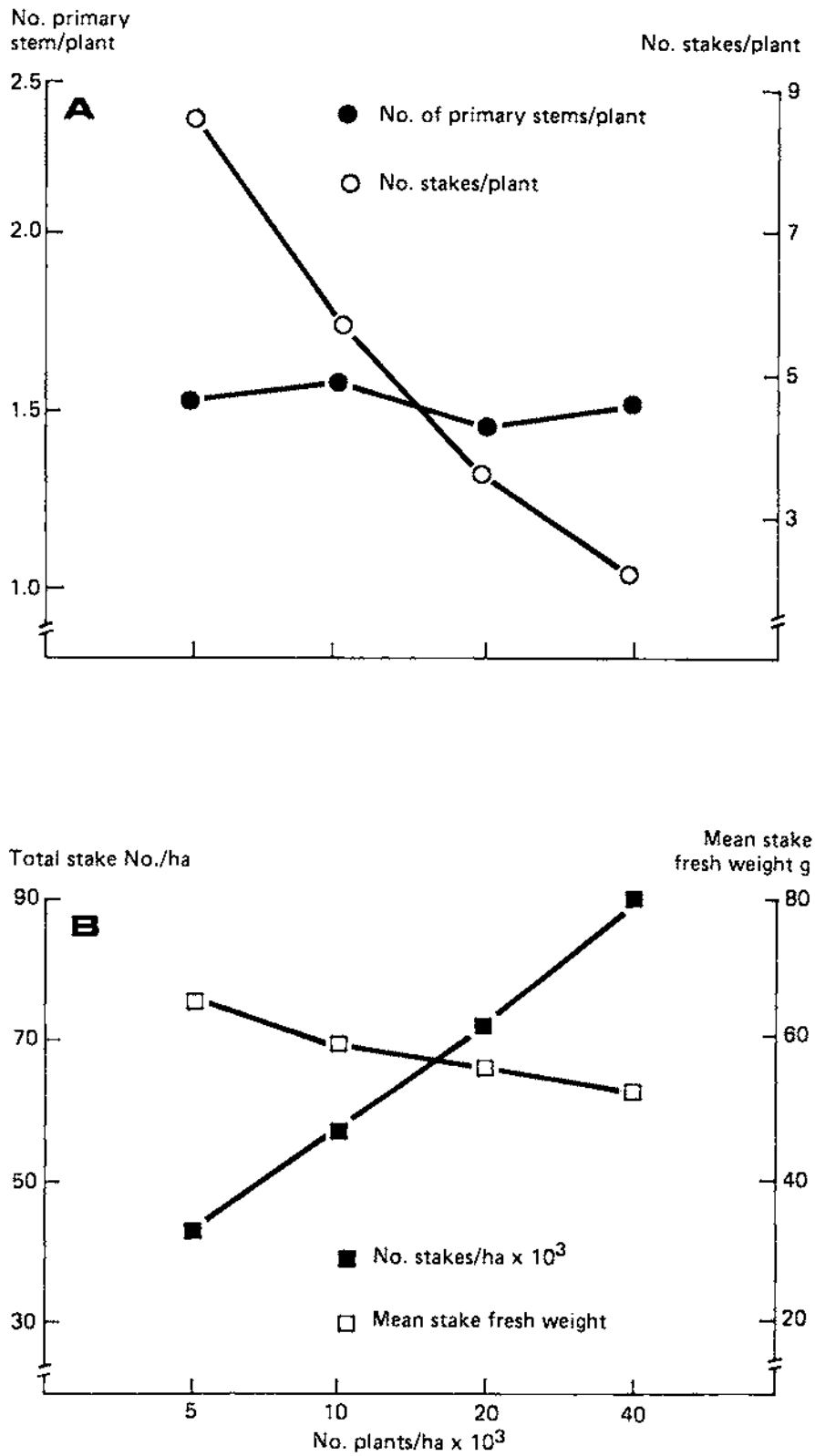


Figure 2. Effect of planting density on number of primary stems, stakes and stake weight in cv. M Ven 77. Carimagua, 1982.

A stake production index (fresh weight of standard size stakes over total plant top fresh weight multiplied by 100) was calculated to demonstrate differences in stake production efficiency of the tops. Similar to stake number per plant, the stake production efficiency increased from 50 to 150 kg N/ha and decreased when more N was applied, the differences being numerically noticeable but statistically nonsignificant. The high stake production efficiency with zero kg N/ha is explained by less elongation of stems without N which allowed selection of a higher proportion of the entire top as planting material with five or more buds per stake whereas with more elongated stems, more stakes had to be discarded due to insufficient bud numbers (Table 2).

Table 2. The influence of N fertilization on quantity and efficiency of stake production and on other growth and yield parameters.

| N level (kg/ha) | Stakes/plant | Stake production index (%) | Total fresh weights Tops (t/ha) | Total fresh weights Roots (t/ha) | Harvest index (%) |
|---|---|---|---|---|---|
| 0 | 3.9 ab* | 8.5 a | 26.5 c | 28.5 b | 52 ab |
| 50 | 3.1 b | 5.6 a | 30.1 bc | 33.0 ab | 52 ab |
| 100 | 3.3 ab | 7.5 a | 28.9 bc | 39.0 ab | 57 a |
| 150 | 5.3 a | 8.0 a | 40.1 ab | 40.6 a | 50 ab |
| 300 | 2.7 b | 4.0 a | 46.9 a | 41.3 a | 47 b |

*Means in the same column followed by the same letter are not significantly different at P = 0.05, according to Duncan's multiple range test.

Data from this experiment show that applications of N up to intermediate levels promote a balance between stem and foliage growth favorable to production of planting material whereas excessively large amounts of N fertilizer reduced the efficiency of the plant to produce stakes but promoted branch and foliage growth.

Plant protection. All types of diseases, insects and weeds may be detrimental to production of planting material in cassava. For diseases and insects the concern is twofold since both can not only reduce production of stakes, they can also be transmitted from mother-plants to new crops resulting in a high risk for productivity. Weeds, compete with cassava for light, nutrients and water. Growth depression in cassava is particularly strong when competition occurs at early growth stages.

A direct response of cassava to different weed control levels during the first 2 months of growth was observed in Experiment 4. According to efficiency of different weed control systems, products and doses, there were different levels of competition between weeds and cassava. The lower the control percentage 50 days after applications, the higher was the competitive effect, reflected by a reduction in total top fresh weight as weed control percentage decreases (only data from CM 342-170 reported, Table 3). Stake production per plant was proportional to total top fresh weight. Uncontrolled weeds reduced top growth to a low level and under these conditions, only every third plant produced one stake of acceptable size and quality. On the other hand, without competition in the hand-

weeding treatment, almost six stakes per plant were obtained. The mean stake fresh weight was rather constant, mainly as a result of the uniform selection criteria.

## Discussion

Using stakes mainly from primary and secondary stems of the plant, it is apparently not indifferent to productivity of subsequent crop from where stakes originate. Stakes from the lower and middle portion of primary stems sprout faster and more vigorously, probably as a result of the greater amount of carbohydrate reserves they can draw on after planting. This, however, appears to be unrelated to thickened root initiation, as a careful analysis of root yield components would suggest. Plants grown from stakes taken from the lower portion of primary stems had noticeably less thickened roots at harvest than those plants originating from stakes of secondary stems. Also, roots from stakes of the former origin were slightly smaller than those from stakes of the latter. These factors together may account for the lower yield of the "old" stakes but the phenomenon is not open to a simple explanation. The possibility of a more efficient dry matter pertitioning in plants grown from younger stakes should not be discarded.

Table 3. The effect of weed competition on growth and stake production in cassava.

| Control systems products - doses*** | Weed control 50 DAA** (%) | Stakes/ plant | Mean stake fresh weight (g) | Total fresh weights tops (t/ha) | Total fresh weights roots (t/ha) |
|---|---|---|---|---|---|
| Frequent manual control | 100 | 5.9 a* | 70 a | 18.8 a | 28.4 a |
| Oxifluorfen 4 lt/ha | 70 | 4.1 a | 71 a | 17.4 ab | 24.6 ab |
| Oxifluorfen 2 lt/ha | 67 | 3.5 ab | 64 a | 14.3 ab | 22.8 ab |
| Diuron + Alachlor 1 kg + 2 lt/ha | 62 | 4.9 a | 63 a | 16.7 ab | 19.2 b |
| Oxifluorfen 1 lt/ha | 51 | 3.3 ab | 63 a | 13.8 ab | 21.9 ab |
| Oxadiazon 2 lt/ha | 30 | 1.1 bc | 69 a | 9.4 bc | 16.9 b |
| No weed control | 0 | 0.3 c | 90 a | 2.6 c | 3.5 c |

*Means in the same column followed by the same letter are not significantly different at P = 0.05, according to Duncan's multiple range test.

**DAA - Days after application.

***Amounts in liters or kilograms of commercial product per hectare.

Information available in this paper and from other workers appears to suggest that the use of high planting densities to increase stake production is uncontroversial, even if as a secondary goal the aim is root production. Plant populations of up to 40 x $10^3$ plants/ha appear reasonable for stake production whereas for an increased, combined stake and root harvest, densities around 20 x $10^3$ plants/ha may be preferable to avoid an overly drastic reduction in root size. No information exists comparing performance of stakes from high density to low density plantings. However, in the light of results discussed in the previous paragraph, the use of somewhat thinner, lower weight stakes coming from high

density planting should not be to the detriment of root production of the subsequent crop.

Reviewing the information on the effect of soil fertility presented here, it is evident that plant nutrition interacts with genotypic characteristics in modifying the plant's growth habit and consequently its stake production ability. To evaluate this modification a stake production index was calculated, indicating which proportion of the above-ground part of the plant may be utilized for propagation and thus allowing to quantify the plant's stake production efficiency. Based on this concept which may be called a "harvest index" for stake production, it was seen that the proportion of stems useful for stake production is in a favorable balance with total top growth when growth is only supported by natural soil fertility or stimulated slightly by low to intermediate fertilization. On the other hand, at high rates of applied nutrients, the efficiency of the plant to provide propagative material diminishes due to more foliage production, a higher proportion of thinner branches and longer internodes, leading to 20 cm stakes with less than the minimum of 5 buds per stake required to ensure plant establishment. Under limited soil fertility conditions, this shift in top growth is promoted by N but probably also by other major or minor elements, according to the prevalent soil nutrient conditions. While present data allow assessment of effect of N on stake production of the crop to which they are applied, the influence of N levels in stakes on the subsequent crop is still largely unknown and remains open to future research.

The influence of pests on the production of planting material in cassava is presently receiving much attention. (Byrne, 1982; Bellotti, in press; Lozano, in press). As related to diseases, insects and mites, this is a vast and complex field due to the twofold risk that pathological and entomological problem pose to a vegetatively propagated crop such as cassava. With regard to weeds, the situation is less complex since there is only a direct influence and no transmission of the problem by stakes occurs. Data presented here show that stake and root production is affected by deficient weed control in almost identical proportions. It is therefore of dual interest to maintain a good control level of this pest when both root and stake production are to be optimized.

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Storage Effects on Planting Material and Subsequent Growth and Root Yield of Cassava (*Manihot esculenta* Crantz)

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## ABSTRACT

Storage of cassava planting material is necessary when harvest and subsequent plantings are separated in time due to drought, flood periods or low temperature.

Stakes lost viability when dehydration reduced moisture content to less than 60%. Storing cassava planting material as 100 cm or longer stems was highly effective to avoid dehydration and maintain viability for several months. Besides moisture, stakes lost carbohydrate reserves during storage, mainly in the form of total and reducing sugars. Mineral element concentration varied during storage, however, a relative increase of N, P and K concentrations in stake tissue was noticed, possibly as a result of total dry matter loss.

Stakes with good nutritional status showed better sprouting and crop establishment than those from a poorly nourished crop. Sprouting and establishment could also be aided by rehydration and bioactivator treatments, resulting in equal or even superior yields with stored than with fresh planting material.

## Introduction

In cassava production, problem of stake storage arise when harvest and subsequent plantings are separated by time often as long as several months. Drought, low temperature or floods are most frequently responsible. Use of fresh stakes is normally preferable to stored planting material (Correa, 1970, 1977a, b; Lozano et al, 1977; Narintaraporn, K. et al, 1978; Silva, 1970), however, with harvest and planting separated in time, a portion of the crop would have to be set aside for later cutting of stakes. This may lead to an undesirable carry over of pest problems and cause difficulties to small farmers both economically and when land availability is limited. Stake storage may therefore be inevitable in certain situations.

In view of scarce information on improved stake conservation methods, a variety of aspects of stake storage was investigated to obtain a better understanding of the transformation and deterioration processes which the planting material suffers during storage. Also, an attempt was made to design practices to improve stake quality before and after storage.

## Materials and Methods

Characteristics of the Experimental Sites. Trials were at CIAT Palmira and Quilichao stations in the Cauca Valley of Colombia, South America, as well as at Caribia, on the Colombian north coast. CIAT-Palmira is at 1,000 m.a.s.l. and has annual precipitation of 1,025 mm in biemodal distribution, 23.7 C annual mean temperature and 72% mean annual relative humidity. The soil is a vertic calcustoll (mollisol) with a silty clay texture, pH 6.0, organic matter 4,1% and a generally high base status and fertility. CIAT-Quilichao, at 1,035 m.a.s.l., has annual precipitation of 1,590 mm, a mean annual temperature of 23.6 C and a mean annual relative humidity of 69.1%. The soil is a typic dystropept (inceptisol) with a clayey texture, pH 4.1, organic matter 6.3% and low P and base status but high aluminum and manganese saturation. Caribia is at 30 m.a.s.l. and has 1,393 mm total annual rainfall, an annual mean temperature of 27.2 C, and 84% mean annual relative humidity. The soil is an unclassified entisol with a sandy loam texture, pH 6.0, organic matter 1.6%, high available P but intermediate to low base status.

Experiment 1: Moisture content and viability of stakes.

Long (120 cm) and short (20 cm) stakes were cut from cassava variety M Mex 11 grown at CIAT-Palmira. Both materials were treated with BCM and Captan at 3,000 ppm each to prevent fungal infestation and then exposed to dehydration in the open during the day, being transferred to a dry room during the night and during rainy periods.

At weekly intervals, material from both long and short stakes was dried at 70 C in a forced draft oven to determine moisture content. Simultaneously, 20 cm stakes of the two groups were planted in the field and their viability assessed. A stake that had not sprouted 2 weeks after planting as counted as not sprouted.

Experiment 2: Changes in mineral element and carbohydrate concentration of stakes during a 6-month storage period.

During 6 month of storage, samples of three entire stems of cultivar M Ven 218 grown at Palmira under high fertility and at Quilichao under low fertility with and without P fertilizer were taken at monthly intervals. Ten cm from each end of a stem was discarded. The remaining 100 cm stem was cut into pieces, weighed, dried and weighed again for moisture determination. Samples were then ground and analyzed for N, P, K, total and reducing sugars, and starch. Mineral element, carbohydrate and cyanide analyses were by CIAT laboratory standard procedures. A description of methodologies is available from CIAT on request.

Experiment 3: Influence of stake nutritional status on sprouting, growth and yield.

After 6 month storage, stakes stored at CIAT-Palmira and CIAT-Quilichao as described for Experiment 2, were taken to a field site near CIAT-Palmira Station and cut into 20 cm planting pieces. A visual classification into good, intermediate and poor quality stakes according to degree of dehydration (fingernail probe for latex emanation), premature sprouting and microbial deterioration was done prior to planting. Stakes were planted vertically in a 1x1 m arrangement on ridges together with fresh stakes of the same variety (M Ven 218) produced at CIAT.

A fertilization of 50, 44, 83, 10 and 1 kg/ha of N, P, K, Zn and B was given at planting and an additional 50 kg N/ha were applied 60 days after planting. Sprouting was monitored during the first month after planting, and plant height, total dry matter and leaf area were determined at intervals of 2, 5, 9 and 11 months after planting. At the 9 and 11 months harvests, root numbers, root sizes and total root weight was also recorded.

Experiment 4: The effect of rehydration and bioactivators on sprouting, growth and yield of cassava grown from stored planting material.

Planting material of variety CMC 40 produced at CIAT-Palmira under non-fertilized conditions was harvested at 12 months age and stored under shady field conditions for 201 days. The approximately 100 cm long stems received a treatment of BCM and Captan (3,000 ppm each) prior to storage. At the end of storage, stored stems were cut into 20 cm long stakes and divided into six groups, each of which received a different pre-planting treatment: Stakes of group 1, 2 and 3 were water-soaked for 0, 60 and 240 min and then treated for 15 min in a fungicide-insecticide solution whereas stakes of group 4, 5 and 6 were soaked in a 1% biactivator solution for 0, 60, and 240 min and then treated for 15 min in a fungicide-insecticide-bioactivator solution.

Fresh stakes of the same variety were also cut and treated for 15 min in either a pesticide solution only or in a pesticide-bioactivator solution.

All stakes were planted at CIAT-Palmira on ridges in a 1x1 m arrangement and a fertilization of 50, 22, 83 and 10 kg/ha of N, P, K and Zn was given with planting. The sprouting process as well as root and top yield at harvest were recorded.

## Results

Stake dehydration. Under sun exposure and without possibility of absorbing moisture from soil or from rain or dew, moisture percentage in the 20 cm stake material declined rapidly from fresh stake value of 72.5% to 15.2% at 70 days after starting exposure. On the other hand, long stakes lost moisture at a much slower rate, moisture percentage never falling below 58% during observation period (Table 1). Viability of planting material stored as 20 cm stakes was seriously affected by dehydration. When moisture fell below 60%, sprouting percentage started to decline sharply and approached zero when 50% moisture was reached, after less than one month of exposure. This finding is in agreement with Wholey (1977) who showed that stakes of variety M Col 1438 lost their viability when moisture content of otherwise healthy stakes approached 50% as a result of dehydration during storage. In contrast, stakes stored as long stems, maintained complete viability over 2 months and a decline in sprouting percentage became noticeable after 70 days of storage. This observation is again in accordance with Wholey (1977) who found long sections of stakes to loose fresh weight and viability slower than short sections.

Changes in element and carbohydrate status. Mineral analysis of stakes showed clear differences in nutritional status according to site and condition of production. In general, stakes produced at CIAT-Palmira had the highest concentrations of all major elements, the advantage being particularly large with respect to N and P. During the 6 months of storage, the concentrations of N, P and K showed a clear tendency of increase.

Table 1. Moisture content and viability of long and short cassava stakes of variety M Mex 11 affected by storage.

| Days of Storage | 20 cm Stake | | 120 cm Stake | |
|---|---|---|---|---|
| | Moisture % | Sprouting % | Moisture % | Sprouting % |
| 1 | 72.5 | 100 | 72.5 | 100 |
| 8 | 62.3 | 85 | 68.4 | 100 |
| 15 | 59.7 | 30 | 67.8 | 95 |
| 22 | 51.8 | 25 | 65.6 | 95 |
| 29 | 48.6 | 5 | 66.7 | 95 |
| 36 | 47.3 | 10 | 63.6 | 95 |
| 43 | 27.0 | 5 | 61.5 | 95 |
| 50 | 25.2 | 0 | 59.0 | 95 |
| 57 | 20.4 | 0 | 58.0 | 100 |
| 70 | 15.2 | 0 | 58.3 | 80 |

Carbohydrates showed a marked reduction during storage at both sites, losses being mostly in the form of soluble carbohydrates (total and reducing sugars). These losses were greatest during the first 60 days of storage and rather small thereafter. Starch percentage showed a strong fluctuation with no specific trend being recognized.

Influence of stake nutritional condition. The visual evaluation of stake quality revealed a clear influence of stake nutritional status on preservation characteristics. Planting material produced at the poor soil site Quilichao showed a low portion of good and intermediate quality stakes and a large quantity of poor stakes. This was even observed when P, the nutrient which is most limiting at Quilichao, had been applied to the plants, no big differences being observed between the 0 and 132 kg/ha P level. On the other hand, the portion of stakes rated "good" was much higher and the portion rated "poor" was lower in the Palmira produced material. Fresh stakes from Palmira had the highest portion of good stakes. Final sprouting percentage taken 2 months after planting confirmed results of visual quality rating, but numerical differences between treatments were small, the Quilichao OP material showing 20.6%, the Quilichao 132 P stakes 20.8% and the Palmira stakes 27.1% sprouting. Fresh stakes reached 100% sprouting on day 21 after planting whereas stored stakes reached their final percentages only after 30 days or later.

Early crop growth as measured by plant height, total plant dry weight and leaf area 2 months after planting was also affected by stake nutritional status. Stored stakes from the fertile site Palmira performed relatively better than from the infertile, non-fertilized Quilichao site. Stakes from Quilichao produced with high P fertilization showed an intermediate position. Differences in early development were numerically visible but could not be secured statistically. On the other hand, data from the 9 months harvest indicated that stakes which started to grow better initially also performed significantly better at harvest. Observation of harvest index, total plant dry weight, total root dry weight and commercial root number per plant showed that, in general, stake material produced under the best nutritional conditions (Palmira) also produced the heaviest plants with the greatest root numbers and root weights. However, ranking from best (Palmira) to

worst (Quilichao 0 P) was not always strictly preserved (Table 2). Harvest data at 11 months after planting did not show further increases in important yield parameters, therefore, only 9 months-data are reported.

Table 2. Effect of stake nutritional status on harvest index, total plant dry weight, total root dry weight and commercial root number per plant, nine months after planting. CIAT-Palmira-Amaime 1981-1982.

| Stake origin and characteristics | Nutritional status | Harvest index (%) | Total dry weight per plant (kg) | Root dry weight per plant (kg) | No. commercial roots per plant |
|---|---|---|---|---|---|
| Stakes grown and stored in Palmira | Good | 61 b[1] | 4.6 a | 2.5 a | 9.1 a |
| Stakes produced with 132 kg P/ha grown and stored in Quilichao | Intermediate | 67 a | 2.9 b | 2.0 ab | 8.2 ab |
| Stakes produced without P fertilizer, grown and stored in Quilichao | Poor | 54 c | 3.3 ab | 1.8 ab | 6.7 b |

[1]Means in the same column followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.

Improvement of stake quality. Rehydration in either water or bioactivator solution was successful in increasing mean stake weight (20 cm length) from 41 g to 44 g after a 240 min soaking period. Rehydration prior to planting also clearly influenced rate of sprouting, the longer the stakes were submerged the faster was sprouting, reaching approximately the rate of fresh stakes with 240 min soaking. Final sprouting percentage was near 100% in all treatments. However, rehydration in water or bioactivator solution did not result in different sprouting patterns.

Vegetative growth expressed as plant height 2 months after planting still reflected differences that treatments imposed during sprouting and crop establishment. Plants from fresh stakes and those from stored stakes subjected to long soaking periods grew more vigorously and taller than those from stored stakes with no or short rehydration periods (Table 3). Although differences in plant height disappeared later during the season (plant height 150 DAP), they persisted in terms of total top weight until harvest.

Plants from fresh stakes treated with bioactivator solution showed the greatest top weights whereas plants from stored stakes without bioactivator treatment produced the least. Overly heavy foliage and branches combined with a relatively small number and consequently weight of commercial roots per plant resulted in a low harvest index, particularly where plants were grown from fresh stakes treated with the bioactivator. On the other hand, a more moderate growth of tops together

with a large number of commercial size roots per plants gave a high harvest index in those treatments where stored stakes had been rehydrated in bioactivator solution.

Table 3. Influence of rehydration and bioactivator solution treatments of stored stakes on subsequent vegetative and root growth of cassava cv, CMC 40. CIAT. 1980.

| Treatments | Plant height (cm) 60 DAP[1] | Plant height (cm) 150 DAP | Weight of tops at harvest (t/ha) | Commercial roots number/plant | Harvest index % |
|---|---|---|---|---|---|
| Stored stakes | | | | | |
| 0 min water soaking + 15 min pesticides in water | 48.8 d[2] | 195.7 a | 44.1 abc | 7.0 abcd | 48.5 a |
| 60 min water soaking + 15 min pesticides in water | 52.0 bc | 210.7 a | 39.4 c | 6.6 cd | 49.0 a |
| 240 min water soaking + 15 min pesticides in water | 48.8 c | 206.0 a | 40.4 bc | 6.8 bcd | 49.2 a |
| 0 min bioactivator soaking + 15 min pesticides + nutrients | 47.7 cd | 202.7 a | 45.2 abc | 6.8 bcd | 47.4 a |
| 60 min bioactivator soaking + 15 min pesticides + nutrients | 47.2 cd | 204.7 a | 47.0 ab | 7.5 abc | 48.1 a |
| 240 min bioactivator soaking + 15 min pesticides + nutrients | 53.5 bc | 210.5 a | 45.5 abc | 7.9 a | 49.7 a |
| Fresh stakes | | | | | |
| Pesticides in water 15 min | 63.5 a | 214.3 a | 49.7 a | 7.6 ab | 45.1 ab |
| Pesticides + bioactivator 15 min | 57.7 ab | 211.8 a | 50.2 a | 6.5 d | 41.5 b |

[1]DAP = Days after planting.

[2]Means in the same column followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.

Total fresh root production of 40.6 t/ha obtained from fresh stakes without bioactivator treatment was similar to the whole trial average of 41.2 t/ha, and no yield from a stored stake planting was significantly inferior to that of the check. On the contrary, there was a tendency of yield to improve over the non-bioactivator-treated check when stored stakes were soaked in bioactivator solution for longer periods of time (Figure 1). On the other hand, the surprisingly low yield of the fresh stake with bioactivator treatment was significantly inferior to most other treatments. Plants of this treatment grew vigorously from early on, forming a dark green, healthy looking canopy. Leafliness throughout the growing season probably resulted in a greater than optimum leaf area for maximum root growth, so that high leaf and branch but low root yield was obtained.

## Discussion

One important process that occurs in cassava planting material during storage is loss of moisture which has a strong influence on stake viability while probably also affecting biochemical transformations within the stakes. Moisture, once lost from a stake, is reabsorbed only in small quantities when dehydrated stakes are submerged in water and rehydration only improves sprouting, growth and eventually yield when the moisture content had not fallen below a critical level. There was a surprising consistency of data obtained in the present studies with those reported by at least one other worker, indicating that the threshold moisture content of stakes was around 50%; below that level, viability suffered seriously. With regard to practical aspects of stake storage, these findings emphasize the importance of creating storage conditions that avoid dehydration since the viability of planting material is irreversibly affected when this process is allowed to advance beyond established limits.

A second, important transformation occurs in stored stakes as a result of continued respiration. As any other living plant tissue, stored stakes continue to respire and thus lose carbohydrates during storage. Rate of loss is particularly high at the beginning of storage and slows down later, the cause for this probably being reduced moisture status of the stakes after longer storage periods. It is probably within this context that increases in major element concentrations may be interpreted, the loss of carbohydrate, detected in the present studies as a reduction mainly of total and reducing sugar concentration resulting in relatively higher concentrations as dry matter losses continued.

With regard to carbohydrate loss, these data show the practical importance of selecting storage conditions that keep respiration at a low level since respiration losses reduce reserves available to stakes after planting and thus diminish sprouting vigor and establishment. In particular, cool storage conditions (but not cold room temperatures) appear desirable.

Furthermore, nutritional status of stakes which was shown to vary according to natural soil fertility levels in different locations and also as a result of fertilizer applications, proved to have an influence both on keeping properties of stakes and on subsequent sprouting, growth and yield. Keeping properties were definitely superior when stakes came from well nourished plants, being vegetatively better developed and consequently showing less moisture and carbohydrate depletion as well as pathogenic deterioration than stakes from poorly nourished plants. The effect of stake nutrition on initial crop growth was small but apparently accumulated over the whole growth cycle resulting in significantly better performance at harvest of stakes with a good rather than with a poor nutritional status. For practical purposes, this means that plants whose stakes are to be cut

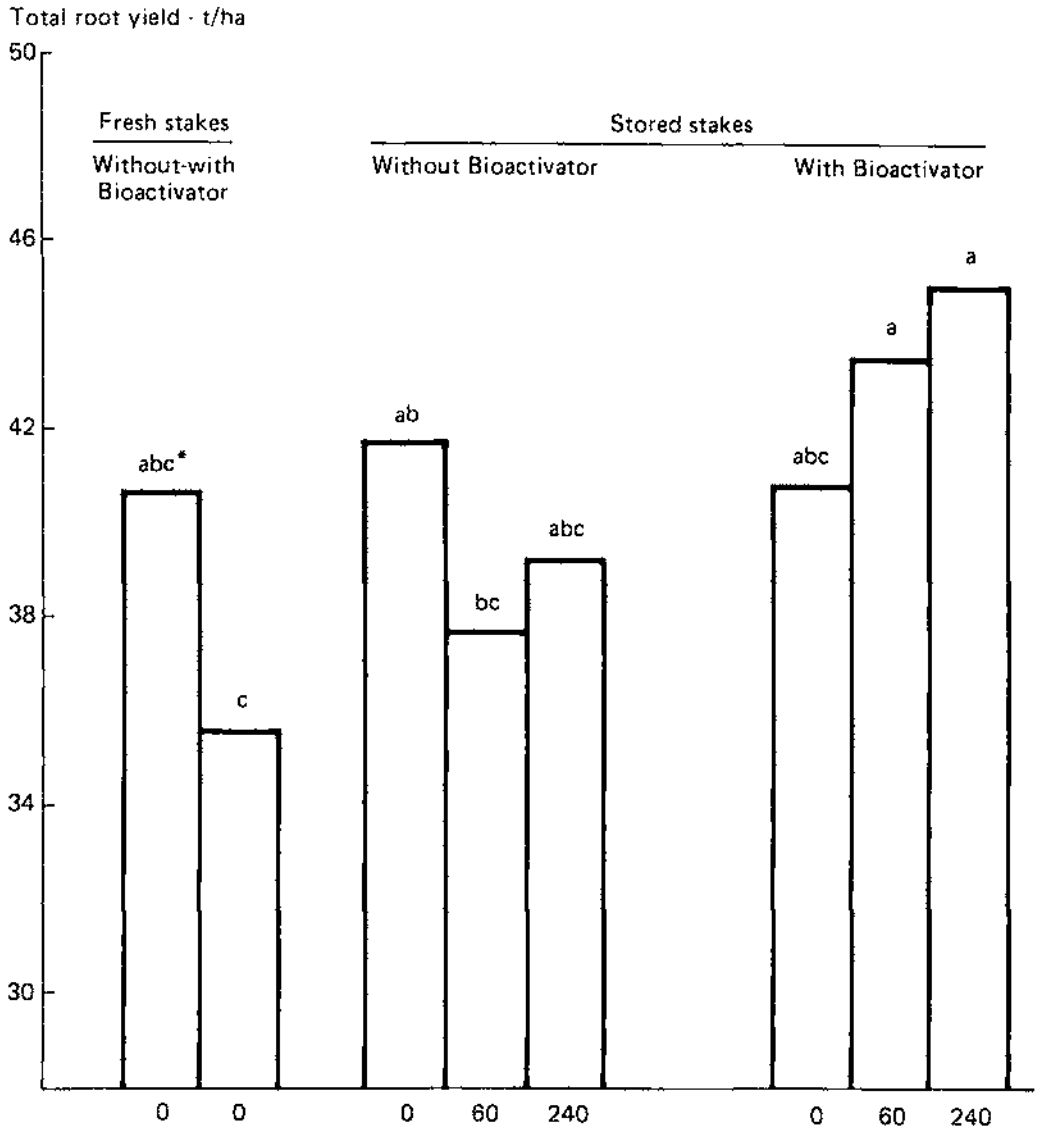


Figure 1. Effect of post-storage treatments on total fresh root yield of cassava cv. CMC 40 grown from stems stored for 201 days. Figures in columns indicate duration of soaking in minutes.

*Columns headed by the same letter represent means not significantly different at P = 0.05, according to Dundan's multiple range test.

and stored away for later use as planting material, should receive a special treatment, either by selecting the most fertile area within a field for stake production or by a more complete and somewhat more abundant fertilization of those areas from where the planting material is to be obtained.

Finally, stakes produced and stored under good conditions can be further upgraded with a combined rehydration-bioactivator treatment which apparently helps to bring them back almost to an "as fresh" condition. The treatment was effective in promoting a favorable balance between top and root growth in plants grown from stored stakes, resulting in high harvest indices and root yields in these plants, the high productivity being particularly surprising in view of the low storage duration of over 6 months. The procedures appear to be time-consuming and to impose high technology requirements but in fact it is simple to carry out and inexpensive (US$25.00/ha), being particularly suited for cassava producers who plant small to medium size areas and consequently need not move overly large quantities of stakes.

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# The Effect of Gibberellic Acid and Gibberellin Inhibitors on Cassava

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## ABSTRACT

The effect of gibberellic acid and gibberellin inhibitors (Alar and RSW-0411) on the physiology of greenhouse grown cassava (*Manihot esculenta* Crantz) was investigated. Foliar application of gibberellic acid and gibberellin inhibitors markedly affected shoot and tuber growth. Gibberellic acid applied to a dwarf cultivar (MSAF2) stimulated shoot growth. This resulted in a decrease in tuber dry mass. Following gibberellic acid treatment, abscisic acid and cytokinin activity in the tuber decreased. Application of gibberellin inhibitors to a tall cultivar (MSAF1) decreased elongation and shoot dry mass. This decreased shoot growth resulted in a significant increase of tuber dry mass.

Tuberization in plants is to a large extent determined by the activities of plant growth regulators. Cytokinins have been considered as being essential for tuber initiation (Tizio and Biain, 1973). This view is supported by the fact that application of kinetin to potato plants induces tuberization (Smith and Palmer, 1970; Mingo-Castel et al., 1976) and by the findings that the endogenous cytokinin activity in potato plants increased when the plants were placed under tuber inducing conditions (Sattelmacher and Marschner, 1978). Kannangara and Booth (1978) also found an increase in cytokinin in the roots of dahlia with tuberization. The level of cytokinin activity did, however, decrease after tuber initiation. Van Staden and Dimalla (1976) found higher activity of cytokinins in "little potatoes" (formed in storage on emerging stolons) than in the mother tubers. It was suggested that the cytokinins act as a storage metabolic sink in this systems.

While considerable attention has been given to the possible role of cytokinins in the tuberization process, less in known about the other hormones. Following tuber initiation the activity of abscisic acid in potato stolons and tubers increased (Krauss, 1978). In experiments where ABA was applied to the leaves, tuber growth was promoted (Abdullah and Ahmed, 1980). These results suggest that increased ABA levels enhances some aspects of the tuberization process.

There are reports that gibberellins influence tuberization by influencing shoot growth (Menzel, 1980; Kuman et al., 1981). Applying gibberellic acid to the tops stimulates leaf and stem growth, while indirectly reducing tuber growth. This suggests that high levels of gibberellins in leaves promote the use of newly formed carbohydrates for shoot expansion. This process can be reversed by gibberellin inhibitors. Cassava yield increases have been reported with CCC (Das Gupta, 1976) and ALAR (Muthukrishnan, 1976).

In this investigation the effect of two gibberellin inhibitors on the growth of a tall cultivar and the effect of gibberellic acid on a dwarf cultivar of cassava was studied. The effect of GA, on the endogenous cytokinin and abscisic acid levels was also recorded.

## Materials and Methods

The experiments used local cassava (*Manihot esculenta* Crantz) cultivars MSAF1 (tall) and MSAF2 (dwarf). Stakes of 40 g were planted in 12 kg loamy topsoil. A complete nutrient solution was given every 2 weeks. After 3.5 months the nutrient solution was withheld from MSAF2 to limit shoot growth.

Gibberellic acid (500 ppm to saturation) was applied to MSAF2, 5 months after planting. Gibberellin inhibitors RSW-0411 (500 ppm to saturation) and Alar (2000 ppm to saturation) were applied to MSAF1, 3 months after planting. RSW-0411 was supplied by Bayer S.A. This regulator belongs to the azole group of chemicals and is at the last stages of development.

Shoot length, leaf area, number of leaves, fresh and dry mass of MSAF1 and MSAF2 were measured at harvest which occurred 86 days and 45 days after treatment, respectively. To determine their chlorophyll content, sections of young leaves were extracted in 100% methanol for 24 h and the absorbance measured at 435 um and 665 um.

### Abscisic acid extraction and bioassay

Samples of fresh tubers were extracted in 80% methanol for 24 h at 5°C, dried down, purified with PVP followed by solvent extraction with ethyl acetate at pH 3.5. The water fraction was hydrolysed at pH 11 and solvent extracted at pH 3.5. All ethyl acetate fractions were pooled and after drying down separated on TLC plates using toluene: ethyl acetate: acetic acid (40:15:2 v/v). The chromatograms were divided into eight equal Rf strips and the inhibitor activity determined using the wheat embryo test (Eeuwens and Schwabe, 1975).

### Cytokinin extraction and bioassay

Samples of fresh tubers were extracted in 80% ethanol for 24 h at 5°C, purified on a Dowex 50W-X8 column, separated on paper using iso-propanol: 25% ammonium hydroxide:water (10:1:1 v/v). The Rf zone 0.2 - 0.9 was eluted and separated on an LH-20 Sephadex column using 10% methanol as solvent. The fractions were assayed for cytokinin activity using the soybean callus bioassay (Miller, 1965).

## Results and Discussion

### The effect of treatments on growth and tuberization

Application of gibberellin inhibitors to MSAF1 caused a marked change in dry matter distribution (Table 1). The total dry mass was not affected by the treatments, but shoot mass was 35% and 16% lower than in the control for RSW-0411 and Alar, respectively. The carbohydrates were apparently diverted to the tubers. Shoot:root ratio decreased significantly. Although the leaf area was reduced by RSW-0411 application, the mass/cm$^2$ of the young leaves was significantly higher. Differences in chlorophyll absorbance were found, but were not significant.

RSW-0411 inhibited shoot elongation more than Alar (Figure 1). The rate of leaf appearance (Figure 2) was not affected by either of the inhibitors. Both regulators have a long residual effect.

Table 1. Dry mass, mass per $cm^2$, and chlorophyll content of leaves of cassava cultivar MSAF1 as affected by gibberellin inhibitors.

| | Control | RSW-0411 | Alar | LSD (0,05) |
|---|---|---|---|---|
| Dry shoot mass (g) | 44.2 | 28.7 | 37.0 | 9.1 |
| Dry mass tubers (g) | 25.4 | 50.7 | 31.5 | 10.8 |
| Shoot/root ration | 1.77 | 0.57 | 1.44 | 0.81 |
| Dry mass increase shoots after application (g) | 19.8 | 8.0 | 13.8 | 6.2 |
| Total leaf area ($cm^2$) | 2,932 | 2,434 | 2,889 | 6.8 |
| Leaf mass mg/$cm^2$ young leaves | 12.8 | 15.9 | 13.6 | 1.8 |
| % chlorophyll absorbance towards control at | | | | |
| 435 nm | - | + 7.0% | + 7.7% | n.s. |
| 665 nm | - | +14.7% | + 6.7% | n.s. |

Shoots of MSAF2 plants had stopped growing after 5 months due to withholding of the nutrient solution. After application of gibberellic acid there was a rapid elongation of the shoots (Table 2). Tubers which apparently acted as sinks before the hormone application now became a source making carbohydrate available for the rapidly growing shoots. The shoot:root ratio changed significantly.

Table 2. Dry mass, cytokinin, and inhibitor levels of cassava cultivar MSAF2 as affected by gibberellic acid application.

| | Treated | Untreated |
|---|---|---|
| Dry mass shoot (g) | 42.2 | 32.3 n.s. |
| Dry mass tuber (g) | 48.6 | 57.6** |
| Zeatin ng/g | 3.5 | 33.7 |
| Ribosylzeatin ng/g | 6.9 | 273.7 |
| Abscisic acid ng/g | 1.5 | 15.8 |

## The effect of gibberellic acid treatment on endogenous hormone levels

Gibberellic acid application to the shoot caused a decrease of both the inhibiter activity (Figure 3) and the cytokinin level (Figure 4). The inhibiter activity is found in the Rf zone that co-chromatographed with authentic abscisic acid. The inhibition around Rf 0.5 might be due to other inhibitors of the

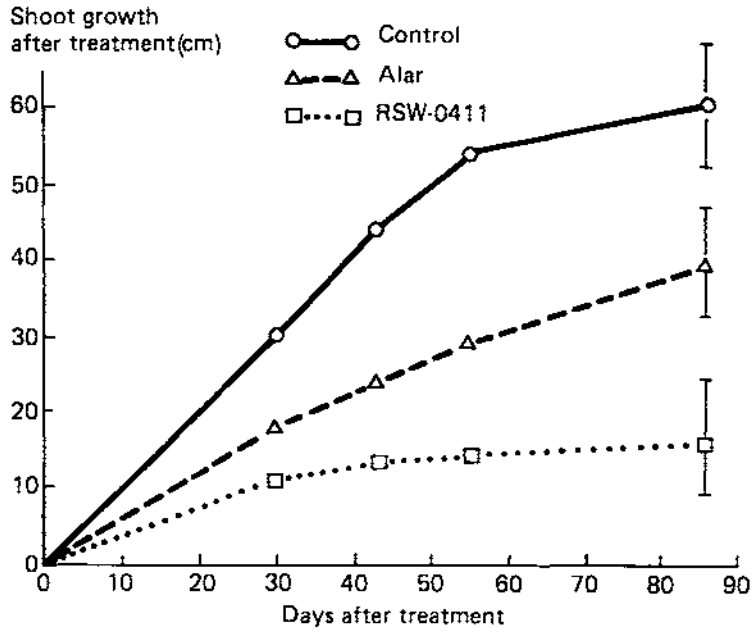


Figure 1. Effect of gibberellin inhibitors on shoot growth of cassava cultivar MSAF1.

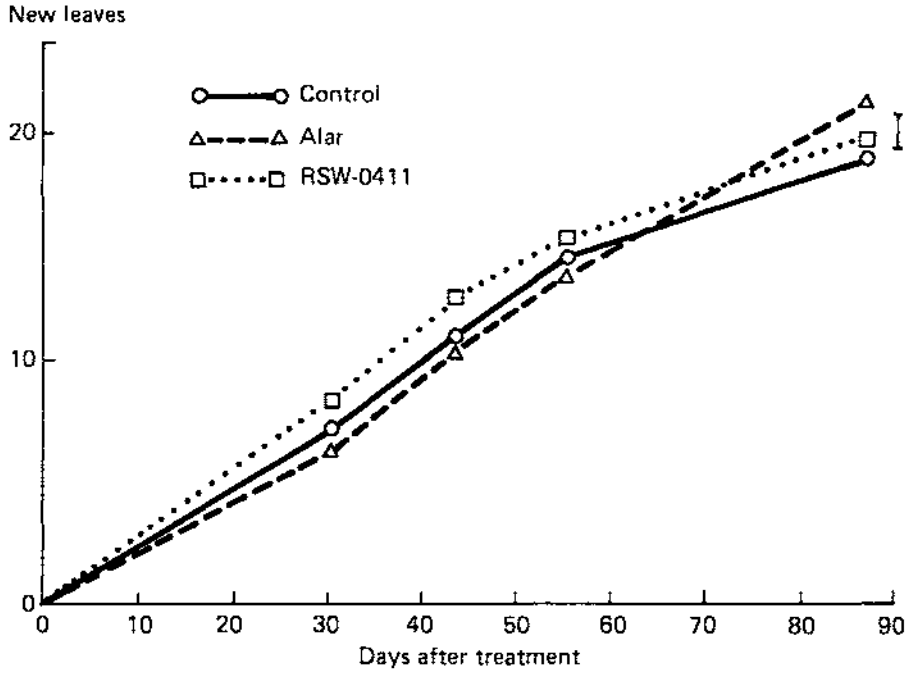


Figure 2. Effect of gibberellin inhibitors on the rate of leaf appearance of cassava cultivar MSAF1.

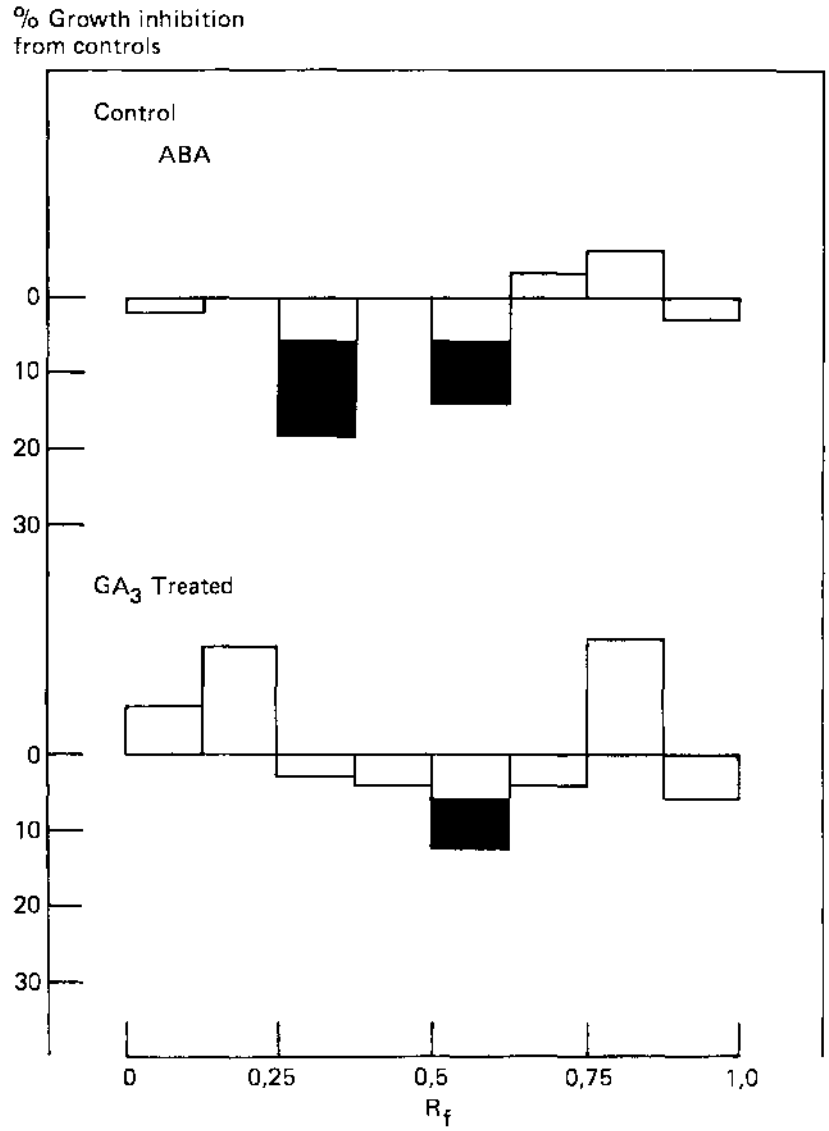


Figure 3. Wheat embryo bioassay for inhibitors extracted from 20 g fresh tubers of gibberellic acid treated and untreated plants. The shaded areas represent regions significantly different from the controls at the 1% level. ABA = abscisic acid.

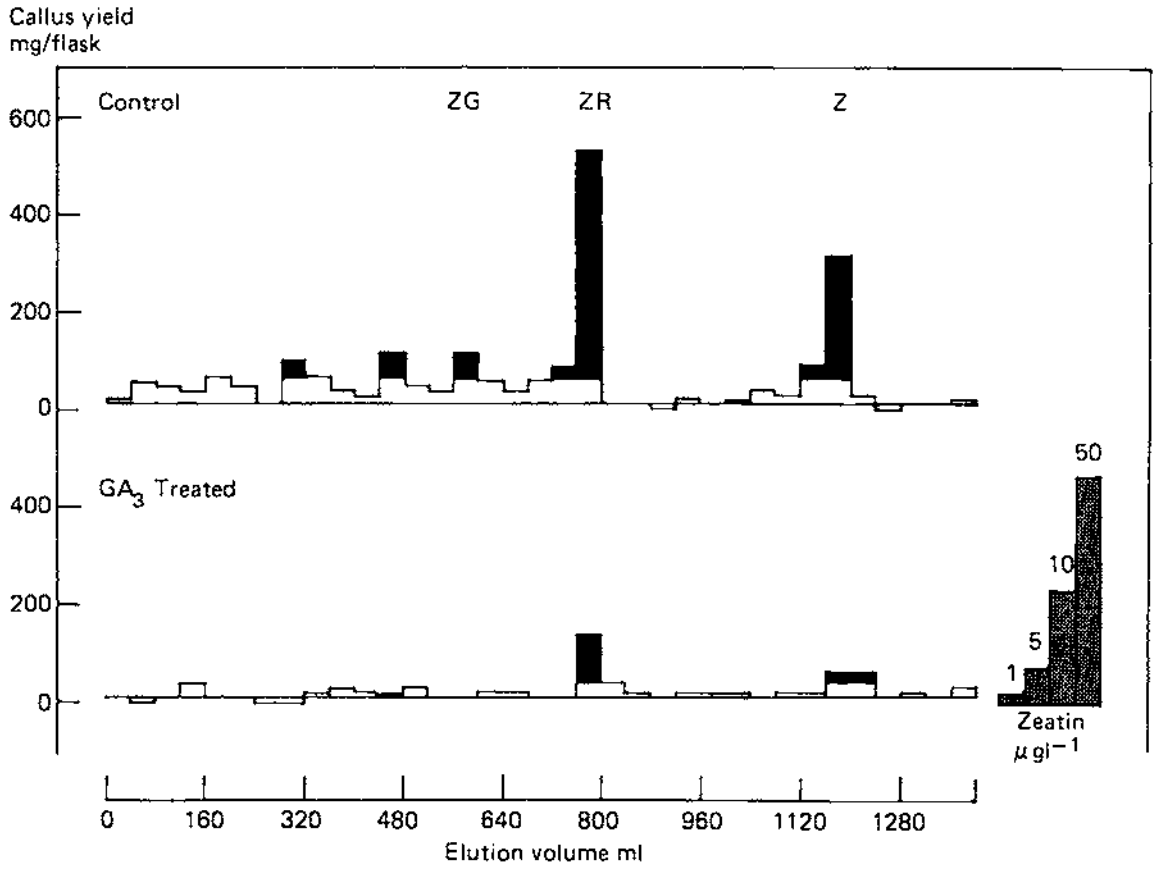


Figure 4. Soybean callus bioassay of extracts from 16 g cassava tubers which were obtained from gibberellic acid treated and untreated plants. After purification the extract was fractionated on a Sephadex LH-20 column eluted with 10% methanol. The shaded areas represent regions significantly different from the mean at the 5% levels. Z = zeatin, ZR = ribosylzeatin, ZG = glucozylzeatin.

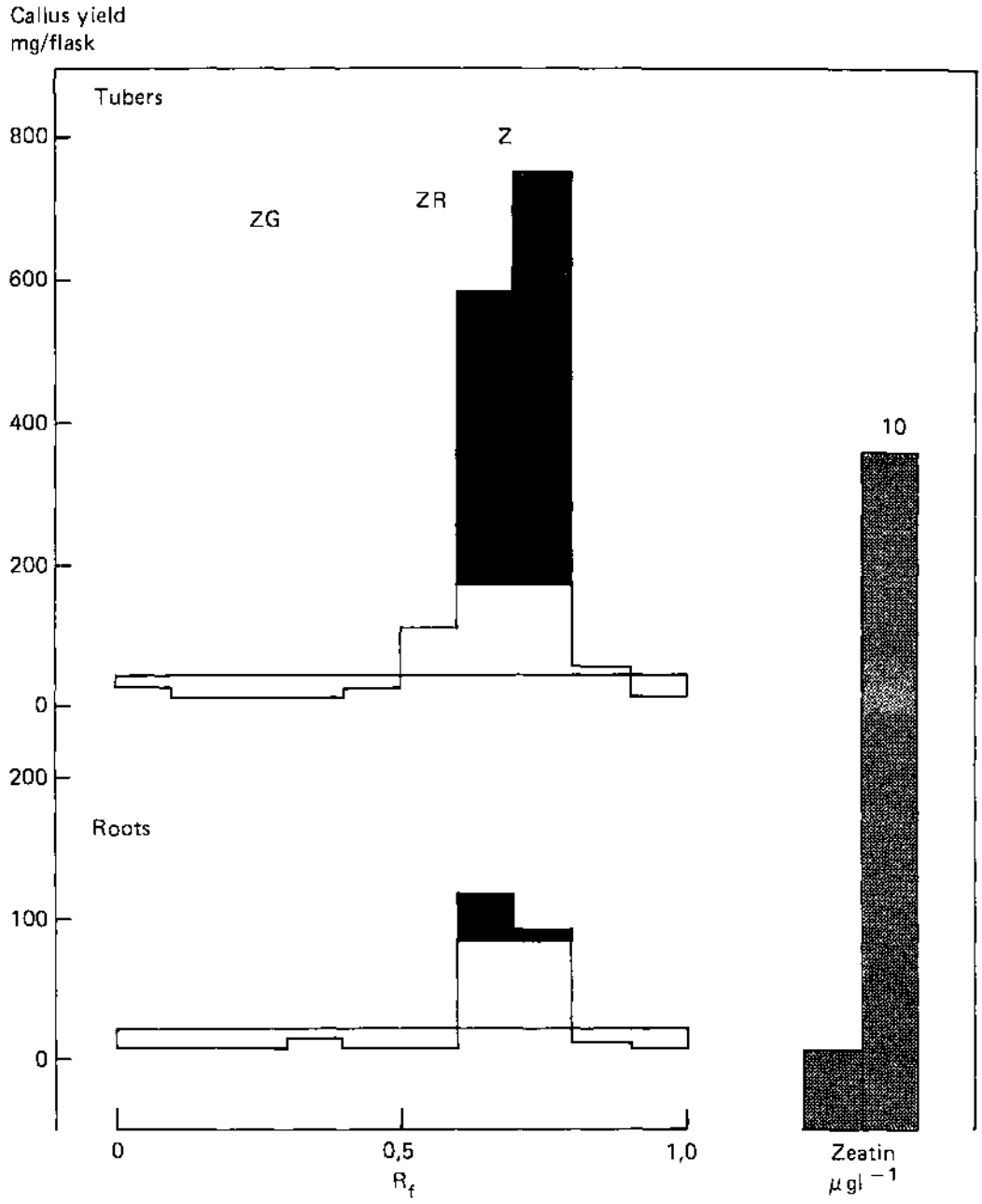


Figure 5. Soybean callus bioassay of extracts from 16 g fresh cassava tubers and roots. Chromatograms were developed in iso-propanol: 25% ammonium hydroxide:water (10:1:1:v/v). The shaded areas represent regions significantly different from the mean at the 5% levels. Z = zeatin, ZR = ribosylzeatin, ZG = glucosylzeatin.

β-inhibitor complex. High activity of both zeatin and ribosylzeatin and some activity of glucosylzeatin were found in expanding tubers.

High activity of inhibitors and cytokinins appears to be associated with sink activity. It is known that cytokinins are involved in cell division. In rapidly growing tubers many cell divisions take place. A comparison of cytokinin activity in roots and tubers of cassava shows much higher activity in the tubers (Figure 5).

Gibberellic acid and gibberellin inhibitors have a drastic influence on the physiology of cassava. Application of these regulators alters the dry matter distribution between the shoot and the tubers. In practice the gibberellin inhibitors can be used to limit excessive leaf growth and increase the tuber yield.

Plant hormones appear to play a key role in the source-sink relations in the plant. Gibberellic acid favors the sink activity of the shoots, while cytokinins and abscisic acid have been found to be associated with sink activity in the tubers.

Acknowledgements

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Cassava Productivity in Intercropping Systems

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ABSTRACT

Performance of cassava in various associations with maize, cowpea, yam and upland rice was evaluated in two ecological zones of Nigeria to determine suitable food crops(s) for intercropping with cassava. Fresh root tuber yields of sole cassava were significantly higher than the yields under the various mixtures. Cassava/cowpea and cassava/maize gave the lowest cassava yield reduction of 11% and 15% respectively. Cassava intercropped with maize, however, gave the highest energy yield which was significantly higher than the returns from cassava/maize/cowpea/rice polyculture. The highest LER was observed with cassava/maize intercrop. Planting cassava in double rows between two rows of maize, cowpea or yam significantly improved cassava productivity over cassava monocrop. Choice of adequate planting time and plant densities could further improve efficiency of the double-row system.

Cassava, *Manihot esculenta* Crantz, is traditionally grown in association with other food crops in Nigeria. The short-term food crops--yams *Dioscorea* spp., maize *Zea mays* L., cowpea *Vigna sinensis* and vegetables--are usually harvested earlier, leaving cassava and weeds as "cassava/grass fallow" for more than 6 months before piecemeal harvesting of the crop begins.

Thus, cassava is almost always subjected to severe competition with other food crops and grass and a better exploitation of the hybrid vigour of recommended improved varieties is not always realized. Cassava yield under this system is known to be relatively low. Although increasingly mono-cropped, a majority of farmers grow crop mixtures involving cassava and over 95% of the total output of cassava root tubers in Nigeria is by this system. The reason is that it is more profitable to intercrop (Ezumah and Okigbo, 1980). Risk of crop failure from pests, diseases, and inclement weather is considerably reduced by the practice.

Research should therefore focus more on improving the productivity of the system. The potential is large for increasing yields of component crops of the various mixtures in relation to their yields when planted alone. Improvements have been achieved by the right choice of planting time and adequate spacing (Ezumah and Okigbo, 1980). Generally, intercropping produces maximum benefits when interplant competition is minimized (Trenbath, 1976; Burgos, 1980). This paper reports work to determine best crop species to go with cassava and the optimum spatial arrangement for cassava-based polyculture in the savannah and rainforest zones of Nigeria.

## Materials and Methods

Used were the following crop combinations: cassava/maize, cassava/rice (upland), cassava/maize/cowpea, cassava/cowpea, cassava/maize/cowpea/rice and sole crops of cassava, maize, cowpea, and rice. They were tested in 1980/81 at Umudike in the rainforest zone (7°33'N, 5°29'E) and at Otobi (7°39'N, 8°32'E), in the savannah belt of Nigeria. Cassava was planted at 1x1 m spacing, maize, cowpea, and rice at 0.3x1 m spacings. Upland rice variety OS6 was seeded at 10 seeds per hole. Cassava (variety TMS30211), maize (Farz24) and cowpea (Ife Brown) were used.

Maize, cowpea and rice were planted on top of the ridge between two cassava stands in the two-crop combination treatments. In three to four crop mixture treatments the crops were staggered on the space between two cassava stands at uniform spacing of 0.3 m. The Umudike and Otobi experiments were established in April and July 1980, respectively.

Another experiment to determine the best spatial pattern for the crops was set up at Umudike in April 1981. The treatments were: cassava and yam, with cassava in double row and yam in single row; cassava in double row and cowpea; cassava interplanted with maize, and sole crop of cassava as control. Two types of seedbed-ridge and flat were the main treatments which were split for the various crop associations. Cassava was spaced at 0.6x1 m and yam at 1x1 m. A density of 33,000 was maintained for cowpea and maize. Fresh tuber yields of cassava and yams were taken at harvest. Grain yields were recorded at 14% moisture. Energy yields were computed using the method of Onyenuga (1968). Land equivalent ratio (LER) was computed using the formula:

$$LER = \frac{\overset{m}{\underset{i=1}{}} y_i}{y_{11}}$$

where $y_i$ = yield of crop in a mixture

$y_{11}$ = yield of the sole crop

(IRRI, 1974, 1975)

## Results and Discussion

The effect of various crop mixtures was invariably a lowering of cassava yields relative to its yield as sole crop. Effects varied with crop mixtures and ecological conditions (Table 1). The main reason for the low yields observed at Otobi was a high incidence of the cassava mealybug, Phenacoccus manihoti Mat-Fer, and green spider mite, Mononychellus tanajoa Bondar, complex. The pests were on the plant longer because of the long dry season prevailing in the zone (October - May). Consequently, cassava yields were unusually low for the zone.

The Umudike results appear to represent the normal performance of the crop. Cassava performed better with cowpea or maize than with upland rice in two-crop combination system. Yield reduction in cassava increased with increase in the number of component crops in the mixture with four-crop combination giving the lowest yield of cassava root tubers. The fourth crop--upland rice (OS6)--had good vegetative growth but failed completely to head at the Umudike site.

Table 1. Fresh root tuber yields of cassava in various mixtures with food crops in two ecozones of Nigeria, (t/ha) 1980/81.

| Crop mixtures | Location | | Losses from intercropping | |
|---|---|---|---|---|
| | Otobi | Umudike | Otobi | Umudike |
| | | | % | |
| Cassava (control) | 27.0 | 30.70 | 0 | 0 |
| Cassava/cowpea | 7.90 | 27.30 | 71 | 11 |
| Cassava/maize | 6.30 | 26.20 | 77 | 15 |
| Cassava/cowpea/rice | 10.30 | 24.50 | 62 | 20.20 |
| Cassava/maize/cowpea | 9.5 | 24.00 | 65 | 22.00 |
| Cassava/rice | 9.5 | 22.80 | 65 | 26.00 |
| Cassava/maize/cowpea/rice | 5.8 | 18.8 | 78 | 39 |
| S.E. ± | 0.87 | 2.5 | | |

Energy yields (EY) and land equivalent ratios were computed for a better evaluation of the various crop combinations. Table 2 shows that cassava/maize gave the highest energy yield although the mixture did not yield significantly better than other 2- or 3-crop mixtures. Three-crop component mixtures appeared to be the limit for the highest energy returns. Cassava sole crop was the highest energy yielder compared with sole crops of maize or cowpea.

Cassava and maize intercrop gave a higher LER than cassava and cowpea mixture (Table 3). Both energy yields and LER of the cassava/maize/cowpea combination compared favourably with values for cassava/maize combination and indicate an advantage for intercropping. With LER above unity the crop components apparently made complementary use of growth resources (Ludwig, 1950). In the case of cassava/maize combination the aerial and soil environments might have been better exploited by differential canopy profiles and rooting depths, respectively.

An attempt was made to minimize competition between component crops and exploit border effects in the double-row cropping experiment at Umudike. Data (Table 4) show that two rows of cassava flanked by single rows of either maize, yam or cowpea yielded significantly higher than the sole crop of cassava at normal planting densities of the crops. Maize again appeared as a better companion crop of cassava, encouraging significant cassava yield increases over cowpea or yam-cassava associations. Planting on ridge or flat made no significant difference on the yield of cassava. Cassava appears to benefit from component crop interaction when planted in double-rows than when mixed with other crops in the row. It is evident that cassava monoculture is wasteful of growth resources: the initial runoff and soil loss before the canopy closes, nutrients lost in drainage and runoff; Burgos in 1980 showed that five times as much phosphorus was lost in cassava monoculture as was absorbed by the crop; he also observed larger soil magnesium loss than absorption; aerial environment is usually inefficiently exploited due to mutual shading of leaves.

The double-row system exploits the border effect (de Mattos et al., 1980) minimizes mutual shading and intraplant competition, consequently increasing yield of cassava above the level as a monocrop.

It may be concluded that land productivity is higher under cassava-based polyculture than under cassava monoculture. In cassava-based polyculture, the double-row spatial arrangement improves performance of the cassava crop over its monoculture. Greater improvements are possible with better adjustments in planting time and plant densities.

Table 2. Energy yields of crops grown sole and in various mixtures with cassava in a rainforest zone of Nigeria.

| Crop mixtures | Energy yield ($10^6$ Cal/ha/yr) |
|---|---|
| Cassava/maize | 22.9a* |
| Cassava/rice | 21.8a |
| Cassava/maize/cowpea | 21.7a |
| Cassava | 21.6a |
| Cassava/cowpea | 21.2a |
| Cassava/maize/cowpea/rice | 16.5b |
| Maize | 2.7c |
| Cowpea | 0.4c |
| Rice | 0 |
| S.E. | ± 0.8 |

*Same letters indicate no significance by the Range Test.

Table 3. Yields of component crops and LER of the various crop mixtures at Umudike.

| Crop mixtures | Yields (t/ha) | | | |
|---|---|---|---|---|
| | Cassava | Maize | Cowpea | LER |
| Sole | 30.7 | 1.8 | 0.4 | 1 |
| Cassava/maize | 26.2 | 1.7 | - | 1.8 |
| Cassava/cowpea | 27.3 | - | 0.22 | 1.4 |
| Cassava/maize/cowpea | 18.8 | 1.2 | 0.15 | 1.8 |

Table 4. Fresh root tuber yields of cassava under various crop mixtures and two tillage practices. 1981-1982.

| Crop mixtures | Ridge | Flat | |
|---|---|---|---|
| Control (cassava sole) | 12.6 | 10.0 | ± 0.22 |
| Cassava/maize double row | 16.9 | 14.8 | |
| Cassava/maize interplanted | 15.7 | 12.1 | |
| Cassava/yam double row | 14.6 | 13.7 | |
| Cassava/cowpea double row | 13.7 | 13.5 | |
| Mean | 14.76 | 12.82 | ± 1.42 |
| LSD 5% for comparison within mainplots (ridge, flat) = 0.91 t/ha | | | |

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# Effect of Stem Cut-Back on Yield and Yield Components of Intercropped Cassava

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## ABSTRACT

Maize/cassava intercropping is practiced widely in tropical cropping systems; however, it is still largely restricted to the small-holder farmer. The major constraints to large-scale production include high labor costs and lack of adequate machinery for operations in intercropping systems. Investigations were carried out to determine the feasibility of mechanizing maize/cassava intercropping, using available planting and harvesting machinery not originally designed for this purpose. Cassava was cut back at 3 heights (80, 60, and 40 cm) at maize harvest to simulate the damage to it if the maize was to be harvested mechanically. Cassava was left uncut in the control plot, and the cassava was left in the field for 12 months.

For cassava planted in the first season (April to August), cutting caused a significant decline in tuber yield and number per plant, but did not affect the leaf area index, stem diameter, number of branches, and final plant height. For cassava planted in the second growing season (September to December), there were no significant differences among treatments in all variables studied. The savings in labor costs adequately compensated for the yield decline in the first season. It is feasible to mechanize maize/cassava intercropping, and agricultural engineers should design machinery suitable for this and other mixed cropping systems.

## Introduction

Intercropping is practiced widely in tropical cropping systems. Its advantages over sole cropping have been documented (Webster and Wilson, 1966; Wrigley, 1969; Igbozurike, 1971; Norman, 1974; and Wilson and Lawson, 1980). In West Africa, traditional agriculture shows a great diversity of crop combinations. Norman (1974) in a study of intercropping combinations in Zaria Province of Kaduna State of Nigeria reported seven most frequent crop combinations covering 61% of the area under cropping. Uzozie (1971) identified nine primary crop combinations in the four eastern states of Nigeria. A common feature of these combinations was the presence of a root crop (cassava or yam/cocoyam) and a grain crop (maize). One of the most popular combinations was maize and cassava.

Despite the prevalence and importance of intercropping throughout the developing world, benefits are still restricted to the smallholder or peasant farmers. Only recently have systematic efforts been made to understand and modernize intercropping. The difficulty of introducing a farm mechanization program into a

system dominated by crop mixtures is regarded as a disadvantage of intercropping (Norman, 1974). The growing together of two or more crops which are morphologically and physiologically different calls for different tools and techniques of production. The benefits of intercropping can be extended to large-scale, mechanized production if the constraints to a large-scale, maize/cassava intercropping are overcome. The major constraints include lack of appropriate planting patterns, lack of adequate machinery, scarcity of labor during peak operations and high labor costs.

Mechanization of small farms with animal power has resulted in increased returns by expansion of cultivated area (Renaut, 1974). However, animal draught is inefficient and suitable only for completely-cleared and naturally-light soils (Jurion and Hensy, 1969). The absence of livestock tradition, lack of suitable grazing land, and the tse-tse fly have greatly reduced and restricted the scope for animal power in the humid parts of West Africa (Curfs, 1976).

In Nigeria, labor is expensive and scarce. Wages have tripled within the past 5 years. There is a shortage of labor during peak operations of land preparation, planting, and harvesting. The drudgery of traditional farming is not attractive to the young and educated, who are being lured away from rural areas to the towns. When the labor force starts to decline, all the increase in demand for agricultural products will have to be met by raising the productivity of labor (Abercrombie, 1972). Very little time is available for harvest of maize in maize/cassava intercrop resulting in huge field losses.

Investigations at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, were to determine the feasibility of selectively mechanizing maize/cassava intercropping, using available machinery, and to obtain information that may guide agricultural engineers in designing machinery suitable for this and other mixed cropping systems.

## Materials and Methods

A simulation trial was conducted in 1980 and 1981 at the IITA experimental farm in southwestern Nigeria. The bimodal character of rainfall distribution in the region results in two distinct growing seasons, (April to July, and August to November). Total annual rainfall varies from 1,000 to 1,400 mm. The soil is classified as Oxic Paleustalf (USDA) or Ferric Luvisol (FAO), and is derived from fine-grained biotite, gneiss and schist parent materials.

In 1980, the experiment started in August, and in April of 1981. The land was prepared conventionally (ploughing, harrowing and ridging). Based on soil tests, fertilizer (60 kg N, 60 kg P and 30 kg/ha K) was applied before ridging. Corn (TZPB) was planted with a rolling injection planter set to give 40,000 plants/ha on 1 m ridges. Cassava was planted by hand 1 m apart on the same ridge as maize, giving a population of 10,000 plants/ha. A preemergence application of a mixture of atrazine (2-chloro-4-ethylamino-6-isoprophylamino-s-triazine) and metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl-)-N-(2-methoxy-1-methylethyl) acetamide] at 2.5 kg/ha was used to control weeds. The maize was handpicked at maturity, 4 months after planting. At the same time, cassava was cut back at heights of 80-, 60-, and 40-cm above ground, to simulate the anticipated damage if the maize was harvested mechanically. In the control, cassava was left uncut. The experimental design was randomized complete block with four replications. Growth and recovery rate of cassava was monitored by periodic measurements of

plant height and leaf area. Cassava yield and yield components were determined at 11 months after cutting back.

## Results and Discussion

In the first growing season (April to July) stem diameter, number of branches and plant height were not significantly different among treatments (Table 1). Leaf area index did not show any trend. Cutting significantly reduced tuber yield by reducing the number of tubers per plant. For cassava planted in the second growing season (September to December) there were no significant differences in stem diameter, number of branches, plant height, tuber yield and number of tubers (Table 2).

Cutting the cassava set back growth and bulking, resulting in lower tuber yields of cut stands compared with the control. Tuber yield in cassava is greatly influenced by the rate and duration of bulking (Enyi, 1973; Wholey and Cook, 1974). Production of new leaves and branches in the cut cassava attracted carbohydrates away from the tuber and any deposition sites. The longer duration of bulking in the control resulted in its ability to produce and fill a greater number of roots. It was observed that cut stands rapidly produced young leaves and retained leaves longer than the control stands during the dry spell (December to February). This, however, did not compensate for the foliage lost by cutting.

The ability of cassava to recover rapidly from physical damage, even at 4 months after planting, and its long growing period suggest that maize may be harvested mechanically in a maize/cassava intercrop without doing irreparable damage to the cassava savings in labor costs and time by mechanically harvesting the maize would adequately compensate for any yield reductions in cassava.

Table 1. Effect of cutting height on tuber yield, number of tubers, number of branches, stem diameter, leaf area index and plant height of cassava (1982).

| Cutting height (cm) | Dry tuber yield t/ha | Number of tubers | Number of branches/ plant | Stem diameter (cm) | Leaf area index | Plant height (cm) |
|---|---|---|---|---|---|---|
| 0 | 17.6 | 9.7 | 83.8 | 4.0 | 7.9 | 364 |
| 80 | 14.2 | 7.3 | 60.5 | 4.0 | 8.5 | 344 |
| 60 | 13.1 | 7.2 | 64.0 | 3.8 | 6.7 | 344 |
| 40 | 13.1 | 7.2 | 67.5 | 3.8 | 9.1 | 361 |
| CV(%) | 9.7 | 13.2 | 21.1 | 6.3 | 14.2 | 3 |
| LSD (0.05) | 2.2 | 1.7 | 24.3 | 0.4 | 4.4 | 19 |

Table 2. Effect of cutting height on fresh tuber yield, dry tuber yield, number of tubers, stem diameter, plant height, (1981).

| Cutting height (cm) | Fresh tuber yield t/ha | Dry tuber yield t/ha | Number of tubers/ plant | Stem diameter (cm) | Plant height (cm) |
|---|---|---|---|---|---|
| 0 | 30.5 | 12.2 | 6.3 | 3.0 | 330 |
| 80 | 29.9 | 12.0 | 5.5 | 3.0 | 317 |
| 60 | 27.2 | 11.1 | 5.5 | 2.8 | 310 |
| 40 | 27.2 | 10.9 | 5.5 | 2.7 | 306 |
| CV (%) | 14.9 | 14.7 | 8.4 | 9.8 | 6 |
| LSD (0.05) | 6.8 | 2.7 | 0.8 | 0.5 | 29 |

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Performance in Association of Cultivars of Cassava (*Manihot esculenta* Crantz) and Cowpea (*Vigna unguiculata* Walp.) of Different Growth Habits

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ABSTRACT

Studies related to improvement of crops growing in association with special emphasis on cassava and grain legumes are reviewed. Objective determining effect of growth habit of component species of the cassava cowpea association, with an experiment in randomized blocks on typic distropept with four repetitions and 24 treatments: (for growth habits of cassava and monoculture of cowpeas) x (four growth habits of cowpea and monoculture of cassava). Only in second cowpea cycle was there a significant interaction between cassava and cowpea growth habits. Height of the cassava and the percentage of photosynthetically active light influenced yield of cowpea planted 220 days after cassava planting. However, these interactions were often not the most important determinants of yields of the components. Results are discussed in terms of general and specific compatibility of the growth habit under consideration. Phenotypic characteristics related to such compatibility are postulated.

Associated plantings of different crops species is a predominant agricultural practice in both the paleo- and neotropics (Francis, Flor, and Temple, 1976). While selection of genotypes suitable for this practice has been by local farmers for centuries, only in the past years has it received attention of professional breeders (Willey, 1979; Ruthenberg, 1977). From crop competition studies, Harper (1963) concluded that performance of associated crops cannot be deduced from performance of individual species in monoculture. Willey (1979), stated that the objective of selection for crop mixtures should be simply to find genotypes which maximize complementary reciprocal effects. Unquestionably, a genotype which will eventually be used in association with another species should be evaluated under those conditions at some stage in the selection process.

The association of cowpeas and cassava appears to offer a means of exploiting to the fullest most resources of the humid tropical environment, both species are relatively tolerant to adverse soil conditions and show reasonable disease and insect resistance under these conditions. The combination of a tall long-season crop (cassava) with a shorter, quicker growing crop (cowpea) should be the ideal combination (Sánchez, 1976) for exploiting the light resources of such an environment as well as minimizing interspecific competition.

Objective of this study was to determine if cassava and cowpea cultivars of different growth habits interacted differently when grown in association. It was hoped a combination of cassava and cowpea plant type could be found which maximized resources available.

## Materials and Methods

A randomized complete block experiment with four repetitions was planted September 15, 1981 on the experimental farm of CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) on a soil classified as a Typic Dystropept, mixed, fine isohyperthermic (Aguirre, 1971) at 600 m above sea level with annual precipitation of about 1,600 mm. Treatments consisted of four different cultivars of cassava and cowpeas, each of different growth habit, in all possible combinations as well as in monoculture, for a total of 24 treatments. Cassava cultivars were differentiated on the basis of height to first ramification and leaf area (Table 1). Growth habits of the cowpea cultivars corresponded to types 7, 6, 3, and 2 of the catalogue published by the International Institute of Tropical Agriculture (1974) where they are identified as climbing, prostrate, semierect, and erect, respectively.

Table 1. Characterization of growth habits of the four cassava cultivars used in the study.

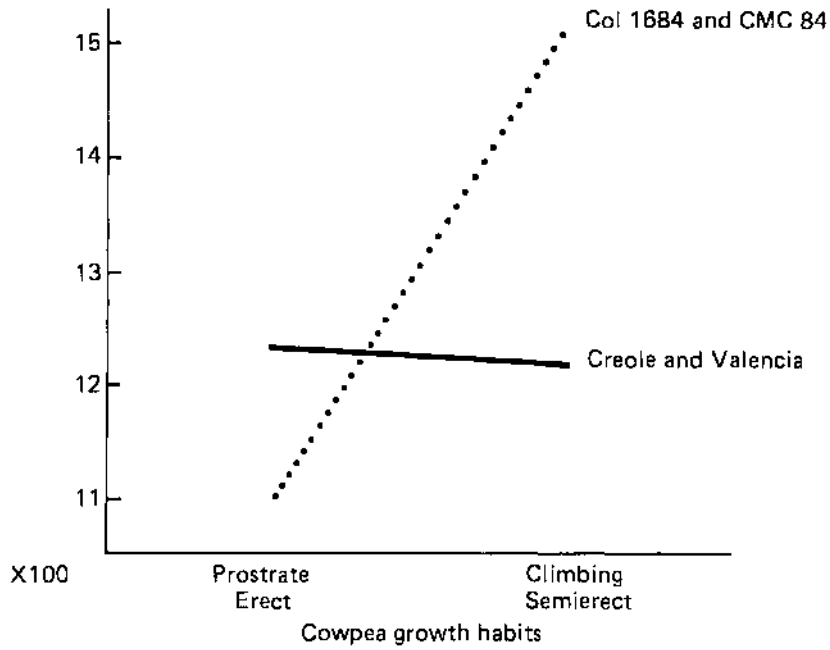
| Cassava Cultivar | Origin | Height from soil surface to first ramification (m)[2] | Canopy height (m)[2] | Canopy width (m)[2] |
|---|---|---|---|---|
| Valencia | Costa Rica | 2.0 ± 0.4[1] | 2.8 ± 0.4[1] | 1.3 ± 0.4[1] |
| Criolla | Honduras | 1.4 ± 0.5 | 2.1 ± 0.3 | 1.6 ± 0.2 |
| CMC 84 | CIAT[3] | 1.8 ± 0.3 | 2.6 ± 0.3 | 1.5 ± 0.3 |
| COL 1684 | Colombia | 0.4 ± 0.2 | 1.3 ± 0.3 | 1.5 ± 0.3 |

[1]Mean ± s.d.

[2]Measurement taken 288 days after planting.

[3]International Center of Tropical Agriculture (CIAT).

The cassava-cowpea system consisted of a single cassava crop and two cowpea crops. The first cowpea crop was planted simultaneously with the cassava except for the climbing types which were used only as a second crop. The second cowpea crop was planted 253 days after the cassava planting when the leaf area index was beginning to decline. Cowpeas of the climbing habit were associated with cassava planted at 1x1 m, while other growth habits were planted in the 2.5 m space between double rows of cassava separeted by 0.83 m. In both arrangements, planted populations of cassava were 10,000 plants per hectare. For climbing, prostrate and semierect cowpeas, plant population were 80,000 pl/ha in association and 133,333 pl/ha in monoculture. For erect cowpeas, plant population in association and monoculture were 160,160 and 266,666 pl/ha, respectively.



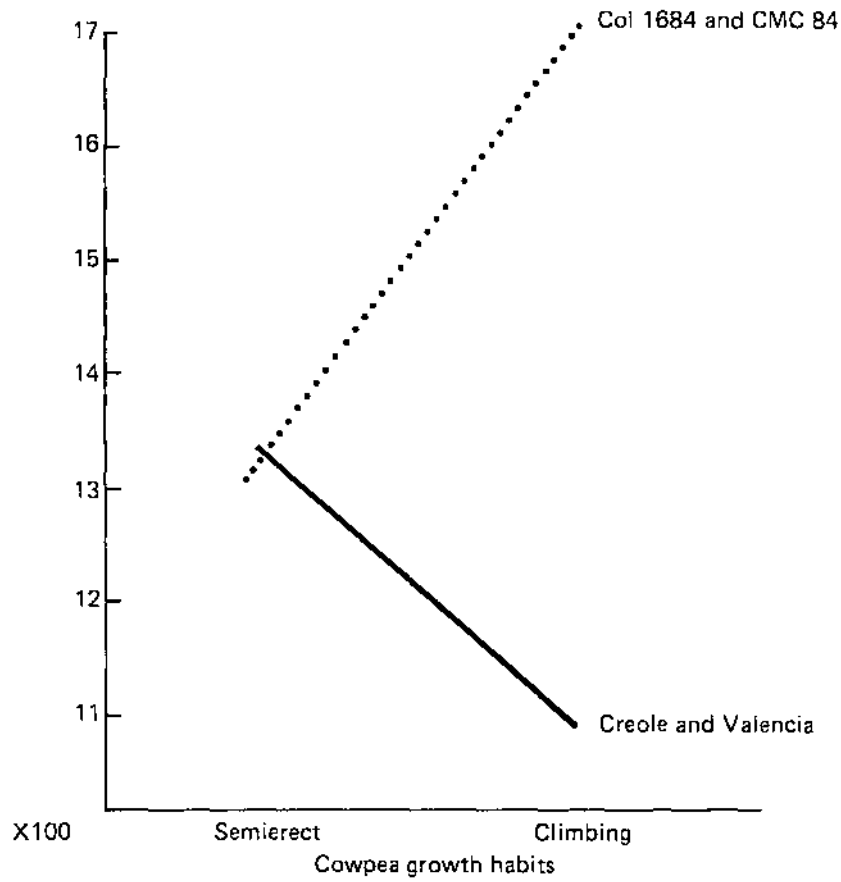
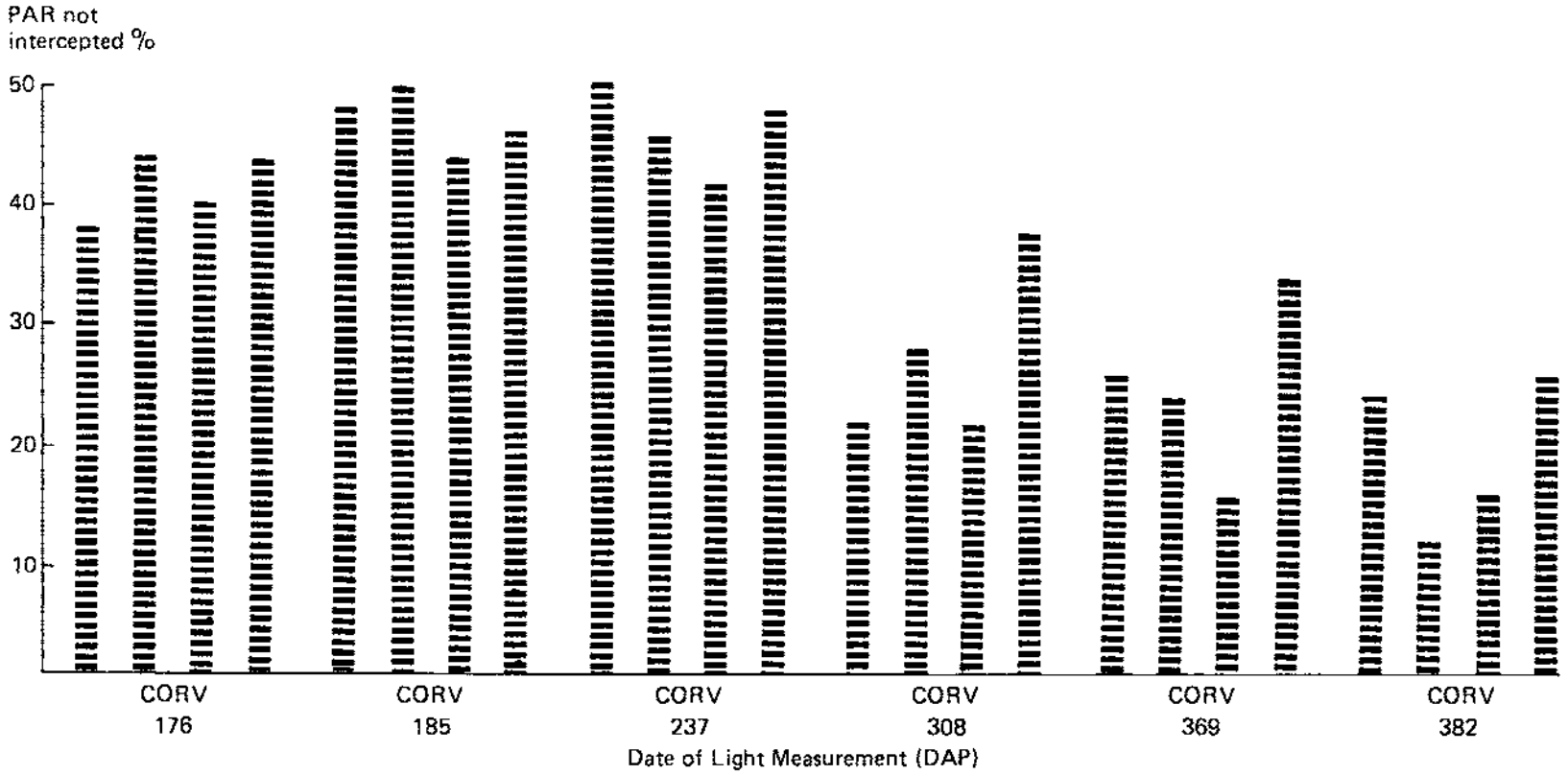




Figure 1. Mean yields of two groups of cassava cultivars as affected by association with cowpeas of different growth habits.




Abbreviations for Cassava Cultivars:

C – CMC 84
O – Colombia 1684
R – Creole
V – Valencia

Figure 2. Photosynthetically active radiation not intercepted by four cassava cultivars at six dates after planting.

Soil analysis of the experimental area indicated: ph 5.a, O.M. 77.77, Exch Ca, Mg, K, and Al: 4.0, 1.0, 0.4, and 0.3 me/100 ml respectively, available $P_2O_5$ (modified Olsen) - 14.2 µg/ml for which 0.5 T/ha agricultural limestone, 20 kg/ha N, 44 kg/ha $P_2O_5$ and 42 kg/ha $K_2O$ were recommended.

Premature branching of cassava due to insect attack was prevented by application of Methamidophos at 0.5 Kg/ha. A mixture of Benomyl and Carbaryl at 0.5 g a.i/l and 1 g a.i/l, respectively, was applied to cowpeas for control of leaf diseases and Diabrotica spp. Cassava was pruned at 90 days to eliminate lateral shoots.

Dry matter in stems, leaves, and petioles as well as leaf area index was determined on a two plant sample of cassava at three dates previous to harvest when a 16-plant area was harvested for dry matter and yield. Cassava was harvested 440 days after planting. Height and width of plant canopy for both cowpeas and cassava were determined at monthly intervals. Percent of photosynthetically active radiation (PAR) not intercepted by cassava was measured 176, 186, 237, 308, 369 and 382 days after planting with a LICRO LI-190SB sensor above the canopy and a LI-191SB line quantum sensor at ground level, utilizing a transect of 6 m for plots with cassava planted in double rows and of 2 m for plots with cassava at the 1.0x1.0 m spacing.

Cassava roots were dried for 72 hours at 70°C. Both cowpea and cassava yields were corrected for stand by an analysis of covariance (Steel and Torrie, 1980).

## Results and Discussion

### Effect of Cowpea on Cassava Yields

Yields of cassava for different treatment combinations provided two distinct patterns. In the "CMC 84" and "Col 1684" cultivars, cowpea plant types reduced cassava yield in this order: erect-postrate-semierect-climbing. This effect might be explained by the fact that the latter two cowpea types offered less competition, due to later planting of the climbing type and high disease incidence in the second planting of the climbing type and high disease incidence in the second planting of the semierect type. In the other two cassava cultivars ("Creole" and "Valencia"), no such trends were observed although the factors affecting cowpea development (planting date and disease incidence) were the same.

Statistical analysis further clarified these trends although F tests for main effects of cowpea type and cassava type as well as for interaction were not statistically significant. However, one degree of freedom tests for certain components of the interaction showed significance at the 5% level and are illustrated in Figure 1. Thus, cowpea plant types affected the two groups of cassava cultivars in a significantly different manner. Reason for the two trends in cassava response to cowpea plant types is not immediately apparent as the cassava cultivars presenting a similar response are of dissimilar growth habits (Table 1). More detailed analysis of yield components of cassava cultivars will be necessary to explain the trends observed.

Photosynthetically active radiation (PAR) not intercepted by the cassava canopy at six dates are shown in Figure 2. In general, non-intercepted radiation increased for the second sampling date (186 DAP), when it had an average value of 41.3%. At the third sampling date (237 DAP), non-intercepted PAR began to decline

and maintained this trend until the last date on which measurements were taken (382 DAP) when it was 19.1%. As a second cowpea planting was made 253 days after planting, it is these latter three determinations (made at 308, 369, and 382 DAP when the non-intercepted PAR was 27.3, 25.1, and 19.1% of the PAR, respectively), which determine the light available to the second cowpea crop. From Figure 2, it can also be noted that "Valencia" variety intercepted the smallest amount of light during this period, with a mean 32.4% non-intercepted PAR for the last three dates. The "Creole" cultivar only transmitted 18.1% of the PAR while the "CMC 84" and "Col 1684" cultivars failed to intercept moderate (24% and 21%, respectively) amounts of the radiation.

The effect of these differences on cowpea yield in the second crop are indicated where yield appears to be directly proportional to amount of light not intercepted by the cassava cultivars. Yields for semierect plant type are not included as this cultivar was heavily attacked by anthracnose and failed to yield.

Table 2. Cassava and cowpea yields resulting from combinations of different cultivars.

| Cassava cultivar | Cowpea Cultivar | Yield of Cassava (kg/ha) | Yield of Cowpea (kg/ha) 1st cycle | 2nd cycle | Total yield |
|---|---|---|---|---|---|
| CMC 84 | Erect | 9,778 ab | 660 | 136 | 796 bfg |
| | Prostrate | 11,734 ab | 1,125 | 184 | 1,309 abfg |
| | Semierect | 13,714 ab | 167 | 0 | 167 fg |
| | Climbing | 16,386 ab | 0 | 388 | 388 dfg |
| Col 1684 | Erect | 10,631 ab | 379 | 136 | 515 defg |
| | Prostrate | 11,095 ab | 1,705 | 340 | 2,045 a |
| | Semierect | 12,327 ab | 152 | 0 | 152 fg |
| | Climbing | 17,552 a | 0 | 794 | 794 cg |
| Creole | Erect | 14,386 ab | 526 | 130 | 656 bfg |
| | Prostrate | 13,584 ab | 1,519 | 77 | 1,596 abfg |
| | Semierect | 14,749 ab | 131 | 0 | 131 f |
| | Climbing | 9,987 ab | 0 | 377 | 377 dfg |
| Valencia | Erect | 11,141 ab | 877 | 320 | 1,197 abfg |
| | Prostrate | 10,184 b | 960 | 524 | 1,484 abcfg |
| | Semierect | 11,890 ab | 208 | 0 | 208 fg |
| | Climbing | 11,477 ab | 0 | 993 | 993 befg |

Values followed by the same letter do not differ significantly at P = 0.05.

From the better performance of the "CMC 84" and "Col 1684" cultivars when with the climbing cowpea, which was only planted 253 days after the cassava, it can be concluded that these varieties were adversely affected by competition by cowpea in the period soon after planting. These effects were strongest with the prostrate and erect cowpeas, which would be expected to produce the greatest competition, the former due to its greater vigor and the latter due to the higher population. Poor competing ability of the semierect cowpea is reflected in the low yields of cowpeas and relatively high yields of cassava obtained by this combination with all cassava cultivars.

The greater light penetration allowed by the "Valencia" cultivar, permitting higher cowpea yields in the second planting, is offset by the relatively lower yield potential of this cultivar, as well as by the fact that the highest yields of cowpea were produced by the prostrate types, in which yields of the first planting were much higher than in second planting. Thus, total yields of prostrate cowpeas with "Col 1684" and "Criolla" varieties was higher than with the "Valencia" cultivar despite the significantly higher yield with the latter cultivar in the second planting. All cassava cultivars outyielded the "Valencia" cultivar when associated with the prostrate cowpeas, although this difference never attained statistical significance.

Final choice of the best combination of cassava and cowpea cultivars would have to depend on local preferences and market conditions. In areas such as northern Brazil where cowpea is important in the diet, a farmer would readily sacrifice 2,000 kg/ha of cassava for an additional 1,000 kg/ha of cowpeas. However, in the case of the "CMC 84" and "Col 1684" cultivars, subtitution of climbing for prostrate cowpea would entail a 5,000 kg/ha reduction in cassava yield to be offset by only a 1,000-1,300 kg/ha gain in cowpea yield. It should be noted, however, that the "CMC 84" and "Col 1684" cultivars are bitter, requiring processing to produce a saleable product, which would thus reduce the return.

With "Creole" and "Valencia" cultivars, the only ones acceptable in areas such as Central America where bitter cassavas are not used, the substitution of prostrate for climbing cowpea would be more readily made involving, as it does, only a small decrease, and in the case of "Creole," a slight increase, in cassaya yield while cowpea yield would increase by some 500 kg/ha. Because of the higher yield of "Creole" cultivar and the fact that the prostrate cowpea yielded much better in the first planting with this cultivar than with "Valencia," one would conclude that this cultivar would be preferred despite the higher yield of the second crop cowpea with the "Valencia" cultivar.

The performance in association of cowpea and cassava cultivars of different plant type depended not only upon competitive ability but also on yield capacity of the different components. The higher yield capacity of the postrate cowpea and of the "Creole" cassava cultivar appears to be as important as the low light interception of "Valencia" cultivar especially as the smaller leaf area associated with lower light interception might also be responsible for lower yields of cassava. In fact, it would seem that the combination of two aggressive plant types was more productive than the association of less aggressive, complementary plant types which should have offered less mutual competition.

The authors thank Dr. Julio Henao, of the statistics unit of CATIE, for help in the statistical analysis and Mr. Gregorio Fuentes for assistance in the field measurements. Thanks are also due to Dr. Jonathan Woolley, formerly of CATIE, presently cropping system agronomists at CIAT, for help in designing the experiment.

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The Relationship between the Altitudinal Limit of Cassava and Soil Temperature in Papua New Guinea

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ABSTRACT

Observations were made on the usual upper altitudinal limit of cassava (*Manihot esculenta* Crantz) at 31 locations in Papua New Guinea. The mean upper altitudinal limit was found to be 1770 m. The 9:00 a.m. soil temperature at 10-cm depth was recorded as 17.9°C at a location at 1770 m.

Experimental work done in Australia suggests that a mean soil temperature of 18°C is the useful lower limit for satisfactory establishment of cassava. It is suggested that the upper altitudinal limit of cassava in Papua New Guinea is related to soil temperature. An ecological approach in a tropical highland environment and an experimental approach in a subtropical environment have both identified a soil temperature of 18°C as one of the limiting factors in cassava establishment and growth.

Field Nutrition Studies of Cassava

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ABSTRACT

Coastal soils of Queensland are of generally low chemical fertility and fertilizer application is necessary for most commercial crops. Field experiments were conducted to investigate the mineral nutrition of cassava on several soil types commonly found in northern Australia.

When cassava was grown after sown pasture, applied nitrogen promoted growth of plant tops, but there was no positive effect on economic yield. Absorption of nitrogen, phosphorous and potassium was closely linked with total biomass production. In high latitude areas of S.E. Queensland, there was a large seasonal variation in crop growth rate and hence absorption of the mineral nutrients varied greatly within a year.

Cassava in this environment, particularly under high soil fertility conditions, produced high leaf and stem dry matter. The leaves were mostly shed at the beginning of winter and large quantities of mineral nutrients were returned to the soil. Stem incorporation into the soil after the harvesting of underground storage organs would also contribute to the return of the nutrients and hence the maintenance of soil fertility.

## Field Studies of Environmental Effects on Growth and Yield of Cassava

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ABSTRACT

An understanding of the growth responses of cassava to environmental factors such as temperature, photoperiod, incident radiation, and available soil moisture is central to studies of crop adaptation. Field experiments, using the Australian standard cultivar (MAUS7), were conducted to investigate the effects of these factors.

Growth analysis experiments in north (17°S) and south (27°S) Queensland using a range of planting times, irrigation levels, and densities for crops grown to age 24 months with adequate nutrition were employed. The sequential harvests enabled calculation of crop growth rate and the partitioning of this growth to leaf, stem, and storage root. These data will be used to examine the relationships among the growth variables and the environmental factors. In this paper a summary of the results is presented, and the major implications for cassava production in northern Australia are discussed.

## Studies with Cassava Planting Material

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ABSTRACT

Relationships between the length, quality, planting angle, and population density of cassava stem cutting and subsequent growth and tuber yield were studied in the field in southeast Queensland. Changing orientation from vertical to oblique to horizontal did not significantly affect yield for 40-cm stem cuttings, but resulted in a small yield reduction for 20-cm cuttings. The use of light thin cuttings from upper parts of the plant reduced yield slightly when compared to heavy thick cuttings from basal parts of the plant.

In another experiment, cutting length and plant population density were varied in an attempt to manipulate stem number per plant and the uniformity of stem distribution per unit area, and to examine the effects of such changes on crop growth and yield. At a given plant density, smaller planting pieces resulted in smaller stem numbers per plant, a small reduction in total biological yield, but an increase in distribution of assimilate to roots. It is concluded that yield is relatively independent of planting techniques, and small stem cuttings can be used if there is a need to conserve planting material.

## Effects of Soil Moisture, Bulk Density, and Tillage Treatments on Tropical Root Crops

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ABSTRACT

This report describes the effects of field, lysimetric and greenhouse investigations on growth, root development, and yield of tropical root crops under varying soil moisture and bulk density regimes, and different systems of seedbed preparation. The basic information reported is on plant-water relations of cassava, sweet potato, and cocoyam; root growth-soil density relationship for cassava, and tuber yield of cassava grown under no-till and conventional methods of seedbed preparation.

During the daytime (0800-1700 hours), the stomatal diffusion resistance of the lower side of a leaf varied between 1-17, 1.5-13 and 1.5-21 sec $cm^{-1}$ for cassava, sweet potato and cocoyam, respectively, depending on the cultivar and water table level. In the same sequence, leaf water potential ranged between -1.8 and -3.6, -3 and -11.3 and -0.4 and -8.2 bars, respectively. Although statistically insignificant, the root length density of cassava varied between 0.02 - 0.06 cm root length $cm^{-3}$ soil, root weight density between $0.1 \times 10^{-4}$ to $18 \times 10^{-4}$ kg $cm^{-3}$ and dry weight of tuberous roots between 0.01 - 0.99 kg/plant depending on time of harvesting and soil compaction levels. The bulking rate of tuberous roots was always higher in soilbeds compacted to bulk densities of 1.4 and 1.8 g $cm^{-3}$ than to 1.6 g $cm^{-3}$. Tuber yield of cassava was not affected by tillage methods.

## Leaching Losses and Recovery of Fertilizer Nitrogen in Cassava/Maize Intercrop Grown in Lysimeters

Author: B.O. Njoku, M.C. Igbokwe, and A.C. Ohiri, National Roots Crops Research Inst., Umudike, Nigeria.

ABSTRACT

The ability of cassava/maize intercrop to utilize applied fertilizer nitrogen in the high rainfall zone of Nigeria was tested in filled-in lysimeters during two cropping seasons. Maize and cassava together recovered 36.6% and 43.7% of the applied N in 1979 and 1980, respectively. Maize was more efficient than cassava in recovering fertilizer N. Maize grain absorbed 16.5% and 24.8% of the applied N in 1979 and 1980, respectively, while 6.4% and 4.5% were taken up by cassava tuberous roots. A high proportion of the total precipitation was recorded as percolates once the soil was saturated. Percolation was higher in lysimeter units that received no N treatment than those treated with 100 kg N/ha.

# Evaluation of Cassava for Leaf and Root Production in Sierra Leone

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ABSTRACT

Cassava is the second most important food crop in Sierra Leone after rice. Both the tuberous roots and leaves are eaten.

Studies over a 2-year period show that variety Nucass 3 significantly outyielded the other varieties while the local cultivar, Cocoa, had the lowest production.

Cassava varieties reacted differently to leaf harvest in terms of tuberous root yields. Compared with plants whose leaves were not harvested, there was a total fresh tuberous root yield reduction ranging from 22% to 42% when leaves were harvested monthly.

Cassava (*Manihot esculenta* Crantz) is the second most important food crop after rice in Sierra Leone. Tuberous roots and leaves are both important in diets of the people.

Average root yield is 4.4 t/ha (Central Statistics Office, 1972), which compares unfavourably with the African average of 9 t/ha. Cassava improvement work started in the country some years ago with seeds obtained from the International Institute of Tropical Agriculture (IITA), Nigeria. The main objectives were to develop cultivars with high yield, disease and pest resistance, good consumer acceptability and wide adaptability.

The work resulted in the release of several improved varieties. This paper reports on performance of five of these varieties together with a local check over two growing seasons.

Several authors (Ahmad, 1973; Singh and Chaudhury, 1975; Dahniya et al., 1981) have reported adverse effects of leaf harvests on yield of tubers so another study was to determine response of varieties to leaf harvests.

## Materials and Methods

Five improved cassava varieties, Nucass 1, Nucass 2, Nucass 3, Rocass 1, Rocass 3 and a local cultivar, Cocoa, were planted on 23 May 1980 on upland gravelly soil described by Odell et al., (1974) as Orthoxic palehumult at Njala University College Experimental farm.

The experiment was a RCB with four replications. Each plot consisted of four ridges, 1 m apart with 12 stakes planted 1 m apart on each ridge.

The plants were harvested for tubers a year after planting with the two central ridges excluding the end plants as sampling unit. Data on number of tubers per plant, individual tuber size and yield (t/ha) of fresh and dry tubers were recorded. The study was repeated during the 1981/82 planting season.

In determing response of the cassavas to leaf harvest, the varieties were planted on 21 May, 1981 on upland gravelly soils. The cassava varieties made up the main plots which consisted of four ridges, 1 m apart with 10 plants 1 m apart per ridge. The subplots were made up of two ridges and the 16 centre plants per subplot served as sampling units.

Leaves from the top 30 cm of each branch were plucked starting 5 months after planting. This continued monthly until 13 months after planting but no leaf harvests were made on the 9th and 10th months because of low leaf numbers due to the severe dry season.

The plants were harvested for tubers 2 weeks after the final leaf harvest and data on tuber yield, size and numbers were taken. The experiments were entirely rainfed and no fertilizers were applied.

## Results and Discussion

### Tuber Yield and Yield Components

Nucass 3 produced significantly more (25.5 t/ha) fresh tuberous root than the other varieties while the local cultivar, Cocoa, had the lowest fresh yield of 5.9 t/ha (Table 1). This significantly higher yield is mainly attributable to greater number of tubers produced by Nucass 3 rather than individual tuber size.

Table 1. Tuber yield and yield components of cassava varieties.

| Variety | Fresh tuber yield (t/ha) | Dry tuber yield (t/ha) | Tubers plant | Fresh Wt./tuber (g) |
|---|---|---|---|---|
| Nucass 1 | 15.5 | 5.2 | 4.7 | 351 |
| Nucass 2 | 14.3 | 4.2 | 3.6 | 403 |
| Nucass 3 | 25.5 | 7.0 | 7.6 | 341 |
| Rocass 1 | 12.4 | 4.4 | 4.0 | 326 |
| Rocass 3 | 9.7 | 3.7 | 2.7 | 370 |
| Cocoa (Local) | 5.9 | 2.2 | 2.2 | 285 |

Dry tuber yield shows that Nucass 3 has lower dry matter content (27.5%) than the other varieties. This has great implication for processing the variety into the two most important local food forms, foofoo and gari.

Root yield per se of a variety is not a reliable indicator of the quantity of gari it produces (Ibe and Ezedima, 1981). The best and simplest criterion for predicting garification rate of roots prior to processing into gari is the tuber dry matter content (IITA, 1981). Sanneh et al., (1982) after evaluating varieties Nucass 1, 2 and 3 for suitability to produce gari and foofoo concluded that Nucass 3 was unsuitable while the other two were acceptable.

Varietal Response to Leaf Harvest

Total fresh leaf yield of Nucass 3 (7.9 t/ha) was significantly higher than those of the other varieties. The local cultivar, Cocoa, had the lowest leaf yield of 3.3 t/ha (Table 2).

Varieties reacted differently to leaf harvest in terms of tuberous root yields confirming an earlier report by Dahniya et al., (1981). The fresh tuberous root yield of Cocoa was reduced by 22% as a result of leaf harvest while decreases of 33%, 40%, 27%, 42% and 36% were recorded for varieties Nucass 1, 2, 3, Rocass 1 and 3, respectively.

Number of tubers per plant was unaffected by leaf harvest (Table 2). Since the first leaf harvest was taken 5 months after planting, it appears that the number of storage roots was determined early in the growth of the plants as reported by Wholey and Cock (1974) and Hunt et al., (1977). Individual tuber size of the control plants significantly exceeded those of plants with harvested leaves in all the varieties except Cocoa.

Table 2: Effects of monthly leaf harvested on various yield attributes of cassava.

| Variety | Leaf harvest | Fresh leaf yield (t/ha) | Fresh tuber yield (t/ha) | Dry tuber yield (t/ha) | Tubers plant | Fresh Wt./tuber (g) |
|---|---|---|---|---|---|---|
| Nucass 1 | None | 0.0 | 20.1 | 6.7 | 5.8 | 351 |
| | Monthly | 5.2 | 13.5 | 4.5 | 6.8 | 200 |
| Nucass 2 | None | 0.0 | 18.9 | 5.6 | 4.6 | 418 |
| | Monthly | 4.1 | 11.4 | 3.4 | 4.5 | 278 |
| Nucass 3 | None | 0.0 | 26.9 | 7.4 | 7.5 | 419 |
| | Monthly | 7.9 | 19.6 | 5.4 | 8.5 | 231 |
| Rocass 1 | None | 0.0 | 16.8 | 5.9 | 4.4 | 375 |
| | Monthly | 4.2 | 9.8 | 3.5 | 4.6 | 219 |
| Rocass 3 | None | 0.0 | 14.7 | 5.6 | 3.7 | 397 |
| | Monthly | 3.9 | 9.4 | 3.6 | 3.4 | 278 |
| Cocoa | None | 0.0 | 5.0 | 1.9 | 2.6 | 195 |
| (local) | Monthly | 3.3 | 3.9 | 1.5 | 2.2 | 183 |

Results show that the local cultivar is better adapted to leaf harvest since tuber yield, individual tuber size and numbers were not significantly affected by leaf harvest as was the case with the improved varieties. However, leaf and root yields of the variety are low. Although improved varieties were more severely affected by leaf harvest, their total leaf and root yields are far superior to that of Cocoa.

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# Breeding Cassava for Adaptation to Stress Conditions: Development of a Methodology

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## ABSTRACT

Cassava (Manihot esculenta Crantz) appears to have an advantage over many tropical crops in its adaptation to marginal agricultural areas, especially in terms of drought tolerance, tolerance to high soil acidity, and ability to produce reasonably well on soils of low fertility. Wide genetic variability also exists for resistance to most disease and pest problems affecting cassava. CIAT's cassava breeding program is designed to exploit the adaptation of cassava to various physical and biological stress factors by selection over a range of moderate to high stress environments. The selection environments are described and a decentralize breeding methodology outlined.

## Introduction

Empirical evidence gained over many years of cultivation as well as recent studies suggest that cassava (Manihot esculenta Crantz) has a comparative advantage over many crops in its adaptation to important low productivity and even marginal agricultural areas. Cassava has long been known for its ability to survive and produce reasonably in water stress situations, on soils of low fertility, on soils of high aluminum saturation and low pH, in diverse climatic conditions, and with low inputs for disease and insect control.

In a world where food production increase will rely on bringing marginal lands into production, cassava can play an important role as an efficient calorie producer especially in less resource-rich countries where the level of inputs required for more demanding crops is often economically prohibitive.

At the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, the genetic improvement of cassava is being directed principally toward maximizing productivity under low input conditions. Adaptation to many biological and physical environmental stresses is being sought through breeding rather than through purchased inputs. Nevertheless, simple and inexpensive cultural practices also form an important part of the technological package.

This paper describes common stresses which limit productivity of cassava, the definition of discrete edapho-climatic zones for cassava production, the presently available germplasm base for cassava improvement, and the methodology which has been developed at CIAT for breeding for improved productivity under stress conditions.

## Common Stresses in Cassava Production

In most regions, cassava is grown with zero or low fertilizer application, without irrigation, without chemical control of diseases and pests, and in generally low productivity environments. Throughout its long growing cycle, cassava commonly is exposed to a wide range of physical and biological environmental stresses.

### Temperature and photoperiod

Cassava is principally grown in the lowland tropics, but extends into the northern and southern subtropics and into the highland tropics up to 2,200 m a.s.l. In the subtropics, low winter temperatures and long summer days may cause high stress for unadapted clones. CIAT studies (CIAT, 1981) suggest that long days can drastically reduce yields but that varietal differences in photoperiod sensitivity apparently exist. Likewise, Irikura et al (1979) have clearly shown that distinct genotypes are required for high altitude (mean temperature less than 22°C) compared to the lowland tropics.

### Soil water availability

In many regions cassava must tolerate extended dry periods without supplemental water supply. Dry periods of 3 to 5 months or even longer are common. In addition, shorter dry periods during the rainy season are normal in low rainfall regions. Cassava is able to utilize water extremely efficiently by rapidly reducing leaf area under stress (Conner et al, 1981). Under drought stress, top growth is reduced proportionally more than root yield, often resulting in minimal reductions in root yield (Conner et al, 1981).

### Ambient relative humidity

Recent physiological studies have shown cassava to be very sensitive to low relative humidity of the atmosphere. Rapid stomatal closure and highly reduced photosynthetic rates accompany stress caused by low relative humidity (CIAT, 1981).

### Soil characteristics

Though soil fertility and pH status can be readily modified by addition of fertilizers and lime, this option if often not practiced by small farmers with limited economic resources. Much cassava production is on soils of low nutrient status, high aluminum saturation levels and/or low water-holding capacity.

### Pests and diseases

The long growing cycle of cassava makes it a potential host over a range of environmental conditions even within the same region. Build-up of different pest and disease complexes may be favored at various periods during the growth cycle. Under traditional growing systems pests and diseases are normally not major yield constraints, the modernized cultural practices, including monocropping, higher density planting, and continuous cassava cultivation, have generally contributed to worsening pest and disease problems (Lozano et al, 1983).

## Edapho-Climatic Zones for Cassava Production

The existence of such a wide range of environmental conditions for which cassava improvement must be directed, along with yield and quality considerations, makes breeding for wide adaptability across all components of environmental variability a practical impossibility. CIAT has delineated six combinations of edapho-climatic characteristics which appear to constitute a necessity for basically different genotypes (Table 1). Edapho-climatic zones (ECZ's) are defined first on the basis of temperature: lowland tropics (ECZ 1, 2, 3); middle altitude tropics (ECZ 4); highland tropics (ECZ 5) and subtropics (ECZ 6). Further division within the lowland tropics is based on rainfall distribution and soil characteristics: low to moderate rainfall with long dry season (ECZ 1); moderate to high rainfall with acid savanna soils (ECZ 2); high rainfall well distributed throughout the year (ECZ 3).

Table 1. Cassava edapho-climatic zones and their principal characteristics.

| Edapho-climatic zone | General description | Representative areas |
|---|---|---|
| 1 | Lowland tropics with long dry season, low to moderate annual rainfall; high year-round temperature. | North-eastern Brazil; north coast of Colombia; northern Venezuela; Thailand, southern India; sub-Sabelian Africa. |
| 2 | Acid soil savannas; moderate to to long dry season; low relative humidity during dry season. | Llanos of Colombia and Venezuela; Cerrado of Brazil; savanna of Southern Mexico. |
| 3 | Lowland tropics with no pronounced dry season; high rainfall; constant high relative humidity. | Amazons basin region of Brazil, Colombia, Ecuador, and Peru; rainforests of Africa and Asia. |
| 4 | Medium altitude tropics; moderate dry season and temperature. | Andean zone; Costa Rica; Bolivia; Brazil; Africa; the Philippines. |
| 5 | Cool, tropical highland areas, with mean temperatures of approximate 17-20°C. | Andean zone; highlands of tropical Africa. |
| 6 | Subtropical areas, with cool winters and fluctuating day-lengths. | Southern Brazil; Paraguay, northern Argentina; Cuba; Northern Mexico; southern China; Taiwan. |

Potential importance of pests and diseases in cassava is largely dependent upon climatic and soil conditions of a region, along with presence of a susceptible host and cultural practices. Thus, each ECZ can be identified with a unique combination of disease and insect pest problems (Table 2). For example, bacterial blight requires minimum critical day-night temperature fluctuations to become epidemic; superelongation disease requires extended rainy periods, phoma leaf spot

requires constant low temperatures, and mites and thrips are most serious during extended dry periods (Lozano et al, 1981).

Obviously, it is unlikely that any given region will have all the pests and diseases defined as potential problems for that edapho-climatic zone. Micro-environmental variations, differences in cultural practices, differences in varietal susceptibility, and whether or not the pest or pathogen has been introduced, will all affect the balance of biological problems in a given cassava plantation.

Colombia, where CIAT is headquartered, contains a wide range of climatic and soil conditions as well as most of the pest and disease problems which affect cassava. Areas representative of five of the six ECZ's have been identified in Colombia, excepting only a subtropical region with cool winters and fluctuating photoperiods. CIAT has developed intensive selection programs for ECZ's 1, 2, 4 and 5, in Colombia, and collaborates with national research programs for selection in all zones.

## The Available Germplasm Base for Cassava Improvement

Cassava completed the major part of its evolution in Latin America, up to the time of the arrival of Europeans in the Americas when it was carried to Africa and Asia. Thus the present gene pool of cassava can basically be considered to have developed under the selection pressures imposed by tropical American conditions. Cassava growing areas of the Americas encompass a high diversity of climatic and soil conditions, and consequently genetic adaptation to a high diversity of conditions has evolved.

The evolution of cassava has been largely directed by conditions existing in traditional agricultural systems, including intercropping, varietal mixtures, spatial separation of cultivated areas, and fertility management by rotation and fallowing. These management conditions probably contributed to moderation of disease and insect pressures, and thus the level of genetic resistance required to maintain populations at subeconomic levels was not high. Nevertheless, the resistance which did evolve was in many cases due to multiple mechanisms, each under multigenic control. This type of resistance can be expected to be stable and durable.

Because agriculture was extensive rather than intensive, competitiveness with associated crops and root quality were more important in cassava than productivity per unit area (Kawano and Jennings, 1981). Traditional varieties often evolved with low harvest index, i.e., a large proportion of top growth compared to roots.

Many majors crops have undergone a long history of genetic modification by plant breeders, often under conditions of good land preparation, high soil fertility, irrigation and artificial disease and insect control. Under these controlled and uniform conditions of selection, inherent tolerance to environmental stresses is unnecessary. Consequently, resistance genes were lost from breeding populations, or reduced to low frequencies. If at some later time, selection for resistance was initiated, resistance had to be built upon a narrow genetic base and often resulted in single--mechanism resistance under mono--or oligogenic control.

Table 2. Importance of various physical and biological environmental factors in different edapho-climatic zones for cassava production.

| Environmental factor | Controlability other than by genotype[1] | Potential for adaptation through breeding[2] | Probability of stress effects in each edapho-climatic zone[3] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | I | II | III | IV | V | VI |
| Physical Environment | | | | | | | | |
| Temperature | 0[4] | ++ | 0 | 0 | 0 | + | +++ | +++ |
| Ambient Rel. Humidity | 0 | ++ | +++ | +++ | + | ++ | + | + |
| Photoperiod | 0 | ++ | + | + | + | + | + | +++ |
| Soil water | + | ++ | +++ | +++ | + | + | + | + |
| Soil acidity | ++ | ++ | + | +++ | ++ | + | ++ | ++ |
| Soil phosphorus | ++ | ++ | ++ | +++ | ++ | ++ | ++ | ++ |
| Biological Environment | | | | | | | | |
| Bacterial blight | + | +++ | ++ | +++ | + | ++ | + | +++ |
| Cercospora leaf spots | + | +++ | ++ | ++ | ++ | ++ | + | ++ |
| Phoma leaf spot | + | +++ | 0 | 0 | 0 | + | +++ | ++ |
| Superelongation | + | +++ | ++ | +++ | ++ | ++ | + | +++ |
| Anthracnose | + | ++ | +++ | +++ | ++ | ++ | ++ | +++ |
| Root rots | ++ | + | + | + | ++ | +++ | ++ | +++ |
| Green cassava mite | ++ | +++ | +++ | +++ | + | ++ | + | + |
| Red spider mite | ++ | ++ | +++ | ++ | + | ++ | + | + |
| Thrips | + | +++ | +++ | +++ | + | +++ | + | + |
| White fly | ++ | ++ | ++ | ++ | ++ | ++ | + | + |
| Hornworm | +++ | + | ++ | ++ | ++ | ++ | + | ++ |
| Shoot fly | ++ | + | ++ | + | ++ | ++ | + | ++ |
| Lace bug | + | ++ | ++ | +++ | + | ++ | + | + |
| Mealy bug | ++ | ++ | +++ | +++ | ++ | ++ | + | + |
| Scale insects | +++ | + | ++ | ++ | ++ | ++ | ++ | ++ |
| Weeds | +++ | + | +++ | +++ | +++ | +++ | +++ | +++ |

[1]The degree to which a given factor can be modified in its effect on the plant, other than modification genetically of the plant.

[2]The estimated potential for changing genotype to adapt to different states of each factor, based on known genetic variability, type of gene control and heritability.

[3]Stress effects for physical factors defined as resulting from low temperature, low relative humidity, long photoperiod, low soil water availability, high soil acidity and low soil phosphorus.

[4]Subjective evaluation, where: 0 = zero or near zero, + = low, ++ = moderate, +++ = high.

In cassava, modern breeding practices have only recently been applied and the genetic base remains in a nearly untouched condition. Breeding populations include wide genetic diversity and gene frequencies for many traits have not yet been changed dramatically. This situation provides a unique opportunity in a major crop to build upon diverse sources of low and moderate resistance to environmental stress.

CIAT maintains a germplasm collection of more than 3,000 clones from most cassava-growing regions of Latin America (Table 3). This native diversity serves as the germplasm base for genetic improvement efforts.

Table 3. Origin of cassava accessions maintained at CIAT.

| Country of Origin | Numbers of Accessions |
|---|---|
| Colombia | 1,759 |
| Venezuela | 253 |
| Brazil | 535 |
| Peru | 150 |
| Ecuador | 125 |
| Cuba | 73 |
| Mexico | 65 |
| Panama | 21 |
| Puerto Rico | 16 |
| Costa Rica | 16 |
| Dominican Republic | 5 |
| Paraguay | 3 |
| Bolivia | 3 |
| Malaysia | 3 |
| Thailand | 1 |
| Total | 3,028 |

## A Breeding Strategy

The overall cassava breeding strategy at CIAT consists of: (1) germplasm accession evaluation in diverse ECZ's in Colombia; (2) parental selection and formation of gene pools for each ECZ based on performance of germplasm accessions; (3) hybrid evaluation and selection primarily within but also across ECZ's; and (4) recommendation to national programs for testing of selected clones and/or progeny of specific crosses.

The breeding scheme is basically one of simple recurrent selection, where selected hybrids are further utilized as parents to continually improve the base populations. In the present discussion, emphasis is given to breeding for stress adaptation although a wide range of other traits are also considered in the breeding program.

### Evaluation sites

Evaluation for stress tolerance has historically followed one of two distinct approaches: evaluation under highly controlled conditions where only a single

stress factor in permitted to be manifested, or evaluation under field conditions where environmental variability may be high and various stress factors interacting. After the accumulation of considerable experience in both approaches, CIAT now gives priority to evaluation under field conditions for most characteristics. Selection of appropriate evaluation sites thus becomes one of the most crucial aspects of a breeding program.

CIAT, as an international organization, has responsibility for development of improved cassava germplasm to meet the needs of all cassava growing countries, and not only Colombia where it is located. This obviously implies that some level of wide adaptation will be essential for the new varieties. However, we have seen that the combination of resistances/tolerances to all the potential yield-limiting stresses of cassava is a virtual impossibility. Furthermore, it is now evident that common combinations of stress exist, and that these form logical subdivisions of breeding objectives.

The principal evaluation and selection sites should then combine as many of the potential stress factors as possible for the particular edapho-climatic zone to make the final selected products as broadly relevant as possible within similar regions. Moderate and high stress situations assure that selected clones will have adequate resistance or tolerance over a wide range of conditions, including regions where particular stresses may not exist, or exist in low levels. On the other hand, selection under non-stress situations would result in clones with insufficient resistance under stress. Characteristics of principal evaluation sites are given in Table 4.

Germplasm evaluation

Most CIAT germplasm collection has been evaluated in the north coast region (ECZ 1), the eastern plains (Llanos Orientales) (ECZ 2) and at CIAT-Palmira headquarters (ECZ 4). To a smaller degree evaluations have been done in Popayán, an Andean highland site (ECZ 5). All evaluations are carried out without disease or pest control, without irrigation, and with low levels of fertilizer applications only in the lowest fertility sites. Emphasis in evaluation is for overall performance and integrated resistance to stresses as demonstrated by root yield and quality at the end of the growing season.

Colombian North Coast (ECZ 1). Under the high temperature, long dry season conditions of the north coast region of Colombia, principal stresses are from low soil fertility, a long dry season (4-5 months) and mite attack during the dry season. Bacteriosis, superelongation and root rots are problems in some years when rainfall is above normal. Low yield and low dry matter characterisize most germplasm accessions when evaluated in this region. General average yield of the germplasm evaluations in single-row trials was 1.8 kg/plant. Average dry matter content was 28.3%.

Carimagua (ECZ 2). Principal yield constrains in Carimagua in the Llanos Orientales are low native soil fertility, high aluminum saturation and low pH, bacterial blight, anthracnose, superelongation disease, mites thrips, and mealybugs. Disease problems have received the most emphasis in germplasm evaluations, as their severity precludes any reasonable yields in the absence of moderate to high resistance levels. Only about 1% to 2% of the germplasm accessions show reasonable combined resistance to the stresses in Carimagua (Table 5).

Table 4. Principal climatological and edaphic characteristics of sites for cassava germplasm evaluation in Colombia.

| | Edapho - climatic zone | Altitude (masl) | Mean temperature | Annual rainfall (mm) | Soil texture | Soil pH | Organic matter (%) | P Bray II (ppm) | K (meg/100g) |
|---|---|---|---|---|---|---|---|---|---|
| Media Luna | I | 10 | 27.2 | 800-1,200 | Sandy loam | 6.6 | 0.7 | 7.2 | 0.08 |
| Valledupar | I | 120 | 28.0 | 700-1,100 | Sandy loam | 6.9 | 1.1 | 25.0 | 0.22 |
| Carimagua | II | 200 | 26.2 | 1,800-2,600 | Silty clay | 4.7 | 3.2 | 1.9 | 0.14 |
| CIAT-Palmira | IV | 1,000 | 23.8 | 600-1,500 | Clay | 7.4 | 4.1 | 81.5 | 0.69 |
| Popayan | V | 1,760 | 18.0 | 1,800-2,500 | Clay loam | 5.5 | 7.4 | 2.0 | 0.04 |

Table 5. Combination of characters required for cassava germplasm by edapho-climatic zone in Colombia.

| Target area | Principal breeding objectives for each area[1] | Level of expression | Accessions (No.) |
|---|---|---|---|
| North coast | Root yield (kg/plant) | ≥ 3.5 | 1 007 |
| (ECZ 1) | + Harvest index | ≥ 0.5 | 432 |
| | + Root dry matter (%) | ≥ 35 | 313 |
| | + *Mononychellus* mite damage[2] | ≤ 2 | 57 |
| | + Thrips damage[2] | ≤ 2 | 42 |
| Carimagua | Bacterioris damage[2] | ≤ 3 | 55 |
| (ECZ 2) | + Superelongation damage[2] | ≤ 3 | 21 |
| | + Mononychellus mite damage[2] | ≤ 3 | 6 |
| | + Vatiga damage[2] | ≤ 3 | 4 |
| Popayan | Phoma damage[2] | ≤ 2 | 17 |
| (ECZ 5) | + *Oligonychus* mite damage[2] | ≤ 2 | 10 |

[1]Data from CIAT-Palmira: root yield from single row trial, harvest index, root dry matter, mite and insect ratings. Data from Carimagua: bacteriosis and superelongation ratings. Data from Popayán: Phoma ratings.

[2]Disease, mite, and insect ratings on a 1 to 5 scale, where 1 = very low damage; 5 = very high damage.

CIAT-Palmira (ECZ 4). CIAT-Palmira headquarters are in a fertile, middle altitude inter-Andean valley, where rainfall is low but normally well distributed throughout the year. Except for root rots, disease are generally at low levels. Thrips mites and mealy bug populations can be high, especially during extended dry periods. Most cassava germplasm accessions are adapted to CIAT conditions to the extent that they can continually be maintained and multiplied. Average yield and root dry matter content of germplasm bank accessions evaluated at CIAT were 3.9 kg/plant and 35.1%, respectively.

Popayan (ECZ 5). Low ambient temperature, phoma leaf spot and anthracnose are the principal factors limiting adaptation of cassava in Popayan. Because low temperature tolerance per se is difficult to evaluate, most emphasis in preliminary evaluation of the germplasm bank is on plant vigor and disease resistance. The number of accessions with good adaptation to these stress conditions is very limited; the small number which are adapted have nearly all been collected from similar highland regions.

In summary, many germplasm accessions (which have been or still are nearly all cultivated varieties) seem to be well adapted to traditional cultural practices in areas where they evolved, in the sense that they can produce low but stable yields (Lozano et al, 1983). However, most do not seem to be able to fully exploit improved cultural practices. Yield potential, disease and insect resistance, and root quality all need to be improved. Thus the cassava program's emphasis is on creating new improved genotypes through hybridization and selection.

## Parental selection and hybridization

In each zone, best-performing accessions are evaluated through several cycles. Those which give stable performance in terms of integrating edaphoclimatic adaptation, resistance, yield and quality, are selected as parents and enter hybridization blocks. Single trait selection is largely avoided, as an inefficient methodology for achieving overall acceptability of hybrids. Some level of broad adaptability across zones is an additional advantage for potential parents, to avoid selection for high site-specificity for the Colombian selection sites.

Crossing blocks are separated for the low to medium altitude tropics, the highland tropics and the subtropics. For zones within the low to medium altitude tropics, crosses are directed primarily among clones adapted to the same zone, but also crosses between materials for different zones are made to transfer and recombine specific characteristics.

## Hybrid selection

Ideally, selection would be in as many sites as possible, to identify the best genotypes for every different environment. On the other hand, for logistic and administrative reasons, number of sites must be limited. Studies at CIAT have developed a methodology for logical balance to breeding for wide adaptability compared to specific adaptability in the given ECZ's.

Planting of $F_1$'s directly in principal selection sites. The maximum adaptability to a given ECZ should be achievable by initiating selection directly from the $F_1$ stage within the representative region. To achieve this theoretical optimum $F_1$ seeds have been planted directly in the fields at Carimagua, Media Luna

and Popayan (Table 6). In summary, two principal problems were observed with selection beginning with the $F_1$ in moderate and high stress selection sites: (1) seed germination was variable and generally well below what is expected under favorable conditions; (2) plant development is generally slower for seed-derived plants, and yield formation seems to be particularly delayed.

These data suggest that selection of $F_1$'s in diverse stress conditions may not only be difficult logistically, but also difficult for agronomic reasons.

Preliminary selection in CIAT-Palmira. Different production constraints in Carimagua (low soil fertility, CBB, superelongation) and Popayán (low temperature, phoma leaf spot), compared to CIAT-Palmira. Effectiveness of selection in CIAT conditions must be limited for eventual adaptation in these zones. One interesting case is for selection for ECZ 1 (Media Luna in CIAT program) and ECZ 4 (CIAT-Palmira) where some of the major yield constraints seem to be common.

Studies assessed the possibility of preliminary selection at CIAT-Palmira for adaptation in ECZ 1. $F_1$ seeds were planted directly in the field at Media Luna, and seedlings transplanted in CIAT-Palmira. At harvest, five stakes from each plant in both CIAT and Media Luna were planted in a single row trial in Media Luna. The lack of a correlation for either yield per plant or harvest index in CIAT with yield in Media Luna indicates that selection in CIAT for this zone may not be effective. A highly significant correlation was observed between root yield in the $F_1$ generation and root yield in the single row trial, with $F_1$ plants harvested in Media Luna. These data illustrate that for Media Luna conditions, selection for yield in CIAT-Palmira is much less effective than *in situ* selection at Media Luna.

Current selection scheme at CIAT. As a result of previously described studies, the current selection scheme has been developed which involves: (1) planting all $F_1$ progeny at CIAT headquarters where adequate care can be given to young seedlings, and where they develop normally; (2) harvest at 6 months; (3) mild selection to eliminate inferior genotypes; (4) cutting two stakes per plant, one remains in CIAT, the other sent to the principal selection site of the ECZ for which the cross was made. This intermediate selection stage following the $F_1$ is denoted as "$F_1C_1$" (first clonal generation of the $F_1$) to signify evaluation and selection procedures similar to that of an $F_1$ from true seed. Selection continues within each ECZ, and simultaneously the selected clones are maintained, evaluated and multiplied in CIAT-Palmira. At the intermediate selection stages, clones are tested across ECZ's to evaluate for reaction to a broad range of physical and biological environmental factors, and for general broad adaptation.

Throughout all stages of evaluation emphasis is given to selection for combined tolerance/resistance to the yield-limiting factors within each ECZ, as well as high yield potential and good root quality. The end result is clones having broad adaptability *within* each ECZ, but not necessarily across widely different zones. This strategy allows rapid progress by limiting the number of characters which must be combined for any given clone, while at the same time developing genotypes for the entire range of target area conditions. Germplasm can then be moved internationally to areas with similar edapho-climatic and pest conditions, with high probability of successful adaptation.

Table 6. Summary of results of hybrid cassava seeds direct-planted in moderate and high stress sites in Colombia.

| Site | Year | Number of seeds planted | Germination (%) |
|---|---|---|---|
| Media Luna | 1980 | 3,961 | 28.3 |
| | 1981 | 3,570 | 53.6 |
| Valledupar | 1981 | 1,935 | 40.9 |
| Carimagua | 1978 | 21,610 | 38.5 |
| | 1979 | 36,404 | 26.5 |
| | 1980 | 13,086 | 44.2 |
| | 1981 | 9,834 | 29.9 |
| Popayán | 1980 | 171 | 26.0 |

Table 7. Average yield data of promising cassava germplasm accessions and hybrid lines. Summary of seven years of trials by CIAT regional trial and varietal improvement sections at 12 Colombian locations.

| Genotype | | Fresh root yield (t/ha/yr) | Root dry matter Content (%) | Dry root yield (t/ha/yr) |
|---|---|---|---|---|
| Germplasm Accession | | | | |
| M Col 22 | (47)[1] | 22 | 34 | 7.4 |
| M Col 1468 or CMC 40 | (55) | 28 | 30 | 8.4 |
| M Col 1684 | (55) | 30 | 31 | 9.3 |
| M Ven 218 | (28) | 25 | 33 | 8.2 |
| Hybrid Line | | | | |
| CM 91-3 | (25) | 29 | 34 | 9.8 |
| CM 321-188 | (24) | 33 | 35 | 11.4 |
| CM 342-55 | (22) | 32 | 29 | 9.2 |
| CM 342-170 | (21) | 29 | 33 | 9.4 |
| CM 489-1 | (23) | 35 | 29 | 10.3 |
| CM 507-37 | (20) | 28 | 31 | 8.8 |
| CM 523-7 | (20) | 23 | 37 | 8.4 |
| Local Control | (79) | 17 | 33 | 5.7 |

[1]Figures in parenthesis indicate number of trials in which each genotype has been tested.

Source: CIAT. 1981. Cassava Program 1981 Annual Report. Cali, Colombia.

## Advances in Selection

The breeding strategy has resulted from a careful evolution of experience in cassava research at CIAT and other institutes. CIAT has been selecting cassava in a range of low, moderate, and high stress environments since the earliest years of the cassava program. Regional trials data over 7 years illustrate the high potential for increasing cassava productivity with simple technology (good land preparation, stake selection and treatment, adequate planting density, and timely weed control) combined with new varieties (Table 7). In all low to medium altitude sites (selection for high altitudes is recent), selected clones have outyielded local varieties. Similar results have been observed in international trials (CIAT, 1980). In addition to many clones having high tolerance to stresses in individual ECZ's, others have been identified with broad resistance across several distinct zones. These data provide solid evidence for the potential of increasing the productivity of cassava in stressful environments by breeding combined with simple cultural practices. At the same time, these stress-tolerant clones can respond to higher productivity environments.

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# A Comprehensive Breeding Approach to Pest and Disease Problems of Cassava

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## ABSTRACT

The relationship of edapho-climatic characteristics to cassava genotypes and their pests and diseases is discussed. The stability of genotypes on an ecosystem basis and in relation to their resistance to biotic factors as well as to growers' socio-economic needs and priorities are also discussed. On the basis of these, an improvement program is suggested which integrates several parameters of evaluation.

Cassava (*Manihot esculenta* Crantz) is a vegetatively propagated crop domesticated and improved by traditional growers for more than 4000 years (Leon, 1977). Traditional clones are the result of a slow process of a nature-man system of improvement in which nature has made the crosses and man the evaluation, selection, and multiplication. What we have observed in relatively unperturbed systems is a biological stability (relative absence of pest outbreaks and low but stable yields) apparently the result of interaction of adapted local varieties and traditional cultural practices (multispecific or multiclonal plots).

Within regional populations great genetic variation often exists. Commonly, many clones have a degree of resistance to most biotic and physical stresses in the ecosystem where they were selected along with the quality required to fit the socio-economic needs of the growers.

## Cassava Domestication and Selection

*Manihot esculenta* originated in America with a major center of diversity in South America and a secondary center in Guatemala and Mexico (León, 1977). It has been disseminated through south Brazil, Paraguay, north of Argentina to central Mexico, Cuba, and the Caribbean Islands.

Early plantations were probably isolated, locally by forests and regionally by mountains. Growers followed a slash and burn agricultural system in which cassava was planted in association with other crop species. In some areas, notably in Brazil, this system has evolved to a multiclonal monocropping system in which several clones are mixed or planted in close association. Land preparation, weed control and selection of the planting material have become more sophisticated since cassava was domesticated. Many planting systems may be found in a relatively small area, and vary regionally also.

Many cassava varieties produce out-cross seed in the normal cropping time. Mature seeds fall to the ground where they lie dormant. As the land is prepared for further cultivation the trash and weedy vegetation are burned. The heat releases the cassava seed from dormancy and the seeds germinate. In Amazonas and other regions the growers notice and care for the most vigorous seedlings and follow their performance comparing them with their "parent" varieties. If the new plant survives (a "what-is-left" integrated evaluation procedure) and if it gives a satisfactory "yield", or if planting material from known cultivars is limiting, stakes from it are used as planting material in the following cycle. Continued satisfactory performance leads to an increasing contribution of the new type to cassava production.

## Cassava/Ecosystem Relationships

The most commonly encountered description of cassava before the 1970's was as a rustic crop, resistant to almost all biotic and abiotic problems, and particularly well suited to regions with poor soils and prolonged drought (Phillips, 1974). Treatments of the crop often implied that it was adapted to a wide variety of environments. However, earlier descriptions really reflect the plasticity of the species rather than of a particular cultivar.

Recent experimental results demonstrate that the impression of a strong cassava-ecosystem interaction of traditional cultivars is correct:

1. Etiological and epidemiological investigations show that cassava pests (diseases, insects, mites) are not universal. Their presence and incidence are limited by specific climatic and/or edaphic characteristics that restrict them to ecological zones.

2. When planting regional and introduced genotypes in four edapho-climatic zones and evaluating the most important parameters for cassava production during three consecutive cycles it was found that the local regional varieties generally produced poorly in all other edapho-climatic zones.

3. Mean reactions of groups of clones from contrasting edapho-climatic zones and from similar edapho-climatic zones, showed that native cultivars in each environment had the highest levels of resistance to the limiting factors existing in each zone (Figure 1). No cultivars were resistant to the biotic constraints of more than two edapho-climatic zones. Resistance to the main limiting factors of a given edapho-climatic area is much higher in cultivars from areas similar to the testing site than in those edapho-climatic zones with a substantially different set of limiting factors.

## Stability in Cassava

Stability is probably best judged by the continued survival of genotypes in a region. Many examples exist in different cassava growing areas: The clone Rayong I was probably introduced to Thailand earlier than 1960 and it is today grown on over a million hectares (Sinthuprama, 1978); Sta. Catarina was selected in Sao Paulo about 70 years ago and it is currently being planted on more than 300,000 ha in this state and the Campo Cerrado of Brazil; Secundina has been planted for more than 20 years in the north coast of Colombia on approximately 7,000 ha; Chiroza has been grown in Caicedonia, Colombia, on more than 6,000 ha since 1970. In

practically any edapho-climatic zone where cassava is grown one or more widely planted native genotypes which have been used for many years are still used.

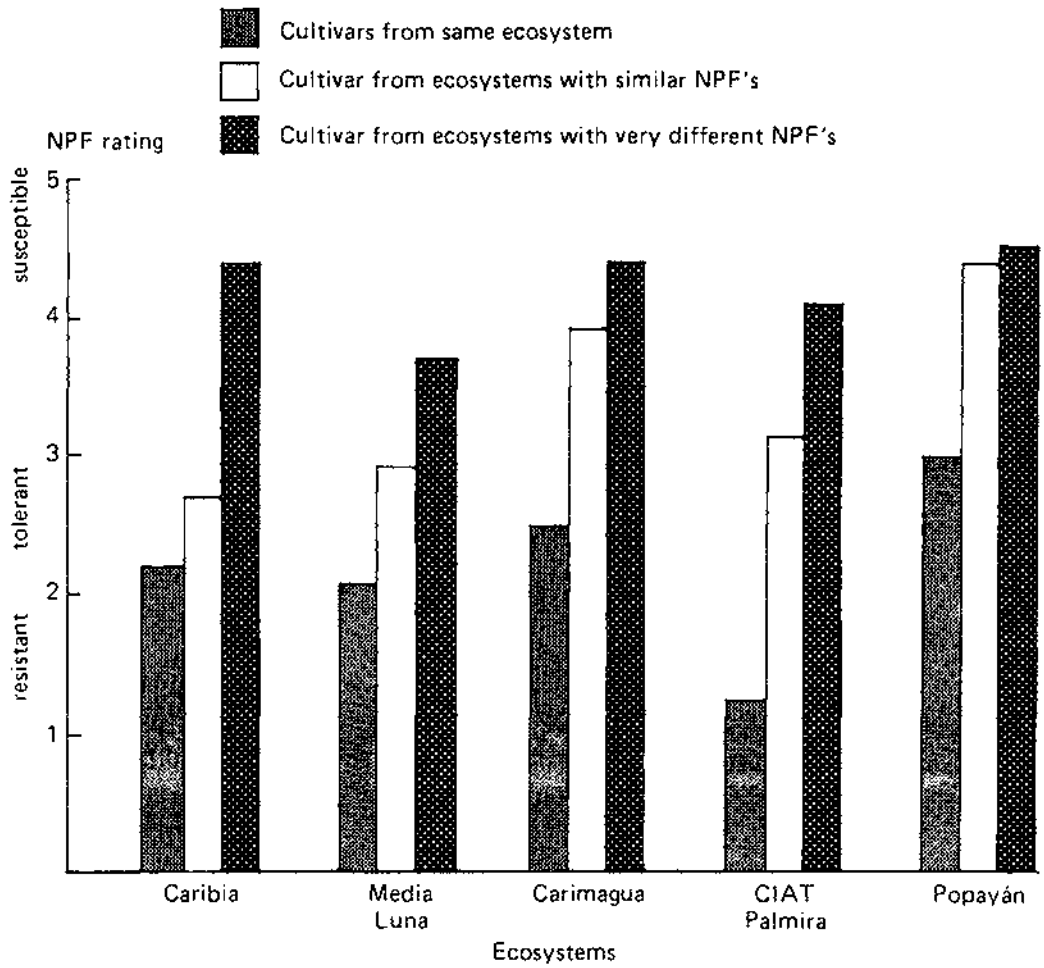


Figure 1. Mean reaction of 25 cassava cultivars (collected or selected in four different edapho-climatic zones and all planted across edapho-climatic zones) to the negative production factors (NPF's) present in each site.

The stability of yield in nine consecutive-year trials has been recorded in the Popayan area for native and introduced genotypes. In the Carimagua zone, yield, cutting, and starch production and the stability of plant reaction after CBB epidemic infections for several growing cycles has also been recorded for introduced and native clones, but generally the data available on other parameters regarding stability and its complexity on cassava have not been investigated in depth.

## A Program for Genetic Improvement

Based on considerations of the previously described physical, biological and socio-economic parameters, a basis for genetic improvement of cassava is presented. The discussion focuses on the principles of choice of evaluation sites, evaluation methodology, and parameters of evaluation.

## Evaluation Sites

The number of evaluation sites necessary in a breeding program depends upon diversity of the target area, and the breeder's ability to select in any given site for performance in a specified region. In general terms, the evaluation sites should be where soil characteristics (pH, structure, fertility) and climate (rainfall distribution, relative humidity, temperature ranges and photoperiod) are similar to these of the target area. The number of evaluation sites must necessarily be limited by what is practically and economically feasible for a program to manage.

The biological and physical stresses or constraints to production of each edapho-climatic zone are often multiple and complex. To select genotypes with the widest possible adaptation to different constraints within a region, the selection site should ideally include a wide range of stress conditions, in moderate to high levels, and with a degree of season to season repeatability.

## An Evaluation Methodology

Evaluation should permit selection of genotypes with durable integrated resistance to most constraints in the target production area. On this basis, ideally, select under field conditions, where stress balance factors provide opportunity for simultaneous considerations of various factors, resulting in an integrated resistance. Artificial inoculations or special cultural practices may be useful to increase intensity or uniformity of given constraints, or even to decrease the intensity if a stress factor appears to have potential of masking all genetic differences in the material being evaluated due to its intensity.

Selection should include periodic evaluations of each constraint during the periods of the growth cycle in which it is expressed (e.g., diseases during rainy periods; insects and mites during dry periods). The durability of the resistance of selected material can be partially confirmed by continuous evaluations during several growing cycles, where planting material is produced in situ from the previous cycle.

Finally, some integrated measure of adaptation/resistance in the edapho-climatic zone is more important than the individual disease or insect evaluations. The integrated measure may be a general evaluation of plant health for the top growth, combined with root yield and quality. Including standard local and selected checks permits rational decisions about relative performance of new materials.

## Parameters of Evaluation

The following parameters of evaluation have been taken into consideration in CIAT's Cassava Program. Some have been described previously (Nestel and MacIntyre, 1975).

a. Germination. Record simply by counting number of plants one month after planting.

b. Vigor. Vigor is evaluated subjectively and relative to the particular trial with reference to standard check varieties. A vigor rating is made from 3 to 5 months after planting.

c. Plant type. The evaluation of plant type is divided into three components: number of levels of branching, height of first branch, and plant height.

d. Leaf area. Leaf area index of about 3.0 has been defined as near optimum for cassava (Cock, 1976). Because measure of leaf area is impractical for evaluation of large numbers of genotypes, a simple measure of the length of stems maintaining foliage is used during early evaluation stages to give some idea of the potential of a clone for continued photosynthesis up to the end of the growing cycle.

e. Disease, insect, and mite resistance. Evaluations are based on a damage rating scale, closely related to the level of genetic resistance.

Most appropriate planting time is one which corresponds to that most commonly used by farmers in the target region. Thus, the balance of disease and pest pressure under which evaluation is done will be similar to that under commercial conditions. If the crop is commercially planted during different times of the year, the selection program should conform.

f. Yield and harvest index. A generalization under high productivity environments, select for high harvest index in early selection stages, low productivity environments, select for yield itself, along with reasonable harvest index.

g. Yield of planting materials. Stem piece (cuttings) yield and quality are important for productivity and durability of genotypes so these should be quantified during evaluation.

h. Root quality. Quality of roots may be critical to acceptability of a variety intended for human consumption. Quality is normally less critical for industrial uses.

1. Starch content and quality. Yield of the crop is appropriately expressed either as dry matter or starch production, the two being closely correlated.

2. Pre-harvest root rot. A simple measure of percentage rotted roots at harvest can distinguish varietal differences where environmental conditions permit moderate expression of root rot.

3. Post-harvest root deterioration. An evaluation procedure for physiological deterioration involves scoring 15 cm root pieces after 3 days of storage (CIAT, 1979), with a large number of replicates. The combination of physiological and microbial deterioration can be evaluated after 1 or 2 weeks of storage.

4. HCN content. A rapid picric acid determination gives a good general indication of HCN presence in the roots and is useful when many genotypes are to be evaluated.

5. Cooking quality. Taste, texture, bitterness and fiber can be evaluated subjectively after cooking.

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Cassava Germplasm in Australia

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ABSTRACT

Information on the origin and productivity of cassava germplasm in Australia is presented. Two distinct sources of genetic material are available to Australian agronomists, physiologists and breeders. One group (denoted by the prefix, M Aus) is made up of the remnants of largely undocumented introductions made early in this century and rediscovered in recent years surviving along roadsides, creek banks, and in household or municipal gardens. The second group consists of material introduced in the last ten years from Thailand, Puerto Rico, and CIAT in Colombia.

Data on root yield and other characters of physiological interest are presented for representatives of both sources of germplasm. The locally collected cultivar, M Aus 7, has given the highest yield under our experimental conditions in southeast Queensland. Recently introduced cultivars are not as productive as locally collected cultivars, particularly during the first year of growth. Some vigorous cultivars of the recent introduction group, in particular Ceiba from Puerto Rico, show improved yield performance during the second year, while the less vigorous types from both groups fail to increase yield substantially after the first year. Some possible physiological reasons for the different yield performance of these two germplasm sources are discussed, and the options open for improvement of cassava germplasm in Australia are considered.

# Food Quality and Chemical Composition

## Changes in Cyanide Content of Cassava Tissues as Affected by Plant Age and Variety

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ABSTRACT

Two cassava varieties, CMC-40 (low cyanide) and CMC-84 (high cyanide), were studied from the 9th to the 12th month of age of plants. Highest cyanide concentration was in the root and the lowest in the parenchyma; the leaves showed intermediate concentration as compared to the root tissues. Roots of CMC-40 had high levels of cyanide in their peels, especially at 9 months of age; the cyanide in the root peels of both varieties diminished with the age of the plant. Concentration of cyanide in the parenchyma was the most stable parameter and was practically not affected by plant age; the cyanide content of the root parenchyma of variety CMC-84 was approximately three times higher than that of roots of variety CMC-40 (623 ± 25 vs 234 ± 10 ppm, dry matter basis). Changes in cyanide content of leaves of CMC-40 were more pronounced than in variety CMC-84. Ninety percent or more of total cyanide in cassava tissues was present as the cyanogenic glucoside or bound cyanide.

## Introduction

Cassava roots, an excellent source of carbohydrates, are used in a wide variety of food products for human consumption. While only the parenchyma is the edible part of the root, the root cortex or peel is used by itself or as a component of whole-root chips for animal feed. Cassava leaves are also used in some countries as food vegetables or as animal feed.

Cassava contains the cyanogenic glucosides linamarin and lotaustralin (Conn, 1969). Medical studies (Ermans et al., 1980) have demonstrated that cassava ingestion, together with iodine deficiency, is a factor in the etiology of endemic goitre and cretinism in Central Africa. It is thought that the goitrogenic factor is thiocyanate produced by the cassava cyanide detoxification processes of the body.

Cassava varieties grown under similar edaphoclimatic conditions differ widely in root cyanide content (Gómez et al., 1980). In addition to varietal differences, other factors appear to affect cyanide content of cassava tissues (Bolhuis, 1954; De Bruijn, 1971). The variety and the age of the plants are normally considered as two important factors affecting both the yield and the quality of cassava roots. Because of limited information on this subject (Cooke and De la Cruz, 1982), one study has been carried out at CIAT to ascertain effects of these

two factors on the cyanide content of cassava tissues. Roots and leaves of two varieties (CMC-40, low-cyanide cultivar, "sweet", and CMC-84, high-cyanide cultivar, "bitter") were evaluated, from 9 to 12 months of age, at monthly intervals.

## Materials and Methods

Two cassava varieties, CMC-40 and CMC-84, were planted in adjacent fields in April 1980, at a density of 1x1 m (10,000 plants/ha); a total of 4,400 stakes of each variety was planted. The soil had a pH range of 7.2 to 7.8, a phosphorus level of approximately 40 Bray-11 ppm and in general good characteristics for cassava production previously described (Kawano et al., 1978). Total rainfall during the year of study (April 1980-March 1981) was 740 mm, with two drought periods (July-September and November-January); the overall average ambient temperature was 23.9°C.

At monthly intervals, from January 1981, areas of 560 plants (after borders were discarded) were harvested. From the total sampling area, 20 plants of each variety were selected at random ensuring that each sample plant was bordered all around. Leaves and roots of each plant were weighed in the field and immediately transported to laboratories in paper bags; leaf and root tissue samples were prepared for cyanide analyses within 1 and 3 hours after harvest, respectively.

Leaves of each plant were chopped, mixed and an accurately-weighed ~4 g sample was immersed in orthophosphoric acid, homogenized and filtered (Cooke, 1978). Roots were cleaned with a soft brush or washed if necessary. About an hour after measurement of specific gravity, the peel (root cortex) of each root was removed with a knife and then peel and parenchyma (peeled root) tissues of each sample plant were weighed. Cross transverse slices of peeled roots were cut along the length of the roots of each plant to obtain a representative sample for cyanide analyses. Root parenchyma slices and peels from roots of each sample plant were separately diced and manually mixed before samples were taken for analyses. Parenchyma (~60 g) and peel (~10 g) weighed samples were rapidly transferred (~5 min after the beginning of the milling operation) into orthophosphoric acid and homogenized. Total and free cyanide contents were determined in the leaf and root tissue homogenates using an enzymatic assay (Cooke, 1978). The dry matter (DM) content of leaf samples was determined by drying a 10 g sample of the chopped tissue to constant weight at 60°C in a convection oven whereas DM of parenchyma and peel tissues was determined in a vacuum oven at 90°C. Cyanide concentration in the cassava tissues is expressed on dry matter basis and data was analyzed for statistical significance by analysis of variance using the Statistical Analysis System (1979).

## Results and Discussion

Figure 1 shows changes in total cyanide content in peel and parenchyma of the roots as well as in leaves of plants of the two varieties studied. Highest concentration of cyanide was in the peel and lowest in the parenchyma; the leaves showed intermediate cyanide contents, when compared with the root tissues. Roots of variety CMC-40, considered a low-cyanide cultivar, had high levels of cyanide in their peels, especially at 9 and 10 months of age; cyanide in root peels of both varieties diminished with age of the plant and this decrease was more pronounced in roots of variety CMC-40.

Concentration of cyanide in the parenchyma was the most stable parameter and was practically not affected by plant age; cyanide content of the parenchyma in

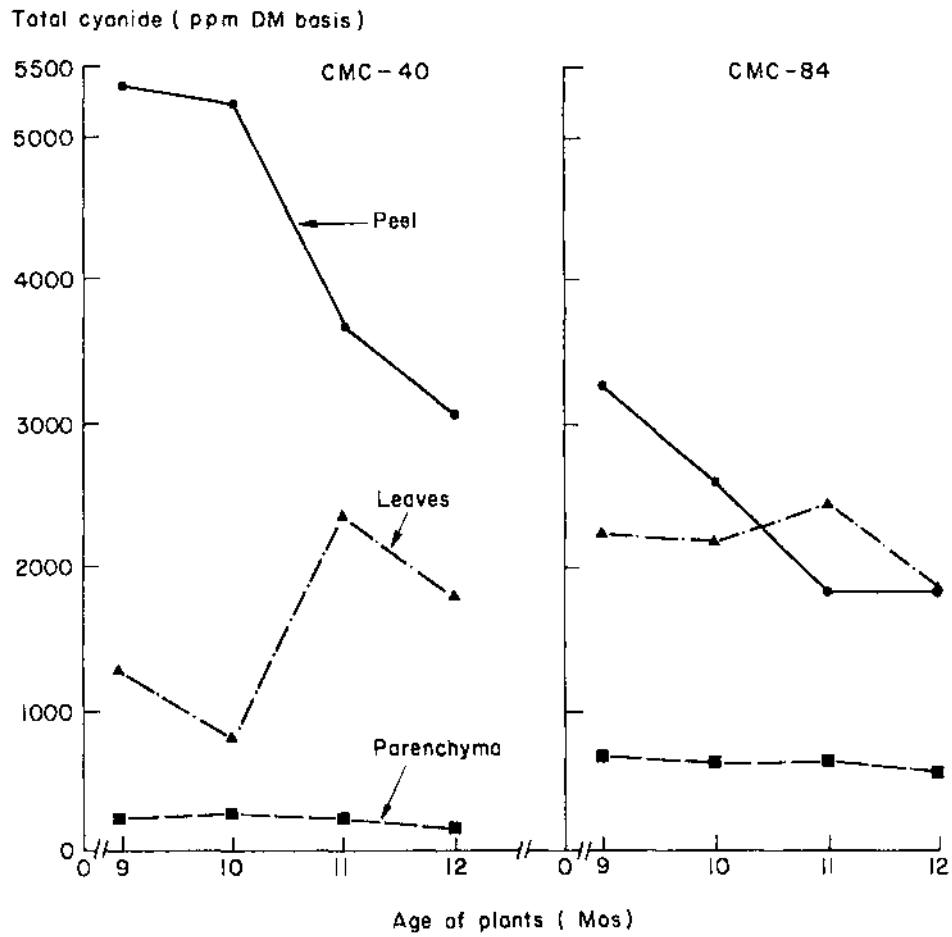


Figure 1. Effect of age of plant on total cyanide content in cassava leaves and roots (peel and parenchyma).

roots of variety CMC-84 was approximately three times higher ($P < .05$) than that in roots of variety CMC-40 (623 ± 25 vs 234 ± 10 ppm on DM basis).

Cyanide content in leaves did not follow a definite trend and changes observed throughout the experimental period differed between the two varieties; changes in cyanide content of leaves of variety CMC-40 were more pronounced than those of variety CMC-84.

Results of cyanide analyses have also confirmed (Nartley, 1978; Gómez et al., 1980) that 90% or more of the total cyanide in cassava tissues is present as cyanogenic glucoside (linamarin) or bound cyanide and only a small proportion (3% to 10%) is found as free cyanide (Figure 2). Proportions of free and bound cyanide in tissues of variety CMC-84 appeared to be less affected by age of plant than in the samples of variety CMC-40; these proportions in the parenchyma tissue were also less variable than those of the root peel and leaves (Figure 2).

Linear correlation coefficients were computed (Table 1) between cyanide levels of tissues analyzed for each variety and sampling date. Some significant correlations, notably with the variety CMC-84, were found between cyanide levels of leaves/root peel and peel/parenchyma, but practically no relationship between those of leaves and parenchyma. These results explain the lack of success of attempts made to obtain a close correlation between cyanide content of leaves and roots so as to predict cyanide level of the latter (root parenchyma) without the need for harvesting the plants.

Table 1. Linear correlations of total cyanide contents in leaves and roots (peel and parenchyma) of the varieties CMC-40 and CMC-84.

| Variety and age of plants | n | Peel parenchyma | Peel leaves | Leaves parenchyma |
|---|---|---|---|---|
| | | Linear correlation coefficients (r) | | |
| CMC-40 | | | | |
| 9 | 20 | 0.45 | 0.11 | 0.13 |
| 10 | 20 | 0.35 | 0.18 | 0.00 |
| 11 | 18 | 0.60** | 0.25 | 0.30 |
| 12 | 20 | 0.66** | 0.15 | 0.35 |
| CMC-84 | | | | |
| 9 | 19 | 0.63** | 0.40 | 0.06 |
| 10 | 20 | 0.56* | 0.57** | 0.57** |
| 11 | 15 | 0.77** | 0.58* | 0.10 |
| 12 | 20 | 0.62** | 0.66** | 0.37 |

* = $P < 0.05$; ** = $P < 0.01$.

Acknowledgments

The authors thank Déborah de la Cuesta and Teresa Salcedo for help in laboratory analyses and to Eduardo Granados for collaboration in statistical analyses.

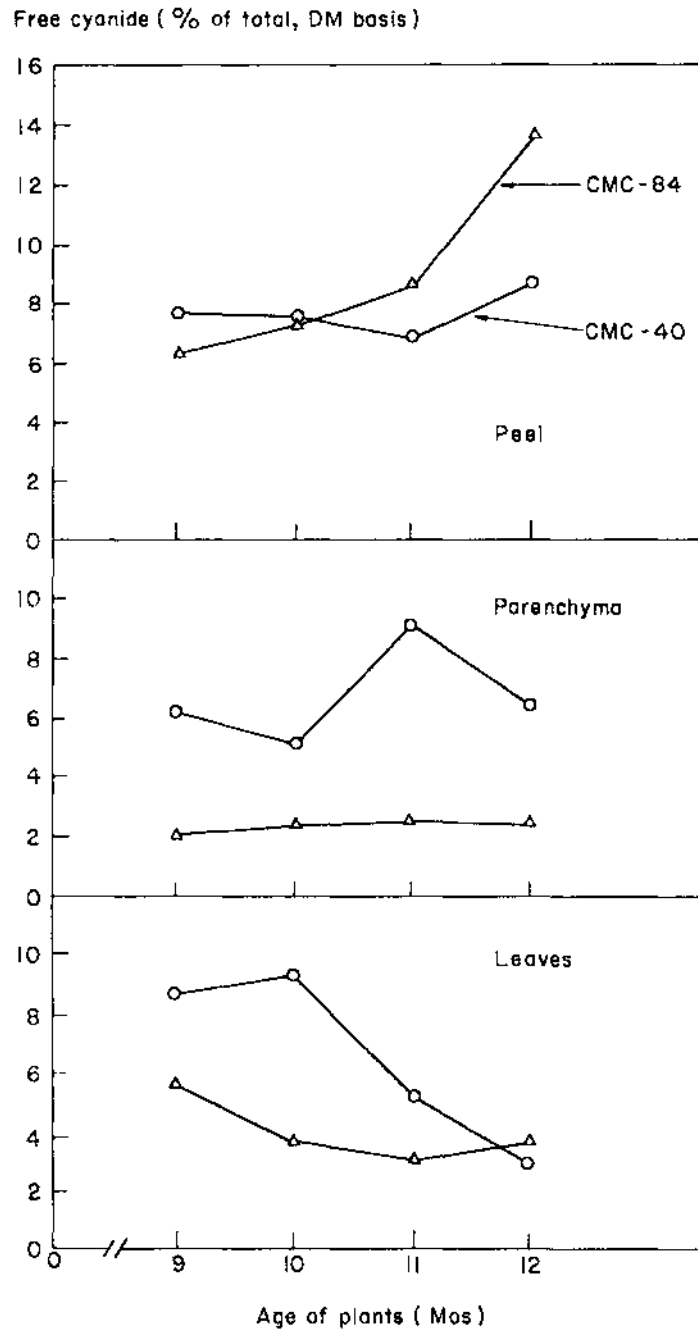


Figure 2. Free cyanide (% of total) in cassava tissues as affected by age of plants of two varieties.

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Processing and Detoxification of Cassava

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ABSTRACT

Cassava contains the cyanogenic glucoside linamarin, which, on hydrolysis, yields hydrocyanic acid, one of the most toxic plant substances known. After processing, some of the cyanide is still left in the product and has been implicated in the etiology of such diseases as goiter and tropical ataxic neuropathy. Because of this, efforts are now being made to products that are cyanide-free.

The various methods of processing are reviewed with emphasis on the production of gari, which is one of the most typical and best studied products. The rate of detoxification in each process is shown. Experiments simulating the various processes aimed at improving the quality of the products are discussed, and the rate of detoxification is given. The detoxification problems are reviewed. On the whole, it appears that sun-drying is an inefficient method of detoxifying cassava; however, soaking in water is much more efficient. The best combination is sequential soaking, sun-drying, and cooking, which will virtually remove all the cyanide.

## Introduction

One would wonder why a fibrous toxic root with hardly any protein could be the staple of millions of people in the tropics where the actual nutrient that is in short supply is protein. There is also energy shortage as only about 68% of the energy requirement is available (Gutiérrez and Anderson, 1972). Hence, it is desirable to produce more of it, and future demand will increase because it is not regarded in the tropics as an inferior food.

From the literature cassava represents about 14% to 58% of the total caloric intake in 14 countries, and when this is limited to certain areas of a particular country, the true picture will emerge. For example in south eastern Nigeria cassava contributes about 43% to 73%, and if taken with yams about 82% to 93% of the total calorie intake. Normanha (1970) reported that in Brazil in 1962-63 cassava consumption was 124 kg person per annum at the national level, representing an urban intake of 42 kg and rural intake of 200 kg. Phillips (1974) maintained that cassava will continue as an important staple in the human diet and can supply about 500 million persons with about 50% of their energy need. By 1990 it is possible in spite of the increase in production, Africa may only have about 5% surplus, although the Far East and especially Brazil would have a lot of surplus.

From reports of several investigators it could be summarized that the population which lives on cassava and its products have higher serum and urinary concentration of SCN than the control population in Europe or elsewhere with little or no consumption of cassava. Moreover differences also occur from one region to the other as well as in the methods of preparing cassava-based meals. The question then arises as to whether this SNC overload is due to the original cyanide content of the fresh cassava roots or of the cassava products eaten. It is pertinent that Bourdoux et al (1982) found distribution of cyanide content of fresh cassava roots among the Ubangi, Kivu and Bas, Zaire regions of Zaire where there is SNC overload and high cases of goitre are as follows:

The percentage of innocuous roots (HCN content less than 50 ppm) increased from 45% in Ubangi to 56% and 80% in Kivu and Bas Zaire respectively. In contrast the percentage of dangerously poisonus (HCN content higher than 100 ppm) was almost identical in Ubangi (24%) and Kivu (21%) and was markedly lower in Bas Zaire (4%).

It is therefore essential to review the various methods of preparation of cassava-based foods and find out the extent of detoxification by the various methods and also suggest means of improvement of the methods.

Detoxification

When cassava is processed into foodstuffs, not all the cyanogenic of glucosides are eliminated. Some remain and are ingested. In the absence of B-glucosidese, most glucoside is excreted unchanged in the urine and very little from the feces (Oke and Adewusi, 1981). However, if taken together with leaf components or other ingredients that may contain a B-glucosidase (in addition to the residual linamarase and cyanogenic glucoside which will react on rehydrating) then hydrolysis takes place and hydrocyanic acid (cyanide) is librated. As is well recognized cyanide is one of the most powerful poisons known. It is destructive to all forms of life in which it affects both the individual cells such as the important nerve cells, and also reasts with hemoglobin of the red blood corpuscles to form cyanohemoglobin. Death results shortly after a sufficient dose is ingested. It interferes with enzymes which play an important part in life processes and is therefore a violent protoplasmic poison for all forms of life whether they be bacteria, yeast or germinating seeds. In certain fish ova it suspends the autolytic process accompanying death so that the cells remain in condition between life and death for several days. On the other hand if the amount of cyanide released is minimal then the body has a very efficient system of detoxification to thiocyanate (SNC) through the enzyme rhodanese as has been reviewed by Oke (1969).

Toleration of hydrocyanic acid in foodstuffs and animal feeds, and methods of reducing it in fresh roots to within suitable limits, are major problems in the use of cassava products. It is difficult to remove the last traces without making the food unsuitable for consumption. Even when the sweet variety is boiled or dried or when the bitter is fermented there is still the possibility of some residual cyanide, and the range may be wide, 10 to 120 ppm, depending on the cyanide content of the fresh root.

It appears that fufu prepared by soaking and sun-drying cassava is the most efficient detoxification process (HCN sometimes less than 1 ppm) whereas those prepared by sun-drying alone e.g. fuku is less efficient (HCN about 17 ppm).

Those fermented and fried could be effective provided it is fried with palm oil while fermentation and syn-drying seems to be very effective.

Since peeled cassava root contains about 61% water and a soluble toxic cyanogenic glucoside, then the first stage in the detoxification is the removal of at least part of the water which will cary the toxin with it. This is done in several ways as already described (e.g. putting in a sack and weighing it down with stones, centrifuging as is done commercially, use of mechanical press, manual squeezing). Most of residual glucoside (and water) is then eliminated by some form of heating. In some cases there is an initial step of soaking the root for some days during which the microflora in the cassava cause fermentation which is now to be complementary to the activity of the endogenous linamarase which effectively carry out the degradation. Maduagwu and Oben (1981) found that inhibition of linamarase activity by 1,5-gluconolactone (a potent inhibitor of B-glucosidase activity) resulted in a significant lowering of the degradation of linamarin by about 35% in 24 hours and 65% in 72 hours. On the other hand when glucose is included in the above medium, there is an enchanced degradation by about 10% especially after 36 hours which is presumably due to an increase in microbial population in situ. Since various cassava species contain different amounts of sugars this may become an important factor in the relative rate of fermentation. When fermentation was inhibited by sterilization or by addition of sodium iodoacetate, the rate of disappearance of bound cyanide from the medium was similar to the control especially within the first 48 hours indicating that it is the endogenous linamarase that effectively cause the breakdown of the linamarin.

In some cases detoxification is carried out by heating only. This seems to be effective in some cases and not in others because the heat may result in the breakdown of the enzyme linamarase without affecting the glucoside. Thus cooking destroys the enzyme at about 72°C leaving about 90% of the glucoside intact. In a similar way simple drying of slices or rasped root is capable of removing about 90% of the glucoside at 60°C but is less effective if heating is carried out at 100°C due to denaturing of the enzyme. On the contrary Paula and Rangel (1939) reported that cassava containing 39 ppm was reduced to 17 ppm by sun drying and to 6 ppm by oven drying. Joachin and Panditteserkere (1944) reported that boiling a variety of cassava roots containing 103 to 232 ppm could reduce the cyanide content to 27 to 87 ppm without correlation to the initial content of cyanide in the roots. Those that did not become soft and floury on boiling were least affected. Raymond et al (1941) was able to reduce the cyanide content from 332 to 10 ppm by boiling while Paula and Rangel (1939) got rid of all the cyanide in their root by boiling only. Steeping in warm water for short periods before drying can reduce the cyanide content to a considerable degree especially if it is grated as well. Thus Razafimaherry (1953) reported that the Madagascar food product, Bournoka, which is prepared by steaming, is free of cyanide.

From the traditional processing of cassava, the glucoside is eliminated either at the soaking (fermentation) stage or else during the heating stage (especially with palm oil) or both. In Nigeria the effect of cyanide toxicity is counteracted by giving palm oil and it is interesting that gari prepared by drying the fermented cassava pulp with palm oil usually does not contain any cyanide compared 5 to 20 ppm in those fried without palm oil (Oke, 1979). The effect of palm oil on cyanide toxicity is the subject of investigation at present (Oke and Fumiyan, 1982).

Again, among various cassava products, gari is the one that has been extensively studied and so most of the mechanism of detoxification will be

inferred from it. Bark or cassava contains most of the enzyme while the inner part contains little. During peeling and grating the enzyme comes into contact with the glucoside and hydrolysis takes place librating cyanide, the rate depending on the length of time contact is made. This is probably why fermentation is allowed to proceed for days. This could, however, be accelerated if the whole root is grated as the activity of the enzyme in the bark (and leaves) is so great that hydrolysis is complete within a very short period (1 hour). A lot of work has been done in this respect by Meuser and Smolnik (1979). As is well known the first stage of breakdown of linamarin is hydrolysis to glucose and cyanohydrin, and the latter then breaks down to acetone and hydrocyanic acid. So the cyanide in cassava can occur as free hydrocyanic acid or as bound (glucoside or cyanohydrin). However, because of the high instability of cyanohydrin at pH values over 5.0 (the pH of the pulp is usually about 6.0) the equilibrium is usually to the right i.e. release of cyanide (Cooke, 1978) and so Meuser and Smolnik (1979) devised a means of getting rid of the fruit water in gari preparation to limit the cyanide content to less than 10 ppm. The next problem is getting rid of the residual cyanide by heating. Their results from different drying techniques show that freeze drying or flash drying eliminates only the free cyanide which accounted for only 50% of the total cyanide present; whereas roller drying or drum drying of the fresh pulps at pH of 5.5 to 5.8 removes all the cyanide almost completely. Here thermal decomposition of the glucoside probably takes place and the equilibrium to the right (i.e. cyanide release) is favored. On the other hand roller drying of fermented pulp or drum drying of fermented and dewatered pulp results in high residual cyanide due to the lowering of the pH to 3.8 which favors the equilibrium to the left i.e. high stability of cyanohydrin. Under this condition there is no more release of cyanide and equilibrium between bound and free cyanide is stabilized in favor of the bound cyanide in the form of cyanohydrin. The optimum condition was therefore chosen for the drying of the chips i.e. in a warm air stream.

Table 1. Composition of cassava and its products (% of dry matter).

| | Cassava | Gari | Fufu | Lafun | Kpokpogari |
|---|---|---|---|---|---|
| Starch | 89.3 | 87.8 | 95.8 | 96.4 | 78.1 |
| Sugars | 5.0 | 0.5 | 0.6 | 0.8 | 0.5 |
| Protein | 2.5 | 1.0 | 0.6 | 0.8 | 1.5 |
| Minerals | 2.5 | 1.1 | 0.5 | 2.0 | 5.2 |
| Crude fiber | 3.2 | 0.6 | 0.2 | 0.7 | 4.2 |
| Ether extract | 0.5 | 0.1 | 0.1 | 0.4 | 0.0 |
| Hydrocyanic acid (ppm) | 380 | 19 | 25 | 10 | 11 |

Another way of eliminating the cyanide is by allowing the fermentation to proceed for longer period (5 days) to allow the water binding capacity of the mash to be sufficiently changed so that the fruit water can be pressed out to a reasonable degree, carrying with it the toxic cyanide. The bound cyanide can also be eliminated from unfermented pulp by diluting the fruit water. About 50% of the fruit water can be separated as a relatively concentrated solution. This is extremely useful for the elimination of the acidic and toxic fruits water. Using this newly developed process the cyanide content of the gari prepared by Meuser and Smolnik (1979) can be eliminated almost completely.

To understand fully the mechanisms involved in detoxification processes and be able to improve on the traditional methods, the preparation of the various foodstuffs was simulated in the laboratory (Bourdoux et al, 1982; Ketiku et al, 1978). It was found that by increasing the soaking time or boiling time the detoxification process could be improved significantly. The improved method gave cyanide concentration of about 1 ppm as opposed to an average of about 10 ppm (range 1.25 ppm) for the traditional methods. As indicated for fuku, drying the roots for 1 to 2 days showed an increase in the cyanide content. This was due to removal of water from the roots which range from 14% in the first day through 51% in the second day and progressed to about 70% by the eighth day without concomitant loss of cyanide. This therefore resulted in an increase in the cyanide content. Heating in an oven to constant weight at low temperatures gave a similar result to sun-drying. Starting with the fresh root (73.5 ppm) the cyanide content increased to 116.7 ppm on heating at 60°C, but dropped to 28.5 ppm, at 105°C and less than 1% at 165°C. The latter two temperatures are higher than the decomposition temperature reported for linamarase, 72°C (Joachim and Panditteseke re, 1944) and linamarin, 150°C (Cerighelli, 1955). This means that at such high temperatures, though the linamarase is destroyed, the linamarin is decomposed by heat and so this is an effective method of detoxification. Unfortunately such temperatures are never attained in practice.

More details of the reactions taking place when cassava is heated at different temperature has been given by Cooke and Maduagwu (1978).

About 29% and 26% of the bound cyanide were lost after drying at 46.5°C and 60°C, respectively, for 18 hr, while the corresponding figures for free cyanide were 82.5% and 83%, respectively. The similarities were probably due to the stability of linamarase at these two temperatures. At higher temperatures of 80° and 100°C there was a faster drying rate with a loss of about 96% free cyanide in both cases but 10% of the bound cyanide at 80°C and 15% at 100°C, the increase probably being due to enzymic browining at 100°C (McWeeny et al, 1974). Drying at lower temperatures caused a gradual drying which took longer at moisture contents and temperatures at which linamarase is active whereas at higher temperature it is very rapid with low moisture contents and above the temperature of stability of linamarase.

Bourdoux et al (1982) found that soaking cassava roots for one day decreased the cyanide content from 108.2 to 59.5 ppm and finally to 2.9 ppm in 5 days (over 97% loss). Cooke and Maduagwu (1978) on the other hand found that rapid stirring in cold water produced a negligible decrease in bound cyanide after 4 hours but about 90% of the free cyanide was removed and most all of this could be accounted for in the water. Leaving overnight caused a marked decrease in the bound cyanide accompanied by a sour smell, indicative of fermentation. However, the free cyanide had returned to about the initial concentration probably due to endogenous linamarase activity following cellular desintegration or to microbial glucosidase activity. Over 90% of the free cyanide was removed on boiling for 15 min, but the bound cyanide was removed more slowly about 55% after 25 min. The loss in bound cyanide was parallelled by an increase in the cyanide content of the water used for boiling. The free cyanide content increased initially and then decreased probably due to the volatility of the free cyanide.

On the whole it therefore appears that sun-drying is an inefficient method of detoxifying cassava while soaking is much more efficient. The best combination will be sequential soaking, sun-drying and cooking which will virtually remove all the cyanide. It therefore appears that the differences in the amount of cyanide

intake in different regions will depend on the method of processing and the cyanide content of the fresh root, and this will affect the concentration of the serum SCN level.

## Conclusion

In most methods of processing cassava into foodstuffs there is usually residual cyanide which could vary from traces to high amounts. Among the population that consume these products, a high incidence of thyroid malfunction has been reported and this has been correlated with the ingestion of cassava products. It is therefore necessary to study more closely the traditional methods of processing cassava so as to detoxify the cyanide. More accurate analytical techniques would be needed in order to be able to follow the principles involved in the detoxification processes and be able to improve on it.

Finally we need to study more carefully cases of acute toxicity of cassava and its products so as to determine the factors involved in the toxicity i.e. whether it is the cyanogenic glusosides or other constituents which have not yet been isolated. We know that rapeseed contains saturated and unsaturated nitriles in which the cyanide grouping is not directly linked to sulphur, and this can also result from the hydrolysis of rapeseed glucosinolates (Lo and Hill, 1972). These substances while rather unstable, are very toxic with and $LD_{50}$ for rats of about one-eight of that of goitrin. Thus the severe growth depression exhibited by pigs, chicks and rats consuming raw ground rapessed could be atributed to nitriles rather than the known goitrogens. Also the fact that chlorogenic acid, a potent trypsin inhibitor, has been identified in the polyphenolic fraction of rapessed (Lo and Hill, 1972) could be a pointer to the fact that there might be other potentially toxic substances in cassava not yeat discovered. In addition certain unexpected chemical reactions occur in vivo which are not always detected. For example when intact apricot kernels are steeped in cold water considerable quantities of soluble matter are extracted along with the bitter cyanogenic glycosides prunasin and amygdalin. Endogenous emulsin catalyses the hydrolysis of these two glycosides to glucose and mandelonitrile and the latter then reversibly disassociates into benzaldehyde and hydrogen cyanide. When an attempt was made to recover the extracted matter by concentrating the aqueous solution at temperatures below 40°C, there is a production of new bitterness not attributable to the original cyanogenic glycosides. Spectroscopic characterization confirmed the presence of benzyl bensoate (4), mandelamide (5), butyl B-D-glucopyranoside (6) and benzyl B-D-glucopyranoside (7). The two glucosides possessed an intensely bitter taste and the probable mode of formation was worked out by Godfredsen et al (1978).

In view of the above, one might ask whether there might be other goitrogens presents in cassava or the diets of the people in the goitre-endemic areas reported by Ekpechi (1964) and De Lange (1973). Can it be due to their diathesis? We know that not all forms of nutrient have equal activity and that, for unknown reasons, some individuals have greatly increased requirements while others are susceptible to toxicity from excess. Have these people lost the ability to dispose of the thiocyanate being formed or are they metabolizing the glucoside at such an unsual rate that there is enough thiocyanate to compete with iodine, or is the problem simply one of iodine or protein deficiency? I pose these problems so that none of the salient points will be overlooked in our subsequent interpretation of data to prove the exact causes of goitre.

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Cyanide Content of Cassava Cultivars in Relation to Nitrogen Fertilization

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ABSTRACT

The effect of nitrogen fertilization on the cyanogenic glucoside content in the leaves and storage roots of four cassava cultivars (TMS 30001, 30211, 30395, and 30572), which were selected for low cyanide content, was investigated in field experiments. The cyanide level in the processed product *gari* was also determined.

Nitrogen fertilization significantly raised the hydrocyanide content in the leaves and storage roots of the cassava cultivars. After processing, all four cultivars contained similar cyanide levels in the *gari*. Traditional processing considerably reduced the cyanide level in this product.

# Observations on Cassava Mealybugs in the Americas; their Biology, Ecology and Natural Enemies

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ABSTRACT

Mealybugs constitute one of the major production problems on cassava (Manihot esculenta) in Africa and the Americas. Mealybug species identified on cassava in the Americas include Phenacoccus manihoti, P. herrene, P. gossypii, and P. grenadensis. Since its introduction into Africa from the Americas, P. manihoti has caused considerable yield losses in parts of Africa, especially Zaire. In the Americas, outbreaks of P. herreni have been reported from several areas of Brazil, Colombia, and the Guianas. These two species are similar taxonomically and cause similar damage symptoms, but differ markedly in their bionomics.

The initial attack and most severe damage by both species is to the plant growing point. Apical leaves are deformed and bunched, resulting in a "cabbage-like" effect to the growing point. High mealybug populations combined with dry season stresses can cause severe defoliation, shortening of internodes, excessive branching, dwarfism, and distortion of stems and branches. The biology of the two species differ in that P. herreni is bisexual, while P. manihoti reproduces parthenogenetically. Studies of the biology of P. herreni show that the female passes through three instars before reaching the adult stage; the complete cycle of egg through adult is 49.5 days. The male passes through four instars before the winged, adult stage; the total cycle is 29.5 days.

Numerous natural enemies of mealybugs have been identified. Biological control combined with host-plant resistance offers a safe and economical means of controlling these pests.

Mealybugs are part of an extensive complex of insects and mites that attack cassava (Bellotti and Schoonhoven 1978). They constitute a major production problem of cassava (Manihot esculenta) in the Americas and Africa. The most important species are Phenacoccus herreni, P. manihoti, P. gossypii, P. grenadensis, P. cerca surinaensis and Ferrisia virgata (Yaseen and Bennett, 1979). P. grenadensis, P. cerca surinaensis and F. virgata appear to be of only minor importance. Occasionally high populations of P. gossypii are on cassava, but this is not its primary host and attacks are usually localized (CIAT 1977).

The two most important species are P. herreni and P. manihoti. Outbreaks of P. herreni have been reported from several areas of the Americas, especially

Brazil and Colombia. Since introduction into Africa, P. manihoti has caused considerable yield losses in parts of Africa, especially Zaire. These two species are similar taxonomically and in plant damage symptoms but differ markedly in bionomics (Cox and Williams 1981).

Mealybugs are a "new" pest in cassava; only in recent years have serious outbreaks been reported. A literature search discloses that prior to about 1976, reports on mealybugs attacking cassava are limited and of minor importance.

## Species origin and distribution

Both P. herreni and P. manihoti probably originated in the neotropics. The exact origin in the Americas has not been determined. Silva (1977), reported a mealybug attacking cassava in Belem, Brazil, as early as 1973; Albuquerque (1976) reported a serious mealybug outbreak in 1975 in Belem, destroying about 150 varieties in the cassava collection. The most recent report of mealybug outbreaks in the Americas was in Pernambuco, Brasil (Bellotti and Reyes 1982); mealybugs were first observed in this area in 1978 (Bellotti pers. observation) and populations have continued to increase since. Also during 1978 mealybugs were found in Carimagua in the Colombian Llanos (Varela and Bellotti 1981).

Initially there was some confusion as to the taxonomic identification; the species in northeastern Brazil and the Colombian Llanos were identified as P. manihoti, the same as or similar to P. manihoti described in Africa. However, recent taxonomic studies separate them into two species, P. herreni and P. manihoti (Cox and Williams 1981). Both species are in the Americas, but only P. manihoti is described from Africa.

P. manihoti was found in Paraguay in 1980 (Belloti, pers. obs.) and surveys by Yaseen (1981a and 1981b) located this species in Brazil (Mato Groso) and Bolivia, as well as Paraguay. P. manihoti appears to have been introduced within the last 4 or 5 years into Paraguay, being found only within 50 kilometers of Caacupe, where it was originally discovered. P. herreni has been reported from Colombia, Guyana and northeastern Brazil (including states of Pernambuco, Cerá, Pará and Amapa).

## The biology of cassava mealybugs

P. herreni. Biology studies of P. herreni were on greenhouse potted plants of cassava variety M Col 113. Recently emerged nymphs were placed on leaves and isolated with small leaf cages. Daily observations were made on nymphs and adult development. Oviposisional capacity was also measured.

The female is cream colored and oval shaped throughout its life cycle. It is soft-bodied and segmented, with short antennae and three pairs of legs. Upon emerging from the egg and after each nymphal molt, its body is translucent; the female later proceeds to cover herself with small waxy secretions giving a cottony appearance.

After emerging from the eggs, nymphs remain within the ovisac for a short time and then migrate rapidly in search of a feeding site. They may remain feeding at this site throughout the nymphal stage unless disturbed or if necrosis forces them to seek another feeding site.

It is impossible to distinguish sexes during the first instar; however, sexual dimorphism is manifest during the second instar. The first female instar averages 7.7 days during which the nymphs, usually called "crawlers," migrate in search of a feeding site. The second and third female instars are 5.1 and 5.6 days, respectively. Apart from increased size, no fundamental differences occur in appearance between these two instars. The fourth instar, the adult stage averages 24.8 days.

Table 1. The life cycle of Phenacoccus herreni on cassava plants (var. M Col 113) under greenhouse conditions*.

| | Females | | | | Males | | |
|---|---|---|---|---|---|---|---|
| Instar | No. days (average) | Range (days) | No. observations | Instar | No. days average | Range (days) | No. observations |
| Egg | 6.3 | 6-8 | 205 | Egg | 6.3 | 6-7 | 205 |
| 1st. | 7.7 | 6-9 | 79 | 1st. | 7.5 | 6-8 | 34 |
| 2nd. | 5.1 | 4-7 | 81 | 2nd. | 6.0 | 5-7 | 34 |
| 3rd. | 5.6 | 5-7 | 82 | 3rd. | 2.8 | 2-4 | 32 |
| Adult | 6.4** | 6-7 | | 4th. | 3.1 | 2-4 | 32 |
| | 18.4*** | 15-21 | 47 | Adult | 3.8 | 2-4 | 28 |
| Totals | 49.5 | 42-59 | | | 29.5 | 23-24 | |

*T = 28°C to 38.20°C; RH = 66% (90%-35%)

**Preovipositional period of female

***Ovipositional period of female

The male adult is winged, soft, and fragil with reduced mouth parts. Its body is rose colored with a pair of white wings and two pairs of white, waxy, caudal filaments as long as its body. Legs are well-developed and antennae are two-thirds as long as the body. The male passes through four nymphal instars before the adult stage. The first male instar is identical to the female with an average duration of 7.5 days. The second instar is 6 days; beginning on the fourth day the nymph changes from a cream color to pink. On the fifth day it begins to form a white cottony cocoon, within which it remains until the adult emerges. No feeding takes place during the third and fourth instar within the cocoon as mouth parts atrophy and are nonfunctional. The third instar which averages 2.8 days is the prepupal stage and the nymph begins to transform into an adult. The fourth instar, or pupal stage, is 3.1 days and rudiments of wings and antennae appear. The adult, once formed, remains within the cocoon for one day before emerging then is very active for 2 to 4 days searching for females. One male may copulate with various females.

Parthenogenosis did not exist in the population studied. The male is indispensable for reproduction; if females are not fertilized there is no oviposition. Females can be fertilized immediately upon entering the adult stage. Oviposition is initiated 3 days after copulation. Before oviposition starts the female begins to form a cottony sac, the ovisac, on the posterior end of its body. Eggs are oviposited within this sac. Formation of the ovisac continues throughout the egg

laying period but does not cover all of the female body. The ovipositional period averages 18.4 days but may last up to 21 days.

The average number of eggs oviposited was 773 (529-1028) during the 18.4-day period. Maximum oviposition during the third day of 80 eggs per female slowly declined to 10 eggs on the last day of ovipositon. Eggs are cream colored, measuring 0.38 mm long by 0.20 mm wide. Incubation period is 6.3 days.

When females were isolated without males, they lived up to 23 days. When males were placed with unfertilized, 15-23 day old females, the ovisac formed in 2-3 days. The average of 200 eggs per ovisac had a sex ratio of three females to one male.

Growth differs between the sexes. Females continue to increase in size until the adult stage, maintaining the same length-by-width measurements throughout its cycle. The major male growth period is during the second instar; the length-by-width relationship increasing throughout its instars resulting in an elongated adult form.

Table 2. Size and growth of Phenacoccus herreni on cassava (var. M Col 113) under greenhouse conditions*.

| | FEMALES | | | | MALES | | | |
|---|---|---|---|---|---|---|---|---|
| Instar | Observations | Length mm (increase) | Width mm (increase) | Length/width relation | Observations | Length mm (increase) | Width mm (increase) | Length/width relation |
| Recently hatched | 25 | 0.42 | 0.20 | 2.1 | 25 | 0.42 | 0.20 | 2.1 |
| 1st. | 50 | 0.71 (0.29) | 0.33 (0.13) | 2.1 | 38 | 0.70 (0.28) | 0.32 (0.12) | 2.2 |
| 2nd. | 50 | 1.1 (0.39) | 0.46 (0.13) | 3.4 | 35 | 1.32 (0.86) | 0.46 (0.14) | 2.9 |
| 3rd. | 48 | 1.5 (0.40) | 0.8 (0.34) | 1.9 | 35 | 1.33 (0.01) | 0.51 (0.05) | 2.6 |
| 4th. | | - | - | | 34 | (-0.02) | (-0.05) | 2.8 |
| Adult | 40 | 3.1 (1.6) | 1.4 (1.4) | 2.2 | 30 | 1.46 (0.15) | 0.37 (-0.09) | 3.9 |

*Temp. = 28°C to 38°C; RH = 66% (35% to 90%)

P. gossypii. The life cycle of P. gossypii was studied with females placed on excised cassava stems (M Col 113) in the laboratory (temp. 26°-28°C, 75-85% RH). Three nymphal instars averaged 8.6, 5.7 and 6.3 days, respectively. Adult females survived up to 21 days. Oviposition started between the fifth and seventh day and continued for 5 days. An average of 328 eggs per female was oviposited with most eggs produced the first day, steadily decreasing thereafter. All eggs remain in an egg pouch on the posterior part of the female's body until the nymphs hatch.

Table 3. The life cycle of Phenacoccus gossypii on cassava plants (var. M Col 113) under laboratory conditions*.

| FEMALES | | | | MALES | | | |
|---|---|---|---|---|---|---|---|
| Instar | No. days (average) | Range (days) | No. observations | Instar | No. days (average) | Range (days) | No. observations |
| Egg | 7.4 | 6-9 | | Egg | 7.4 | 6-9 | |
| 1st. | 8.59 | 7-10 | 32 | 1st. | 8.5 | 7-9 | 10 |
| 2nd. | 5.71 | 4-7 | 32 | 2nd. | 6.0 | 4-9 | 10 |
| 3rd. | 6.34 | 5-7 | 32 | Prepupa | 2.1 | 2-3 | 10 |
| Adult | 18.9 | 17-21 | 32 | Pupa | 2.1 | 2-3 | 10 |
| | | | | Adult | 2.03 | 1-3 | |
| TOTAL | 46.94 | 39-54 | | TOTAL | 28.13 | 22-36 | |

*Temp. = 26° to 38°C; RH = 75%-85%

While nymphs in all instars are mobile they may feed in one site for several days. They prefer to feed on the underside of leaves or on tender stems. The female is wingless, whereas males have wings enabling flight. Males pass through two nymphal stages, (8.5 and 6.0 days, respectively), a prepupal (2.1 days) and pupal (2.1 days) stage before adults emerge. Adult males live up to 3 days.

P. manihoti. Studies on P. manihoti in the Americas have only recently been initiated. African results indicate that the female of this species is parthenogenetic and no males have been observed in the field or laboratory (Nwanze et al 1979). The female life cycle is similar to P. herreni with three nymphal instars before the female reaches the adult, forth instar stage. The preovipositional period averages 5.2 days and the mature adult or ovipositional period is 20.2 days. The total duration average 46.2 days (range of 27 to 56 days). The adult female oviposited an average total of 440 eggs over a 20.2 day span. Nymphs and adults are creamy-white and covered with a thin layer of white, wooly substance (Nwanze et al. 1979).

## Ecology and behavior of P. herreni

Plant infestation. Natural infestation is generally initiated by first instar nymphs which usually migrate to the apical part of the young growing shoot of the plant. Initial population build-ups are usually around the growing point. The plant reaction is a rosetting effect to the apical leaves giving a cabbage-like appearance to the growing shoot that also provides some measure of protection for this initial colony. This plant reaction may occur with only a few nymphs present, indicating injection of a toxin into the plant by nymphs or female adults.

Mealybug populations growing points may increase considerably: on one shoot in Pernambuco, Brazil, 30 males and 150 females were counted. As population increases, mealybugs migrate from the shoot and disseminate to all other plant parts. Dispersion begins on stems and eventually all leaves are infested. Infes-

tation is always on the leaf underside, beginning at the leaf/petiole juncture, along the veins and eventually covering the whole leaf.

Heavy infestation results in plant stunting, defoliation, deformation of the growing shoot, shortening of internodes and distortion of stems. Heaviest infestations occur during the dry season. Outbreaks in Pernambuco over a 3 year period coincided with an overall decrease in rainfall. Increased mealybug populations in Colombia also occur during dry periods, thus increasing drought stress.

Onset of the rainy season stimulates plant growth and mealybug populations decrease. Severe deformation of stems may be recognized upon initiation of plant growth. Stems have a corkscrew appearance, forming 360° circles with some stems turning at almost right angles. Although populations may decrease dramatically during rainy periods, mealybugs are still present in considerable numbers. Slight deformation of the shoots can still be observed and, when opened, nymphs, adults and ovisacs are found. Shoot deformation can be observed in numerous plants even during the rainy period, however, plant damage is greatly reduced. Mealybugs may also be found on stems, especially around the lateral buds, and on the underside of middle and lower leaves. Often the smallest and weakest plants are attacked most. Regrowth from basal buds also displays considerable infestation during the rainy periods.

Dissemination of *P. herreni*. Preliminary field experiments in Colombia show that wind is a major factor in dissemination of mealybug from one field to another. Cassava plots were planted about 100 meters from a heavily infested field in the Colombian Llanos. Those fields sown in the direction of the prevailing winds became rapidly infested with mealybug nymphs, while plots up-wind of the infested field remained uninfested. Dissemination from one area or country to another is facilitated by infested planting material. In recently planted fields in Pernambuco, Brazil, stakes and plant debris were infested with mealybug. Nymphs were often feeding within the lateral buds of these plant parts.

In addition, cassava stems are often stored for varying lengths of time during dry periods while waiting for rains to resume or during cold months in sub-tropical areas of southern Brazil and Paraguay). Mealybug-infested stems stored during these periods disseminate the pest from one growing cycle to another.

## Behavior of *P. gossypii* on cassava

*P. gossypii* has a wide host range and cassava is only an occasional host. Usually populations are controlled by numerous natural enemies. Females deposit egg sacs around the axil of branching stems or leaves, on the underside of the leaf where the leaf petiole joins the leaf, or around buds on the main stem. High populations give a cottony appearance to the green or succulent portion of the stem and on the leaf undersurface. Infestations within a field are often in patches and may occur in areas where heavy use of pesticides eliminated natural enemies. Damage symptoms are significantly different than those of *P. herreni*. *P. gossypii* feeding causes leaf yellowing and eventually defoliation beginning with the basal leaves. There is no rosetting of the shoots or distortion of shoots and stems. High populations of *P. gossypii* also occur during dry periods.

## Behavior of P. manihoti on Cassava

The ecology and behavior of P. manihoti is similar to that of P. herreni. Terminal points are attacked first then the petioles and expanded leaves. Internodes are shortened, there is leaf curling and reduced new-leaf growth. As population density increases, all green parts of the damaged shoots eventually die. Infestation of lower leaves through natural leaf fall during the dry season gives the plant a "candlestick" appearance (Leuschner and Nwanze, 1978). With onset of the rainy season mealybug populations drop considerably and within a month new leaves and shoots are abundant. Nymphs and adults persist on cassava plants during the wet season and serve as inoculum at the beginning of the dry season. Dissemination of P. manihoti is primarily by planting material and wind (Nwanze et al. 1979).

## Yield losses due to mealybugs

The effect of mealybug attack on production of cassava roots in the Americas has not been quantified. Observations indicate that populations of P. manihoti and P. gossypii are not sufficiently high to cause root reduction. However, populations of P. herreni in northeastern Brazil are sufficiently high to reduce yields. Indications are of root reductions up to 80% while in Pernambuco, Brazil, traditional cassava farmers are replacing it with alternate crops.

Reports from Africa show measured yield losses of 45% in experimental plots (Atur and Okeke, 1981).

## Natural enemies of cassava mealybugs

In general, biological control of mealybugs on agricultural crops has been successful (Debach, 1964). The potential exists for successful control of cassava mealybugs with natural enemies. Natural enemies associated with cassava mealybugs include predators, parasites and pathogens. Approximately 25 parasites of P. gossypii, P. herreni and P. manihoti have been registered in the Americas. Twenty-three of these are in the Encyrtidae family and include the genera Anagyrus, Aponagyrus, Aenasius, and Acerophaga. The fungal pathogen Cladosporium sp. has recently been identified parasiting P. herreni in Brazil and Colombia.

Approximately 43 predators have been reported on the above three mealybug species. Most belong to the family Coccinellidae, primarily of the genera Hyperaspis and Nephus. Insect orders represented include Neuroptera four Chrysopa species and two Sympherobius sp.), six dipteran species (including Ocyptamus sp. and Kalidiplosis sp.), five hemipteran (including Zellus sp.), Coleoptera (including 22 Coccinellidae and two Staphylinidae), and two lepidopteran (including Pyroderces sp.). One list contains some 75 natural enemies - parasites, predators, hyperparasites - of these mealybugs. Most of these species have been reported from cassava fields. Some have been found on these mealybugs, especially P. gossypii, feeding on other crops.

Two species of mealybugs P. herreni and P. gossypii and their potential biological control in the Americas will be further discussed. They present two distinct situations with different modes of attack and while cassava is not the preferred host of P. gossypii it appears to be so for P. herreni.

Table 4. Predation* and parasitism** of the mealybug Phenacoccus gossypii feeding on cassava by natural enemies over five consecutive weeks in field cages***.

| Weeks after exposure to natural enemies | % predation of ovisacs | % predation of nymphs and adult-females | % parasitism of nymphs and adult-females |
|---|---|---|---|
| 1 | 64.4 | 76.6 | 5.1 |
| 2 | 78.4 | 94.6 | 4.8 |
| 3 | 94.6 | 87.9 | 8.8 |
| 4 | 96.6 | 70.6 | 6.7 |
| 5 | 100 | 73.2 | 9.6 |

*Predators = Kalodiplosis coccidarum, Chrysopa sp. Coccinelidae and Reduviidae.
**Parasite = Anagyrus sp.
***Field cages = 3x3x2 m.

P. gossypii has numerous natural enemies. Its mode of attack exposes populations (on the tender portion of the stems and on leaf undersurfaces) to predation and parasitism by natural enemies. In studies at CIAT (1979) cassava cultivars were infested at 45 days with six P. gossypii egg masses and protected in screened cages to prevent attack by natural enemies. Mealybug dispersal resulted in 44.9%, 41.0%, and 14.1% of the biological stages being located on the basal, middle and upper third of the plant, respectively. Effectiveness of several enemies on controlling P. gossypii were studied in field cages (CIAT, 1980). When mealybugs became numerous (about 26,000 nymphs and adults per cage) natural enemies were allowed entry. Predator and parasite populations were recorded for 6 weeks, by which time mealybug populations were almost zero.

In general, a higher percentage of predation than parasitism resulted and the latter never averaged more than 10%. Predation of ovisacs, principally by K. coccidarum, reached 100% after 5 weeks, and predation of nymphs and adults reached 96%, primarily due to Chrysopa and Reduviids. Major predators were Chrysopa, K. coccidarum and several Coccinellids and Reduviids. Anagyrus spp. were the predominant parasites. In cages where mealybugs were most numerous, K. coccidarum was the heaviest predator while Chrysopa, the Reduviids, and some Coccinellids predominated in cages with lower mealybug populations. Mealybug populations decreased steadily during 6 weeks.

High populations of the dipteran predator K. coccidarum have been observed in greenhouse colonies of both P. gossypii and P. herreni. However, field populations have been erratic. It was initially observed predating on eggs within the ovisac, but larvae have also been found predating nymphs, especially adult females, when ovisacs are not available. It remains in the ectoparasitic stage and seldom causes nymphal mortality until the ovisac is formed, then it predates eggs until completing its life cycle. Its ectoparasitic stage is important for survival when host populations are low. A female:male ratio of 2:1 was observed.

Table 5. Populations of five natural enemies observed attacking mealybug (*Phenacoccus gossypii*) populations on cassava over five consecutive weeks in six exposed field cages*.

| Weeks after exposure to natural enemies | Average number of natural enemies per cage** | | | | |
|---|---|---|---|---|---|
| | PREDATORS | | | | PARASITES |
| | *Kalodiplosis coccidarum* | *Chrysopa* sp. | Coccinellidae | Reduviidae | *Anagyrus* sp. |
| 1 | 492.0 | 33.3 | 61.0 | | 17.5 |
| 2 | 40.5 | 27.8 | 20.7 | 35.7 | 8.3 |
| 3 | 50.0 | 30.0 | 28.3 | 10.0 | 2.3 |
| 4 | 11.7 | 23.8 | 2.3 | 12.0 | 0.2 |
| 5 | 2.3 | 18.7 | 3.2 | 7.0 | 0.2 |

*Field cages 3x3x2 m.

**Average per cage for 6 cages.

The average number of *K. coccidarum* per ovisac varied depending on host availability. When ovisacs were numerous, three predator larvae were found, on average, per ovisac (from 1-5) and higher predator populations resulted in 5 larvae per ovisac (range 2-8). Initial studies of *K. coccidarum* indicate a life cycle of 12 days (at 28°C) to 16 days (at 22°C).

In recent years, studies at CIAT have concentred on the *P. herreni* since this is of greater economic importance. Natural populations of this mealybug were studied in cassava fields at CIAT. During 1981 systematic evaluations of populations of its natural enemies were made by collecting infested plant parts from 13 locations and identifying emerging parasites and predators. Collections were made during July, August, and September when mealybug populations were highest. Five major enemies were identified. *Ocyptamus* was by far the most predominant predator accounting for 68% of the total natural enemies observed and was found in 85% of the fields surveyed. Other predators collected were of the genera *Cleothera*, *Sympherobius*, and *Chrysopa*. *Anagyrus* sp. was the major parasite observed and accounted for 19.2% of the enemies collected.

During September 1982, similar evaluations were made. A variety of natural enemies was collected. In the first sampling, 13 predator species were identified and 12 in the second sampling. The predator collected in greatest numbers was *K. coccidarum* which did not appear in the 1981 sampling. The most prominent parasite found was the microhymenopteran *Acerophaga coccois*. This parasite represented 85% of the parasites collected in the first sample and 92% of those in the second. Although this parasite was collected in previous years at CIAT, it was not collected in such high numbers. A colony of this parasite has been established and further studies are planned.

During a *P. herreni* outbreak in Pernambuco, Brazil, several predators and parasites were collected. Predators included the dipterans *Ocyptamus* sp. and a Cecidomyiidae (possibly *Kalodiplosis*); the Coleopterans, *Hyperaspis notata*, *Hyperaspis* sp. and *Nephus* sp.; a *Chrysopa* sp.; a Carabidae; the Reduviidae, *Zellus* sp. and an unidentified Anthocoridae; a Lepidopteran, *Pyroderces* sp.; and three



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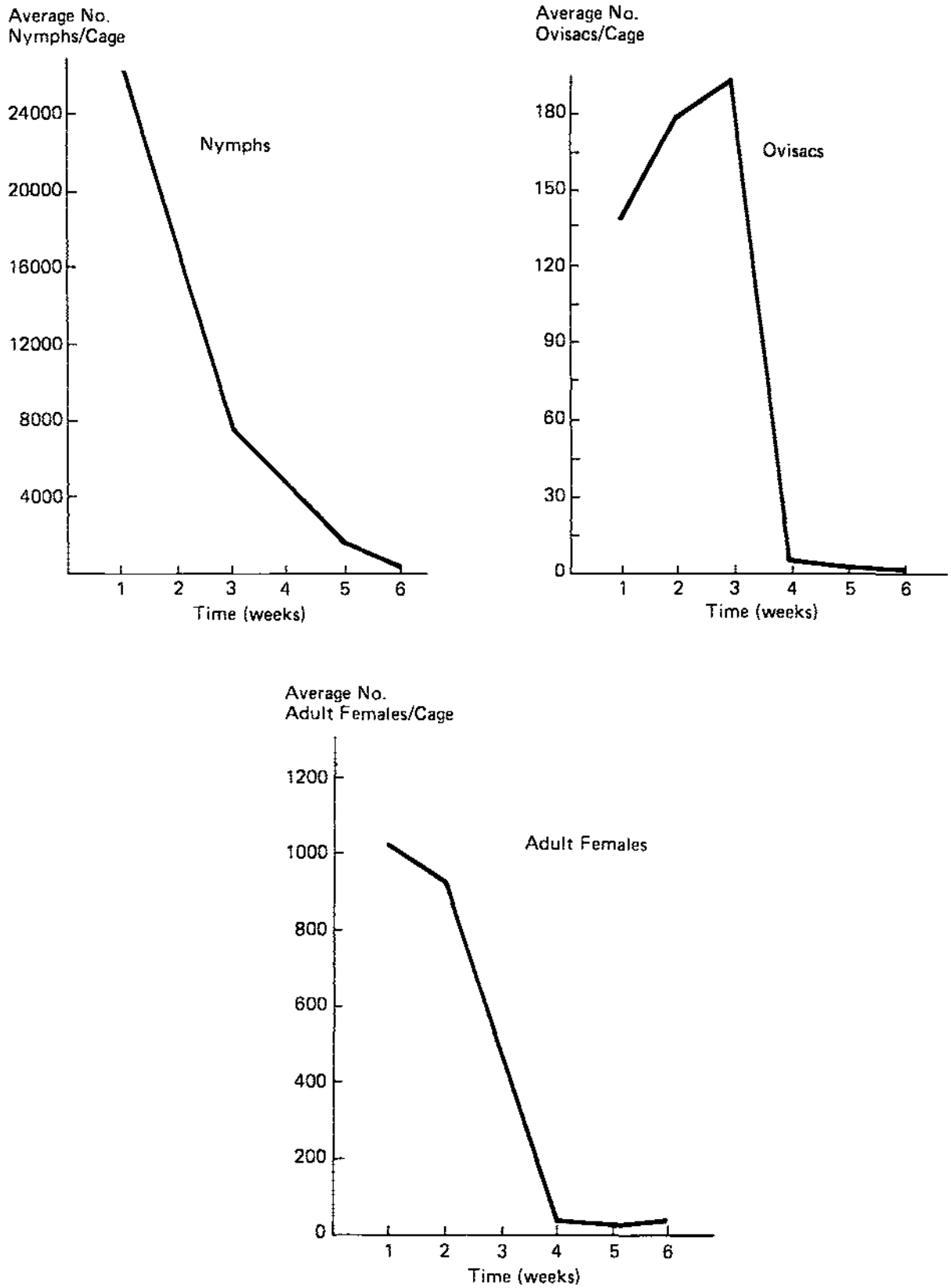


Figure 1. Reduction in number of ovisacs, nymphs and adult females of *Phenacoccus gossypii* by its natural enemies.

Table 6. Population of natural enemies of the mealybug Phenacoccus herreni in 13 CIAT cassava fields.

| Natural enemies | % of total enemies | % of field surveyed |
|---|---|---|
| Ocyptamus stenogaster | 68.3 | 84.6 |
| Cleothera sp. | 14.6 | 46.1 |
| Anagyrus sp. | 9.2 | 61.5 |
| Sympherobius sp. | 4.4 | 38.4 |
| Chrysopa sp. | 3.3 | 30.8 |

Table 7. Parasites and predators collected on high field populations of Phenacoccus herreni at CIAT, Palmira.

| Date: | Sept. 2, 1982 | | | Sept. 14, 1982 | | |
|---|---|---|---|---|---|---|
| | No. Species | No. Indiv. | % of total | No. Species | No. Indiv. | % of total |
| Parasites | | | | | | |
| Hymenoptera | | | | | | |
| Acerophaga | 1 | 288 | 86 | 1 | 377 | 92 |
| Other Hymen. | 6** | 19 | | 11** | 32 | 08 |
| Predators | | | | | | |
| Coleoptera | 7 | 26 | 37 | 5 | 9 | 7 |
| Neuroptera | 2 | 5 | 7 | 1 | 1 | 1 |
| Diptera | 2 | 30 | 43 | 1* | 106 | 84 |
| Lepidoptera | 2 | 9 | 13 | 3 | 8 | 6 |
| Psocoptera | | | | 1 | 1 | 1 |
| Hymenoptera | | | | 1 | 1 | 1 |

*Kalodiplosis coccidarum

**Includes hyperparasites

hymenopteran parasites of the family Encyrtidae, one an Anagyrus sp. An Ocyptamus sp. was observed in high populations but was hyperparasitized.

At both CIAT and in Pernambuco, Brazil, the fungal pathogen Cladosporium was observed parasitizing P. herreni nymphs and adults. Fungal attacks give mealybugs a sooty, dark-gray appearance. A high rate of parasitism was observed in cassava fields in Pernambuco. Observations indicate that the fungus may be most effective only under high populations. However, the fungus can be easily cultured on a medium and offers the possibility of spray applications in fields when mealybug

populations are low, thereby preventing population build-ups. Further research should be directed toward this pathogen.

The search for natural enemies of P. manihoti recently began in Paraguay, Brazil and Bolivia. Several parasites and predators have been described. Parasites include Apoanagyrus lopezi, Aenasius vexans and Acerophagus sp. (all are Hymenoptera: Encyrtidae). Predators include the Coccinellidae, Hyperaspis notata and Hyperaspis notata and Hyperaspis sp., and the genera Exochromus and Olla. Additional predators include Crysopha sp., Sympherobius sp., Ocyptamus sp., and Kalodiplosis sp.

A problem in this mealybug/natural enemy complex is presence of several hyperparasites which can reduce populations of the natural enemies. Ocyptamus sp. is a frequent predator of mealybugs and appears to be an efficient one, however, as its populations build up, there is increased hyperparasitism. Since Ocyptamus is a fairly universal predator, it will be difficult to introduce it into areas where it does not already exist and is already accompanied by its hyperparasites. However, precautions should be taken to avoid introduction of hyperparasites of other natural enemies of the mealybug.

## Summary

Mealybugs constitute a major pest problem on cassava in the Americas, causing severe losses in root yields. Current outbreaks are confined to localized areas. However, if they disseminate to other favorable cassava growing areas potentially they can cause more severe losses. Several species attack cassava but P. herreni appears to be most economically important. The exact origin of this species in the Americas is not known although it is reported from several countries (Brazil, Guyana and Colombia). P. manihoti, a closely related species causing crop losses in Africa, is reported from Brazil, Paraguay and Bolivia. Possibly these two species have a common geographic origin.

P. herreni and P. manihoti are taxonomically similar as is their mode of attack and the plant damage symptoms they cause. Both species attack the growing point and cause a rosetting effect to the apical leaves resulting in a cabbage-like appearance to the shoot. Heavy infestations will result in plant stunting, defoliation, deformation of the growing shoot, shortening of internodes and distortion of stems. Presence of a toxin is indicated. High mealybug populations and severe plant damage coincide with dry periods.

P. herreni and P. manihoti differ markedly in their bionomies. P. manihoti reproduces pathenogenically while P. herreni is bisexual. Males of P. manihoti have not been observed in populations studied; males of P. herreni are essential for reproduction and oviposition is initiated only after copulation. Females of both species have similar life cycles: P. herreni 49.5 days and P. manihoti 46.2 days. Both pass through three instars before the adult stage. Oviposition is greater with P. herreni, 773.6 eggs per female vs. 440 for P. manihoti.

Dissemination of both species is similar with wind as a major factor in movement of mealybugs from one field to another. Dissemination from one area to another is facilitated by infested planting material.

Cassava mealybugs have numerous natural enemies and considerable potential exists for biological control. Approximately 25 parasites and 43 predators of P. gossypii, P. herreni, and P. manihoti have been registered in the Americas.

However, the geographic origin of P. herreni and P. manihoti has not been determined, therefore the most efficient natural enemies of these two species may not yet have been observed. Exploration for the origin of these pests and their natural enemies is an essential component of a biological control program.

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Serological Diagnostic of African Cassava Mosaic by Immuno-Enzymatic Method

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ABSTRACT

African cassava mosaic disease infects more than 95% of cassava plants in the Ivory Coast. The suspected causal agent, cassava latent virus, is a geminivirus. It was purified from systematically infected Nicotiana benthamiana. An antiserum was prepared by injecting rabbits with the purified virus.

Testing of cassava plants by classical serological methods, such as microprecipitin and gel-diffusion precipitin tests, was not possible because the virus level in cassava leaves is very low. It was possible, however, to detect virus in cassava using enzyme-linked immunosorbent assay (ELISA).

Cassava mosaic disease is a major pest of cassava (Manihot esculenta Crantz) in Africa. Most cassava cultivars show severe symptoms in the coastal areas of Ivory Coast, although healthy plants are still found in the middle and the northern parts of the country.

The causal agent is presumed to be a virus, first isolated in East Africa: cassava latent virus (CLV, Bock et al., 1978). The same pathogen was characterized in the Ivory Coast (Walter, 1980) and in Nigeria (Adejare and Coutts, 1982). For all virologists, there is circumstantial evidence that CLV plays a role in the etiology of cassava mosaic disease.

Reported here are trials for serological detection of CLV in cassava plants.

## Materials and Methods

Experiments used original isolate of CLV described by Walter (1980) and propagated on Nicotiana benthamiana in insect-proof glasshouses. CLV was purified according the procedure of Walter (1980).

Antiserum to CLV was prepared by injecting two rabbits once a week intramuscularly (using Freund's incomplete adjuvant) during 6 weeks. The antiserum obtained had a reaction end-point of 1/256 in double-diffusion precipitin test with purified CLV. It did not react with sap from virus-free N. benthamiana at a dilution of 1/8.

The method used for enzyme-linked immunosorbent assay (ELISA) was described by Clark and Adams (1977). Globulins are purified from antiserum, and a sample is

conjugated to alkaline phosphatase. Coating globulin was used at 10 ug/ml and enzyme-conjugated globulin was diluted 1/400.

Samples to be tested were prepared by grinding leaves with an Ultra-Turax, in phosphate buffered saline (PBS) pH 7.4; containing 0.05% Tween 20, 2% polyvinyl pyrrolidone and 0.2% ovalbumin.

Absorbance at 405 nm was measured by means of a spectrophotometer Titertek Multiscan.

## Results and Discussion

### Detection of virus in leaf extracts

By using double-diffusion precipitin tests, it was hazardous to detect CLV in diseased *N. benthamiana* and it was not possible to obtain positive reaction with diseased cassava, probably because virus concentration in the plant was too low.

In *N. benthamiana* and cassava, CLV was always detectable by ELISA. The reaction was significantly distinguishable from that of healthy samples at a dilution of 1/2,048 for *N. benthamiana* extracts, and at a dilution of 1/256 for cassava extracts, using leaves from the apex.

For *N. benthamiana*, absorbance at 405 nm was regularly decreasing according to the dilution of the extract for cassava extracts, the maximum of absorbance was found at a dilution between 1/12 and 1/16 (g/ml). There were probably inhibitors of the reaction in the cassava extracts. The same type of interference is reported by Sequeira and Harrison (1982). This inhibitory effect of cassava can be removed by treating leaf extracts with organic solvent such as chloroform.

### Detection of CLV in mature cassava leaves according to the severity of symptoms

Symptoms on cassava leaves were estimated by Cours (1951) with a scale from 0 to 5. According to this notation, leaves of diseased cassava were collected either from different plants or from the same plant in the field and grouped according to the strength of the symptoms. Six leaves of each category of the scale were tested by ELISA. Positive results were obtained only with categories 3, 4 and 5 (usually younger leaves), namely only with severely infected leaves, suggesting that virus content in leaves noted 1 to 2 (usually older leaves) was very low. Serological test thus seems less sensitive than direct observation of symptoms for diagnosis in the field.

CLV could also be detected from infected leaves of *Manihot glaziovii*.

ELISA represents a good method for detecting natural hosts of CLV in wild plants; either directly after sample collection in the fields or as a means of control after mechanical inoculation on *N. benthamiana*.

It appears therefore that an increase of the titre of the antiserum would increase the sensitivity of the test. Sequeira and Harrison (1982) with a different method of purification obtained good yields of CLV and they have prepared antiserum with a titre of 1/500. We are now working to produce an antiserum more specific with a higher titre.

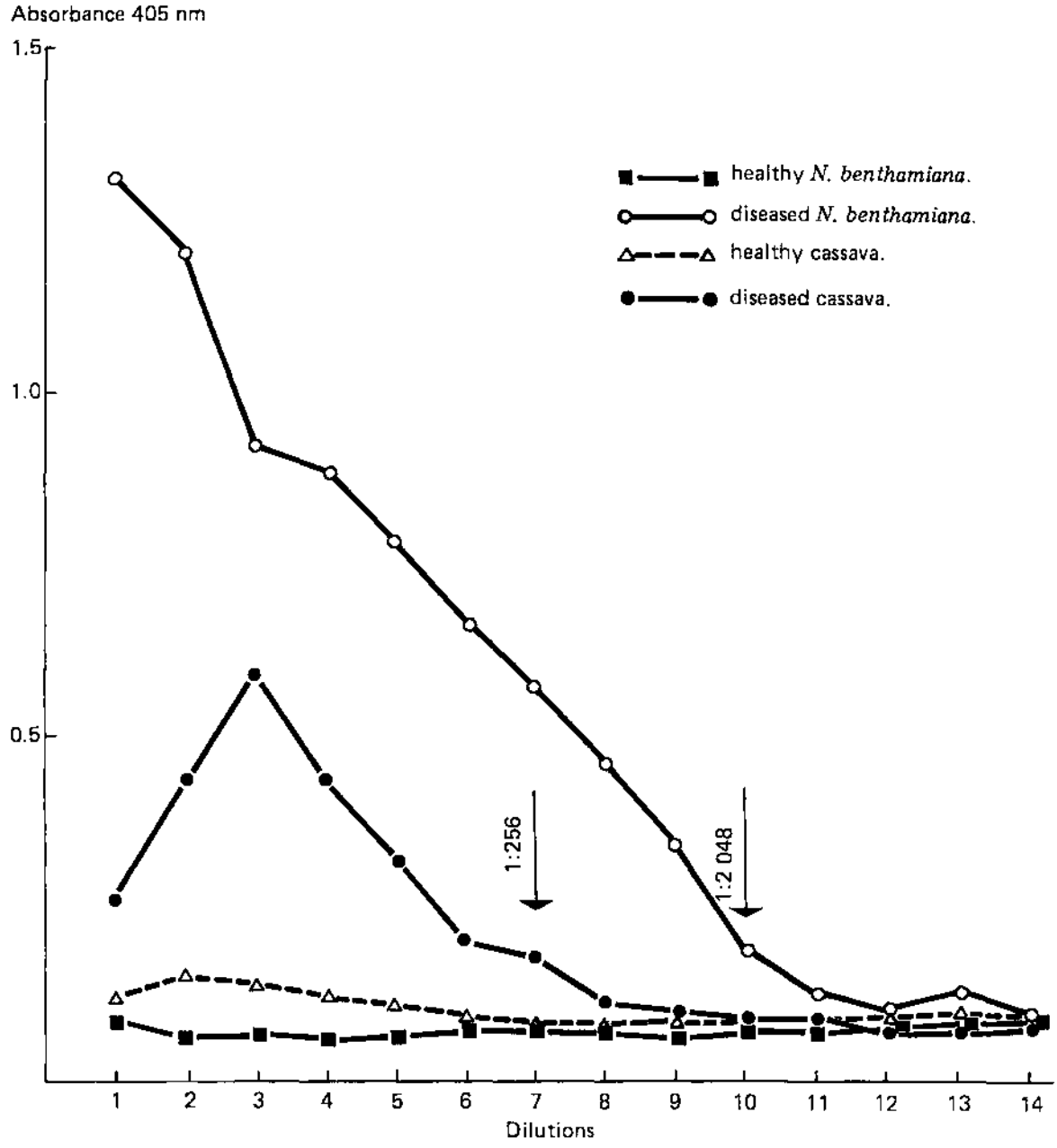


Figure 1. Detectability of cassava latent virus by ELISA in leaf extracts from Nicotiana benthamiana and cassava.

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Investigations on the Biology and Ecology of Oligota minuta Cam. (Coleoptera: Staphylinidae) a Predator of Mononychellus tanajoa (Bondar) (Acari.: Tetranychidae) in the Neotropics

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ABSTRACT

The biology of Oligota minuta has been studied as part of an investigation seeking to find and evaluate predators of Mononychellus tanajoa. The egg, larval and pupal stages last 2.0 to 3.0; 9.0 to 10.5, and 4.0 to 5.0 days, respectively, at a temperature of 26.8° ± 2.2°C. It is adapted to feed on mites infesting cassava. The larvae consumed 59.1 ± 6.5 mites of 52.8 ± 7.2 eggs of M. tanajoa. Larvae and adults both feed on eggs as well as active mite stages. The species survive periods of low host density on cassava by moving on to other hosts and has attributes of a promising predator for trial introduction against the mite in Africa.

## Introduction

Mononychellus tanajoa (Bondar) was discovered in Uganda in 1971 (Lyon 1973). Since then, the mite has rapidly spread and is now in almost all cassava growing areas in the Afrotropics. The mite was described from Brazil (1939). Doreste (1981) has split it into three: tanajoa, progresivus and manihoti. Recent investigations in Kenya indicate the presence of tanajoa and progresivus in East Africa (Yaseen et al., 1982). The same two species also occur in Nigeria, West Africa (Flechtman, pers. comm.)

The mites of tanajoa complex cause severe damage in the Afrotropics. These are not considered serious pests in areas of natural distribution and it has been assumed that predators keep populations below injurious levels. A survey for the natural enemies of these mites in the Neotropics by the Commonwealth Institute of Biological Control, Trinidad, is to evaluate them for trials in Africa. Yaseen (1982) and Yaseen and Bennett (1976) have reported several predators including 14 phytoseiid mites, 6 coccinellids, 3 cecidomyiids, 4 staphylinids, 1 anthocorid and a Thysanopteron.

Oligota minuta Cam. is one of the important predators of tetranychid mites infesting cassava. It was described by Cameron (1931) from specimens collected from Trinidad; as the name implies, it is very small. Frank (1972) has revised the Caribbean species and clarified records in the literature thus: Cameron's collections from Jamaica were labelled as O. laxata and recorded as such by

Blackwelder (1943) and specimens from Cuba were also misidentified and recorded as O. centralis by Bierig (1934).

## Distribution

O. minuta is widespread in the Neotropics and was previously known from Antigua, Cuba, Grenada, Jamaica, and Trinidad (Blackwelder 1943, Frank op. cit.). During present investigations it was also encountered in the Bahamas, Montserrat, St. Kitts, and Tobago in the Caribbean and Brazil, Colombia, Ecuador, French Guyana, Guyana, Surinam, and Venezuela in South America.

## Hosts

This staphylinid is specially adapted to feed on mites and is known to attack several spider mites including Oligonychus pratensis (Banks), Tetranychus tumidus Banks and Tetranychus spp. on several hosts (Frank op. cit.). During present surveys it was found on cassava in association with Mononychellus caribbeanae (McGregor), M. mcgregori Flechtmann and Baker, M. tanajoa, M. progresivus Doreste, M. manihoti Doreste, Oligonychus peruvianus (McGregor), Tetranychus sp. probably urticae Koch and Tetranychus sp. in various areas in the Caribbean and South America.

## Descriptions of immatures stages

Measurements are given in Table 1.

Table 1. Body measurements of immature stages of O. minuta.

| Stage | No. examined | Length (mm) | | Width (mm) | |
|---|---|---|---|---|---|
| | | Range | Mean ± SD | Range | Mean ± SD |
| Egg | 30 | 0.25 - 0.32 | 0.28 ± 0.03 | 0.17 - 0.21 | 0.19 ± 0.02 |
| Larva 1st instar | 25 | 0.63 - 0.97 | 0.78 ± 0.11 | 0.15 - 0.18 | 0.16 ± 0.01 |
| 2nd instar | 25 | 1.27 - 1.91 | 1.49 ± 0.18 | 0.23 - 0.38 | 0.29 ± 0.04 |
| 3rd instar | 25 | 1.61 - 2.29 | 1.87 ± 0.21 | 0.32 - 0.42 | 0.38 ± 0.03 |
| Pupa | 20 | 0.77 - 1.18 | 0.90 ± 0.11 | 0.38 - 0.54 | 0.46 ± 0.04 |

## Biology

A laboratory culture of O. minuta was established by confining adults collected from cassava on potted lima bean plants infested with Tetranychus tumidus or T. urticae. Mated females were placed on a young plant with only two or three heavily infested leaves to obtain eggs. These were removed from the bean plant and placed on a section of cassava leaf in individual cages of clear plastic petri dishes 25 mm in diameter and 5 mm deep with a piece of moist filter paper below the cassava leaf to provide humidity. Edges of the dishes were coated with petroleum jelly before covering to prevent escape of larvae. Mononychellus eggs or immature stages were placed on a section of cassava leaf and offered to the larva. The amount of food consumed was recorded and cassava leaf replaced daily by a fresh leaf with known numbers of prey. The cages were observed in the morning and evening. All observations were at laboratory temperatures of 26.8 ± 2.2°C and relative humidity varying from 90.5% in the morning to 55% in the afternoon.

## Life history

After hatching, the larva remained inactive near the egg shell for about an hour before starting to search for prey. Before moulting, the first and second instar larvae became motionless and adheared firmly to the leaf surface by the last abdominal segment. This period of inactivity lasted for a few hours and the next instar emerged through a longitudinal slit along the anterior half of the dorsum. The freshly moulted second or third instar larvae also remained motionless for about an hour before resuming the search for prey. The third stage larva ceased all movement after completion of feeding and firmly attached the last abdominal segment to the leaf surface resting for more than half a day as a prepupa. In the absence of adequate pupation sites, these failed to pupate and perished on the leaf surface. When provided with moist folded towelling tissue they readily moved and pupated in the tissue folds. Under field conditions, pupae have not been seen on the plant; presumably pupation takes place in the soil. The duration of immature stages is given in Table 2.

Table 2. Duration of immature stages of *O. minuta*.

| Stage | No. observed | Days Range | Days Mean ± SD |
|---|---|---|---|
| Egg | 50 | 2.0 - 3.0 | 2.8 ± 0.3 |
| Larva | 37 | 9.0 - 10.5 | 9.9 ± 0.7 |
| 1st instar | 48 | 2.0 - 3.5 | 2.7 ± 0.5 |
| 2nd instar | 42 | 2.5 - 3.5 | 3.1 ± 0.4 |
| 3rd instar | 37 | 3.4 - 4.5 | 4.2 ± 0.3 |
| Pupa | 37 | 4.0 - 5.0 | 4.4 ± 0.5 |
| Total | 37 | 16.0 - 18.0 | 17.1 ± 0.6 |

The adult emerged through a mediodorsal slit in the anterior half of the pupal skin. It was light brown at first, remaining near the pupal skin for several hours until the integument hardened and became dark. On becoming active the adults search for prey. Mating took place a day after emergence. The male and the female faced opposite directions during mating. Mating lasted for several minutes and was repeated several times by the same pair. Oviposition began two to three days after mating. Although a few eggs were laid along the leaf mid-rib, most were deposited in the open among mites on the lower surface. Females lived up to 16 days and laid an average of 20.8 ± 3.1 eggs. Males lived up to 12 days.

## Feeding

Larvae were fed on *Mononychellus* eggs or active immature stages or both. Newly hatched larvae prefer mite eggs to active stages perhaps because their mandibles are comparatively weak and only pierce the body cuticle with difficulty. Second and third instar larvae prey on both eggs and active stages. On contacting prey the larvae pierce the egg shell or the hysterosoma of the mite with the mandibles, suck the body contents making a series of regurgitation-like movements, and discard the exoskeleton after consuming the internal tissues. An egg or an immature mite stage took approximately 2.5 to 4 minutes to consume and a female mite up to about 8 minutes. The mites made no effort to escape when attacked but became motionless and succumbed. After consuming a host the larva usually re-

mained stationary for 10 to 15 minutes before resuming search for prey but sometimes continued searching without rest. The first prey encountered on a densely infested leaf was not necessarily attacked. Adults, which were more active than larvae, preyed on both eggs and mites and consumed the exoskeleton of the mite as well.

Adults consumed 97-142 eggs and mites in 7-16 days with an average of 119.9 ± 15.4 and average daily consumption of 10.9 ± 2.1 mites and eggs.

Field observations

In Trinidad O. minuta is regularly associated with tetranychids on cassava. While it attacks Tetranychus urticae on cassava it was observed that heavy infestations of this mite on tomatoes (Lycopersicum esculentum) and beans (Phaseolus spp.) and several other plants with highly pubescent leaves in adjacent plots were seldom attacked. However, T. urticae infestations on cassava are infrequent and usually confined to old plants with retarded growth and poorly nourished leaves. Young vigorous plants are attacked mainly by Mononychellus spp. and this constitutes the principal prey of the staphylinid.

Sampling of O. minuta on cassava showed that seasonal incidence is synchronized with that of tanajoa complex. The mite were scarce during sustained heavy rains from mid-July until December or January and the predator was also rare during this period. During the dry season in March when the populations of mites showed upward trends on cassava, O. minuta adults appeared and fed on the mite. It gradually increased in numbers and fluctuations in the predator population closely related with those of the mite. Fortnightly observations in the southern plains of Trinidad during May to August 1974 showed an average of 15.5 O. minuta larvae per leaf when the average host density was 2,571 per leaf during May to mid-July, decreasing to 6.2 per leaf as the host population fell to 1,058 per leaf from mid-July to mid-August. The mite population was completely dislodged during a tropical storm accompanied by heavy rains in the third week of August and when the plants were examined on August 27, the predator population had also completely disappeared.

Regular examination of samples consisting of the top 15 leaves from five heavily infested and five moderately infested cassava plants during the dry season showed 73-120 O. minuta larvae and adults on the former and 28-44 on the latter. Numbers of predators also vary in relation to the infestation levels on leaves of individual plants and 79.7% to 86.7% of the predator population occurred on leaves 6-10 which harbored most of the mite populations; the eight leaf carrying the largest number of mites had 25.8% to 26.3% of the predators. Numbers of adults on densely infested leaves are usually higher in the early part of the morning.

Weekly counts in an experimental plot containing 10 cassava varieties in 1975 indicated that differences in the predator population were related more closely with host density than with cassava variety. Larger numbers occurred on varieties Black Stick and Brown Stick which harbored high mite populations than on variety Maracas Black Stick which had few mites. During the peak period of mite population in June and July, variety Black Stick which harbored the highest average mite population of 2,383 and also the highest average predator population of 22 per sample of leaves 6-10 in June, showed a lower host density of 1,885 mites per sample in July while variety Brown Stick, which had a mite population of 1,942 and 16 O. minuta per sample in June, showed a higher (2,517 per sample) mite population in July. This suggests that when abundant, the staphylinid suppresses the mite populations.

## Discussion

Oligota minuta is widely distributed in the Neotropics thereby indicating an adaptability to a wide range of habitats, climatic conditions and prey mites. The population density seems closely associated with that of its prey, M. tanajoa and other tetranychids on cassava in Trinidad and several other areas in the Neotropics. Its activity is well synchronized and its distribution pattern similar to that of M. tanajoa. It is voracious and both larvae and adults prey on eggs as well as the motile mite stages. The developmental period is short and with a fairly high reproductive potential and several overlapping generations it rapidly builds up large populations which destroy appreciable host scarcity on cassava by moving over to mites on other plants. These are characters considered promising for a predator of tetranychids by McMurtry et al. (1970). Consequently, it merits introduction for trial against the mite in Africa.

## Acknowledgements

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A Summary of Recent Research on the Superelongation Disease of Cassava

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SUMMARY

Recent research on pathogen taxonomy, sexual reproduction, host range and physiology are summarized along with investigations into the nature of superelongation disease resistance. The previously unreported sexual stage of Sphaceloma manihoticola, causal agent of superelongation disease of cassava, is presented as an Elsinoë species (Loculoascomycetes, Myriangiales). Cross-inoculation studies, symptomatology, colony, characteristics, and morphological comparisons among isolates, type specimens, and published descriptions support proposed synonymy of the Elsinoë from cassava with E. jatrophae and E. brasiliensis under the same Elsinoë brasiliensis. Sphaceloma manihoticola is retained, and S. krugii is combined with S. poinsettiae under the latter name. In vitro production of gibberellin $A_4$ by the pathogen was demonstrated through combined gas chromatography-mass spectrometry of purified culture extracts. Field resistant and field susceptible cultivars were treated with different concentrations of gibberellin $A_4$ and inoculated with the pathogen. No difference in response to the hormone was detected between resistant and susceptible cultivars when evaluated for change in length and susceptibility. All cultivars showed an increase in internode length at $10^3$ µg/µl hormone concentration, and all showed increased level of disease over control when inoculation followed hormone application. Regardless of field susceptibility, stem tissue of all cultivars tested develop resistance to the pathogen after about 8 days. Hormone production appears to confer an advantage to the pathogen by inducing growth and increasing the amount of susceptible juvenile tissue. Disruption of stem cuticle significantly increases level of disease as measured by number of lesions, percent of susceptible tissue diseased, and number of diseased internodes. Inoculations of selected cultivars of diverse origins and morphology with isolates of diverse origins in all combinations yielded variable, but significant cultivar x isolate interactions suggestive of pathogenic specialization. It is hypothesized that specific host-isolate incompatibility is only part of a complex of resistance mechanisms in field resistant cultivar.

The superelongation disease of cassava, first reported in the Tolima Valley of Colombia in 1972 (3), has since been reported throughout wide areas of South and Central America and the Caribbean. The CIAT cassava pathology section has

conducted research on disease etiology, physiology, and epidemiology, and pathogen taxonomy and physiology, much of it in cooperation with Cornell University. This paper summarizes most important results of these studies. Detailed data supporting the findings here have or will be published elsewhere (8, 9, 10, 11).

## I. Pathogen Taxonomy and Sexual Reproduction

The genus Sphaceloma de Bary (Melanconiales) currently composes more than 50 species, the majority in tropical and subtropical regions. The pathogen attacks flowers, fruits, leaves, and stems, causing characteristic scab lesions as well as necrotic leaf spots. Conidia are small, unicellular and hyaline, formed in a more or less acervulus-like structure or, more commonly, on continuous fertile layers of densely packed phialidic conidiophores. Under certain conditions, some species may form a larger, 0-2 septate, pigmented, thick-walled, spindle-shaped spore. This form, originally described from Sphaceloma fawcetti Jenkins (5) has been referred to as the "fawcetti" conidium (7) and has been implicated in long-distance wind dissemination of the pathogen (21).

The genus Elsinoë Racib. (Loculoascomycetes, Myriangiales) contains over 40 species and has been shown to be the perfect state of all but one species of Sphaceloma for which the sexual stage is known. Host symptoms are identical to those caused by Sphaceloma spp. Bitunicate asci, found solitary in locules, usually contain eight hyaline or slightly pigmented ascospores which are commonly 3-septate, often with a longitudinal septum in one or more internal cells.

In 1950 Bitancourt and Jenkins (2) described a species of Sphaceloma, S. manihoticola on cassava (Manihot esculenta Crantz, Euphorbiaceae). Their description and decision to consider it a new species was based entirely on symptomatology and host position within the Euphorbiaceae, since no spores or other fungal reproductive structures were visible in their specimens. They also observed symptoms which they attributed to the same pathogen on M. glaziovii Muell. Arg., but made no mention of internode elongation in their description of symptoms. Bitancourt and Jenkins (2) stated clearly that they considered the new species as provisional, pending later opportunity to examine fresh specimens containing reproductive structures.

Symptoms of superelongation disease include necrotic leaf spots, hypertrophic leaf-vein, petiole and stem cankers, characteristic of scab disease caused by Sphaceloma (4). In addition, severely affected plants show marked elongation of the internodes, from which the disease name is derived. The causal agent was identified as a species of Sphaceloma by Krausz (6) who decided that it should be considered S. manihoticola, even though it was impossible to determine if it was the same species described by Bitancourt and Jenkins. Prior to this study, no Elsinoë had been reported from Manihot spp.

Since 1942 several species of Sphaceloma and Elsinoë have been described as pathogens on weedy and ornamental plants related to cassava in Central and South America. Euphorbia brasiliensis, Eu. heterophylla L., Eu. hypericifolia L. and Eu. prunifolia L. are all weeds susceptible to Sphaceloma-Elsinoë spp. and common in cassava growing areas. Scab-susceptible Eu. pulcherrima Willd. (the "poinsettia") is a common ornamental shrub. Jatropha curcas L. as well as J. aconitifolia Muell. var. papaya Arbelaez are trees often found in hedgerows between fields or as ornamentals in cassava growing areas.

## Experimental

Isolates of Sphaceloma spp. were obtained from various Euphorbiaceous hosts in Latin America. These were cultured as described elsewhere (9) and comparisons made of colony, conidiophore, and conidial morphology. Cross inoculations with all the Sphaceloma-Elsinoë species and hosts under consideration were conducted and conidial dimensions from each host compared. The morphology of an Elsinoë spp. found on lesions of SED-affected cassava was studied, and the pathogenicity of single-ascospore isolates on cassava and other Euphorbiaceous hosts tested.

## Findings

Colony morphology of the different species of Sphaceloma was so variable as to be of limited usefulness as a criterion for distinguishing species. Conidial dimensions of isolates from several hosts considered to be hosts of distinct Sphaceloma-Elsinoë species were not found to differ significantly. No other reliable means of separating these species could be found. Conidial dimensions of isolates from cassava, Jatropha spp., Euphorbia brasiliensis and Manihot carthaginensis were all found not to differ. Isolates from poinsettia (E. pulcherrima), E. heterophylla, and E. prunifolia, though significantly larger than the former group, did not differ significantly among themselves. The latter group also were found to produce fawcetti conidia, absent in the former group. Cross-inoculations with all possible host-pathogen combinations followed the same pattern as conidial dimensions.

Ascoma were observed on hypertrophic tissue of cassava leaves, petioles, and stems of plants collected during the rainy seasons when rains were regular. These structures were present on material from Mexico (Tabasco), Costa Rica, the Dominican Republic and Colombia (Departments of Casanare, Cauca, Magdalena, Meta, and Vichada). Extensive examination of material from the other host species showing scab symptoms yielded no sexual structures.

Ascoma on cassava are pulvinate (occasionally applanate) and convoluted to smooth, solitary or coalescing, 20-130 µm in diameter. They originate subepidermally and are composed of a hyaline pseudoparenchyma with a distinctly pigmented epithelium, giving the structure a dark appearance when viewed from above. Asci (usually with eight ascospores) are bitunicate and globose (13-22 µm in diameter) and occur singly in locules with poorly developed walls. Mature ascospores (11-14 x 3-7 µm) are hyaline, have transverse septa at which they show slight constriction, and commonly have a longitudinal septum in one or more of the internal cells. One end of the spore is typically somewhat broader than the other. Germination is by production of conidia or direct, with one or more germ tubes produced from each cell, near the septa. Fragmentation of ascospores was occasionally observed, particularly with dried specimens.

Based on comparisons of published descriptions and extensive examination of herbarium type specimens, and the results of the morphology and cross-inoculation studies, Elsinoë antidesmae, E. heveae, and E. venezuelensis are considered to be distinct species and should be retained. However, the differences among E. brasiliensis, E. jatrophae, and the Elsinoë from cassava are not considered sufficiently great to warrant their continued treatment as separate species, and should all be considered to be E. brasiliensis. Sphaceloma manihoticola is, therefore, the correct name for the imperfect state of E. brasiliensis as well as the causal agent of superelongation disease. Similarly, S. krugii does not differ

sufficiently from S. poinsettiae to be considered distinct, and is combined with the latter under the name S. poinsettiae.

The host range of E. brasiliensis is considerably expanded and includes Manihot spp., Euphorbia brasiliensis (a cosmopolitan weed), Jatropha curcas and J. aconitifolia var. papaya (ornamental trees). This has important implications for cassava in other parts of the world. It is likely that should S. manihoticola be introduced into Asia or Africa, weedy Euphorbiaceous hosts will prevent its eradication. Similarly, as has been the case with the CIAT station, complete eradication of the pathogen appears impossible. Quarantine programs in areas free of SED should be aware that other Euphorbiaceous hosts notably the attractive ornamental Jatropha spp. may carry cassava pathogens. Finally, considering that there is a common sexual stage, in addition to the wide host range, it is likely that a high degree of pathogenic variability is present in most populations of S. manihoticola.

## II. Pathogen Production of Gibberellin $A_4$

Krausz (6) in early work on the disease unsuccessfully attempted to isolate a fungus-produced plant growth regulator responsible for the internode elongation. Plant hormones are known to be involved in many plant diseases. The classic case is that of bakanae disease of rice caused by Gibberella fujikuroi (Saw.) Wr. from which the plant hormone gibberellin (GA) was first isolated. The most obvious symptom of this disease is internode elongation of juvenile rice plants not unlike that observed in superelongation disease. Given this similarity in symptoms, we felt that a GA-like compound produced by the fungus may be responsible for the hypertrophic symptoms. This portion of the study was undertaken to determine if the pathogen is capable of producing a GA in vitro that reproduces secondary symptoms in the absence of the pathogen. Finding that the case, subsequent studies were conducted to determine if field resistance or susceptibility of cultivars were correlated to sensitivity to the hormone.

### Experimental

Isolates of S. manihoticola were grown in liquid medium for 2-3 weeks. Culture filtrate was purified by acid-base partitioning followed by silica gel column chromatography. Fractions from the chromatography were passed through combined gas chromatography-mass spectrometry and compounds identified based on the resulting mass spectra. Biological activity was determined using lettuce seedling hypocotyl bioassay and treatments of young cassava plants with purified hormone.

Young plants of cassava cultivars known to differ in their levels of field susceptibility to SED were treated with increasing concentrations of gibberellin A4. After 7-10 days, depending on experimental particulars, lengths of newly emerged internodes of treated and control plants were measured and plants then inoculated with conidial suspensions of the pathogen. After incubation, plants were evaluated for percentage of stem area diseased and length of diseased area. Data were analyzed using analyses of variance and covariance.

### Findings

Results of purification and analyses of fungal extracts demonstrated unequivocally that S. manihoticola produces gibberellin A4 in vitro (11). Application of the purified hormone to cassava plants reproduced the stem elongation and leaf deformation symptoms. The only other fungus known to produce gibberellins is

Gibberella fujikuroi, an unrelated pathogen of rice. All nine cultivars tested responded to applications of $GA_4$ by increased internode length. Significant increases over control were detectable at concentrations of $1x10^3$ μg/μl test solution. At each concentration and over all concentrations the amount and percent susceptible area diseased on field susceptible (FS) cultivars and field resistant (FR) cultivars differed significantly. No relationship between minimum [$GA_4$] required to elicit significant elongation response and varietal susceptibility was detected. While the rates of elongation as functions of increasing [$GA_4$] differed significantly among cultivars there was no difference between FS and FR cultivars when the data were analyzed using analysis of covariance with [$GA_4$] as the covariate and field susceptibility as a class variable.

All cultivars showed increasing amounts of disease with increasing hormone concentration. This suggests that $GA_4$ production may confer an advantage to the pathogen by increasing the amount of susceptible juvenile tissue. As in the case of internode length, rate of change of the amount of diseased area did not vary with cultivar field susceptibility. In some cultivars, high [$GA_4$] not only increased the total amount of disease on a plant, but also increased the percent of susceptible tissue involved in lesions, or tissue susceptibility, with important implications for secondary cycles and epidemic development in the field.

## III. Some Characteristics of Resistance

In almost all national and international programs a key approach to improving cassava yields is breeding improved varieties. Because cassava is vegetatively propagated from farmer-produced "seed," long cycle (up to 24 months) and grown with few inputs, a fundamental goal of improvement programs must be varietal stability. The discovery that the sexual stage of the pathogen is common, together with a wide host range, argues that the potential exists for tremendous variability within pathogen populations. Whether within this variability are found high levels of pathogenic specialization becomes of critical concern to breeding programs, since most evaluations for SED disease resistance are carried out at only one site.

### Experimental

Several experiments were conducted to test the influence of removing stem cuticle of young cassava plants on subsequent level of disease. Immediately prior to inoculation, stems of plants of cultivars ranging from highly susceptible to highly resistant were subjected to gentle abrasion by a water-soaked cotton swab. This treatment has been found to remove stem culture with minimal damage to underlying tissue. Alternatively, one half of a stem was treated to remove the cuticle while one half was left with cuticle intact. In all experiments an equal number of treated and untreated plants were used. Stem cuticle thickness of young tissue from plants growing in a heavy SED region (Carimagua Station, Meta, Colombia) was measured and level of SED on the cultivars taken at the time of tissue collection.

Cross inoculation studies were conducted using 30 isolates of diverse geographical origin and over 60 cassava cultivars. Space limitations permitted only five to six cultivars to be inoculated with 10-11 isolates in all possible combinations at any one time. Level of disease was determined after 10 days, and was measured as the number of internodes involved (recorded as continuous variable) and the percent of affected stem area directly involved with lesions.

Data from the inoculations were analyzed using a two-way analysis of variance with the primary interest being significant cultivar x isolate interactions. Cultivar x isolate mean tables were inspected for suspicious interactions when significant or near significant F-ratios were calculated for cultivar-isolate interactions. Cultivars and isolates involved in relatively strong interactions were included for repeat experiments to test the stability of the interactions.

## Findings

For all cultivars, regardless of known field susceptibility, disruption of stem cuticle significantly increased the amount of disease on the treated stems compared to the untreated stems. However, susceptible cultivars always remained more susceptible than resistant cultivars. Thus stem cuticle is not a primary determinant of resistance. No correlation was found between stem cuticle thickness and level of field resistance. Stem tissue was found to become resistant with age. Stem tissues of all cultivars, regardless of their level of resistance (or susceptibility), became completely resistant after about 10 days. This resistance is unaffected by cuticle removal, and its mechanism is unknown. Removal of cuticle increased the length of diseased stem tissue, thus it is believed that cuticle acts as a defensive barrier over susceptible juvenile tissue until the age-related mechanism develops. Cuticle probably acts simply by preventing the inoculum from adhering to the stem.

Two-way analysis of variance of the results of the inoculations, evaluated as number of infected internodes and percent susceptible area diseased, revealed significant cultivar x isolate interactions for most of the inoculations using the isolates and cultivars selected from the initial group by their performance in the preliminary experiments. Inspection of the results showed several isolates that were commonly involved in the interactions, while others showed no specific interaction with any cultivars used in these experiments. Likewise, some cultivars showed no evidence for specific interaction with the isolates used, while others did.

In light of the significant cultivar interactions, it is not appropriate to consider grand means as reflections of differences in virulence or resistance for the isolates and cultivars. Several isolates consistently had the lowest mean disease levels over all cultivars in different experiments. However, examinations of the mean tables revealed that this was usually because one or two cultivars behaved as though they were differentially resistant to these isolates, lowering the overall isolate mean. Other cultivars were as susceptible to these "less virulent" isolates as they were to the "more virulent" isolates. Thus, while there was some trend indicative of differences in virulence it was not strong.

While high levels of physiological resistance to all isolates was encountered in stem tissue of some cultivars, none were found to be "immune" or to have a hypersensitive-like response. The leaves of all cultivars showed rather high susceptibility under the experimental conditions. Cultivar x isolate interactions typically were such that the cultivar appeared differentially resistant rather than differentially susceptible. Similarly, interactions were rarely "complete." That is, two isolates causing significantly different amounts of disease on one cultivar tended not to reverse order of virulence on another cultivar. Rather, they would cause equal amounts of disease. Another interesting result was that some cultivars that have a high level of apparently stable field resistance showed significant interactions with some isolates and showed levels of physiological susceptibility comparable to those cultivars very susceptible in the field. Thus,

factors other than physiological host-pathogen compatibility appear to be involved in the development of superelongation disease epidemics in the field.

It is important to consider in a technique such as that used here to detect host-isolate interactions that one is simply evaluating one, and the first, exposure of the plant to the pathogen. In the field SED is multicyclic, and the ability of the cultivar to limit subsequent generations may be equally, or more, important that the susceptibility at one, or the first, encounter. Any glasshouse evaluation of resistance must include means of evaluating this. Additional parameters of evaluation should include incubation and latency periods, final lesion size, sporulation rate, and conidia size.

To evaluate importance of pathogenic specialization phenomenon within the context of host species and cassava breeding programs, it is necessary to determine whether or not the interactions observed are real. Several independent lines of evidence suggest that, although weak and subject to variation, there is specific adaptation of resistance in some cultivars to virulence factors found in the pathogen population. First, in all inoculations the relative response of a cultivar with known high field susceptibility to the same isolates remained rather constant. There were only two isolates showing significant differences in their relative virulence on this cultivar over different inoculations using the standard technique. These isolates do not enter into evaluations of interactions. Second, statistically significant interactions were repeatable. In general, most cultivars used in the detailed experiments showed interation with some isolates and these were consistent with earlier observations. This is to be expected since most of the cultivars and isolates were selected out of the preliminary inoculations because they appeared to show specific interactions. It is significant that those cultivars which uniformly showed initial very high susceptibility or very low susceptibility with no interactions remained stable in subsequent inoculations over the same as well as other isolates.

Summary of the data in the form of a cultivar x isolate table is not presented here. Presentation of the data in such a form could be misleading and possibly be interpreted as providing evidence for "races." We feel that the relationship between E. brasiliensis and cassava is such that to define "races" and "differentials" would impose wholly arbitrary and simplistic limits on a dynamic and fluid system.

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## Electrophoretic Detection of Frog Skin-Infected *Manihot esculenta*

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### ABSTRACT

Frog skin (FS), a cassava (*Manihot esculenta* Crantz) disease of unknown etiology, can cause yield losses of up to 100% in susceptible cultivars. The symptoms of the disease are restricted only to the below-ground parts of infected plants. The initial symptom of the disease is the formation of small longitudinal fissures along the root epidermis, followed by excessive development of the bark. The excessive corky tissue around the fissure later gives rise to "lip-shaped" lesions. The affected roots are usually fibrous, thin, and without any stored starch.

Analyses of partially-purified preparations, obtained from FS-affected 'M Col 33' cassava plants, by polyacrylamide gel electrophoresis in the presence of sodium dodecyl sulfate (SD-PAGE) revealed a marked increase in the concentration of a normal host protein (MW 45.000 d) in infected tissue, as compared to FS-free controls. This phenomenon has been consistent in SDS-PAGE analyses of leaf and root extracts of FS-affected 'M Col 33', 'Secundina', and 'Quilcace-PR' cassava plants, and of leaf extracts of 30 other different cassava genotypes.

The electrophoretic method is suitable for the detection of FS-affected cassava plants grown under glasshouse and field conditions.

## Investigations of *Mononychellus tanajoa* (Bondar) and the Cyanogenic Glucosides of Cassava *Manihot esculenta* Crantz

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### ABSTRACT

The leaves of 23 varieties of cassava (*Manihot esculenta* Crantz) were analyzed for cyanogenic glucoside content using the method of Ikediobi, Onyia, and Eluwah (1980). Population densities of the cassava mite *Mononychellus tanajoa* on each variety were simultaneously determined. Surprisingly, regression analysis indicated a positive correlation between the mite population density and the cyanogenic glucoside levels.

# The Development of a Through Circulation Solar Heated Air Drier for Cassava Chips

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## ABSTRACT

A pilot scale through circulation drier using solar heated air has been developed for drying cassava chips. Described is design of the drier system, which includes a bottom ventilated drying bin, centrifugal fan and solar collector. In evaluation trials the variables studied were drier loading (37.5 to 150.0 $kg/m^2$), airflow (11 to 18 $m^3/min.\ m^2$) and varying air conditions in the range 24 to 28°C and 62 to 72% RH. Design parameters for drier scale-up are presented.

## Introduction

The great potential in tropical Latin American countries for using dry cassava as a source of carbohydrate in animal feed concentrates (Pachico, 1980; Gómez, 1982) has led to the need for developing efficient methods of drying that are technically and economically suited to production and cost structures prevailing in the region. Natural drying on concrete floors is the method most commonly employed for drying cassava for animal feed. During the 1970s research by various workers aimed at improving natural drying techniques, both on concrete floors (Thanh, 1979) and in vertical and inclined trays (Roa, 1974; Best, 1978). These study results have led to greater understanding of the effect that factors such as chip geometry, loading density and ambient conditions have on the rate of drying.

Despite improvements in drying efficiency and advantages of natural drying over artificial drying in terms of relatively low capital and operating costs, the method remains totally dependent on the weather. Consequently, natural drying is not practical in areas with year round high relative humidity and in regions with marked wet seasons. The periods in which natural drying is possible are restricted. In these cases, the use of forced air, through circulation driers, operating with ambient or heated air, or a combination of both, provide an economically feasible alternative to fully artificial, continuous drying plants whose scale and costs of operation are such that their use in Latin America has seldom met with success (Crown, 1981; Freivalds, 1982).

This paper reports preliminary results of a joint project between the Centro Internacional de Agricultura Tropical, CIAT and the Universidad del Valle, Cali, Colombia, with a principal objective to develop and evaluate a forced air through circulation cassava drier for use by farmers' associations on the Atlantic Coast of Colombia (Ospina et al, manuscript in preparation). The complete evaluation will include a technical and economic comparison of ambient, solar heated and fuel

fired air systems: results of trials of the solar heated air system only are presented here.

## Drying system

The drying system constructed at CIAT is an adapted version of the system developed at the Centro Nacional de Treinamento em Armazenagem, CENTREINAR, Brazil (Sinicio and Roa, 1980) and consists of a solar collector, a centrifugal fan and a drying bin (Figure 1). The centrifugal fan draws air through the solar collector and passes it through a 305 mm diameter duct into the plenum chamber of the drying bin.

The solar collector, with an area of 10 $m^2$, is constructed on a concrete base and is made of a 200 mm layer of fine stones upon which are placed concrete blocks, arranged longitudinally along the collector. The concrete blocks, 200 mm square section and 400 mm long, are designed so their cavities may be oriented to maximize solar radiation absorption. The stones and blocks are painted mat black. Above the blocks, a polythene cover is supported by chicken wire and the lateral brick walls of the collector. CIAT's proximity to the equator has made it unnecessary to incline the collector.

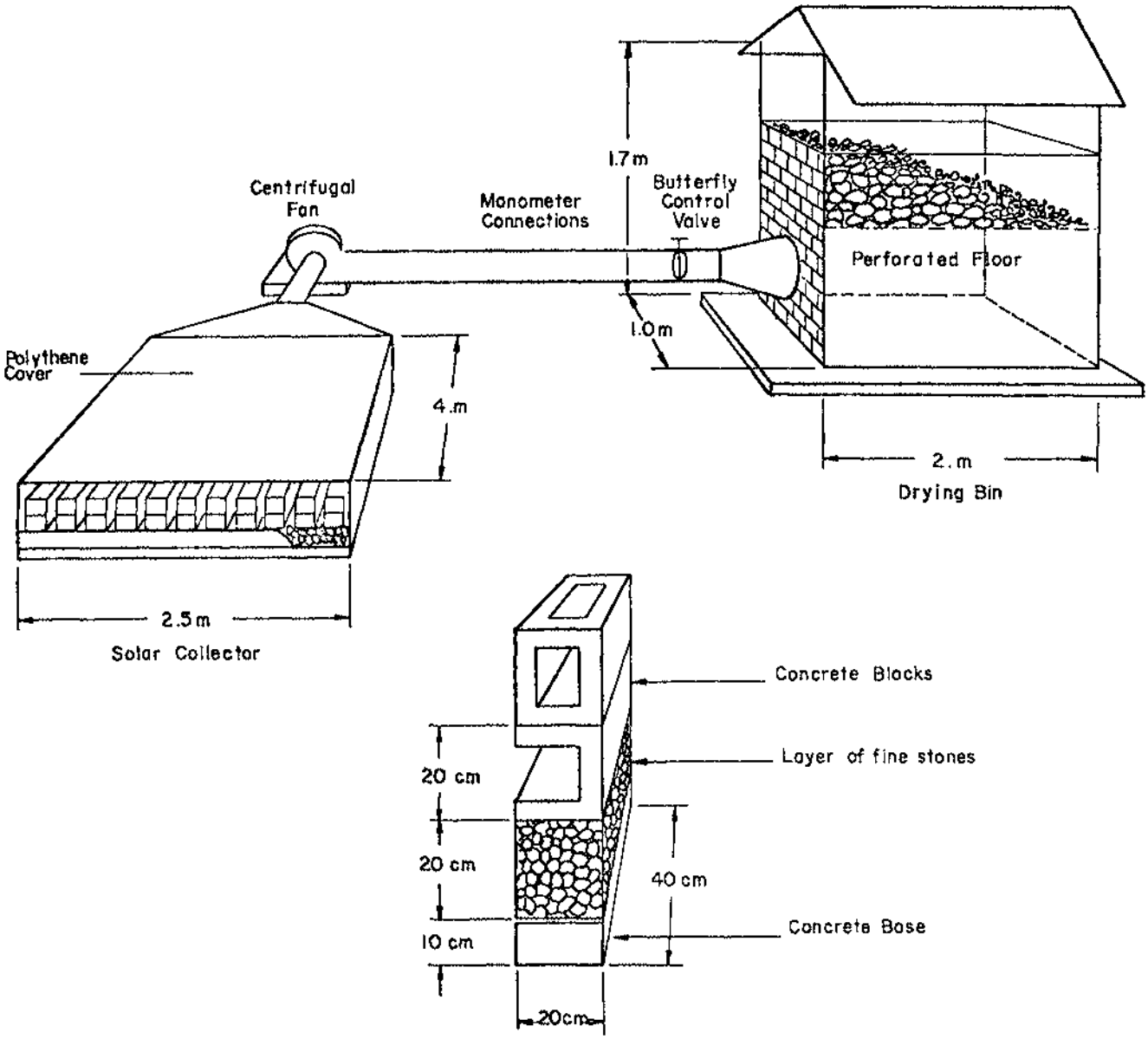
The centrifugal fan has forward curved blades driven at 600 rpm by a 1.5 hp electric motor. Air flow can be varied between 0 and 38 $m^3$/min by adjusting a butterfly valve placed before the plenum chamber. Air flow is measured with a pitot tube connected to an inclined manometer.

The drying bin, with dimensions of 1.0x2.0x1.7 m high, is constructed of brick with a concrete floor. At a height of 60 mm above the floor and supported by wooden cross beams, a galvanized steel sheet with 3% opening (3 mm diameter holes) is placed. Onto this perforated floor, which has an area of 2 $m^2$, are loaded the cassava chips to be dried. The drying bin is protected from the rain by a corrugated sheet roof raised 800 mm above the walls.

Thermohydrographs are used to monitor ambient temperature and relative humidity and air conditions in the plenum chamber. Solar radiation is measured using an integrating pyranometer.

## Procedure

The cassava variety used in the trials was HMC 1, harvested from 12 through to 15 months. The whole cassava roots were washed in a concrete tank before chipping in a Thai type chipping machine (Thanh, et al, 1979). The cassava chips were sampled for fresh moisture content and then loaded into the drier. The change in moisture content of the cassava chips during drying was determined by weighing three 200 mm diameter sampling cylinders placed in the drying bed. At the end of the drying period a further sample of dry cassava was taken for moisture determination. On both fresh and dry samples, moisture content measurements were carried out by drying to constant weight in an oven at 60°C. During drying the cassava was turned at 0800, 1200 and 1600 hours to prevent deterioration of the upper layers of chips, and the fan was operated continuously day and night.




DETAIL OF INTERNAL SOLAR COLLECTOR CONSTRUCTION

Figure 1. Through circulation cassava drying system with solar collector.

To date three sets of trials have been undertaken as part of the evaluation of the drying system. The objectives of each set of trials were as follows:

1st set: To determine optimum drier loading.
2nd set: To determine optimum airflow rate.
3rd set: To determine the optimum time of starting drying.

## Results and Discussion

In analysis of results the parameter used to compare trials is the rate of loss of moisture, in kg of water per hour per square meter of drying floor. This parameter, which is a function of the initial moisture content of the chips, the airflow rate and the temperature and relative humidity of the drying air, gives an indication of drying efficiency.

The results of the first set of five trials, in which the loading rate was varied from 37.5 to 150.0 kg of fresh cassava chips per square meter of drying floor are in Table 1. The drying time increases with increasing loading, however, the rate of loss of moisture is highest at 2.04 kg/h $m^2$ for a loading of 150 kg/$m^2$, followed by 1.90 kg/h $m^2$ for a loading of 75 kg/$m^2$. At the 150 kg/$m^2$ loading, discoloration of the cassava chips occurred after 36 hours and a faint malodorousness was observed. It was therefore believed that this loading was too high to produce dry cassava of an acceptable quality. On the other hand, the 75.0 kg/$m^2$ loading gave a drying time of 25 hours which, taking into account practical plant operating conditions, is too long for a one-day-per-batch system. Under the circumstances it was decided to opt for the 125 kg/$m^2$ loading which, drying in 45 hours, would fit into a 2-day-per-batch operation.

In the second set of trials, the airflow rate was varied between 11 and 18 $m^3$ per minute per square meter of drying floor, at a constant drier loading of 125 kg/$m^2$, Table 2. The rate of loss of moisture for the two extreme conditions of airflow rate were the same at 1.82 kg/h.$m^2$. However, at the 18.3 $m^3$/min.$m^2$ airflow rate the relative humidity of the drying air was six points higher, which suggests that the higher airflow rate will be necessary to allow for the worst drying air conditions encountered.

Finally, a set of four trials was conducted in which drying was started at 0800, 1100, 1400 and 1700 hours, Table 3. The results clearly indicate that in terms of drying time and rate of loss of moisture it is advantageous to initiate drying in the later hours of the afternoon. Starting at 1,700 hours makes best use of the night hours, when relative humidity of the air is high, to remove moisture from the fresh cassava chips and then, on the second day of drying, the hottest hours are available to terminate the process.

An important parameter for selecting an appropriate fan for the drying system is the pressure drop through the drying bed; this never exceeded 0.33 inches water gauge. It was observed during the drying trials that the pressure drop decreased during drying as the resistance to airflow was reduced, presumably because the chips, on losing moisture, lost their tendency to adhere to one another. There was also a noticeable shrinking of the drying bed, for a drier loading of 125 kg/$m^2$, the thickness of the layer of cassava chips decreased from approximately 250 mm to 180 mm.

Table 1. Determination of optimum drier loading.

| Drier loading $kg/m^2$ [a] | Initial moisture content % dry basis | Mean airflow rate $m^3/min.m^2$ [b] | Conditions of drying air T°C | %RH | Drying time h [c] | Rate of loss of moisture $kg/h\ m^2$ [d] |
|---|---|---|---|---|---|---|
| 37.5 | 184 | 13.4 | 25 | 67 | 22 | 1.10 |
| 75.0 | 173 | 12.0 | 28 | 59 | 25 | 1.90 |
| 100.0 | 178 | 10.6 | 28 | 63 | 43 | 1.49 |
| 125.0 | 178 | 11.2 | 27 | 66 | 45 | 1.78 |
| 150.0 | 212 | 11.0 | 28 | 63 | 50 | 2.04 |

[a]Drier loading in kg of fresh chips per square meter of drying floor.

[b]Mean airflow rate over the drying period in cubic meters per minute per square meter of drying floor.

[c]Drying time in continuous hours from the time of starting at 1400 hours.

[d]Rate of loss of moisture in kg per hour per square meter of drying floor.

Table 2. Determination of optimum airflow rate. (Drier loading 125.0 $kg/m^2$)[a]

| Mean airflow rate $m^3/min.m^2$ [b] | Initial moisture content % dry basis | Conditions of drying air T°C | %RH | Drying time h [c] | Rate of loss of moisture $kg/h\ m^2$ [d] |
|---|---|---|---|---|---|
| 18.3 | 230 | 24 | 71 | 48 | 1.82 |
| 15.7 | 190 | 25 | 71 | 49 | 1.67 |
| 12.5 | 228 | 27 | 62 | 71[e] | 1.22 |
| 11.3 | 249 | 26 | 65 | 49 | 1.82 |

[a]Drier loading in kg of fresh chips per square meter of drying floor.

[b]Mean airflow rate over the drying period in cubic meters per minute per square meter of drying floor.

[c]Drying time in continuous hours from the time of starting at 1400 hours.

[d]Rate of loss of moisture in kg per hour per square meter of drying floor.

[e]In this trial drying was interrupted for 18 hours because of rain.

Table 3. Determination of the optimum time of starting drying. (Drier loading 125.0 kg/m$^2$[a] and mean airflow rate 16.5 m$^3$/min.m$^2$[b].

| Time of starting drying h | Initial moisture content % dry basis | Conditions of drying air T°C | %RH | Drying time h[c] | Rate of loss of moisture kg/h m$^2$[d] |
|---|---|---|---|---|---|
| 0800 | 203 | 25 | 72 | 54 | 1.55 |
| 1100 | 209 | 26 | 69 | 49 | 1.73 |
| 1400 | 227 | 26 | 67 | 47 | 1.85 |
| 1700 | 214 | 26 | 67 | 46 | 1.85 |

[a]Drier loading in kg of fresh chips per square meter of drying floor.

[b]Mean airflow rate over the drying period in cubic meters per minute per square meter of drying floor.

[c]Drying time in continuous hours from the time of starting at 1400 hours.

[d]Rate of loss of moisture in kg per hour per square meter of drying floor.

The detailed evaluation of the solar collector has not been concluded. However, during the period of these trials the collector gave average increases in air temperature of between 1° and 3°C, corresponding to reductions of between 4.4% and 9.6% in relative humidity. Yet to be determine is whether the additional cost of the solar collector is justified in terms of increased drier loading, as compared with drying using ambient air alone.

## Future work and conclusions

These preliminary results indicate that basically two areas require further investigation. First, a comparison of one-and 2-day drying needs to be made, as the former may be more convenient in terms of root supply to the processing plant and will definitely produce dry cassava of a higher visual quality. It was hoped to evaluate quality of the dried product by measuring the condensed tannin content, production of which during drying could account for the brown discoloration observed. Unfortunately the high tannin content of the periderm (bark) interfered with the results. Secondly, to make better use of the drying capacity of the air, which after a certain drying period leaves the drying bed unsaturated, a double bed bin or a two bin reversible airflow system will be tested.

Although it is evident that further development work is needed, results from these trials show that at a drier loading of 125 kg/m$^2$ and an airflow rate of 18 m$^3$/min.m$^2$, it is possible to dry cassava chips in 2 days, using solar heated air at average temperatures ranging between 24° and 28°C and relative humidities in the range 62% to 72%. This is equivalent to a requirement of 8 square meters of drying floor and 146 cubic meters per minute of airflow for each ton of cassava chips to be dried.

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Cassava Storage Root Yield Losses from Root-Knot Nematode (*Meloidogyne incognita* and *M. javanica*) Parasitism

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SUMMARY

The root-knot nematodes, *Meloidogyne incognita* race 2 and *M. javanica*, significantly (P = 0.05) reduced stalk height, stalk weight and storage root ("tuber") weight of two cassava (*Manihot esculenta*) cultivars, TMe 30555 and TMe 30572, after a 15.5-month growing period in the tropical rainforest zone of southern Nigeria.

A slight reduction in mean plant height in conjunction with a severe reduction in stalk weight would provide an inferior and less robust planting stake for the next crop. Nematode galls were not observed on storage roots but only on fine feeder roots. At harvest the feeder roots generally remain unseen in the soil and any yield reduction may be attributed to other causes or the problem may pass unnoticed.

Cassava (*Manihot esculenta*) supplies about 60% of the daily food calories for the majority of people living in the world's tropic zone. Global importance of cassava has greatly increased with the rise in population, its use as a source of animal feedstuffs, and as raw material for industry. Cassava raw root production annually exceeds 100 million tons and in conjunction with the vegetable use of the leaves as a valued protein source, the crop assumes considerable importance in the total world output of foodstuffs. Cassava is also of considerable social, economic and political importance as it is almost wholly a product of developing nations.

The study of nematodes as pests of cassava has received little attention considering that the crop is one of mankind's major sources of carbohydrate and is a major factor in the economies of some countries. However, the fact that nematode infection of cassava is widespread has long been documented (1, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20). Sasser (17) estimates that about 6% of the world production is lost to nematode attack. A loss of 6 million tons of carbohydrate is highly significant in a food-short world. This paper reports on parasitism of two root-knot nematode species on two cultivars of cassava.

## Materials and Methods

Two cultivars of cassava, TMe 30555 and TMe 30572, were planted in microplots at IITA in the rainforest zone of Nigeria. The microplots were formed of concrete pipe and had a surface area of 0.26 $m^2$ with a soil depth of 1 m. One month prior to planting, each microplot was fumigated with an overdose of D-D Mixture at

600 l/ha to eradicate all nematodes. During fumigation, the soil surface was sealed with black plastic sheeting. Three weeks after planting cassava stakes and when roots had developed, each microplot was inoculated with about 10,000 eggs of Meloidogyne incognita race 2 or M. javanica. Noninoculated control plots were included. The trial was a completely randomized design with 20 replications. The root-knot nematode cultures had been reared on tomato in the greenhouse. Eggs were harvested using the sodium hypochlorite method of Hussey and Barker (8). The cassava stakes were planted at the beginning of the rains and were not irrigated through the 4-month dry season which began 8 months later. The cassava was harvested at 15.5 months and 3.5 months into the rainy season of the second year.

Soil populations of the root-knot nematode juveniles were determined by taking three 100 $cm^3$ cores from each microplot with a soil sampling tube 2.5x20 cm. Nematodes were isolated from the soil using the modified Baermann funnel method (21) and concentrated by the settling-siphon method (2). The roots were subjectively rated for the degree of gall development.

## Results and Discussion

Soil sampling showed a wide variation in root-knot nematode juvenile population levels and populations were grouped according to density for analysis (Table 1). Root-knot index means show greater feeder root-gall expression by M. incognita on both cassava cultivars than by M. javanica. Root-gall expression was about the same on both cassava cultivars for the two nematode species (Table 2). No gall formation was observed on storage roots. Based on egg counts, M. incognita reproduction was not significantly different on the two cultivars while M. javanica showed a greater rate on TMe 30572 (Table 3). M. javanica juvenile populations ranged from low to very high on both cassava cultivars, while M. incognita had juvenile populations up to medium on TMe 30572 and high on TMe 30555. M. incognita juvenile populations did not reach high densities on either cassava cultivar.

Table 1. Categories of soil populations of root-knot nematode juveniles after 15.5 months of parasitism on cassava by Meloidogyne incognita race 2 and M. javanica.

| Root-knot nematode population density | Mean number juveniles per liter of soil | Range |
|---|---|---|
| None | 0 | 0 |
| Very low | 117 | 200 - 34 |
| Low | 450 | 500 - 400 |
| Medium | 950 | 1,300 - 600 |
| High | 2,150 | 2,500 - 1,800 |
| Very high | 5,150 | 7,500 - 2,800 |

The grand means of both nematodes on the two cassava cultivars were significantly different (P = 0.05) for each population level for stalk height, stalk weight and storage root weight (Figure 1). The phenomenon of increased plant growth under light nematode parasitism (Figure 1, Table 4) has been reported previously (3, 4, 19).

Table 2. Root-knot index means on cassava feeder roots after 15.5 months of parasitism by *Meloidogyne incognita* race 2 and *M. javanica*. Root-knot index scale of 0 = no galling; 4 = maximum galling. Means of 20 replications.

| Nematode | Root-knot index | | Mean |
|---|---|---|---|
| | TMe 30572 | TMe 30555 | |
| *M. incognita* | 2.95 | 2.7 | 2.82 |
| *M. javanica* | 1.9 | 2.2 | 2.05 |
| Mean | 2.42 | 2.45 | |

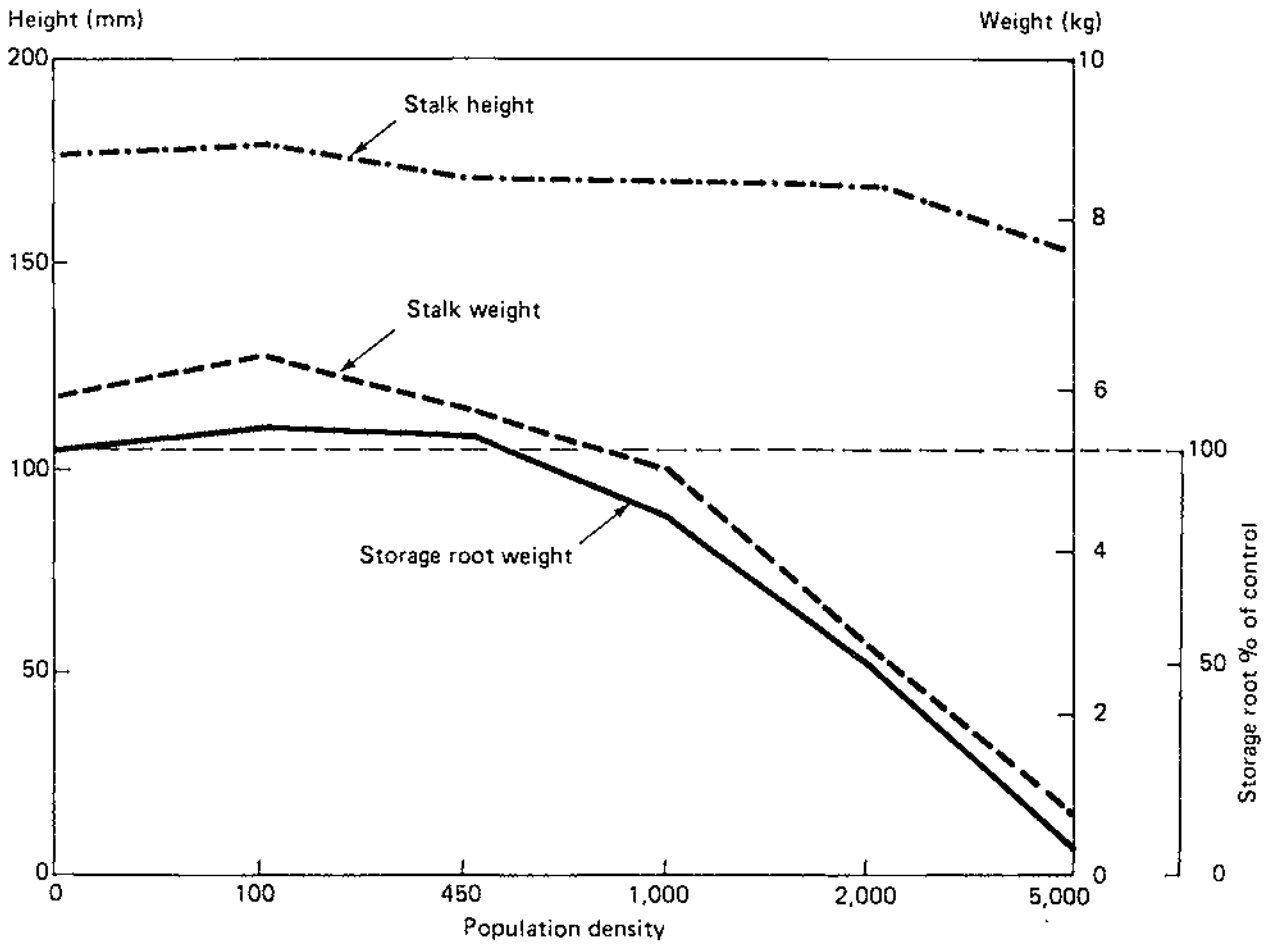
Table 3. Mean numbers of root-knot nematodes eggs/g of cassava feeder root tissue after 15.5 months of parasitism by *Meloidogyne incognita* race 2 and *M. javanica*. Means of 20 replications.

| Nematode | Number of eggs | | Mean |
|---|---|---|---|
| | TMe 30572 | TMe 30555 | |
| *M. incognita* | 432 | 503 | 467 |
| *M. javanica* | 1,230 | 112 | 671 |
| Mean | 831 | 308 | |

As seen in Figure 1, the slight reduction in mean plant height coupled with the severe reduction in stalk weight would provide an inferior and less robust planting stake for the following crop. The graph shows that a storage root yield reduction of about 17% to 50% can occur without a noticeable decline in plant height. As the root galls are on the fine feeder roots and generally remain unnoticed in the soil, a yield smaller than expected may be attributed to other causes or the problem may pass unnoticed.

Table 4. The grand summary of relative storage root weights of cassava after 15.5 months of parasitism by the root-knot nematodes, *Meloidogyne incognita* race 2 and *M. javanica*.

| Root-knot nematode population density | Relative storage root weight % |
|---|---|
| None | 100 |
| Very low | 106 |
| Low | 104 |
| Medium | 83 |
| High | 50 |
| Very high | 2 |




Root-knot nematode on cassava.

Figure 1. The grand summary of stalk height, stalk weight and storage root weight of two cassava cultivars, TMe 30555 and TMe 30572, after 15.5 months growing period in association with Meloidogyne incognita race 2 or M. javanica.

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Effect of Whole-Root Chips Loading for Drying Cassava on Trays or Concrete Floor on Cyanide Losses

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ABSTRACT

Roots of varieties CMC-40 and CMC-84 from 15-month-old plants were used in this experiment. Three loadings for drying on trays (10, 15 and 20 kg $m^{-2}$) and two for concrete floors (10 and 12 kg $m^{-2}$) were studied. At these loading rates floor drying was more efficient in reducing cyanide than tray drying. Increasing the loading of chips on trays up to 20 kg $m^{-2}$ resulted in higher cyanide losses than with lower loadings, especially with the high cyanide variety, CMC-84. Proportion of free cyanide in dried chips appeared to progressively increase as the loadings on trays were incremented. Floor and tray drying chips of the low-cyanide variety produced dried chips containing 100 ppm or less of total cyanide, on a dry matter basis. These levels were not reached with chips of the high-cyanide variety.

## Introduction

Sun-drying, either on concrete floors or inclined trays, is the most widespread method of drying cassava chips for animal feed. Duration of the sun-drying process depends on several factors such as climatic conditions (ambient temperature, solar radiation, relative humidity, windspeed), the geometry, size and uniformity of the chips, initial moisture content of chips and loading rates of fresh chips per unit area of drying surface.

Cassava varieties differ widely in cyanide content of their root tissues (Gómez et al., 1980). Most cyanide in cassava is bound cyanide in the form of cyanogenic glucoside, linamarin (Conn, 1969; Nartey, 1978; Gómez et al., 1980). Once physical structure of roots is disrupted, cyanogenic glucoside is normally hydrolyzed by the enzyme linamarase, present in cassava tissues with highest concentration in root cortex or peel, forming hydrocyanic acid (Conn, 1969). The drying process is an efficient way of eliminating cyanide in cassava roots (Correia, 1947; Cooke and Maduagwu, 1978; Maduagwu and Adewale, 1981; Gómez, 1982).

Objective of this study was to ascertain the effect of several loading rates of fresh cassava chips of two cassava varieties (one a low-cyanide cultivar, CMC-40, and the other a high-cyanide cultivar, CMC-84) on cyanide elimination by the sun-drying process on a concrete floor and on inclined trays.

## Materials and Methods

Roots of varieties CMC-40 and CMC-84 from plants harvested at 15 months of age, grown under identical conditions, were used in this experiment. Unwashed harvested roots were chopped through a Thailand-type chipping machine (Thanh, et al., 1979). Fresh whole-root chips were immediately weighed and spread on either concrete floor platforms (22 $m^2$ each) or inclined trays (1.5 $m^2$ each). Three (10, 15 and 20 kg $m^{-2}$) and two (10 and 12 kg $m^{-2}$) loading rates were studied for drying on trays and on concrete floors, respectively, for each variety. A total of 12 trays and three concrete platforms per variety at each loading rate were assayed. Samples of fresh and dried chips were taken from every two trays and from two equal sub-areas of each concrete platform so that six samples per treatment were analyzed.

Immediately after fresh chips were spread on the experimental drying surface a 60 g sample was taken, immersed in phosphoric acid, homogenized and filtered and the homogenate used for cyanide analyses by the enzymatic assay (Cooke, 1978); total and free cyanide were determined by this assay and bound cyanide (linamarin) was obtained by difference. Chipping and sampling operations were coordinated so as to keep the time elapsed between them to a minimum; the immersion of the sample in phosphoric acid took place approximately 15 minutes after the whole-roots were chipped. Chips were periodically turned during the drying period, manually on the trays and using a wooden rake on the floor. Meteorological conditions at the drying site were recorded throughout the experimental period. At the end of the drying period, samples of dried chips were taken, ground and analyzed for dry matter (DM) and cyanide contents. DM determination was performed by drying samples to constant weights at 60°C. All cyanide contents are expressed on a DM basis. The experimental information was statistically analyzed using the analysis of variance procedure (SAS, 1979) for each variety separately.

## Results and Discussion

Meteorological conditions recorded at the drying site throughout the experimental period and duration of the drying periods for chips of each variety are summarized in Table 1. Because climatic conditions were more favorable (higher ambient temperature and solar radiation, lower relative humidity and higher windspeed) during the sun-drying period for chips of the variety CMC-84, they dried faster than those of the variety CMC-40. For each variety, chips spread either on trays or on a concrete floor at a loading rate of 10 kg $m^{-2}$ required approximately the same time for drying; however, increasing the loading rate to 12 kg $m^{-2}$ on the floor extended the drying period by about one day (Table 1).

Fresh chips of variety CMC-84 contained higher ($P \leq .05$) levels of DM as well as of cyanide than those of variety CMC-40 (Table 2). The total cyanide levels in fresh chips of roots from the 15-months-old plants of the two varieties were similar to those found with the same cultivars when they were 12 months old (Gómez and Valdivieso, manuscript in preparation). Although most cyanide in root tissues, the peel cortex and parenchyma (Gómez and Valdivieso, 1983), was present as bound cyanide (~90% and 10% free), chipping of whole roots allowed rapid hydrolysis to occur, converting bound to free cyanide so that content of free cyanide in fresh chips increased to 29% and 18% ($P \leq .05$) for varieties CMC-40 and CMC-84, respectively, associated with a proportional reduction in the bound cyanide content.

Table 1. Meteorological conditions at the drying site and duration of drying periods.

| Parameter | Drying period for variety | |
|---|---|---|
| | CMC-40 | CMC-84 |
| Average meteorological conditions | | |
| Air temperature, °C | 25.5 | 28.0 |
| Solar radiation, cal g $cm^{-2}$ $h^{-1}$ | 70 | 90 |
| Relative humidity, % | 76 | 72 |
| Windspeed, km $h^{-1}$ | | |
| at 2 m above ground | 4.1 | 4.6 |
| at 0.3 m above ground | 1.5 | 2.8 |
| Duration of drying periods, h | | |
| on trays | 75 | 53 (56)* |
| on concrete floor at | | |
| 10 kg $m^{-2}$ | 77 | 53 |
| 12 kg $m^{-2}$ | 102 | 76 |

*Number in parenthesis is the drying time at the loading rate of 20 kg $m^{-2}$ on trays.

Table 2. Dry matter and cyanide contents in fresh whole-root chips of cassava varieties CMC-40 and CMC-84.

| Parameter | CMC-40 | CMC-84 |
|---|---|---|
| Dry matter, % | 36.8 ± .6[a] | 40.7 ± .3[b] |
| Cyanide contents, ppm DM basis | | |
| Total | 336 ± 14[a] | 706 ± 18[b] |
| Bound | 241 ± 12[a] | 577 ± 17[b] |
| Free | 95 ± 4[a] | 129 ± 3[b] |
| Free-cyanide, % of total | 29 ± .7[a] | 18 ± .4[b] |

[a,b]Means in the same row bearing different superscript are different ($P < .05$). Each value is the mean of 30 samples ± the standard error of the mean.

Cyanide content of dried chips as affected by drying surface (trays vs floor) and loading rates of fresh chips per unit area are presented in Table 3. These results can be summarized as follows: (1) sun-drying either on trays or concrete floors produced chips with final DM content in the range of 91% to 95%; (2) chips dried on concrete floors showed lower ($P \leq .05$) total cyanide contents than those dried on trays, in both varieties; (3) increasing loading rates from 10 to 20 kg $m^{-2}$ on trays allowed a more efficient ($P \leq .05$) cyanide elimination, as shown by the decrease in cyanide contents in dried chips at the higher loading

Table 3. Effect of sun-drying (on trays or concrete floor) and loading rates on the cyanide content in dried chips of two cassava varieties[1].

| Parameter | Drying surfaces and loading rates (kg $m^{-2}$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Trays | | | | Floor | | |
| | 10 | 15 | 20 | SEM[2] | 10 | 12 | SEM[2] |
| | VARIETY CMC-40 | | | | | | |
| Dry matter, % | 93.8 | 92.6 | 91.0 | .31 | 92.5 | 94.9 | .39 |
| Cyanide content, ppm DM basis | | | | | | | |
| Total | $71^{a}$ | $66^{a}$ | $58^{a}$[3] | 2.36 | $50^{b}$ | $29^{c}$ | 3.78 |
| Bound (linamarin) | $57^{a}$ | $50^{a}$ | $43^{a}$ | .39 | $33^{b}$ | $11^{c}$ | 1.27 |
| Free CN, % of total CN | $20^{a}$ | $24^{a}$ | $26^{a}$ | .96 | $35^{b}$ | $64^{c}$ | 4.48 |
| Total CN eliminated, % | $78^{a}$ | $77^{a}$ | $81^{a,b}$ | 1.23 | $82^{b}$ | $93^{c}$ | 1.72 |
| | VARIETY CMC-84 | | | | | | |
| Dry matter, % | 91.0 | 91.0 | 91.4 | .22 | 92.4 | 91.6 | .33 |
| Cyanide content, ppm DM basis | | | | | | | |
| Total | $310^{a}$ | $189^{b}$ | $162^{b,c}$ | 16.45 | $107^{d}$ | $142^{c}$ | 8.27 |
| Bound | $279^{a}$ | $138^{b}$ | $103^{c}$ | 3.83 | $61^{d}$ | $91^{c}$ | 2.81 |
| Free CN, % of total CN | $10^{a}$ | $27^{b}$ | $37^{c}$ | 2.93 | $43^{d}$ | $36^{c}$ | 1.76 |
| Total CN eliminated, % | $58^{a}$ | $74^{b}$ | $77^{b}$ | 2.30 | $85^{c}$ | $77^{b}$ | 1.81 |

[1]Each value is the mean of six samples.

[2]Pooled standard error of the mean, for each drying surface.

[3]Means in the same row bearing different superscripts are different ($P < .05$).

rate; (4) a similar effect ($P \leq .05$) was observed on concrete floor drying (10 vs 12 kg $m^{-2}$) with the chips of variety CMC-40, but not with those of variety CMC-84; (5) the proportion of free cyanide in chips dried on concrete floors was higher ($P \leq .05$) than those of chips dried on trays; (6) in most cases total cyanide eliminated during the drying process accounted for 74% to 93% of the initial cyanide content and (7) dried chips of variety CMC-84 contained considerably higher cyanide levels than those of variety CMC-40, especially in chips dried on trays.

Data from this study demonstrate that the sun-drying process, especially on concrete floors, eliminates most (74% to 93%) of initial cyanide content of fresh whole-root chips (Table 3); chips of variety CMC-84 dried on trays at a loading rate of 10 kg $m^{-2}$ lost only 58% of their initial cyanide content. In general, most remaining cyanide in dried chips is still found as the cyanogenic glucoside. It has been suggested (Cooke and Maduagwu, 1978) that sun-drying would lead to greater losses of cyanide than oven-drying because of longer drying times and at moisture contents and temperatures at which endogenous linamarase is active.

A maximum content of 100 ppm of hydrocyanic acid has been set as one of the quality standards for the importation of dried cassava chips or pellets to the European Economic Community (Anonymous, 1977). All dried chips of the low-cyanide variety, CMC-40, showed total cyanide concentrations less than 100 ppm, but dried chips of the high-cyanide variety, CMC-84, especially those dried on trays, had higher cyanide contents than this established limit. Little information exists as to the maximum cyanide content which can be safely ingested. This depends not only on cyanide content of dried cassava chips but also on level of inclusion of cassava meal in animal feed diets. Research in progress at CIAT (Gómez, personal communication) would suggest that cassava meal containing approximately 300 ppm of total cyanide and present in diets for broilers (0-4 weeks) up to a level of 30% does not produce any apparent adverse effects on animal performance. Further studies are needed to elucidate the toxic level of cassava cyanide for animal feeding.

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# Least-Cost Rations Containing Cassava Meal for Broilers and Growing Pigs

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## ABSTRACT

A least-cost formulation program using cassava meal at a price equivalent to 80% of the current price of sorghum indicates that cassava can be incorporated in practical rations at levels of 20% to 30% for broilers (0-8 weeks) and 30% to 40% for growing pigs (weaning to market weight). Cassava meal is used as a substitute for feed cereal grains, sorghum or maize. Results of feeding trials with broilers and growing pigs show that even cassava meal prepared from roots of high cyanide-containing varieties, such as M Col 1684, if properly dried, can be satisfactorily incorporated at the levels mentioned above in compound or balanced feeds for these species, producing results similar to those obtained with standard practical rations. Experimental data on bodyweight gain, feed consumption, feed conversion and economic evaluation are presented and discussed.

## Introduction

Although the literature on use of cassava as animal feed is extensive (Nestel and Graham, 1977) the actual inclusion of cassava meal in practical balanced poultry and swine feeds in tropical cassava-producing countries is limited. One reason is the relatively high market price of cassava roots, despite low prices obtained by farmers at the production site. This difference is a consequence of several factors, including the limitation of cassava production to the amount required to satisfy the fresh root market and also the short post-harvest life of the fresh root. A pilot project aimed at development of small scale agroindustries on the north coast of Colombia (Ospina et al., 1983) involving cassava processing and drying for the animal feed market is currently producing results showing that this type of enterprise is technically and economically feasible under the agricultural production systems of that area.

In most, and possibly all, tropical Latin American countries, the poultry industry consumes the largest proportion (up to 70%) of compound or balanced feed production (Pachico and Lynam, 1981). It therefore constitutes the most important potential market for cassava as an animal feed. In Brazil, Cuba, Mexico, Venezuela and elsewhere in Latin America, commercial scale swine production enterprises with a high level of technology are now increasing in importance as markets for balanced feeds.

Experimental results reported on use of cassava meal in broiler diets typically show large variability and lack of consistency; the recommended levels of cassava meal inclusion in broiler diets ranged from 10% (Vogt, 1966) and 30%

(Montilla et al., 1969, 1975; Armas and Chicco, 1973; Enriquez et al., 1977) to 50% of the diet (Olson et al., 1969; Tejada and Brambila, 1969; Enriquez and Ross, 1967; Chou and Müler, 1972; Armas and Chicco, 1973). Some discrepancies in these studies were due to differences in the experimental conditions and in the type of cassava root processing. The results of swine experiments were more consistent than those using poultry and have recently been summarized (Gómez et al., 1982); the inclusion of 30% to 40% of cassava meal in growing pig diets has given satisfactory results.

The amount of cassava meal used in balanced feeds is determined by quality, by price relative to other feedstuffs (cereal grains) which cassava is replacing and by cost of protein-supplying ingredients used to supplement low protein content of cassava meal. Cost of this last factor commonly reduces the price paid for cassava meal to 80% of the current price of sorghum or maize. Using a computarized linear program to formulate least-cost diets with this relative price of cassava meal and current prices of common feedstuffs, levels of inclusion of cassava meal range from 20% to 30% of the diet for both broilers and growing pigs. Based on these considerations, the present study was undertaken to evaluate least-cost diets containing 20% and 30% of cassava meal for feeding broilers (0-8 weeks) and growing finishing pigs (20 to 90 kg body weight).

## Materials and Methods

### Preparation of cassava meal

Cassava meals used in feeding experiments were prepared by sun-drying whole-root chips on a concrete floor at a loading rate of 10 kg of fresh chips per square meter. A high-cyanide (CMC-84) and several low- to medium-cyanide containing varieties were used for the poultry and pig feeding trials, respectively. Dried chips were ground through a hammer mill and the resulting cassava meal used as an ingredient of the experimental diets. The average total cyanide contents in the cassava meals used for poultry and pig experiments were 61 and 51 ppm (dry matter basis), respectively; approximately 75% of the total cyanide was present as the cyanogenic glucoside (linamarin) with the remainder as free cyanide.

### Poultry experiment

A total of 444 one-day-old Hubbard chicks were divided into 12 groups of 37 chicks each. Three dietary treatments (0%, 20% and 30% cassava meal) with four replicates each were assayed. In each dietary treatment two types of diets were prepared, the starter and the finisher, which were supplied from 0 to 4 and 4 to 8 weeks, respectively. Diets were fed ad libitum in self-feeders and water was available from automatic waterers. Management and sanitary programs used were the standards for raising broilers on floor. Body weight and feed consumption for each experimental unit (37 chicks) were registered at 4, 7 and 8 weeks, respectively.

### Pig experiment

Thirty-six weaned-crossbred pigs with an average body weight of 20.0 ± 1.2 kg and an average age of 60 days were allocated on the basis of weight and sex to six pens with three barrows and three gilts per pen. Three dietary treatments (0%, 20%, and 30% cassava meal) with two replicates each were assayed. Diets for the growing phase were fed until pigs reached approximately 50 kg, after which the finishing diets were fed. The trial lasted 13 weeks. Diets were fed ad libitum

Table 1. Composition (%) of least-cost diets containing 0, 20% and 30% cassava meal* for broilers.

| Price** | Ingredient | Starting diets (0-4 wk) 0 | 20 | 30 | Finishing diets (4-8 wk) 0 | 20 | 30 |
|---|---|---|---|---|---|---|---|
| Col.$/kg | | | | | | | |
| 15 | Sorghum | 67.09 | 44.32 | 32.94 | 70.94 | 48.17 | 36.79 |
| 12 | Cassava meal | ..... | 20.00 | 30.00 | ..... | 20.00 | 30.00 |
| 29 | Soybean meal | 21.52 | 22.68 | 23.25 | 19.55 | 20.70 | 21.28 |
| 35 | Fish meal | 8.00 | 8.00 | 8.00 | 5.00 | 5.00 | 5.00 |
| 38 | Tallow | .44 | 1.89 | 2.62 | 1.07 | 2.53 | 3.25 |
| 14 | Bone meal | 2.24 | 2.38 | 2.45 | 2.65 | 2.79 | 2.85 |
| 10 | Salt, iodized | .25 | .25 | .25 | .32 | .32 | .32 |
| 168 | Commercial premix | .20 | .20 | .20 | .20 | .20 | .20 |
| 280 | Methionine | .11 | .13 | .14 | .13 | .15 | .16 |
| 300 | Coccidiostat | .10 | .10 | .10 | .10 | .10 | .10 |
| 228 | Antibiotic | .05 | .05 | .05 | .05 | .05 | .05 |
| | Calculated nutrients, % | | | | | | |
| | Crude protein | 22.13 | 21.18 | 20.70 | 19.67 | 18.72 | 18.25 |
| | Calcium | .93 | .97 | .99 | .88 | .92 | .94 |
| | Phosphorus, total | .50 | .50 | .50 | .48 | .48 | .48 |
| | Phosphorus, available | .24 | .25 | .26 | .28 | .29 | .30 |
| | Lysine | 1.20 | 1.20 | 1.20 | 1.00 | 1.00 | 1.00 |
| | Methionine | .50 | .50 | .50 | .45 | .45 | .45 |
| | Metabolizable energy, Mcal/kg | 2.95 | 2.95 | 2.95 | 3.00 | 3.00 | 3.00 |
| | Cost, Col.$/kg | 20.67 | 20.62 | 20.59 | 19.98 | 19.92 | 19.89 |

*Sun-dried whole-root chips of variety CMC-84, a high-cyanide cultivar.

**Exchange rate at time of experiment: US$ ~64 Colombian pesos.

in self-feeders and water was available from automatic nipples. Body weight and feed consumption for each pen were periodically registered throughout the experimental period.

## Economic assessment of feeding trials

An economic evaluation of feeding trials used current feedstuffs and live broiler and pig prices (Col.$) in Cali as of June 1982. Actual cost of diets was estimated by adding a 12% charge to the overall calculated average price of all diets in each trial; this charge amounted to 2.43 and 1.91 pesos per kilogram of poultry and pig diets, respectively. These amounts covered cost of labor in different operations required for diet preparation as well as depreciation of equipment used. Fixed costs for each trial included estimated costs of labor, administration, vaccines and drugs, utilities, and depreciation of housing and equipment.

Table 2. Composition (%) of least-cost diets containing 0, 20% and 30% cassava meal* for growing-finishing pigs.

| Price** | Ingredient | Growing diets 0 | 20 | 30 | Finishing diets 0 | 20 | 30 |
|---|---|---|---|---|---|---|---|
| Col.$/kg | | | | | | | |
| 15 | Sorghum | 65.49 | 42.37 | 29.34 | 70.55 | 46.81 | 35.13 |
| 12 | Cassava meal | ..... | 20.00 | 30.00 | ..... | 20.00 | 30.00 |
| 7 | Molasses, cane | 9.08 | 12.65 | 14.47 | 9.26 | 13.04 | 14.93 |
| 21 | Cottonseed meal | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 |
| 29 | Soybean meal | 8.58 | 6.21 | 7.55 | 4.85 | 3.15 | 1.95 |
| 35 | Fish meal | 1.94 | 4.18 | 3.77 | ..... | 1.85 | 2.98 |
| 14 | Bone meal | 1.70 | 1.07 | .95 | 1.97 | 1.39 | 1.07 |
| 2 | Calcium carbonate | .51 | .53 | .59 | .60 | .63 | .64 |
| 10 | Salt, iodized | .46 | .41 | .42 | .50 | .46 | .44 |
| 50 | Vegetable oil | ..... | .33 | .64 | .02 | .42 | .61 |
| 160 | Commercial premix | .20 | .20 | .20 | .20 | .20 | .20 |
| 228 | Antibiotic | .05 | .05 | .05 | .05 | .05 | .05 |
| 280 | Methionine | ..... | ..... | .014 | ..... | ..... | ..... |
| | Calculated levels, % | | | | | | |
| | Crude protein | 17.16 | 15.89 | 15.38 | 14.63 | 13.37 | 12.73 |
| | Calcium | .80 | .80 | .80 | .80 | .80 | .80 |
| | Phosphorus | .60 | .60 | .60 | .60 | .60 | .60 |
| | Lysine | .70 | .70 | .70 | .50 | .50 | .50 |
| | Methionine | .26 | .26 | .26 | .20 | .20 | .20 |
| | Digestible energy, Mcal/kg | 3.15 | 3.15 | 3.15 | 3.15 | 3.15 | 3.15 |
| | Cost, Col.$/kg | 16.87 | 16.22 | 16.02 | 15.94 | 15.31 | 14.98 |

*Sun-dried whole-root chips of several low and medium cyanide-containing varieties.

**Exchange rate at time of experiment: US$ ~64 Colombian pesos.

Interest on working capital was estimated by pro-rating the 30% annual interest rate on the capital invested (cost of animals at the beninning of trials, fixed and feeding costs). In the case of poultry, a total of at least four lots of broilers (7-8 weeks periods) could be raised throughout the year on the same premises, whereas for pigs only three lots (~3 months periods) could be fattened per year. Therefore, interest on the working capital used was 7.5% (30 ÷ 4) and 10% (30 ÷ 3) for poultry and pig feeding trials, respectively.

Actual results of feeding trials, expressed as the number and live weight of animals and feed consumption, have been used in the economic evaluation. Calculations were performed on the basis of lots or groups of 1,000 chicks or 10 pigs because these size groupings are frequently found at the level of small scale enterprises.

Net returns were obtained by sustracting total expenses from the income represented by the sale of live animals and in the case of poultry the value of the litter sold as fertilizer was also considered. Net return was also expressed as a percentage of total investment or expenses.

## Results and Discussion

Results of the broiler feeding trial are summarized in Table 3. The mortality of chickens, which mainly occurred during the first 2 weeks, was slightly higher for the group fed diets containing 30% cassava meal although it was near the normal range (~5%) (North, 1978). There were no significant (P>.05) differences among the biological results of the three experimental groups for any of the parameters studied; the average body live weights at 7 and 8 weeks were similar to those found normally in commercial broiler enterprises (North, 1978). The feed coversion (units of feed consumed per unit of body weight gain) was similar for all three groups especially at 7 weeks, but it tended to be slightly better for the group fed the 20% cassava meal diet than for the other two groups; thus, the data indicated that to obtain 100 kg of live broiler weight at 7 weeks, 215 kg of diet containing 20% cassava meal were required whereas for the same amount of gain, 220 and 224 kg of diets with 0% and 30% cassava meal, respectively, were necessary.

Table 3. Performance of broilers fed least-cost diets containing varying levels of cassava meal.

| Parameter | Cassava meal (%) in diets | | | |
|---|---|---|---|---|
| | 0 | 20 | 30 | SD* |
| Chicks at end of trial (no.)** | 141 | 140 | 137 | .... |
| Mortality (%) | 4.7 | 5.4 | 7.4 | .... |
| Avg. body wt/chicken (kg) | | | | |
| at 7 wk | 1.69 | 1.75 | 1.63 | .05 |
| at 8 wk | 2.01 | 2.08 | 1.97 | .08 |
| Feed consumed/chicken (kg) | | | | |
| 0-7 wk | 3.64 | 3.69 | 3.58 | .13 |
| 0-8 wk | 4.61 | 4.74 | 4.57 | .18 |
| Feed conversion*** | | | | |
| 0-7 wk | 2.20 | 2.15 | 2.24 | .04 |
| 0-8 wk | 2.34 | 2.33 | 2.36 | .04 |

*Pooled standard deviation = Error mean square.

**Initial number of chicks per treatment: 148 with an overall average body weight of 36.3 ± .5 g.

***Units of feed consumed per unit of body weight gain.

Data on the performance of growing-finishing pigs are in Table 4. The results of all three experimental groups were also similar (P>.05) but pigs fed diets containing 20% and 30% cassava meal reached a final live weight with

practically 5 and 1 kilogram more, respectively, than the group fed the diet without cassava meal; these differences were reflected to a lesser extent in the average daily gain per pig throughout the entire experimental period. The feed conversion tended to improve as the level of cassava meal in the diets was increased; pigs fed the control diet (0% cassava meal) required 339 kg of feed per 100 kg of live weight gain whereas the ratios for the pigs fed diets containing 20% and 30% cassava meal were 337 and 331, respectively.

Table 4. Performance of growing-finishing pigs fed least-cost diets with varying levels of cassava meal*.

| Characteristic | Cassava meal (%) in diets 0 | 20 | 30 | SD** |
|---|---|---|---|---|
| Pigs/group (no.) | 11*** | 12 | 12 | .... |
| Avg final wt/pig (kg) | 89.9 | 94.7 | 91.1 | 2.20 |
| Avg daily gain (kg) | .77 | .82 | .78 | .02 |
| Avg daily feed (kg) | 2.55 | 2.77 | 2.54 | .06 |
| Feed conversion | 3.39 | 3.37 | 3.31 | .10 |

*Overall avg initial weight: 20.0 ± 1.2 kg. Experimental period: 91 days.

**Pooled standard deviation = Error mean square.

***One pig was eliminated during the first two weeks of the experiment.

Table 5 presents results of the economic assessment of poultry and pig feeding trials. Least-cost broiler diets containing 20% cassava meal produced the largest returns at 7 weeks, but diets containing 30% cassava meal led to the lowest economic performance despite the apparently similar biological results; for this group to reach an economic output equivalent to that of the control diet (0% cassava meal) the mortality occurring in that group (7.4%, Table 4) would have to be reduced to practically 0%. The economic evaluation of the poultry trial at 8 weeks, not shown in Table 5, gave returns of 17.5%, 20.2% and 14.7% of the total expenses for groups fed diets with 0, 20% and 30% cassava meal, respectively.

On the other hand, results of the pig feeding trial (Table 5) showed profitability increased as level of cassava meal in diets was incremented from 0% through 20% to 30%; these results were a consequence of the slightly higher body growth rate and the improvement of feed conversions (less units of feed required per unit of gain) observed when the inclusion of cassava meal was increased. The most economic results were obtained with the group fed the 30% cassava meal diet.

Although this type of evaluation may be greatly effected by such factors as actual fixed costs, variable interest rates on capital invested, price of ingredients and fluctuation of live animal marketing prices, results suggest that under current conditions in Colombia the use of cassava meal, at 80% of the price of sorghum, produced the most economical and productive broiler and growing-finishing pig performance at levels of 20% and 30% of the diets, respectively. It is assumed that similar or better results could be obtained under practical, commercial

conditions and evaluations at this level will be required to reconfirmed these experimental results.

Table 5. Economic assessment of poultry and pig feeding trials*.

| Item | Cassava meal (%) in diets 0 | 20 | 30 |
|---|---|---|---|
| | --------Colombian Pesos-------- | | |
| Poultry trial - Lot of 1,000 chicks at 7 weeks | | | |
| Chicks and fixed costs** | 48,600 | 48,600 | 48,600 |
| Feed cost | 74,310 | 77,060 | 74,580 |
| Interest on working capital*** | 9,218 | 9,425 | 9,239 |
| Total expenses | 132,128 | 135,085 | 132,419 |
| Live broilers at $100/kg + litter ($1,220) | 161,770 | 167,470 | 152,810 |
| Net return | 29,642 | 32,385 | 20,391 |
| Return, % of expenses | 22.4 | 24.0 | 15.4 |
| Pig trial - Lot of 10 pigs | | | |
| Weaned pigs at $170/kg | 33,830 | 34,170 | 34,000 |
| Fixed costs, estimated | 7,550 | 7,550 | 7,550 |
| Feed cost | 42,270 | 44,239 | 39,983 |
| Interest on working capital*** | 8,365 | 8,596 | 8,153 |
| Total expenses | 92,015 | 94,555 | 89,686 |
| Live pigs at $120/kg | 108,000 | 114,000 | 109,200 |
| Net return | 15,985 | 19,445 | 19,514 |
| Return, % of expenses | 17.4 | 20.6 | 21.8 |

*Results of biological evaluations have been used in these calculations.

**Includes $28,800 and $19,800 for cost of 1,000 one-day-old chicks and fixed costs for raising them, respectively.

***See text for explanations.


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Cassava Root and Foliage Meals in Laying Hen Diets

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ABSTRACT

Two experiments were carried out on the use of cassava foliage flour, particularly in combination with root flour. In experiment I, two main energy sources, maize and cassava root flour dried above 100°C (HRYT), in combination with five levels of cassava foliage flour (HFY): 0, 5, 10, 15, and 20%, were evaluated in a 5x2 factorial arrangement. Leghorn hens were used (4 groups of 12 pullets and 10 layers assigned to each treatment). In experiment II, three main energy sources, maize, HRYT, and sun-dried cassava root flour (HRYS), in combination with three levels of HFY: 0, 10 and 20%, were evaluated. Black Sex Link hens were used (4 groups of 15 pullets and 12 layers assigned to each treatment). Hens were placed in individual metal cages and daily records were made of feed consumption and egg production. The results indicate a) with HRTY and HRYS satisfactory body weights at 50% egg production were obtained, though inferior as compared to maize; b) rations based on HRYT adversely affected egg production; c) a slight decrease of egg production observed with HRYS may be due to the deterioration of the cassava quality caused by the long-drying period; d) with HFY egg production was normal up to 20% level combined with maize, and only up to 10% with HRYS; e) a strong root-foliage interaction was observed that adversely affected the productive performance when the foliage flour level was increased--this may be due to the increase in HCN concentration.

Cereals as a source of energy and soy as a source of protein constitute the fundamental ingredients of the classical pelleted feeds for poultry. As much the first (with the exception of rice) as the second, do not give good results in tropical ecosystems means that of countries in these areas, only those with considerable importing capacity have been able to develop a prosperous poultry production industry.

The search for substitutes for cereals to make up the energy component has made possible the use of rice, cassava, root meal and sugar cane products and by-products as excellent energy sources for poultry. With these, cereal grains (maize, wheat, sorghum) can be substituted partially completely in the feeds.

With reference to the utilization of cassava root meal in feeds for laying hens, the known results are conclusive in the sense that cereals can be completely substituted for by cassava root meal without affecting the laying percentage, the feed efficiency and the internal egg quality (Enriquez y Roos, 1972; Montilla et al., 1973; Portal et al, 1977 and Eshiett and Ademasun, 1978).

In relation to the protein components, advances have been slower and more limited. However, many research workers are convinced there are various ways to achieve substitution of imported soy meal in poultry feeds, one of these being the use of leaf proteins.

As Oke (1973) affirms, green plants represent the most economical and abundant potential source of protein by the synthesis of amino acids through photosynthesis from primary elements available in almost unlimited quantities: solar energy carbon dioxide, water and nitrogen (atmospheric in the case of leguminoses and other plants). The amino acids in a more stable form -proteins- are stored in the leaves. The cassava plant has an exceptional value as much for the quantity as for the quality of its foliage proteins (Montilla, 1982).

Portal et al., (1972), report that cassava leaf meal supplies pigments capable of producing a good color of the egg yolk and they can completely substitute alfalfa meal in feeds for laying hens, without adverse effect at the levels studied (10% being the greatest) with respect to the percentage laying, weight of the egg and feed efficiency. According to the results of Montilla et al., (1982), laying hens utilize well up to 20% cassava leaf meal, especially if this is provided from birth, which probably is due to a conditioning of the digestive tract to feeds with a relatively high fiber content.

The purpose of this paper is to study effect of combining cassava root meal (two methods of preparation) with different levels of cassava foliage meal in laying hen diets.

## Materials and Methods

Two experiments were conducted, the first of 510 days and the second, 400 days. In experiment I, the effect was studied of substituting completely in feed for laying hens, corn meal for cassava root meal dried mechanically at 120°C, (two sources of energy), combined with five levels of cassava foliage meal: 0%, 5%, 10%, 15% and 20%, resulting in a factorial 2x5. Composition of feeds for the laying period is in Table 1.

These were isoproteic but not isoenergetic, although a brisk fall in the caloric value was avoided by addition of small quantities of animal fat for each increase in the level of foliage. Each hen received 100 gm/day. During the brooding and growing periods, the feed with the same energy sources and same percentages of foliage, was administered at libitum, both in Experiment I and in Experiment II. The foliage meal was prepared from green material cut at intevals of approximately 90 days and of different varieties; drying was in the sun on a cement floor. A total of 480 white Leghorn birds was used, giving each treatment four groups of 12 birds each, during the brooding and growing periods and of 10 birds each group in the laying period.

In experiment II, three energy sources were studied: corn meal, cassava root meal, prepared by means of sun drying (on a cement floor) and cassava root meal dried mechanically at a temperature of approximately 120°C. Each energy source was combined with three levels of cassava foliage meal, of the same type as that used in Experiment I: 0%, 10% and 20% resulting a factorial 3x3. The feeds were prepared with a formula similar to those of the corresponding levels of foliage used in Experiment I. A total of 540 commercial red Sex Link birds was used in each treatment, four groups of 15 birds in the brooding and growing periods which were reduced to 12 birds in the laying period.

Table 1. Experimental diets for laying hen levels of cassava foliage meal.

| Ingredients | CRM 0% | CRM 5% | CRM 10% | CRM 15% | CRM 20% | C 5% |
|---|---|---|---|---|---|---|
| Corn meal | 64.00 | 57.25 | 53.75 | 50.25 | | |
| Soybean meal | 13.50 | 12.00 | 10.50 | 9.00 | 7.50 | 22.50 |
| Wheat bran | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | |
| Cotton seed meal | 4.00 | 3.50 | 3.00 | 2.50 | 2.00 | 3.50 |
| Meat and bone meal | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Fish meal | 3.50 | 3.50 | 3.50 | 3.50 | 4.50 | |
| Blood meal | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Calcium carbonate | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 | 6.00 |
| Bone meal | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | |
| Animal fat | | 0.25 | 0.75 | 1.25 | 1.75 | 1.50 |
| Cassava foliage meal | | 5.00 | 10.00 | 15.00 | 20.00 | 5.00 |
| Minerals | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| Vitamins | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| Cassava root meal | | | | | | 52.00 |

CRM = Cassava root meal;
C = Corn meal.

After observing the daily feed consumption of the hens, the amount of feed was adjusted to 112, 117 and 122 gm/hen/day.

## Results and Discussion

### Experiment I:

In Table 2 are body weights at different ages and the feed conversion at the 10th and 21st week of age, at the later age of which the birds reached 50% laying. In Table 3 the F values are given for the data presented in Table 2. Tables 4 and 5 present the mean values for laying percentage in the 4 trimesters and the corresponding F values respectively.

For the body weight increase at the 10th week, a highly significant difference ($P<0.01$) is seen for cassava root meal (R); this is probably explained by the uniformity of the data, since the values are very similar both for the birds which received corn meal (681 g) and those which received R (668 g) respectively; a similar explanation can be given to the highly significant difference for lineal foliage (FI) at the same age although a slight fall in the weight increase appears, relatively pronounced with the higher level of foliage studied. When the birds reach 50% laying (21 weeks of age) no significant differences between treatments exist (see Tables 2 and 3). In the same tables, note that the body weights at 6 months and at the year of laying are lower for the birds which consumed cassava root meal ($P<0.01$). The high significance for Fc, Fcu and R x Fcu does not appear to be of great importance.

For the feed efficiencies at the 10th and 21st weeks, highly significant differences ($P<0.01$) for FI, only appear at the earliest age, which is not of great importance since, as can be seen at 50% laying, the feed conversion indices are little affected (see Tables 2 and 3).

Table 2. Experiment I. Average values for body weights and feed efficiencies at different ages.

| Treatments* | | Body Weights (g) | | | | Feed Conversion | |
|---|---|---|---|---|---|---|---|
| | | 10th week | 21st week (50% laying) | 6th month laying | 1 year laying | 10th week | 21st week |
| CRM-CFM | 0% | 689 | 1301 | 1323 | 1313 | 4.93 | 6.23 |
| CRM-CFM | 5% | 683 | 1302 | 1277 | 1268 | 5.01 | 6.22 |
| CRM-CFM | 10% | 696 | 1321 | 1303 | 1291 | 5.03 | 6.14 |
| CRM-CFM | 15% | 691 | 1291 | 1250 | 1218 | 5.13 | 6.27 |
| CRM-CFM | 20% | 645 | 1272 | 1261 | 1320 | 5.59 | 6.38 |
| CM-CFM | 0% | 695 | 1318 | 1476 | 1491 | 4.89 | 6.16 |
| CM-CFM | 5% | 678 | 1315 | 1348 | 1296 | 5.02 | 6.17 |
| CM-CFM | 10% | 663 | 1291 | 1416 | 1375 | 5.20 | 6.28 |
| CM-CFM | 15% | 660 | 1335 | 1411 | 1474 | 5.30 | 6.19 |
| CM-CFM | 20% | 629 | 1265 | 1343 | 1407 | 5.48 | 6.49 |

*CRM = Cassava root meal; CFM = Cassava foliage meal.

Table 3. Experiment I. Weight increments, body weights and feed conversion at different ages.

| | Weight Increments | | Body Weights | | Feed Conversion | |
|---|---|---|---|---|---|---|
| | 10th week | 21st week | 6 month laying | 1 year laying | 10th week | 21st week |
| R | 7.94 ** | 1 NS | 59.41 ** | 71.79 ** | 1.36 NS | 1 NS |
| Fl | 31.57 ** | 2.09 NS | 7.70 ** | 1 NS | 117.01 ** | 4.12 NS |
| Fc | 5.93 * | 1.52 NS | 2.00 NS | 11.22 ** | 7.52 ** | 1.91 NS |
| Fcu | 4.11 NS | 1.04 NS | 5.41 * | 9.47 ** | 2.55 NS | 1 NS |
| R x Fl | 2.94 NS | 1 NS | 1.50 NS | 1 NS | 1 NS | 1 NS |
| R x Fc | 1 NS | 1 NS | 1 NS | 1 NS | 6.27 * | 1 NS |
| R x Fcu | 1 NS | 1 NS | 8.56 ** | 26.78 ** | 2.23 NS | 1 NS |

R = Cassava root meal; F = Cassava foliage meal.

The laying percentage (Tables 4 and 5) was reduced in the birds which received cassava root feeds without, apparently, any effects due to different levels of foliage.

With respect to the levels of foliage, only a cuadratic effect (Fc) is observed in the first trimester and a cubic effect in the second trimester, both of which are highly significant ($P<0.01$), probably due to the poor behavior of the birds with the 5% foliage feed and the unequal behavior of all the treatments in

Table 4. Experiment I. Percentage Laying in the Four Trimester and Total Laying Period.

| | TRIMESTERS | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Year |
| CRM - CMF* 0% | 45.8 | 41.2 | 48.2 | 53.4 | 47.2 |
| CRM - CMF 5% | 44.6 | 36.4 | 45.4 | 47.9 | 43.6 |
| CRM - CMF 10% | 41.2 | 33.7 | 48.1 | 53.8 | 44.2 |
| CRM - CMF 15% | 41.1 | 35.4 | 44.8 | 44.7 | 41.5 |
| CRM - CMF 20% | 39.4 | 42.5 | 54.0 | 50.2 | 46.5 |
| C - CFM 0% | 74.3 | 61.2 | 64.2 | 65.0 | 66.2 |
| C - CFM 5% | 38.9 | 52.0 | 66.2 | 66.4 | 55.9 |
| C - CFM 10% | 68.7 | 50.9 | 62.6 | 66.2 | 62.0 |
| C - CFM 15% | 64.3 | 48.2 | 64.9 | 62.1 | 59.9 |
| C - CFM 20% | 73.8 | 54.5 | 66.5 | 59.6 | 63.6 |

*CRM = Cassava root meal; CFM = Cassava foliage meal; C = Corn meal.

Table 5. Experiment I. Percentage laying: F values.

| | % Laying TRIMESTERS | | | |
|---|---|---|---|---|
| Source | 1 | 2 | 3 | 4 |
| R | 143.29 ** | 41.04 ** | 89.12 ** | 66.27 ** |
| Fl | 1 NS | 1 NS | 1.35 NS | 4.33 NS |
| Fc | 13.48 ** | 8.29 ** | 2.32 NS | 1 NS |
| Fcu | 16.10 ** | 1 NS | 1 NS | 1 NS |
| R x Fl | 10.61 * | 1.23 NS | 1 NS | 1 NS |
| R x Fc | 14.36 * | 1 NS | 1 NS | 1.77 NS |
| R x Fcu | 20.01 * | 1 NS | 1 NS | 1 NS |

R = Cassava root meal; F = Cassava foliage meal.

the second period, when there was a marked reduction in laying which may have been caused by bad weather. For the other periods, the foliage level does not affect laying. It is important to emphasize that the body weight of the chickens at the end of the laying period did not reach the normal level for the race even in those birds which received a corn meal feed without foliage; this seems to indicate that the 100 g of feed/bird/day were not sufficient and may have also affected the laying percentage which was lower than that expected even for those birds which received the feed with corn meal without foliage.

Experiment II:

In Table 6 are given the age, body weight and feed conversion at 50% laying. Age was not affected by the energy sources, but was affected by the foliage level,

this effect being small with corn, average with cassava root dried in the sun (CRS) and marked with cassava meal dried at high temperatures (CRT). Something similar is observed for body weight, but with the difference that CRS and CRT (without foliage) also affected this, being 93.4% in the first and 89.0% in the second of the weight obtained with corn meal; a similar situation occurred with reference to the feed conversion index. In all the cases, the marked deterioration which occurs when 20% foliage is combined with CRT, can be seen. As much for age, body weight and feed index conversion significant differences (P<0.05) appear, some of which are highly significant (P<0.01).

Table 6. Experiment II. Age, body weight and feed conversion at 50% laying.

| Treatments | Age (days) | Body weight (kg) | Feed conversion |
|---|---|---|---|
| C - CFM* 0% | 193 | 2.088 | 5.34 |
| C - CFM 10% | 180 | 1.986 | 4.95 |
| C - CFM 20% | 198 | 1.932 | 6.16 |
| CRMS - CFM 0% | 195 | 1.942 | 5.83 |
| CRMS - CFM 10% | 198 | 1.917 | 5.92 |
| CRMS - CFM 20% | 205 | 1.817 | 6.91 |
| CRMT - CFM 0% | 192 | 1.859 | 6.00 |
| CRMT - CFM 10% | 206 | 1.846 | 6.71 |
| CRMT - CFM 20% | 218 | 1.681 | 8.04 |
| Differences (P 0,01) | 24 | 0,166 | 0.92 |
| Differences (P 0,05) | 18 | 0,123 | 0.68 |

*C = Corn meal; CFM = Cassava foliage meal; CRM = Cassava root meal.

The laying percentage for the semester (Table 7) decreases from 76.4% with the feed containing corn meal without foliage to 70.3% and 65.5% when the sources of energy were CRS and CRT (also without foliage). Those differences are highly significant (P<0.01) for CRT and not significant but important from the practical point of view for CRS. Significant differences (P<0.05) also exist between CRS and CRT. When foliage is incorporated into feeds based on corn, although the laying percentage falls slightly, these differences do not reach a point where they become significant; when foliage is incorporated into feeds with CRS, the laying improves slightly with 10% and a drastic fall is observed with 20% (P<0.01). With CRT only small reductions are observed when each level of foliage is added, probably due to the fact that the laying was already reduced, affected by CRT.

The small differences occurring in the weight of the eggs are not important. The weight of the hens at the 6th month of laying was severely influenced by cassava root, with a fall of 10.6% for CRS and of 13.9% for CRT, with respect to the weight of the hens which consumed the feed based on corn without foliage. In almost all cases, a fall in the body weight occurs with each increment in the foliage with differences which vary from significant (P<0.05) to highly significant (P<0.01); this does not occur for 10% foliage with CRS nor on passing from 10% to 20% foliage for CRT which represents the lowest body weight.

Table 7. Experiment II. Percentage laying, egg weight and body weight at 6 months of laying.

| Treatments | % Laying | | | Egg weight | | Body weight at 6 months of laying (kg) |
|---|---|---|---|---|---|---|
| | 1st trimester | 2nd trimester | 6 month period | First | Second | |
| C - CFM* 0% | 71.3 | 81.5 | 76.4 | 59.3 | 60.5 | 2,135 |
| C - CFM 10% | 71.3 | 78.3 | 74.8 | 58.5 | 61.8 | 1,990 |
| C - CFM 20% | 68.0 | 78.5 | 73.3 | 60.3 | 62.0 | 1,895 |
| CRMS - CFM 0% | 65.8 | 75.3 | 70.3 | 57.8 | 60.5 | 1,908 |
| CRMS - CFM 10% | 65.5 | 78.0 | 71.8 | 58.0 | 61.3 | 1,942 |
| CRMS - CFM 20% | 58.3 | 69.0 | 63.5 | 58.8 | 61.5 | 1,773 |
| CRMT - CFM 0% | 60.0 | 71.3 | 65.5 | 57.8 | 58.5 | 1,839 |
| CRMT - CFM 10% | 58.0 | 68.8 | 63.3 | 59.0 | 61.5 | 1,755 |
| CRMT - CFM 20% | 55.0 | 68.3 | 61.3 | 56.8 | 61.3 | 1,742 |
| Differences (P 0.01) | 8.5 | 7.6 | 6.7 | 3.7 | 3.0 | 0,130 |
| Differences (P 0.05) | 6.3 | 6.9 | 4.9 | 2.8 | 2.2 | 0,096 |

*C = Corn meal; CFM = Cassava foliage meal; CRM = Cassava root meal.

## General Discussion

From the analysis and discussion of the experimental data it becomes evident that cassava root meal dried at high temperatures (120°C) is not utilized well by the laying hen, in contrast to what has been reported for broilers (Montilla et al, 1979); in the same way, it performs well to sustain an appropriate growth of chickens in the brooding and growing periods (Experiment I). The fact that in Experiment II the body weight at 50% laying was slightly lower in the hens fed with CRT, is probably explained by the fact that sexual maturity was delayed because the growing period coincided with the period of shortest days (November-December).

The hens which had the greatest delay reached 50% laying after 31 weeks, when the normal is at 23 to 24 weeks. This seems to indicate that CRT only favors the early growth of the birds.

According to Manurung (1974), burning of the cassava during processing is a function not only of temperature but also of the humidity content of the material. In this way, fresh cassava with 66.7% humidity, burns by exposure to 90°C for 5 minutes, but if the initial humidity is reduced to 56.5%, it supports 50 minutes at the same temperature, and with 48.6 humidity it does not burn after 96 hours exposure. In the commercial plant where the cassava was processed, this was added to the dried (at a temperature of approximately 120°C) with its initial humidity. It is quite certain that in addition to the burning, which can be seen by a brown tone in the material, another transformation also occurs in the starches, making them less assimilable for certain species and/or type of animals.

The fact that with cassava root meal dried in the sun, the behavior of the hens was inferior than that of those which consumed corn feed, may have been

influenced by the long period of drying (10 days) of fresh material, due to rainy days which, when the humid material has to be collected and covered, gives rise to fermentative processes which diminish it.

The variation in the climatic conditions during processing are probably the cause of differences in the results between more or less similar experiments carried out by different research workers and even by the same research worker.

It is evident that foliage levels of up to 20% are compatible with an efficient production when they are combined with corn (and probably with any cereal). This does not occur when combined with cassava root, when the highest level tolerated would be 10%.

It cannot be maintained that fiber is the limiting factor, because its incorporation is the same with either of the two sources of energy. It is possible that the problem lies in an increase in the HCN content of the feed because even when foliage and root meals prepared from varieties with an HCN content no higher than 300 to 400 ppm (fresh basis), the results are almost always negative or with a very low concentration (lower than 30 ppm), when the HCN is determined by the AOAC method. Gómez et al (1980) report HCN concentrations of between 43 and 162 ppm in meals dried in the sun and prepared from cassava root in which the HCN content (dry base) was between 32 and 265 ppm. These workers carried out an enzimatic determinations according to the method developed by Cooke et al (1978). If levels of these magnitudes persist in foliage and root meals, there could be an additive effect on combining them at high levels in the feed.

On the other hand, it is convenient to emphasize the fact that the feeds could not be pelleted since the necessary equipment for this was not available. This treatment exercises a very favorable effect on poultry feeds, especially when dusty ingredients with a low density are incorporated into them. Montilla (1982) reports that foliage and root meals only weigh, for unit of volume, 25.2% and 79.2%, respectively, of the corresponding weight for corn meal.

From the results it is concluded:

a) with CRS and with CRT satisfactory body weights were obtained at 50% laying although these were lower when compared with the results obtained on a basis of corn based feeds.
b) the feeds based on CRT adversely affected egg production.
c) a slight reduction on laying observed with CRS could have been due to a deterioration in the quality of the cassava for the long period of drying.
d) with cassava foliage meal the laying was normal up to 20% combined with corn and up to only 10% with cassava root meal sun-dried.
e) a strong root x foliage interaction is observed, adversely affecting the productive behavior, on increasing the foliage level, which could be due to the increase in the concentration of HCN in the feeds.

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Cassava for Food or Fuel?

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ABSTRACT

Developing countries have the special problem of needing to greatly increase energy inputs to increase food and industrial production, yet (face) severe shortages of foreign exchange (with which) to purchase imports. In several developing countries, energy farming could boost rural development, increase agricultural productivity and save scarce foreign exchange. There is a danger though that such a development might compete with food crops. (IFA, 1980).

## Introduction

In mid-1982 the cessation of continuously increasing petroleum prices and the apparent surplus of oil seemingly reduced interest in the "energy problem" - but the problem has not gone away. This paradox is perhaps explained by the fact that in reality the "energy problem" of the 1970's was one of price rather than one of supply. However, in the 1980's, because oil prices are tied to world inflation and because developing countries, as indicated in the opening quote, are faced with a growing need for liquid energy, the energy problem is going to be one of both price and supply. Even if developed countries, the consumers of approximately 73% of all petroleum energy, achieve substantial savings in petroleum use, there is little reason to assume that these additional supplies are easily transferred to the developing countries. Developing countries, because of their generally low level of energy utilization, have only limited opportunities for energy conservation. Therefore, the best that they can do is adopt energy efficient methods while increasing energy consumption. It is within this context that oil deficient developing countries face the "energy problems" of the 1980's.

One suggested solution for developing countries facing dual problems of energy shortages and limited foreign exchange (thereby limiting the ability to import petroleum products), is to develop an agro-energy production system (AEPS). For this paper an AEPS will be narrowly defined as the use of agricultural products (specifically cassava) to produce liquid energy, primarily ethyl alcohol, ethanol, as a gasoline replacement[2]. A number of writers (Brown 1980, FAO 1981) have noted that alcohol fuels offer the most immediate substitute for the increasingly expensive petroleum-based fuels. This possible solution to the energy

[2]In general terms the definition of an AEPS is the use of agricultural products or waste to produce energy.

problem of the 1980's, however, poses alternative problems. First, the possible conflict of using agricultural resources to produce fuel rather than food, and second, fuel resulting from an AEPS is not necessarily cheap, (Table 1)[3]. At the heart of the issue is the question of whether ornot a country has sufficient resources to meet both its food and energy needs. This paper presents an examination of some of the advantages and disadvantages of an AEPS for cassava-producing countries.

Table 1. Ethanol cost based on cost of cassava versus 1980 retail gasoline prices (US$).

| | Cost | | |
|---|---|---|---|
| | Cassava $/ton | Ethanol $/litre | Retail Gasoline Price $/litre |
| Brazil | 8.00 | .14 | .85 |
| Thailand | 23.50 | .39 | .45 |
| South Africa | | | .65 |

Potential for Agro-energy in LDCs

Prima facae developing countries which have an agricultural surplus and an energy deficit are potential candidates for development of an agro-energy system.[4] Surprisingly, only 11 countries meet these conditions (Table 2).

Of the 11 countries, only five - Brazil, Dominican Republic, Kenya, Philippines, and Thailand - produce cassava in excess of domestic food requirements[5]. The six remaining countries either do not produce cassava, Ethiopia[6] and Turkey, or only produce limited quantities of cassava, Argentina, Cuba, South Africa, and Sudan. Because this paper deals only with cassava AEPS, it is the first five countries and South Africa[7] which become the focus of the analysis.

The energy problems of these countries are multi-faceted. In all of them (with the possible exception of South Africa) energy imports account for more than 30% of all export earnings, and the relative importance of energy imports is now two or three times greater than what it was in the early 1960's. In three of the countries - Brazil, Dominican Republic and Thailand - the growth in demand for energy during the period 1974-1979 exceeded the growth in the supply of energy

[3]The ethanol prices presented in Table 1 do not include taxes while the gasoline price includes taxes.

[4]Countries with both agricultural and energy surpluses will probably find agro-energy too expensive.

[5]This condition insures that the physical potential exists for both production of food and fuel from cassava. The same type of condition could be placed on any other agricultural product which might be considered as a potential energy feedstock.

[6]It is doubtful that Ethiopia, as a result of the ongoing military problems, is now self-sufficient in food.

[7]South Africa does not now produce cassava in substantial quantities, but was included in the analysis because the government plans to convert the Makatini Flats in northern Zululand into cassava plantations for producing ethanol. (Brown, 1980).

Table 2. Developing countries which have agricultural surplus and energy deficiency

| | % Self-sufficiency Agricultural | Energy |
|---|---|---|
| Dominican Republic | 141 | 1 |
| Cuba | 139 | 1 |
| Thailand | 131 | 8 |
| Argentina | 123 | 91 |
| Philippines | 121 | 9 |
| Brazil | 119 | 32 |
| Kenya | 114 | 7 |
| Sudan | 112 | 2 |
| Ethiopia | 108 | 10 |
| South Africa | 106 | 91 |
| Turkey | 104 | 36 |

Adapted from FAO 1980

(WB, 1981). The magnitude of the problem, in terms of the need to import crude petroleum, is greatest for Brazil and Thailand (Table 3). It is, however, gasoline consumption, accounting for 9% to 24% of total crude petroleum imports, which is the immediate target of an AEPS, because ethanol substitutes only for this "fraction of the barrel."

Table 3. Crude petroleum production, consumption and import and gasoline consumption, 1980.

| | Crude Petroleum (1,000 MT) | | | | Gasoline as % of | |
|---|---|---|---|---|---|---|
| | Prod. | Cons. | Import | kg/ca. | Cons. | Cr.Pet. |
| Brazil | 8,841 | 54,318 | 43,637 | 442 | 9,616 | 22% |
| Dominican Republic | | 1,340 | 1,457 | 247 | 307 | 21% |
| Kenya | | 3,039 | 3,404 | 185 | 310 | 9% |
| Philippines | 535 | 9,831 | 9,375 | 203 | 1,790 | 9% |
| South Africa | | 13,000 | 15,000 | 394 | 3,615 | 24% |
| Thailand | 10 | 8,718 | 8,908 | 188 | 1,755 | 20% |

Sources: UN, 1982

The ability of all six of these countries to reduce their dependency on external energy sources by the development of a cassava AEPS depends in the first instance on the degree to which cassava production exceeds the demand for cassava as a human food[8]. The two countries with the greatest "surplus" of cas-

[8]Implicit in this initial analysis is the assumption that a country is willing to divert cassava used for non-food purposes to the production of ethanol.

sava, and hence immediate potential to produce substantial quantities of ethanol, are Brazil and Thailand (Table 4).

Table 4. Production and consumption of cassava as a human food, and ethanol equivalence of surplus (1,000 MT).

| | Prod. (1) | Cons. (2) | Difference (1)-(2) | Ethanol (1,000 litres) |
|---|---|---|---|---|
| Brazil | 25,600 | 12,413 | 13,187 | 2,373,660 |
| Dominican Republic | 168 | 138 | 30 | 5,400 |
| Kenya | 592 | 574 | 18 | 3,240 |
| Philippines | 1,182 | 1,098 | 84 | 15,200 |
| Thailand | 8,353 | 373 | 7,980 | 1,436,400 |

Source: FAO, 1982.

Even assuming that a given country appears to have the capacity to produce cassava ethanol at an economical price, there is an initial limit to the amount by which imported fuel can be reduced, because existing cars can only be modified to use a maximum 20% ethanol:80% gasoline ratio. While it is possible in the long run to have an automobile fleet burning 100% ethanol, the immediate limit is that no more than 20% of all gasoline can be replaced by ethanol. Even given this apparently limited market for ethanol only Brazil and Thailand have the potential to development a cassava AEPS capable of replacing 20% of the nation's gasoline (Table 5). South Africa, if it achieves its cassava production targets, would be able to replace 10% of the nation's gasoline consumption with ethanol.

Table 5. Comparison of potential ethanol market (20% of gasoline consumption) and ethanol production (1,000 litres).

| | 20% Cons. gasoline (1) | Potential ethanol (2) | (2)/(1) |
|---|---|---|---|
| Brazil | 2,598,243 | 2,373,660 | 91% |
| Dominican Republic | 82,951 | 5,400 | 7% |
| Kenya | 83,762 | 3,240 | 4% |
| Philippines | 483,658 | 15,200 | 3% |
| South Africa | 976,773 | 489,090 | 50% |
| Thailand | 474,201 | 1 436,400 | 302% |

## Cost and Benefits

The immediate benefits of an AEPS are the apparent savings in foreign exchange. If the six countries produced to the limit of their ethanol capacity or market, and assuming that this replaces an equivalent amount of imported oil, the maximum foreign exchange benefits are as shown in Table 6.

Table 6. Maximum foreign exchange benefits* from production of cassava ethanol.

| | Ethanol potential as percent of oil imports | Dollars benefit of import savings |
|---|---|---|
| Brazil | 4.03 | $ 597,353,000 |
| Dominican Republic | .27 | 1,359,000 |
| Kenya | .07 | 805,000 |
| Philippines | .12 | 3,825,000 |
| South Africa | 2.40 | 123,096,000 |
| Thailand | 10.84 | 119,567,000 |

*Assuming an oil price of $40/barrel.

Again the indication is that only in Brazil, South Africa and Thailand could an AEPS be expected to make a substantial contribution to import savings. Additionally, in the case of Thailand, the foreign exchange savings must be compared to the foreign exchange earnings of cassava exports. The initial comparison suggests that import savings are slightly greater than export earnings of an equivalent amount of cassava exports, assuming an f.o.b. price of $100/ton of pellets. Therefore, it could be argued that the Thais would be indifferent (in terms of foreign exchange) to the use of cassava for the production of pellets or ethanol. However, present attempts to curtail the amount of cassava which can be imported into the European Economic Community (Phillips, 1981) cast doubt on the long run future of this market, and suggest that the ethanol market may become an increasingly viable outlet for cassava.

While foreign exchange contribution of an AEPS may be limited, it may be other aspects of an AEPS which lead to its promotion. It has been calculated that in Brazil every million litres of cassava ethanol imply 96 to 280 jobs, $300,000 of investments, $140,000 to $220,000 in operating expenses, $70,000 in fixed costs, and require 320 to 660 hectares of land (CTP, 1977 and Phillips, 1978). There is little reason to assume that the range of employment creation or the investment cost of establishing a distillery will differ greatly from one country to another. Therefore the Brazilian data coupled with national data on the yield of cassava are used to provide an initial estimate of the investment and land requirements, and employment creation which might be associated with establishment of an AEPS.

Data in Tables 6 and 7 suggest that initial benefits of an AEPS are foreign exchange savings and jobs created[9], and that the costs are those of investment and operation. In this analysis land requirements are considered to be neither a cost nor a benefit, because it was assumed that the introduction of an AEPS did not alter the amount of land devoted to cassava. The conclusion to be reached is given the operating set of assumptions, are:

[9]In this analysis, new jobs represent approximately 5% of the employment creation figures contained in Table 7. The remaining 95% of the employment creation represents a redeployment of labor from production of cassava for non-food markets to the ethanol market.

- that Brazil, South Africa, and Thailand would appear capable of realizing the greatest benefits from a cassava AEPs;
- that the annual foreign exchange savings exceeds investment costs;
- that the potential size of the cassava ethanol market in all six countries except Thailand is, in the first instance, limited by the availability of raw material; and
- that developments in external markets for cassava may determine the Thai interest in renewable energy.

Future of Agricultural Energy Systems

For the Dominican Republic, Kenya and the Philippines a cassava AEPS would appear to be capable of making only a limited impact on the respective economies. For the other three countries an AEPS has the potential of providing up to 20% of the nation's gasoline needs[10]. The benefits of an agricultural energy production system could be increased if employment creation is maximized, which, however, implies increasing cassava production. The prime constraint to such expansion would appear to be the agricultural land base. In the Brazilian, South Africa and Thai cases this does not appear to be a problem. In Brazil it is known that in the northeast alone, farmers with less than 50 hectares have sufficient good, but unused, land to produce 2 billion litres of ethanol, assuming a yield of only 8 tons of cassava per hectare. While the expanse of the northeast mitigates against collecting and processing cassava from the numerous small farmers, it does appear that with proper incentives and development of infrastructure small farmers there would produce the required cassava (Phillips, 1981).

Table 7. Potential investment and land requirements, and employment creation associated with national AEPS.

| | Investment (million $) | Land (1,000 ha.) | Employment creation |
|---|---|---|---|
| Brazil | $711.9 | 1,099 | 227,880 - 664,440 |
| Dominican Republic | 1.6 | 3 | 518 - 1,512 |
| Kenya | 1.0 | 2 | 307 - 896 |
| Philippines | 4.6 | 8 | 1,459 - 4,256 |
| South Africa | 146.7 | 181 | 46,944 - 136,090 |
| Thailand | 142.2 | 176 | 45,523 - 132,720 |

Thailand, on the other hand, would probably have little difficulty in utilizing cassava as a renewable energy source if either the European Market is closed to Thai tapioca pellets, or if petroleum prices experience another sharp increase. In fact the problem which Thailand could face would be that of an excess supply of ethanol.

[10]South Africa is restricting its cassava production targets to 10% of the nation's gasoline needs.

South Africa has identified an area for cassava plantations and should not find land a constraining factor.

In the other three countries data on the availability of unused land suitable for cassava production is not at hand, therefore the possibility of developing an expanded cassava AEPS is not known. Clearly if the land is available it is possible that the marginal benefits of an AEPS in these countries will be greater than in Brazil, South Africa and Thailand. Only a more detailed analysis will demonstrate if this is in fact the case.

This analysis attempted to resolve the food-fuel issue by assuming that cassava price is the same in all markets and that cassava used in the energy market came from the non-food markets or from increased production. These assumptions implied that neither the demand for cassava as an energy feedstock nor the price of such cassava would adversely affect the food market. In the course of the analysis it was not, however, possible to calculate if the energy market would be able to pay a higher price for cassava, and thus divert cassava from the food market. It might be suggested in closing that the relatively high price of cassava ethanol, assuming average cassava prices, does not support the contention that the energy market will cause the price of cassava to rise.

Conclusions here are that only 11 developing countries are now potential candidates for some type of an agricultural energy production system; that only six have a potential of developing a cassava AEPS; and that only three - Brazil, South Africa, and Thailand - can expect to easily realize substantial benefits from such a system. Results are deficient in that the analysis was done at an aggregate level and that it focused only on cassava. This latter deficiency is justified by the fact that this paper presents a method of analysis which is applicable to other agricultural feedstocks.

The important finding of this study is that a limited number of developing countries might realize substantial benefits from the establishment of an agricultural energy production system. The "lull" in the energy problem provides the ideal time for these countries to further explore this possibility, but the "lull" may have removed the immediate incentive to explore this possible solution to the energy problem of the 1980's.

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Pre-Harvest Environmental Effects on Cassava Root Susceptibility to Post-Harvest Physiological Deterioration

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ABSTRACT

Poor post-harvest storage life of cassava roots is due to physiological and microbial processes rendering the roots inedible within 2 to 5 days of harvest. These studies demonstrate that main factors controlling susceptibility of cultivar to physiological deterioration are environmental: plants defoliated due to severe stresses were more resistant than non-defoliated plants of the same cultivar. Site and prevailing pre-harvest environmental conditions also affected degree of susceptibility. Pruning experiments gave results which closely agreed with the defoliation effects and confirmed reports that pre-harvest pruning induced resistance to physiological deterioration. Such induced resistance was obtained for at least 9 weeks after pruning and was unaffected by subsequent regenerative growth. A reduction in root dry matter content occurred following pruning but is not causally related to resistance to physiological deterioration.

## Introduction

Cassava (*Manihot esculenta* Crantz) is the most important staple tropical root crop (FAO, 1981). One of the major factors limiting its increased use as a fresh food is the extremely short root post-harvest storage life caused by the rapid development of a blue-black discoloration (Averre, 1967; Booth, 1976; Lozano et al, 1978; Marriott et al, 1978, 1979), termed "vascular streaking" (Montaldo, 1973) or "vascular deterioration" (Marriott et al, 1978). A physiological reaction initiated between 2 to 3 days after harvest causes the initial loss of acceptability (Booth, 1976; Lozano et al, 1978) followed 5 to 7 days after harvest by microbially induced rotting and fermentation (Lozano et al, 1978) also causing tissue discoloration. Booth (1976) defined the two processes as primary (physiological) and secondary (microbial) deterioration.

Booth (1976, 1977) found that physiological deterioration was initiated near regions of mechanical damage and that curing (high temperature and humidity conditions which encourage wound healing) markedly restricted the development of physiological deterioration. Reduced root susceptibility to physiological deterioration was obtained by pre-harvest pruning of the aerial portion of the plant (Lozano et al, 1978). A translocatable inducing factor was postulated to explain the resistance which developed.

Observations that root susceptibility to physiological deterioration can vary greatly between plants of the same clone (Lozano and Booth, personal communication) lead to work reported here. The susceptibility of several cultivars was evaluated over a 2-year period at one site (CIAT-Palmira), and 26 cultivars were evaluated at a range of sites (Table 1) to document and investigate this observed variability. On the basis of these experimental results, a hypothesis involving preharvest environmental factors is proposed to explain some of this intracultivar variation and results of experiments testing this hypothesis are presented.

Table 1. Climatic and edaphic characteristics of five sites in Colombia.

| | CIAT-Palmira | Carimagua | Caribia | Media Luna | Popayán |
|---|---|---|---|---|---|
| Climatic | | | | | |
| Altitude (m) | 1,020 | 200 | 35 | 10 | 1,760 |
| Mean Tem (°C) | 24.0 | 26.1 | 26.0 | 17.0 | 18.0 |
| Rainfall ($mmy^{-1}$) | 1,000 | 2,031 | 1,308 | 780 | 2,500 |
| Dry season (months) | 5 (bimodal) | 3 | 4 | 4 | 5 (bimodal) |
| Edaphic | | | | | |
| Soil pH | 6.0 | 4.7 | 6.2 | 6.0 | 4.5 |
| Soil fertility | Good | Low | Good | Low | Moderate |
| Soil texture | Clay | Clay-loam | Sandy-clay | Sandy | Clay-loam |
| Al concentration | Low | High | Low | Low | High |

## Materials and Methods

Experiments were at Centro Internacional de Agricultura Tropical (CIAT) station at Palmira, Colombia and also at sites in four different regions of Colombia (Table 1). Stem cuttings were treated with orthocidebavistin (3,000 ppm a.i.) and planted vertically on ridges with 1x1 m spacing. Where possible, plants were irrigated during the 2-month establishment period. In several experiments at each location, plots were evaluated before harvest for defoliation on a percentage basis.

Plants were harvested at 10 to 12 months of age unless otherwise stated. When required, foliage and roots were weighed directly after harvest. Storage rots were harvested manually with care taken to keep mechanical damage to a minimum.

Physiological deterioration was evaluated using a 15 cm root section with minimal mechanical damage (Marriott, 1979; CIAT, 1980). The distal end was covered with 50 gauge PVC film, restricting development of physiological deterioration to the proximal cut surface. After 3 days of storage, the root sections were evaluated by cutting transversely at 2 cm intervals and assigning a 0 to 10 score to each cut surface based on percentage of periphery of the parenchyma deteriorated. The total physiological deterioration susceptibility was obtained by calculating this as a percentage of the maximum possible score for each treatment group (Deterioration %). Roots were stored prior to evaluation either in field conditions, protected from rain and rodents, or in laboratory conditions of 22°C and 60% to 80% relative humidity.

The specific gravity of three roots per treatment was used when required to estimate root dry matter content (CIAT, 1977; Wholey and Booth, 1979). Root cyanide content was determined using the enzymatic method of Cooke (1978). Five roots per treatment were peeled, quartered longitudinally and a longitudinal slice taken from each quarter was rapidly diced and pooled. Three duplicate samples per treatment were analysed.

Experimental designs are described for each experiment individually. Generally, 10 roots were used per deterioration evaluation, taken at random from those of at least five plants. Treatments were assigned at random within field plots.

## Results and Discussion

### Variation in susceptibility to physiological deterioration

The results of evaluating physiological deterioration in several clones during 2 years' trials at CIAT-Palmira are in Figure 1. The amount of variation between the plants of one cultivar grown at the same site was large. M Col 22 previously considered (CIAT, 1977) very susceptible to physiological deterioration, showed Det. % values typical of both resistance and susceptibility. Indeed, M Col 22 has been described (Booth, 1976) as "slightly resistant," while M Col 113 and Llanera were "susceptible." These repeated observations of one cultivar demonstrate that intra-cultivar variation is great and that the indiscriminate use of the terms "susceptible" and resistant" should be avoided.

A further example of this variation was provided by an experiment in which 20 plants, each of four cultivars, were planted at 2-month intervals from May 1978 to January 1979 at CIAT-Palmira. Plots were harvested in August and October 1979, with sufficient plants harvested each time for 20 roots to be obtained per evaluation per plot. Ten roots were evaluated for their Det. %, the remainder being used to determine specific gravity, cyanide and root fiber content.

The Det. % of the four cultivars examined was not stable during the experimental period, although in both harvests M Col 22 was consistantly more susceptible to physiological deterioration than the other three cultivars (Table 2). Plant age did not appear to affect deterioration, although both M Ven 218 and CMC-40 did decrease in Det. % with age in the October harvest only. M Col 22, the cultivar with the highest Det. %, also had the highest dry matter content, thus agreeing with previous findings that the two are positively correlated (CIAT, 1977).

The total and free cyanide contents of the root tissues varied greatly, but there was no general significant correlation between either of these parameters (fresh or dry weight basis) and the Det. %, although isolated significant results did occur. There was no correlation between Det. % and the root fiber content. Further experiments, in which the Det. % and cyanide content were determined in individual roots, also failed to find any general correlation between the two parameters.

### Location effects on physiological deterioration

Since at one site a range of Det. % values were found for one cultivar over a 2-year period, the possibility that pre-harvest or post-harvest environmental components could affect the deterioration was investigated using an experiment in

five diverse Colombian edapho-climatic regions (Table 1). Three plots of 30 plants of each of 26 clones were planted at CIAT-Palmira and four regional sites. The 26 cultivars included representatives from each of the experimental regions and some CIAT-produced hybrid. All cultivars were planted at each site, although not all produced storage roots. No pest control, disease prevention or irrigation beyond the initial establishment period was used to fully expose plants to the prevailing environmental conditions. Plants were harvested at 12 months, except at the cold-climate site of Popayán (15 months). Ten roots per cultivar were selected at random from the three plots and evaluated for physiological deterioration. Root specific gravity and cyanide content (picrate paper method, IITA, 1974) were also determined.

Table 2. Deterioration (%) of M Col 22, Llanera, CMC-40 and M Ven 218 at each of five ages harvested in August and October 1979 at CIAT-Palmira.

| | | Cultivar | | | |
|---|---|---|---|---|---|
| Harvest | Age | M Col 22 | Llanera | CMC-40 | M Ven 218 |
| August | 7 | 66.3 | 27.7 | 8.6 | 22.0 |
| | 9 | 70.9 | 32.7 | 31.1 | 13.7 |
| | 11 | 65.9 | 18.4 | 19.3 | 32.0 |
| | 13 | 87.0 | 22.3 | 17.7 | 14.0 |
| | 15 | 76.3 | 26.9 | 10.3 | 25.4 |
| mean | | 73.3 | 25.6 | 17.4 | 21.4 |
| October | 9 | 84.1 | 13.3 | 27.1 | 40.9 |
| | 11 | 61.7 | 28.0 | 18.9 | 35.3 |
| | 13 | 57.9 | 6.6 | 5.9 | 15.4 |
| | 15 | 70.3 | 15.7 | 6.0 | 9.1 |
| | 17 | 37.7 | 19.3 | 11.3 | 7.7 |
| mean | | 62.3 | 16.6 | 13.8 | 21.7 |

Results are for the 20 clones which produced roots in all five sites (Table 3). At CIAT-Palmira a wide range of Det. % was observed, although the overall mean Det. % was rather low (26.3%) and only three cultivars exceeded 60%. At Carimagua, situated in a region in intense climatic, edaphic and biotic stresses, all cultivars were resistant, 12 of them totally so. Similar results were obtained following evaluations at the two sites on the north coast of Colombia, Media Luna and Caribia, although the resistance was not so complete as at Carimagua. At Popayán a range of Det. % values was found with a mean of 27.2% but the response of individual cultivars was often different from that at CIAT-Palmira. The correlation between Det. % and root dry matter content as estimated by specific gravity was significant at CIAT-Palmira and Popayán, i.e. at the two sites where a wide range of Det. % values occurred (Table 4).

### The effect of pre-harvest environmental stresses on physiological deterioration

In the previous experiment it was observed that plants most resistant to physiological deterioration were in general those which were least adapted to climatic, edaphic and biotic environmental stresses of the site and had consequently suffered defoliation, stunting, dieback.

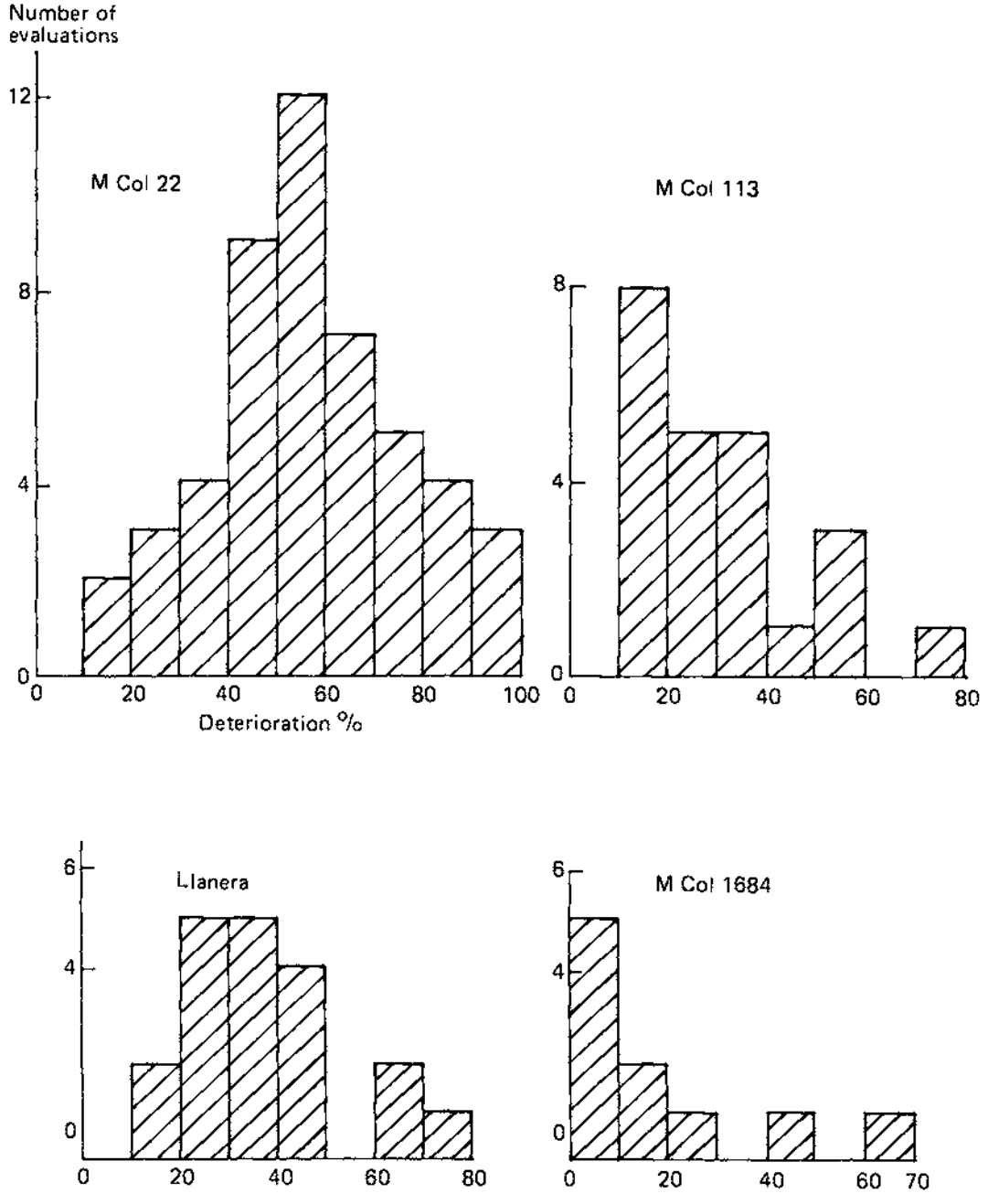


Figure 1. Frequency distribution of Physiological Deterioration Evaluations of Four Cultivars at CIAT-Palmira during 1979-1980.

Table 3. Results of the evaluation of 20 cultivars and hybrids harvested at each of five sites in Colombia as regards their susceptibility to physiological deterioration (%).

| Cultivar | CIAT-Palmira | Carimagua | Media Luna | Caribia | Popayán |
|---|---|---|---|---|---|
| CM 305-120 | 32.4 | 0.0 | 1.8 | 1.7 | 9.3 |
| CM 305-122 | 69.9 | 0.3 | 3.7 | 2.9 | 62.9 |
| CM 321-188 | 60.6 | 0.0 | 0.4 | 4.3 | 68.3 |
| CM 323-64 | 19.5 | 0.0 | 1.1 | 0.1 | 26.0 |
| CM 340-30 | 29.4 | 0.0 | 0.9 | 0.9 | 14.4 |
| CM 344-71 | 18.4 | 0.0 | 1.1 | 0.4 | 64.5 |
| CMC-40 | 1.6 | 0.1 | 1.8 | 1.5 | 8.5 |
| M Col 113 | 12.0 | 0.0 | 3.9 | 0.3 | 32.7 |
| M Col 1684 | 12.7 | 1.6 | 1.3 | 6.5 | 3.6 |
| M Col 72 | 50.2 | 4.0 | 1.4 | 1.1 | 2.3 |
| M Pan 70 | 15.3 | 0.0 | 0.9 | 0.6 | 57.5 |
| M Pan 114 | 2.1 | 0.0 | 0.4 | 1.0 | 5.9 |
| M Bra 12 | 23.3 | 0.0 | 0.4 | 0.1 | 10.2 |
| Sata Dovio | 12.6 | 0.0 | 2.7 | 0.2 | 72.0 |
| Reg. Negrita | 31.6 | 0.0 | 0.9 | 0.1 | 34.3 |
| M Col 22 | 90.1 | 0.0 | 1.4 | 1.7 | 3.8 |
| M Col 638 | 27.1 | 0.2 | 1.1 | 0.6 | 8.8 |
| M Pan 19 | 5.7 | 0.1 | 2.5 | 26.9 | 30.9 |
| M Equ 82 | 8.4 | 1.1 | 1.8 | 1.8 | 4.1 |
| M Ven 77 | 3.0 | 0.3 | 1.6 | 6.9 | 24.7 |

Table 4. Correlation coefficients for the relationship between deterioration (%) and dry matter content calculated for each site.

| Site | n | Correlation coefficient, r |
|---|---|---|
| CIAT-Palmira | 26[1] | 0.68 ***[2] |
| Popayán | 23 | 0.56 ** |
| Caribia | 25 | 0.37 |
| Carimagua | 23 | 0.26 |
| Media Luna | 26 | 0.34 |

[1]All cultivars evaluated for both parameters were used, hence variable n.

[2]Significant at ** $P \leq 0.01$, *** $P \leq 0.001$.

This possible relationship between environmental stresses and the level of physiological deterioration was investigated further at Popayán during 1980. The cultivars chosen included several native to Popayán or similar regions (Regional Negrita, Regional Amarilla, Sata Dovio, CMC-92) as well as some from hot, lowland areas (M Mex 59, M Col 22, M Col 1684). Plots were planted at 3-month intervals in 1978/79 for harvesting 15 months later.

The Det. % did not remain constant throughout the year (Table 5). The locally adapted cultivars increased in susceptibility, as did the less adapted group to a lesses extent. The non-local cultivars, however, maintained a high level of resistance throughout the experiment. The changes in deterioration correlate well with changes in other pre- and at-harvest characters (Table 6). The adapted cultivars increased in yield, foliage weight and dry matter content and defoliation decreased due to improving climatic conditions in line with their increasing susceptibility to physiological deterioration. The non-adapted cultivars, however, consistantly yielded low root and foliage weights and dry matter contents as well as being totally defoliated. In an environment of variable stresses, the fluctuations in susceptibility to physiological deterioration thus here follow the changing status of the preharvest crop.

Table 5. Deterioration (%) of 10 cultivars harvested during 1980 at Popayán.

| Cultivar | | Harvest | | | |
|---|---|---|---|---|---|
| | | March | April | July | September |
| 1. | Regional Amarilla | 7.7 | 10.1 | 82.6 | 84.1 |
| 2. | Regional Negrita | 1.9 | 31.9 | 34.3 | 80.7 |
| 3. | Sata Dovio | [1] | 46.0 | 72.0 | 62.4 |
| 4. | CMC-92 | 3.6 | 11.1 | 33.3 | 78.6 |
| 5. | CMC-29 | | 43.9 | 65.4 | 62.0 |
| 6. | CMC-40 | | 27.0 | 8.5 | 41.7 |
| 7. | M Col 113 | | 37.3 | 32.7 | 72.9 |
| 8. | M Mex 59 | | 6.3 | 2.1 | 6.0 |
| 9. | M Col 22 | | - [2] | 4.0 | 0.0 |
| 10. | M Col 1684 | | - | 3.9 | 2.9 |

[1]Not included in this harvest.

[2]Insufficient roots produced for evaluation.

Table 6. Correlations between deterioration (%) and other plant characters.

| Character | Harvest | | |
|---|---|---|---|
| | April | July | September |
| Dry matter % | +0.23 | +0.69* [1] | +0.81** |
| Defoliation % | -0.50 | -0.83** | -0.88*** |
| Foliage weight (kg plant$^{-1}$) | +0.17 | +0.80** | +0.80** |
| Yield (tons ha$^{-1}$) | +0.10 | +0.80** | +0.90*** |

[1]Significant at * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$.

To test effects of a period of water stress on the level of physiological deterioration of cassava roots, plants of M Col 22 and Secundina were grown individually in plastic containers with a 50:50 mixture of CIAT soil and sand. After 7 months growth, plants were subjected to differing levels of water stress (100%, 60%, 30%, and 10% soil moisture content) for one month, a period sufficient to produce defoliation in the plants of the most severe treatment. Roots from six replicate plants per treatment were harvested after the 1-month stress period. All stress treatments resulted in a significant reduction in the Det. % of the roots compared with the unstressed controls (Table 7), showing that a period of stress can induce resistance to physiological deterioration. The control plants did not, however, produce the high levels of deterioration usually encountered, at least in M Col 22 (compare with Figure 1). This was probably caused by stresses associated with growth restrictions imposed by container size.

Table 7. Effect of defoliation resulting from a period of controlled water stress on the deterioration (%) of roots of M Col 22 and Secundina grown in individual containers at CIAT-Palmira.

| Treatment | M Col 22 | Secundina |
|---|---|---|
| 100% soil moisture content[1] | 22.23 a[2] | 27.17 a |
| 60% soil moisture content | 1.01 b | 0.17 b |
| 30% soil moisture content | 1.63 b | 1.34 b |
| 10% soil moisture content | 4.94 b | 2.38 b |

[1]Approximate values, monitored using a Bouyoucus meter.

[2]Means with the same letter were not significantly different ($P \leq 0.01$) when tested using Duncan's multiple range test.

The previously noted effect of pre-harvest pruning on the susceptibility of roots to physiological deterioration can thus also be seen as a stress-related response. The necessity of postulating a translocatable factor is thus removed. Roots of M Col 22 evaluated after various times between pruning and harvest showed a prolonged resistance to physiological deterioration even when there was no removal of regrowth (Table 8). The resistance continued up to 9 weeks after pruning, when regrowth had reached 0.44 kg/plant (fresh wt.). Associated with the decrease in susceptibility to physiological deterioration was a decrease in root dry matter content from 36.0% to 32.5% during the 9 week period, presumably due primarily to the utilization of root carbohydrate reserves to form the new foliage. The application of gramoxone to the cut stump to inhibit regrowth appeared to lessen this loss of dry matter while not affecting the acquisition of resistance to physiological deterioration, at least during the first 5 weeks of the experiment. Long-term resistance to physiological deterioration and a decrease in dry matter content were also found in 10 cultivars harvested at CIAT-Palmira (Table 9), suggesting that the effect is general.

Table 8. Effect of pruning with and without partial herbicide suppression of regrowth on the deterioration (%) in roots from M Col 22 plants on six dates over a 2-month period.

| Pruning-harvest interval (days) | Control | Pruned | Pruned + Gramoxone | Mean |
|---|---|---|---|---|
| 2 | 60.1 | 52.0 | 34.9 | 49.0 |
| 4 | 42.4 | 29.3 | 25.9 | 32.5 |
| 8 | 54.3 | 24.1 | 18.9 | 32.4 |
| 16 | 59.7 | 20.0 | 16.7 | 32.1 |
| 32 | 48.3 | 6.6 | 5.3 | 20.0 |
| 64 | 47.3 | 12.7 | 11.1 | 23.7 |
| Mean | 52.0 | 24.1 | 18.8 | |

Table 9. Changes in susceptibility to physiological deterioration (%) and in root dry matter content following pre-harvest pruning of 10 cultivars harvested at CIAT-Palmira.

| | Pruning-harvest interval (weeks) | | | | | |
|---|---|---|---|---|---|---|
| | 0 (unpruned control) | | 2 | 6 | 9 | |
| Cultivar | Det. % | Dry matter % | Det. % | Det. % | Det. % | Dry matter % |
| CM 305-120 | 32.4 | 29.7 | 1.6 | 0.0 | 0.0 | 28.0 |
| CM 305-122 | 69.9 | 40.2 | 20.0 | 1.4 | 6.4 | 42.1 |
| CM 344-71 | 18.4 | 33.4 | 0.4 | 0.0 | 0.1 | 26.8 |
| M Col 22 | 90.1 | 34.7 | 1.1 | 0.1 | 0.0 | 31.7 |
| M Col 113 | 12.1 | 36.4 | 1.7 | 0.0 | 0.0 | 23.4 |
| M Col 638 | 27.2 | 33.1 | 1.7 | 0.1 | 0.1 | 25.2 |
| CMC-40 | 1.6 | 29.2 | 2.7 | 0.2 | 0.0 | 22.4 |
| Llanera | 0.6 | 24.2 | 1.9 | 0.1 | 0.0 | 21.7 |
| Ven 77 | 3.0 | 29.7 | 2.4 | 0.0 | 0.0 | 26.5 |
| CMC-92 | 24.6 | 30.0 | 2.3 | 0.0 | 0.0 | 19.5 |
| Mean | 28.0 | 32.1 | 3.6 | 0.2 | 0.7 | 26.7 |

## Conclusions

The method used in these studies for the assessment of physiological deterioration permits standardization of mechanical damage and avoidance of microbial contamination through a short 3-day storage period, unlike some previously used methods in which these variables were not standardized. Hence the substantial variation in response obtained by several workers is hardly surprising.

Results show the pre-harvest environment is the major variable which determines the susceptibility of roots to physiological deterioration once other vari-

ables (damage, fungal contamination) are removed. Defoliation, whether due to insect, disease or drought stresses, or pruning, induces resistance to physiological deterioration but also leads to a lower root dry matter content once regrowth occurs. Thus, the correlation between these two characters is clearly not causal but the result of parallel plant stress response mechanisms.

The terms "susceptible" and "resistant" are often applied to varieties following one or a few evaluations of physiological deterioration. Results show that, as the environmental component is of overriding importance, repeated evaluations in a number of environmentally different sites would be necessary before any genetically based "resistance" could be confidently reported. One would expect locally-adapted cultivars to show a maximal expression of susceptibility in their native regions. Similarly, plants to be evaluated should be in an unstressed state (i.e. disease and pest-free and with adequate water supply) particularly in the immediate pre-harvest period. The pre-harvest environment could be crucial in determining susceptibility since the standard CIAT "susceptible" cultivar, M Col 22 could be "resistant" even at CIAT-Palmira. This could have an important bearing on harvest time in some localities where natural defoliation, which should produce resistant roots, occurs as a result of seasonal climatic conditions.

The use of pre-harvest pruning to induce resistance needs further study, especially as regards quality, before any commercial recommendations can be made. However, the inhibition of regrowth, and hence of carbohydrate reserve depletion, could be a promising treatment. Presumably, some reduction in root quality would be acceptable given an increased root storage life: economic analyses of this are necessary.

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## Developing Cassava as an Industrial Crop in Australia

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ABSTRACT

The current status of cassava as an industrial crop for starch and ethanol production in Australia is described.

Over the last nine years, Australian Cassava Products Pty Ltd has undertaken a research program on cassava agronomy, cultivar selection, and commercial production techniques suitable for the Australian economic environment where labor costs are high. Modern agricultural systems involving a high degree of mechanization, including planting and harvesting operations, are being developed and used to evaluate the commercial potential of cassava on a 4,000 hectare estate in southeastern Queensland. Production costs and the yields needed for cassava to be a profitable crop, competitive with alternatives are reported. Discussion includes methods of land management, production problems in a subtropical climate, and pest and diseases.

## Fuel Ethanol from Cassava: The Baiyer River Experience

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ABSTRACT

The objectives, strategy, and progress of the Papua New Guinea program for evaluation and production of ethanol from biomass as a transport fuel are outlined.

The Baiyer River Alcohol Company was established to develop the first pilot demonstration industry in the highlands of Papua New Guinea. This industry was to produce 2.5 million liters of fuel ethanol per year from cassava. The agricultural strategy, early development, industrial plans, and projected costs of production are discussed in detail. This project has now been cancelled following considerable development work. The major problems encountered by this project are outlined as an example of the difficulties of agroindustrial development in Third World countries.



UNIVERSITY OF GREENWICH

Natural Drying of Cassava for Animal Feed - The Establishment of Small-Scale Agro-industries on the North Coast of Colombia

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ABSTRACT

The paper describes the ongoing cooperative project between the Colombian Integrated Rural Development Programme, the Canadian International Development Agency and the Centro Internacional de Agricultura Tropical, whose objective is to establish small scale cassava natural drying plants on the North Coast of Colombia.

The project initiated with the setting up in collaboration with a group of 15 farmers of a pilot drying plant. In 1981 the plant operated on an experimental basis in order to collect data on drying performance under the conditions prevailing on the North Coast and to ascertain the acceptability of the product by the animal feed industry. In 1982, the plant has been operated on a semi-commercial basis to collect accurate production cost figures and to demonstrate the economic feasibility of replicating the process in other areas of the region in 1983.

From the experience obtained to date it can be concluded that for the successful establishment of drying plants, the following conditions should be met: a) the selection of a processing technology that may be easily controlled and managed by the farmers themselves, b) the integration of crop production, processing and marketing activities and c) the provision of institutional support in terms of technical assistance, training and credit facilities.

# Effect of Cutting Quality on Cassava

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ABSTRACT

Cassava is normally propagated by planting 20 cm long stem cuttings. The general performance as measured by root, starch and cutting yield; plant height; root rot resistance; and root and cutting quality of a native cultivar of long standing use and a recently selected hybrid was investigated to planting material source. Results showed that by using cuttings from plants regenerated after meristem culture, the root and starch yield increased by 69.5% and 70.3%, respectively, compared to traditional planting material. The plant height and the production of good quality planting material were significantly (5% level) higher. When comparing the native cultivar with the selected hybrid, there were no differences in yield (fresh roots) if "clean cuttings" were used. However, significant differences between the native and the hybrid genotypes were found on cutting production and root rot resistance. When using traditional planting material for the native cultivar the hybrid produced around 3.2 times more than the native cultivar. These findings appear to indicate a continuous decrease in the performance of cassava cultivars with time due to the effect of biotic stresses asserted during each cycle. These bring out the need for: a) a careful evaluation of the genotypes during selection by using planting material of equal quality and b) use of clean planting material for a high performance.

In any vegetatively propagated crop yield is related to quality of the planting material used. Cassava (*Manihot esculenta* Crantz) is propagated by planting stem cuttings approximately 20 cm in length. The quality of this planting material is usually visually judged, but selection only occurs if sufficient stem material is available. Due to the long growing cycle of the crop, plants are continuously subjected to pressures from biotic (diseases and pests) and abiotic (climate, soil pH, nutrient deficiency or toxicity) factors which may decrease the quality of the planting material. The general performance of a genotype in a given ecosystem is related to the quality of the planting material which in turn is related to the resistance to biotic or abiotic stresses present.

Most endemic biotic problems are generally eliminated by true seed production (of about 26 viral diseases of potato only three have been reported as seedborn; Salazar, 1980). So far none of the viral problems in cassava have been reported to be seedborn; according to literature only cassava bacterial blight (Elango and Lozano, 1980) anthracnose (CIAT, 1981) and a *Fusarium* sp. (CIAT, 1982) are seedborn pathogens of the crop, but they can be eliminated by heat and fungicide

treatments (CIAT, 1981-1982). However, the sexual propagation of cassava is scattered and rare in traditional systems and is mostly used by scientists in the process of genetic improvement (Hershey and Amaya, 1982). As native or parental genotypes obviously evolved in traditional systems, they have been under biotic and abiotic stresses for a considerable period of time. The effect of such stresses over time on genotypes could have been cumulative decreasing the quality of the planting material after several or many cycles of vegetative propagations. Evaluation of the progeny by comparison with native or parental genotypes without considering the quality of the planting material may give unreliable results.

The effect of cutting quality on cassava performance is preliminarly reported here after comparing results of a year-cycle trials with planting material of a traditional genotype generated from meristem culture with other sources of planting material and with a selected hybrid.

## Materials and Methods

Twenty centimeter long stem cuttings of the cultivar Secundina, a widely grown clone from the north coast of Colombia, from the following sources were used: (1) cuttings from plants generated by meristem culture and indexed for the absence of Frog Skin Disease, Caribbean and Common mosaics (CIAT, 1981 and 1982); (2) cuttings from farms, but selected from plants which were apparently healthy (without mosaic symptoms) and from the mature stems, free from injuries and any signs of cassava pathogens or pests; (3) planting material from farms taken from the mature stem portions of unselected plants, free from injuries and signs of cassava pathogens and pests; (4) planting material selected from mature stem portions of plants showing mosaic, but free from necrotic signs of cassava pathogens and pests; (5) planting material taken from farmer's fields following the farmer's criteria of selection (selection of stem pieces without considering maturity and/or sanitary condition of the cuttings); (6) cuttings from the hybrid CM 342-170 produced at the CIAT-Palmira Experimental Station; and (7) cuttings from the hybrid CM 342-170 selected after a year growth-cycle on a farm near the trials. Two different trials were performed in the north coast (Media Luna region) using the above treatments: One to compare the effect of cutting sources with the local native genotype, and the other to compare the native genotype with the hybrid which was previously selected as promising on the north coast (CIAT, 1980 and 1982). The Media Luna area of Colombia has an average temperature of 27°C and average rainfall 1100 mm/year with a 4-month dry season with essentially no rain. The soil of the locality is sandy with a pH of about 6.3.

All cuttings were treated with a solution mixture containing Captan/BCM (3000 ppm a.i. each) for 5 min before planting in a randomized block design of 30 plants/plot with 4 replicated. Experimental plots were separated by 2 m rows and plants planted 1x1 m apart in flat seedbeds.

The following parameters were evaluated during the 12 month cycle of the trials: percent germination of cuttings, plant height, mosaic symptoms, yields (ton/ha) of fresh roots, starch content and number of cuttings/plant. Starch was estimated by the specific gravity method (CIAT, 1980) and cutting production by counting the number of cuttings produced from the mature stem portion of each plant. Cuttings were also selected visually according to their sanitary state (absence of necrotic lesions caused by pathogens and pests), thickness and weight (Lozano et al, 1977).

As Caribbean mosaic was the most prevalent disease of the area, the presence of this disease in each cutting source was recorded every two months. Readings for all parameters were taken from all plants, except for yield (fresh root and starch) where data were taken only from the 12 central plants, to eliminate the border effect (CIAT, 1979).

## Results and Discussion

The percentage germination of cuttings from farms where no selection criteria were used (Treatment 5) were 20% less than those of the cuttings obtained from other sources in both native and hybrid genotypes and showed significant (5% level) differences. However, percentage germination of cuttings from both the native and the hybrid used from other source were not significantly different.

Plants developed from cuttings obtained from plants generated from meristem cultures averaged 51 cm higher than the plants developed from cuttings obtained from other sources. The height of plants developed from selected (Treatment 2, 3 and 4) or non-selected (Treatment 5) cuttings with or without mosaic was not significantly different, but in general plants with mosaic were shorter than symptomless plants.

Mosaic symptoms were most striking during the rainy seasons, the coolest (21.8°C, maximum; 30.3°C, minimum) periods in the region. During the dry, hot periods (19.3°C, min.; 34°C, maximum) mosaic symptoms decreased and they were barely noticeable at the end of the dry season. This agrees with the results obtained under controlled conditions (Table 1), suggesting that mosaic symptoms are highly heat sensitive. However, when plants were transferred back to a cool environment (20-21°C), severe symptoms reappeared. This was also observed in field trials at the onset of the second rainy season of the growth cycle when plants were 10 months old.

Table 1. Effect of temperature on the expression of mosaic symptoms on variety Secundina (MCol 2063) under controlled conditions.

| Temperature Range* | Severity of Symptoms |
|---|---|
| 21-22°C | Severe† |
| 23-24 | Severe |
| 25-26 | Severe |
| 27-28 | Moderate |
| 28-29 | Moderate |
| 31-32 | Absent |

*Light intensity 4,800-6,400 lux/12 hrs.

†Symptom expression of cassava Caribbean Mosaic on Secundina: severe=leaf distortion and curling, plant stunting; moderate=light leaf distortion, vein clearing; absent=no mosaic symptom expression.

Undoubtedly, visual selection of cuttings has a significant positive effect on yield. This increase also appears to be related to the absence of mosaic symptoms on plants. The highest yield produced by plants produced by cuttings

regenerated from meristem cultures suggest that accumulative unnoticeable factor(s) were present in cuttings from other sources and that they were able to decrease the yield significantly. Similar results were also obtained in relation to the total cutting production (Table 2). The ratio of the quality of the cuttings (good: poor = 2:1) obtained with cuttings produced from meristem culture plants gives the growers a higher possibility of selecting good quality cuttings than when they use other sources of planting material. When planting material is unselected the quality ratio (1:2) tends to decrease the probability of farmers selecting good material for next growing cycle. This may partially explain the gradual but constant decrease in cassava genotype performance as well as the great variability of plant-to-plant yield and general performance often reported in the literature (CIAT, 1979). However, other abiotic or biotic factors for such variability could also be responsible.

The yields (fresh roots or starch content) of the hybrid and the native Secundina were similar, reflecting the similarities in genetic yielding ability of these two genotypes under the environmental conditions where they were tested. However, when unselected Secundina planting material (i.e. farmers usual practice, Treatment 5) was used the hybrid yielded 2.5 times more than the native genotype. Similarly, the yield of the hybrid itself with planting material selected from the farmers' field after the first growing cycle was 32% less than the yield of the plants whose planting material originated from the CIAT's Experimental Station (Table 3). This indicates the great influence of environmental factors (diseases, pests, cultural practices, climate, soil, etc.) in determining the final quality of cassava planting material after each growing cycle. Results also indicate that an accurate evaluation of genotypes can only be made if evaluated material is planted with cuttings which are similar in agronomic (maturity, size, weight, number of nodes) and sanitary (absence of pests, diseases, insects, spider mites) conditions.

From the above results it can be concluded that the performance of a cassava genotype may decrease with time because the biotic and abiotic pressures of the ecosystem on the genotype may act continuously to reduce the quality of its planting material. The yield stability of a good performing genotype is related to the genetic capacity of the genotype to overcome such pressures. The potential performance of a native genotype can be measured only by using high quality planting material obtained through meristem culture and good cultural practices, a fact that has a great influence on final yield and which should be considered when comparing improved genotypes with the native ones during evaluation.

Results also show the great effect that the sanitary condition of the cuttings has on yield. Yields could be increased by visual selection of the most vigorous and healthy plants of plantations, a careful selection of mature-lignified stem portions, free from cankers and mechanical damages, and treatments with appropriate fungicide-insecticides (Lozano et al, 1977). Devoting a plot of each farm exclusively to the production of planting material will greatly help the growers to obtain high quality cuttings if appropriate cultural practices related to soil preparation, fertilization, weed control, insect-disease control, are given to these plantations.

Table 2. Yield (ton/ha), percentage of yield reduction and number of cuttings per plant in the native clone 'Secundina' in relation to cutting source and type of selection.

| Treatment | Cutting Source | Yield (ton/ha) | | | Number of cuttings per plant / quality | |
|---|---|---|---|---|---|---|
| | | Fresh root weight | Starch | Yield reduction (%) | Good | Poor |
| 1 | Secundina from meristem culture. | 24.0 a* | 7.9 a | 0 | 6.2 a | 2.8 ab |
| 2 | Secundina from farms without symptoms of mosaic; selected cuttings. | 19.6 b | 6.2 b | 18.3 | 3.6 bc | 4.9 ab |
| 3 | Secundina from farms without regard to mosaic symptoms; selected cuttings. | 18.2 b | 5.8 b | 24.2 | 3.8 b | 4.4 ab |
| 4 | Secundina from farms with mosaic; selected cuttings | 14.7 c | 4.5 c | 38.7 | 3.2 bcd | 3.5 b |
| 5 | Secundina from farms without regard to mosaic symptoms and without selection of cuttings | 7.3 d | 2.4 d | 69.5 | 3.4 bcd | 5.5 a |

*Values with same letter are not significantly different by Ducan's multiple range test (P=0.05).

Table 3. Yield and number of stakes per plant in the native clone 'Secundina' and the hybrid CM 342-170 in relation to cutting source and type of selection.

| Treatment | Cutting source | Yield (ton/ha) | | Number of cuttings per plant / quality | |
|---|---|---|---|---|---|
| | | Fresh root weight | Starch | Good | Poor |
| 1 | Secundina from meristem culture. | 26.0 a* | 7.6 a | 6.7 a | 3.6 a |
| 5 | Secundina from farms without regard to mosaic symptoms and without selection of cuttings. | 8.2 b | 2.6 b | 3.3 b | 5.4 b |
| 6 | CM 342-170 from CIAT; selected cuttings. | 26.1 a | 7.0 a | 6.3 a | 9.6 b |
| 7 | CM 342-170 from farms; selected cuttings. | 17.8 c | 4.3 c | 6.0 a | 9.1 b |

*Values with same letter are not significantly different by Ducan's multiple range test (P=0.05).

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Effect of Various Factors on Minimal Growth in Tissue Culture Storage of Cassava Germplasm

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ABSTRACT

Several experiments evaluated influence of various factors in tissue culture storage on growth rate and viability of cassava germplasm stored in vitro. Cultivars responded differently to low temperature; thus use of this factor alone was not completely suited for adequate storage. Osmotic concentration, due to presence of mannitol, was only effective if sucrose was also present in the medium and only at 22°C storage. Inclusion of activated charcoal reduced shoot growth rate and increased culture viability, however. In addition, intermediate levels of nitrogen supported viability at 22°C, and larger storage vessels promoted propagation potential of the cultures. It was determined that sufficient growth limitation and high viability could be achieved through storage at 22°C to 24°C and by using media with low osmotic concentration, activated charcoal, and large vessels. Furthermore, minimal-growth storage could be linked to cryogenic techiques as a system for long-term conservation and international exchange of germplasm.

## Introduction

Conventional maintenance of cassava germplasm in the field often exposes the materials to various pests and diseases and to soil and climatic problems. Requirements of land, labor, and other inputs are also high. Stakes can be kept only for a short period due to premature sprouting and insect or microbial attack; in addition, stakes might harbor systemic contaminants. Preservation of varieties by seed propagation may be limited by low or no-seed setting in numerous accessions, strong inbreeding depression, and high genetic segregation. Thus a large number of seed must be collected to preserve the nonfixed alleles of an accession (IBPGR, 1982). Early recognition of these problems stimulated research on tissue culture methods for conservation and international exchange of cassava germplasm.

The ability to consistently regenerate plants from somatic cells in culture is still lacking in cassava. However, methodologies are available to grow plants to maturity from apical meristems of a wide range of germplasm (Roca et al., 1982a). Shoot apical meristem cultures are particularly suited for germplasm conservation, because of their freedom from microorganisms, small space requirements, and high genotype stability.

Limiting culture growth, primarily by means of reduced temperature, has increased the transfer period of cassava clones in vitro (Roca et al., 1982a) by 18

to 24 months, depending upon cultivar (CIAT, 1981). However, temperature stress resulted in culture deterioration in some genotypes (Roca et al., 1982b).

This report summarizes results of experiments to evaluate effects of various physical and chemical factors on rate of growth and the viability of cassava cultures stored in vitro.

## Materials and Methods

Single node cuttings of two varieties obtained from meristem-cultured plantlets were used as explants for the storage experiments. Unless otherwise stated, cultures were stored in Murashige and Skoog (1962) medium with each liter supplemented with 3% sucrose, 1.0 mg thiamine, 100 mg inositol, 0.02 mg 6-benzyladenine, 0.1 mg gibberellic acid, and 0.01 mg naphathalene acetic acid. Test tubes were 25x150 mm with an 0.8% Difco agar (Roca et al., 1982a) and were placed under 1,500 lux illumination, with a photoperiod of 12 hours. Rate of shoot elongation, proportion of leaf fall, number of shoots per culture, and number of nodes formed on each shoot were determined, with six to eight replications per treatment, after 8 to 9 months of storage.

The results by variety were either averaged or presented separately, depending on whether or not the cultivars' responses were similar or different, respectively.

## Results

### Effect of temperature

Storage temperatures lower than 20°C were detrimental to culture survival of many cassava varieties (Roca et al., 1982b). In this experiment, the cultures were stored at 18°, 22° and 30°C, under illuminations of 500, 1,000, and 2,000 lux.

Shoot elongation was directly related to storage temperature in both cultivars, and M Col 1467 grew faster than M Col 22 in all the treatments. Illumination had less effect on growth and viability than temperature. Although the number of shoots of both cultivars increased to 4-6 per culture, with storage temperature, irrespective of illumination, the number of nodes formed per shoot remained either unchanged in M Col 22 or slightly decreased in M Col 1467 when the cultures were maintained at the higher temperature. Thus, viability increased with temperature in M Col 22, but decreased at 22° and 30°C in M Col 1467.

### Effect of osmotic concentration

Although earlier studies showed that high sucrose levels reduced shoot growth, enhanced rooting, and caused phenolic deterioration of some cassava genotypes in storage (Roca et al., 1982a), it was suggested that metabolically inactive osmotica could be more effective than sucrose in limiting culture growth. Thus, nodal cuttings were cultured in three levels of sucrose, combined with four of mannitol, and kept at 22° and 30°C.

At both storage temperatures, mannitol was completely detrimental to culture survival in the absence of sucrose. However, in the presence of 3% sucrose, the addition of minimum levels of mannitol greatly increased the number of shoots per culture and nodes formed per shoot, although it did not change shoot elongation

rates. Shoot elongation increased with 0.25% mannitol, whereas viability did not, however, both decreased at the highest mannitol level. With 6% sucrose, only the lowest mannitol concentration resulted in slow growth at 22°C and much higher viability. Higher mannitol levels however, greatly reduced shoot growth and viability at 22°C, but not at 30°C.

Effect of nitrogen concentration

The nodal cuttings were explanted in media containing 0 to 60 mM of total nitrogen, based in the Murashige and Skoog medium (1962), and stored at 22° and 30°C (Table 1).

Table 1. Effect of nitrogen concentration on shoot elongation and viability of cassava cultures stored in vitro at two temperatures.

| Temperature (°C) | Total N (mM) | Shoot elongation (cm/month) | Leaf fall (%) | Viability | |
|---|---|---|---|---|---|
| | | | | Shoots per culture (no.) | Nodes per shoot (no.) |
| 22 | 0 | 0.2 | 20 | 1.0 | 6.0 |
| | 10 | 0.3 | 65 | 2.0 | 12.0 |
| | 20 | 0.4 | 85 | 2.0 | 13.5 |
| | 40 | 0.6 | 75 | 1.0 | 20.0 |
| | 60 | 0.4 | 50 | 3.0 | 23.0 |
| 30 | 0 | 0.2 | 50 | 1.0 | 6.0 |
| | 10 | 0.3 | 60 | 2.0 | 15.0 |
| | 20 | 0.5 | 70 | 2.0 | 17.5 |
| | 40 | 0.6 | 80 | 5.0 | 18.0 |
| | 60 | 0.8 | 60 | 6.0 | 17.0 |

At either temperature, rate of shoot elongation was directly related to concentration of nitrogen in the medium, becoming detrimental at 0 and 10mM, as shown by predominance of single shoot cultures with very few nodes per shoot. Slow growth rates and high viability were obtained at 22°C with 40 to 60 mM of total nitrogen, and at 30°C with 10 to 20 mM. With 60 mM total nitrogen, the growth rate was too high in the cultures maintained at 30°C, but was low enough at 22°C (Table 1).

Effect of activated charcoal

Deterioration of cultures stored at 20° to 22°C was previously characterized by root browning, defoliation, and dehydration (CIAT, 1981). The inclusion of 4% to 6% sucrose accentuated browning, whereas the increase in cytokinins and gibberellins tended to reduce culture deterioration during storage (Roca et al., 1982b). To further test the reduction of deterioration, nodal cuttings were stored at 22° and 30°C in media containing 0.25% activated charcoal (Table 2).

The addition of charcoal to the medium not only reduced defoliation in both varieties, but also nearly halved shoot growth in M Col 22, without changes in the viability of the cultures stored at both temperatures (Table 2). The cultures retained more leaf chlorophyll and had less browned roots than without charcoal.

Table 2. Effect of activated charcoal on shoot elongation and viability of cassava cultures stored in vitro at two temperatures.

| Temperature (°C) | Activated charcoal (%) | Leaf fall (%) | Shoot elongation (cm/month) | Viability | |
|---|---|---|---|---|---|
| | | | | Shoots per culture (no.) | Nodes per shoot (no.) |
| M Col 22 | | | | | |
| 22 | 0.00 | 50 | 1.5 | 1.7 | 17.0 |
| | 0.25 | 30 | 0.8 | 1.5 | 23.0 |
| 30 | 0.00 | 45 | 1.2 | 2.0 | 13.5 |
| | 0.25 | 40 | 0.8 | 2.3 | 11.5 |
| M Col 1467 | | | | | |
| 22 | 0.00 | 65 | 2.4 | 2.0 | 12.0 |
| | 0.25 | 50 | 2.2 | 3.0 | 13.0 |
| 30 | 0.00 | 60 | 2.3 | 4.0 | 9.5 |
| | 0.25 | 40 | 2.1 | 4.0 | 8.7 |

## Effect of culture vessel size

Leaf contact with the vessel inner surface had earlier been shown to result in bleaching and leaf drop (CIAT, 1981). To try to prevent such contact, the nodal cuttings were cultured in test tubes of 25x150 mm and bottles of 50x140 mm in size, containing 10 and 70 ml of medium, respectively, and maintained at 22° and 30°C (Table 3).

Table 3. Effect of vessel size on shoot elongation and viability of cassava cultures stored in vitro at two temperatures.

| Temperature (°C) | Size of vessel (mm) | Shoot elongation (cm/month) | Leaf fall (%) | Viability | |
|---|---|---|---|---|---|
| | | | | Shoots per culture (no.) | Nodes per shoot (no.) |
| 22 | 25 x 150 (10 ml) | 1.0 | 75 | 9.2 | 8.0 |
| | 50 x 140 (70 ml) | 1.8 | 50 | 17.0 | 10.5 |
| 30 | 25 x 150 (10 ml) | 1.2 | 60 | 8.0 | 9.6 |
| | 50 x 140 (70 ml) | 2.1 | 35 | 10.0 | 9.8 |

At either storage temperature, rate of shoot elongation in large vessels almost doubled; however, leaf fall diminished and culture viability greatly increased, especially at 22°C (Table 3). In addition, leaves and roots remained healthier in the large than in the small vessels.

## Effect of growth inhibitors

Among the growth inhibitors, abscisic acid has effectively slowed down growth in other species (Roca et al., 1982b). To test its effect on cassava, 2.5 through 10.0 mg/l of abscisic acid were added to the storage medium. Culture growth was completely suppressed even at the lowest concentration, at both 22° and 30°C. However, the shoots did not deteriorate completely as expected, but rather remained green.

## Discussion

An in vitro conservation method largely depends on achieving sufficient growth limitation and maximal viability. This study has demonstrated that temperature, osmotic and nutritional stresses, and the cassava genotype can influence the rate of growth and the viability of the cultures during storage. Cultivars such as M Col 1467 grow faster at reduced temperature than do others such as M Col 22. Because M Col 1467 prevails in cooler growing regions, it would probably require more frequent subculturing. Lower storage temperatures than 20°C would drastically reduce viability in varieties such as M Col 22. It seems, therefore, that reduced temperature alone will not completely provide adequate storage conditions for cassava collections.

Growth limitation due to osmotic stress may be exerted through the reduction of water and nutrient uptake and thus, it may be detrimental to culture survival as observed in this study when mannitol alone was present, even at the lowest concentration. High culture viability occured only if sucrose was added to the medium, at a level directly related to the storage temperature. The increase in viability observed when 0.12% mannitol was added to the 3% and the 6% sucrose media, remains without explanation.

Low nitrogen concentration delayed vegetative growth more at 22° than at 30°C; however, intermediate levels of nitrogen, directly related to storage temperature, were needed to support viability, and the lack of nitrogen in the medium was highly detrimental to culture survival.

Low temperature, high osmotic concentration, low mineral nutrition, growth inhibitors, on one hand, and rapid growth and longevity on the other, tend to cause tissue browning, followed by defoliation, and eventual deterioration of the cassava cultures stored in vitro. Browning could be attributed to phenolic oxidation, and gradual shoot deterioration to ethylene-induced senescence, especially when the culture vessels were small or have been tightly capped.

Reduction of defoliation rates and increase in viability of cultures stored in large vessels may be attributed to the dilution of toxic exudates and emanations from the tissues. The increase in culture viability and the reduction in the rate of shoot elongation due to the inclusion of activated charcoal can be explained by the removal of toxic compounds and certain growth hormones through absorbance in the medium. Therefore, sufficient growth limitation and high viability can be obtained through storage at 22° to 24°C with active osmotica at low

concentration, sucrose and activated charcoal included in the media and using large culture vessels.

Nearly 6,000 cassava clonal accessions can be stored in a 5x6x3 m room, using five vessels of 50x140 mm per accession. At present, more than 1,300 cassava cultivars from CIAT's germplasm collection have been transformed into in vitro cultures for storage. Most materials have been maintained for 6 to 24 months, with a total of 0.6 to 1.2 subcultures, respectively. Given the recent advances in the cryopreservation of cassava meristems (Kartha, Leung and Mroginski, 1982), a dual conservation system can be envisaged: the base collection under cryogenic storage, using liquid nitrogen, and the active or working collection, under minimal-growth storage. The latter constitutes a source of materials for quick micropropagation and use in international exchange.

The exchange of cassava clones in vitro reduces the risks of disease dissemination across country boundaries. This is a suitable method for the transfer of genetic resources both from the collection site to the principal germplasm center and from the center to the national programs. In the last 4 years, selected cassava materials have been distributed from CIAT to 15 countries, and over 700 introductions to CIAT have been carried out using in vitro methodologies.

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The Potential of Tissue Culture in Cassava Improvement

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ABSTRACT

Recent developments in plant tissue and cell culture techniques have greatly stimulated interest in the improvement of tropical crop species with respect to the utilization of tissue culture for the distribution and conservation of germplasm and for its genetic manipulation. In the last ten years, cassava has received much research attention in this area.

This paper reviews these recent advances and discusses the prospectives and limitations of culturing protoplasts, embryos, anthers, and other somatic tissues *in vitro*.

# Potato Production in Fiji - Potentials and Constraints

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## ABSTRACT

Potato was first introduced into Fiji in the 1860's. Fiji's potato acreage in 1981 was some 9 ha representing a drop since 1960. To meet demand, 9,596 ton worth F$2.4 million were imported. Potential areas for potato production are Nadala/ Navai/ Nadrau plateaus, Nausori Highlands and Sigatoka Valley where potato was reasonably successfully in the past. Major limiting factor, is widespread bacterial wilt caused by *Pseudomonas solanacearum*. The Department of Agriculture has unsuccessfully experimented with a number of varieties over the years. Since early 1970, introductions of bacterial wilt resistant varieties from Mauritius and the International Potato Center, Peru, show considerable promise, with resistance to bacterial wilt and which produce reasonably high yields of good quality, medium sized tubers.

## Introduction

Even increasing quantities of table potatoes have been imported yearly to Fiji from New Zealand and Australia to satisfy local requirements. Initially, major users were the Europeans with the Fijians and the Indians slowly showing interest. Currently, main outlets for imported potatoes are the Indian community and the hotel trade. During 1980, a total of 9,167 t worth F$2.63 million was brought into the country while in 1981, this rose to 9,596 t worth $2.42 million.

There has always been an interest in growing potatoes locally, primarily as a substitute for imports, thereby saving foreign exchange. Several constraints have contributed to the present situation where only a few farmers in Sigatoka Valley and Navai are growing potatoes on a few hectares of land. Variable yields have been obtained under Fiji conditions ranging up to 25 t/ha (Anon, 1949), although in recent years the average has been 5 t/ha.

## Historical Background

Potato was introduced into Fiji by European settlers in the 1860's (Seemann, 1873). First grown in Rewa in the wet zone, the tubers were not liked because of a soapy taste. Horne (1881) also mentions a few plants being cultivated by the enterprising settlers and the natives and had felt that it would do better in the dry parts of Fiji. Over the years interest in potatoes was maintained with cultivation spreading, particularly to western Viti Levu. Varieties recommended in the 1940's were Brownell and Bismark (Whitehead, 1948). Since 1960, the two main varieties planted by farmers have been Sequoia and Sebago.

Production over the years has fluctuated in both terms of hectarage planted and yield per unit area. Main reason is presence of bacterial wilt disease Pseudomonas solanacearum, and consequently, production has been confined to a 4- to 5-month period from May-June to September-October. The Land Development authority was instrumental in organizing large scale plantings in the mid-1960's with production centered around Nadala/Navai, Nausori Highlands, and the Sigatoka Valley. The Sigatoka Valley has always been the major center of production with significant quantities being harvested even prior to and during World War II. Potato was popular then as a dry zone winter crop for the local store and bazaar trade (Harvey, 1941). The Nadala/Navai and Nausori Highlands schemes peaked in 1966 when 57 ha was planted. They were moderately successful until their virtual closure in 1969 due mainly to the severe incidence of bacterial wilt. The area in potatoes rose to a high of 134 ha, all in the Sigatoka Valley, in 1972 but declined rapidly and in 1981 only 9 ha were planted.

Production methods remained uniform throughout the country, following fairly substantial land preparation with up to 3 or 4 ploughings and a corresponding number of harrowings. Small, single-eye seed pieces are planted 25 to 30 cm apart in furrows 60 to 90 cm apart. There has been little use of fertilizer or dusting of cut seed. Much of the production has been associated with small holdings: for the 1973 crop, 30% of the growers planted less than 0.2 ha with a further 30% with less than 0.4 ha (Davies and Hampton, 1973).

Until 1968, farmers either marketed their own potatoes or dealt through middlemen or small cooperatives. Since then, in different years the Valley Industrial Cooperative Association (VICA) and the National Marketing Authority (NMA) undertook to market the crop at the grower's request. At times these groups handled 70% of the crop at fixed prices: for example, 8.8c and 11c per kg for medium and table grades, respectively, in 1968. In some years low production resulted from bacterial wilt or severe drought. Most farmers marketed their own crop.

Prior to 1973, the main seed suppliers were retail stores in Sigatoka, Nadi and Ba. Then for a couple of years, NMA was made the sole importer of seed from Australia in a move to stabilize the area planted, following which the retail stores in Sigatoka have been handling seed again. Many farmers in the past obtained seed on credit, the usual method of repayment being a guarantee on the part of the farmer to market his crop through the lending body, be it VICA, NMA or another seed supplier. The crop, however, has been attractive for growers with their own initial capital, providing a reasonable gross margin ranging from $450 to $1,000 per ha in 1973 (Davies and Hampton, 1973).

Bacterial wilt has affected production so seriously that few potatoes are now grown. The many varieties imported have all been susceptible except for most recent introductions, providing possibility of re-establishment of the potato industry. The Department of Agriculture has discouraged farmers from large scale potato growing until the selection of a suitable variety. It is expected that 10 ha will be planted to a new variety, CIP 800226 (BR-69.84) in 1984.

## The Potential

Evaluation indicates Fiji has an excellent potential for potato production. A large market exists to which the initial production could be geared. The demand for potatoes currently is approximately 800 tons per month of which a negligible amount is supplied by local production. It is envisaged that the demand would

increase in the future due to the expansion in the tourist industry and to a lesser extent to natural population growth. Earlier attempts at organized planting and marketing have shown that this crop can be successfully grown under Fiji conditions. Prospects appear good for partial if not full import substitution, with possible exports to neighboring South Pacific countries.

It may also be feasible to establish a small processing unit to remove small-sized potatoes from the market as canned whole potatoes for the hotel trade. Sufficient land in suitable areas (Nadala/Navai/Nadrau, Nausori Highlands and Sigatoka Valley) and manpower, are available. The bacterial-wilt resistant variety now recommended has performed well in trials yielding more than 17 t marketable tubers per ha, while Sequoia and Sebago, though susceptible to bacterial wilt, could also be grown with some success.

Extension of the growing season, particularly in the highlands, appears possible. Plantings in April and August would enable locally grown potatoes to be available for 6 months of the year, from July to January. The supply situation could be further improved with a heavily mulched planting in November to mature in February. These considerations coupled with capital inputs, improvements in husbandry, pest and disease control and market protection should enable a thriving industry to be established.

## The Constraints

Major constraints limiting Fijian potato production can be classified into two categories: biological or environmental, and socioeconomic.

### Biological or Environmental Constraints

#### Major diseases and pests

Bacterial wilt has been the most serious disease, limiting potato production in Fiji. Because of difficulty in control, efforts have been directed toward finding a resistant variety possessing other favorable characteristics. Other diseases, important at times, are early and late blights, blackleg, and *Fusarium* sp., and *Phythium* sp. root rot. Serious pests on occasions are greasy cutworm, aphids and thrips.

#### Climate

Potatoes have been grown almost at sea level at Sigatoka and up to 1,000 m at Nadala/Navai on sandy loam and humic latosols. The mean annual temperatures range from 18°C to 20°C in these areas which all experience a dry period of 4 months per year of which 1 month is very dry. These conditions are not ideal for potato production and the situation has been aggravated by all the past production being rain-fed with no provision for irrigation during the dry periods.

### Socioeconomic Constraints

#### Attitude of the farmers

One problem has been that farmers do not regard potato production as a business. Some tend to carry on as an extension of their normal subsistence cropping. Despite recommendations from the Department of Agriculture, farmers have resisted using fertilizers or dusting of cut seed with fungicides, the result being lower

yields. Similarly, little use has been made of chemical sprays to control leaf diseases and insect pests.

## Seed potatoes

Fresh seed has been imported each season from Australia as seed potatoes could not be stored from one season to the next. High ambient temperatures and the long storage period from September/October until April/May resulted in large in-store losses. Shriveled seed tubers with long sprouts resulted in poor growth in the field. Imported seed often arrived late, disrupting the programmed early plantings and was expensive to purchase. Trials had shown that cool storage at 4.4° to 7.2°C was essential if a local seed potato industry was to be developed (Thompson, 1969). However, this would make the seed prohibitively expensive for the farmer.

## Marketing

Organized marketing would be essential if potatoes were to be grown on a large scale. In some years difficulties were experienced in marketing due to damage from hurricanes, growers not holding potatoes for a fortnight after digging to remove those rotting as a result of bacterial wilt and to allow skins to harden, growers selling direct to middlemen at lower prices, lack of proper storage facilities, and the presence of substantial quantities of better quality imported potatoes. Since no cool storage facilities were available, local produce has had to be marketed quickly and efficiently particularly under unfavorable harvesting conditions, such as wet weather.

At times, there was considerable consumer resistance with regard to quality and price of Fiji-produce compared with the imported potatoes.

## Credit

High input costs, especially seed, cause problems mainly for the small farmers necessitating the concentration on growers with their own initial capital and the provision of credit through lending agencies.

## Conclusions

The future for potato production in Fiji appears bright especially with the prospect of a bacterial wilt resistant variety. Other constraints could be overcome or at least minimized through proper planning and an extensive education program involving extension agents, farmers, retail stores handling seed and the marketing organizations.

Due to a readily available secure market, reasonable gross margins, and farmers being interested in growing the crop, it would be easier to implement a new planting program and at the same time bring about changes in farmer attitude and behavior. Until the new variety becomes available in sufficient quantities, there will be a need to improve crop rotation, thus enabling the growing of Sequoia and Sebago. Mulching with sugarcane bagasse, rice straw, grass or reeds to lower soil temperatures and irrigation during the dry periods could improve yields.

Credit could be handled on similar lines as in the past while organized marketing with legislation restricting imports at the time of harvest of local

potatoes and farmers cooperating with the marketing organizations would ensure efficient disposal.

The total seed requirement for the country could be fully imported. However, the recent promising results with low-cost potato stores at ambient temperatures at locations in both the lowlands and the highlands indicate a possibility of local seed potato production especially in the highlands. This coupled with the prospect of more than one planting would mean shorter storage periods and, hence, lower storage losses, enabling good quality seed potato being available whenever needed for planting. The prospect of true potato seed being readily available in the future would provide great impetus to the potato production program and opportunities for unlimited expansion.

Acknowledgement

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Improving Adaptation of the Potato (Solanum spp.) to Hot Climates - Some Physiological Considerations

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ABSTRACT

A set of characters based on physiological manipulations of the potato crop under field conditions, with potential for improving the adaptation of the potato to hot tropical conditions, is presented. Quick emergence, rapid branching, and large leaf size leading to fast self-shading crop cover of the soil are required if short-season, relatively early tuber initiating and fast bulking clones are desired. Maintenance of canopy effectiveness during tuber bulking by increased leaf longevity, greater leaf reflectivity, and lack of lodging are further requirements that, in addition to less heat stress of photosynthesis and reduced foliage and tuber respiration, could lead to yield improvements. Incorporation of tolerance to aluminum is also desirable.

## Introduction

The inability of the potato to tuberize under high temperature has often been cited as the major barrier to its successful production under hot climates (Levy, 1978). Recurrent selection has been largely successful within potato populations at the International Potato Center (Mendoza, 1980) and elsewhere (Levy, 1979) for the ability to tuberize and yield well under hot field conditions; heat-tolerant clones and populations combining both attributes under high temperatures have been developed. Selection frequency was increased from 0.06% to 15% over five cycles of selection, and further work is in progress (Mendoza, 1980). With this level of success, attention can now be turned to the incorporation of certain morpho-physiological characters that, as indicated by agronomic and physiological studies, could better improve adaptation of the potato to hot conditions. A seedling screening technique recently developed (Sattelmacher, 1983) can simplify the efficient screening for tuberization response within large populations while incorporating other important adaptive features.

Tuber yield, particularly under hot conditions, may be limited by a series of morphological, developmental, and physiological functions, independently or in various combinations. Apparent causal relationships between some characters and yield are herein indicated; others, however (e.g., instantaneous photosynthetic rates and yield, Dwelle et al, 1981) although not distinct, merit further attention if yield potential is to be improved.

In this paper, two considerations are presented: First, the benefits of morphological and developmental manipulations, i.e. hastening emergence and early branching, balancing the timing of tuber initiation with the potential for tuber

bulking, and maintenance of complete crop cover over the soil. Second, the benefits of physiological criteria related to heat stress on photosynthesis and respiration, and, inasmuch as more than 30% of soils in the tropics present problems with aluminum toxicity, the incorporation of tolerance to aluminum.

## Morphological and developmental considerations

### Emergence and branching

Quick emergence and rapid crop cover over the soil surface are essential, especially if the crop is to maximize interception of incident radiation, and concommitantly to reduce its soil heating effect. The cooling effect of self-shading on soil temperature can be marked; weighted daytime mean temperatures of 35.5°C for bare soil and 26.0°C under cover of a complete crop have been recorded at 5 cm depth (Midmore, unpublished). Self-shading effects on conservation of soil moisture may also be notable, however, the loss of moisture from an exposed soil surface depends largely on the frequency of rewetting (Milthorpe and Moorby, 1979).

The potato emerges most rapidly when mean soil temperatures at tuber depth are in the range of 22° to 25°C (Sale, 1979; Midmore, 1983); higher temperatures significantly reduce emergence. Genetic differences between north temperate clones and CIP clones, the latter selected for hot climates, have been reported (Midmore, 1983); those with heat-tolerance were the only clones that emerged at the high temperature extreme (30°C), and were quicker to emerge than other clones at soil temperatures closer to the optimum. Hastening emergence from 3 to 5 days as a result of soil cooling during the 35-day period after planting (Midmore, 1983) was accompanied by yield increases of 14% and 28% for two clones. Besides the genetic component, manipulation of age and storage of seed tubers under hot conditions in particular, can be conditioned to hasten emergence and crop cover (Bean and Allen, 1981) with accompanying increase in tuber yield (Table 1). The search for genetic differences between clones for the rate of emergence could be confounded with differences in length of dormancy and physiological age, as is manifested by sprout growth at the time of planting. Proceedures should be sought to reduce this effect.

Table 1. Emergence and tuber yield as influenced by seed tuber storage conditions.

| Storage conditions (107 days) | Emergence (days to 50%) | | Yield (g/plant) | |
|---|---|---|---|---|
| | N565.1 | DTO-33 | N565.1 | DTO-33 |
| Diffused light | 21 | 17 | 314 | 469 |
| Dark | 15 | 15 | 458 | 31 |

High temperature, apart from its effect on the rate of emergence, has also been noted to reduce the number of emerging main stems (Sattelmacher, 1981), a character that may deserve further attention in a breeding program. Selection for more stems per unit of planting material could be one character favoring a quicker canopy cover of the soil.

Since presprouted tubers may have up to 25 of their total 35 leaves differentiated at the time of planting (Borah and Milthorpe, 1962), the rate of leaf production plays a minor role in achieving a complete canopy cover of the soil in comparison so that of axillary branching.

Improvement in the rate of increase of the canopy cover has been studied by pricking out growing points, releasing apical dominance, and stimulating axillary branching. Self-shading of the soil surface was enhanced; reducing soil temperature and effecting more efficient use of incoming radiation. Mean weighted daytime soil temperatures (5 cm depth) 48 days after planting were 26.9°C for stimulated branching vs 30.7°C for the control, and light interception was 55% and 28%, respectively. Stimulated branching improved yield (Table 2) but not for clones with known rapid branching (e.g. DTO 2). In contrast to previous reports (Hammes and Nel, 1973; Menzel, 1981), our experiments in pricking out of growing points did not promote tuber initiation; therefore, yield improvement was probably due to direct effects upon canopy growth and efficiency of its light interception.

Table 2. Tuber yield on four potato clones as effected by pricking out of growing points 30 days after planting.

| 1981 Clone | Treatment | Yield (g/plant) | 1982 Clone | Treatment | Yield (g/plant) |
|---|---|---|---|---|---|
| DTO 2 | Control | 637 | Desiree | Control | 708 |
| | Prick | 466 | | Prick | 746 |
| LT 4 | Control | 300 | Rosita | Control | 515 |
| | Prick | 498 | | Prick | 612 |

The selection for an early canopy-type with large, horizontally displayed leaves, although not corroborated experimentally, should theoretically (Loomis and Rapaport, 1976) assist in achieving a quick crop cover. Circumstancial evidence of the benefit of this character is derived from observations that a Tuberosum-type canopy (fewer and shorter internodes, larger leaves) under high temperature is often associated with heat tolerance. An Andigena-type canopy (long stems, many internodes and small leaves), however, is associated with non-tolerance (Mendoza and Estrada, 1979; Ewing, 1981).

Tuber initiation and bulking period

The dominance of shoot growth early in the crop cycle should later allow a greater allocation of photosynthate to the growing tubers. The photoperiod control of tuber initiation and tuber growth is well documented (Mendoza, 1974; Ewing, 1981) and is strongly stimulated by tropical short days. In the adaptation of potato to hot climates, selection for early tuber initiation and a fast bulking rate has been emphasized, along with selection for high general combining ability (Mendoza, 1980). There is ample opportunity to select for the timing of tuber initiation (Sattelmacher, 1983) as a function of the large amount of genetic variability existing for this trait (Mendoza, 1974). Data exist (Calua and Mendoza, 1982) that indicate that variation in timing of tuber initiation exists within a given maturity class, thus permitting exploitation of a range of initiation and bulking durations to suit local requirements.

Fast emergence and quick crop cover (Figure 1) favored early tuber initiation but at a higher leaf area index (LAI) than that of the slower, later-emerging and initiating treatments. Tuber yields of the former were also greater (Figure 1). Early tuber initiation, but not in combination with a quick foliage growth and crop cover of the soil, can lead to intense competition between developing tubers and foliage (Loomis and Rapaport, 1976). Strong induction to tuberize and a strong sink effect of tubers appear to be related. In some instances, reallocation of assimilates from the haulm to growing tubers compensates for the inability of a small canopy to provide sufficient assimilate (Moorby and Milthorpe, 1975; Midmore and Espinola, 1983). Delay to tuber initiation by planting physiologically younger tubers (Bean and Allen, 1980), by adding extra nitrogen at planting (Simpson, 1962), or by long-day photoperiod treatment (Midmore and Espinola, 1983), enhances canopy size at tuber initiation. The leaf area duration (LAD -- the integral of LAI over time) during the bulking period was markedly increased, as, too, were tuber yields. Excessive delay of tuber initiation, however, may reduce tuber yield since neither extreme self-shading leading to competition for light within the canopy nor the reduced duration available for bulking favor maximum tuber yields.

## Maintenance of complete crop canopy

Canopy growth may cease completely after tuber initiation (Moorby and Milthorpe, 1975), although our experience has not indicated such an immediate decline in shoot growth under hot conditions (Figure 1). At least three points appear important when considering canopy characters subsequent to tuber initiation: leaf longevity, leaf reflectivity, and the prevention of lodging.

The potential for new leaf production is reduced as competition for assimilates between growing tubers and leaf surface are effected. The earlier the competitive effect the quicker leaves senesce (Milthorpe, 1963). Extension of leaf longevity is more important for clones with early tuber initiation, especially if LAD during the bulking period and tuber bulking rates are to be optimized. High temperature, in general, hastens leaf senescence (Borah and Milthorpe, 1962), and variation for this character could be sought with selection being made for improved leaf longevity on the basis of leaf-tagging experiments.

Increased leaf (canopy) reflectivity improved economy of water use, an important factor for potato production under both irrigated and rainfed conditions in the hot tropics, even though it did not directly improve canopy persistance or yield (Table 3). Lower leaf temperatures due to greater reflectivity may indirectly extend leaf longevity and delay senescence. Selection for greater leaf pubescence, an important component of increased reflectivity (Ehleringer and Bjorkman, 1978) and important per se in reduction of transpiration (Waggoner, 1966), should be simple since much variation for this character exists within the Solanum genus (Bukasov and Laknovich, 1971).

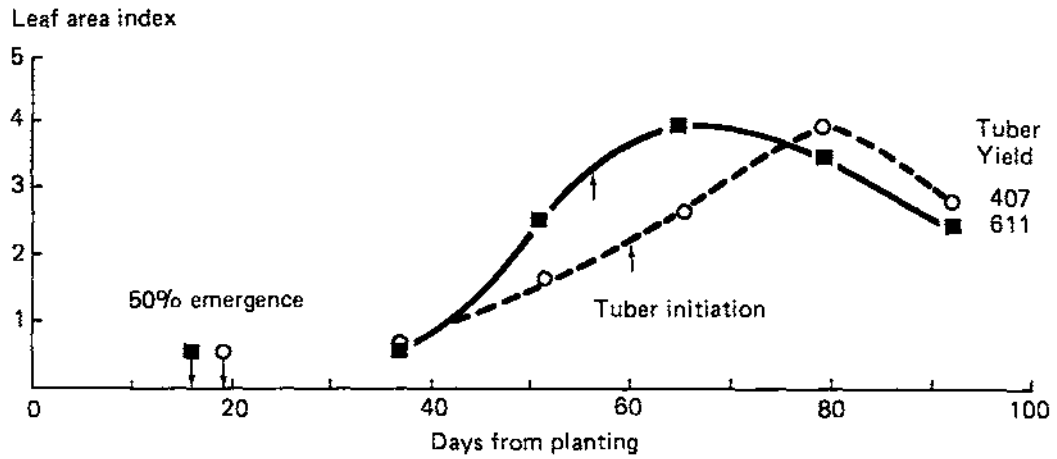


Figure 1. Emergence, tuber initiation, leaf area index and tuber yield (g/plant) as influenced by soil temperature (O warm, cooler), adapted from Midmore (1983).

Table 3. Effect of leaf reflectant (50 g lime in 1 litre water, plus surfactant) on various physical and biological attributes of potato plants.

| Treatment | % Reflected radiation[1] | Leaf temperature[2] | Soil water[3] | LAD[4] | Yield[5] |
|---|---|---|---|---|---|
| Control | 25.8 | 28.3 | 11.8 | 127 | 11.74 |
| Leaf reflectant | 33.4 | 28.9 | 20.7 | 130 | 11.95 |
| t[6] | * | * | * | ns | ns |

[1]Measured at midday with a Licor pyranometer.
[2]Exposed leaf, daily mean.
[3]Gravimetric, morning of irrigation.
[4]Leaf area duration of crop, mean 2 clones.
[5]t/ha, mean 2 clones.
[6]t values. *$P \leq 0.05$, ns not significant.

Lodging of the canopy should be prevented near the end of the season; this presents dual benefits for the potato crop grown in hot climates. Thus efficient interception of solar radiation is maintained, which in turn favors self-shading and therefore cooling of the soil. Once the canopy has lodged, interception is incomplete and soil heating occurs (Midmore, 1983) leading to loss of yield potential and increased respiratory losses by maturing tubers. Selection for sturdy mainstems and, more particularly, branches, could be effected with consequent yield improvement.

## Physiological considerations

### Photosynthesis

Variation in, an optimum temperature for, gross photosynthesis has been recognized between potato clones (Dwelle et al., 1981), with the high temperature decline attributed to direct temperature inhibition of photosynthesis rather than to effects on stomatal conductance. Selections for heat tolerance in the field did not have higher photosynthetic rates under heat stressed conditions (Wivutvongvana, 1979). Efforts, however, to identify relative heat tolerance within the potato at the chloroplast thylakoid and cellular membrane levels have been reported using chlorophyll fluorescence (Hetherington et al, 1983) and electrolyte leakage (Palta et al, 1981) techniques. Both methods served to confirm known tolerances of genotypes to heat in the field (i.e. the ability to tuberize and yield under hot conditions). S. phureja was identified as the major source of heat tolerance in cultivated species by the chlorophyll flourescence method and S. chacoense and S. acaule as potential sources of heat tolerance in additional studies (Smillie et al, 1983). The importance of aclimating some genotypes before making comparisons of their heat tolerances has been indicated (Palta et al). Once aclimated, heat tolerance of S. acaule was improved, although it was still considered as having a low degree of heat tolerance on the basis of electrolyte leakage. In contrast, S. comersonii after aclimation was markedly heat-tolerant as indicated by both the triphenyl tetrazolium chloride reduction and conductivity tests (Palta et al, 1981).

Heat tolerance among potato species in both studies was generally consistent with their ecological distributions. Selection of species for their transfer of that character on the basis of ecological distribution alone would not, however, consistently lead to improvements in heat tolerance. More important, as yet undetermined factors influence the variation in heat tolerance between accessions within species.

### Haulm and tuber respiration

Since dark respiration is more heat-resistant than photosynthesis (Berry and Bjorkman, 1980) (i.e. it continues to increase at higher temperatures than does photosynthesis), selection for lower dark respiration rates, as effected by Wilson (1975) in ryegrass, should at increasingly higher temperature lead to proportionally smaller losses in net photosynthesis. Burton (1966) suggested that above 35°C, net photosynthesis in the potato is reduced to zero, and that under normal, hot tropical conditions, 50% of gross production may be lost through respiration (Burton, 1979). Unconscious selection for less foliage respiration at high temperatures has been effected within clones selected for their performance under hot conditions (AVRDS, 1979; Wivuntvongvana, 1979). Selection for reduced dark respiration of potato seedlings (Sattelmacher, unpublished) has been studied and complete evaluation is in progress.

As the growing season progresses, respiratory losses by tubers increase, particularly when soil temperatures rise as a result of lodging and exposure of the soil surface to incident radiation. The extent of the correlation between respiration rates of haulms and tubers is as yet unknown; however, economies of the latter could markedly improve yield under hot conditions. With the onset of tuber enlargement and later maturity, the maintenance component of respiration (the component generally more responsive to selection) (Wilson, 1975) increases in

importance. Scope for reduction of the maintenance component of tuber respiration during this important phase is to be studied.

Aluminum tolerance

Haematoxylin staining of young potato seedling roots bathed in nutritive solutions with added Al was linearly related to the susceptibility to acid soils of second generation tubers of the same genotypes. Seedlings may be screened and selected before their transfer to a potting medium and subsequent selection for further characters.

Adaptation of potato to hot climates is a multifaceted task, and herein only the morphophysiological contributions have been discussed. Certain approaches have been suggested that could enhance the adaptation of potato to hot climates and therefore merit further attention. Simultaneous inclusion of all components will not be necessary to achieve yield improvement; step-by-step incorporation and maintenance of the ability to survive, tuberize, and provide acceptable yields under harsh environments should suffice.

Resistance to pests and disease is in process of being incorporated into environmentally adapted genotypes.

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# Physiological Aspects of the Adaptation of the Potato to the Hot Humid Tropics

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## ABSTRACT

Clones from the same seedling family were selected for early --and late--tuberization under high temperature conditions. In field experiments at two lowland tropical sites in Peru, the later tuberizing clones outyielded the early tuberizing ones. This was correlated with early senescence of the early tuberizing clones. High temperatures significantly reduced root growth. A causal correlation between the high temperature effect on root growth and the early senescence of the early tuberizing clones is discussed.

## Introduction

The main potato growing areas are concentrated in regions with moderate to cold climates. High temperature represents one of the major physiological constraints for extension of potato production into lowland tropical areas. At temperatures encountered there, tuber yield is depressed severely (Marinus and Bodlaender, 1975). Yield is a product of length of the filling period and bulking rate. Filling period is determined by the onset of tuberization and senescence. At high temperatures tuberization is delayed and earlier senescence of the shoot is also common. Consequently the length of the filling period may be severely shortened. There is evidence that in potato the root system is involved in the control of tuberization (Tizio and Biain, 1973) as well as in the control of senescence (Iwana et al., 1981). At high temperatures the size of the root system is decreased and anatomical abnormalities occur (Krauss, 1980), suggesting a causal correlation between temperature effect on root growth, tuberization and shoot senescence. It is well established from studies with other plant species that activity of cytokinins (synthesized in root tips and involved in control of shoot senescence) decreases at high root temperatures and that shoot application of Kinetin increases heat tolerance (Itai et al, 1978). It was the objective of this work to provide further evidence for the involvement of roots in the heat tolerance of potato.

## Material and Methods

### Screening procedure

Segregated seedling families were selected in a glasshouse for onset of tuberization. In the glasshouse a minimum night temperature of 22°C and a maximum day temperature of 38°C were maintained. (For further details of the screening procedure see Sattelmacher, 1982).

## Field experiments

Evaluation of selected material was in San Ramon and in Yurimaguas. San Ramon is in the foothills of the Peruvian Andes, 800 m.a.s.l. Mean temperature during the experimental period was 24°C. Yurimaguas is in the Peruvian Amazon Basin, 180 m.a.s.l. Mean temperature during the experiment was 27°C (for further experimental details see Sattelmacher, 1982).

## Root experiments

Rooted stem cuttings of different potato cultivars were grown under controlled environmental conditions in water culture (for composition of nutrient solution see Sattelmacher and Marschner, 1978). For the temperature treatment nutrient solution in one set of plants (n = 3) was maintained at 30°C while the control plants were kept at 20°C. Air temperature was 20°C day and 15°C night in both treatments. For determinations of root tip number, roots were stained with neutral red (0,1%), spread on a polyethylene sheet from which a photographic contact print was taken. From this contact print root tips can easily be counted. Root surface area was determined according to Sattelmacher et al, 1982.

## Results and Discussion

A wide range of genetic variation exists in ability of potato clones to tuberize early under high temperature conditions (Figure 1). Selecting for early tuberization appeared therefore possible. However evaluation of clones selected out of the same seedling family for time of tuberization at high temperature conditions revealed that early tuberizing clones were outyielded in Yurimaguas by later tuberizing ones (Figure 2). This was possibly due to the small leaf area at the onset of tuberization (Ivins and Bremner, 1964) and to earlier senescence of the shoot (Figure 3). In the potato the onset of senescence appears to be closely correlated with root growth (Iwana et al, 1981) and earlier tuberizing clones show a smaller root system than later tuberizing clones (Swiezynsky et al, 1978). This seems to be due to the dominance of the growing tuber in competition for carbohydrates.

Root growth is also highly affected by high root zone temperatures (Krauss, 1980). Although root surface area and number of root tips are reduced at 30°C, considerable genetic variation does exist (Table 1).

Table 1. Effect of high root temperature on root surface area and number of root tips in different potato clones.

| | Root surface area ($cm^2$) | | Number of root tips | |
|---|---|---|---|---|
| Clone | 20°C | 30°C | 20°C | 30°C |
| DTO-2 | 2,450 | 2,136 | 10,000 | 7,000 |
| DTO-33 | 1,391 | 502 | 4,000 | 2,300 |
| LT-1 | 2,360 | 400 | 7,000 | 4,000 |
| LT-2 | 4,335 | 2,765 | 25,000 | 14,000 |
| Mariva | 3,200 | 377 | 9,000 | 3,500 |

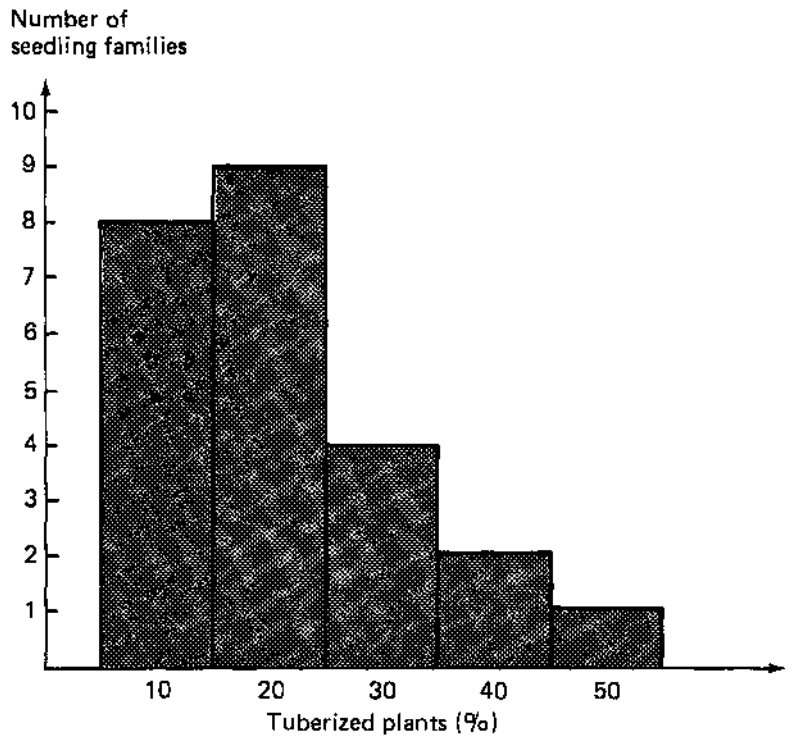


Figure 1. Percent of tuberized plants in 24 seedling families 7 weeks after sowing. Plants were grown in a glasshouse at minimum night temperature of 22°C and maximum day temperature of 38°C respectively. Each seedling family contained a minimum of 60 plants.

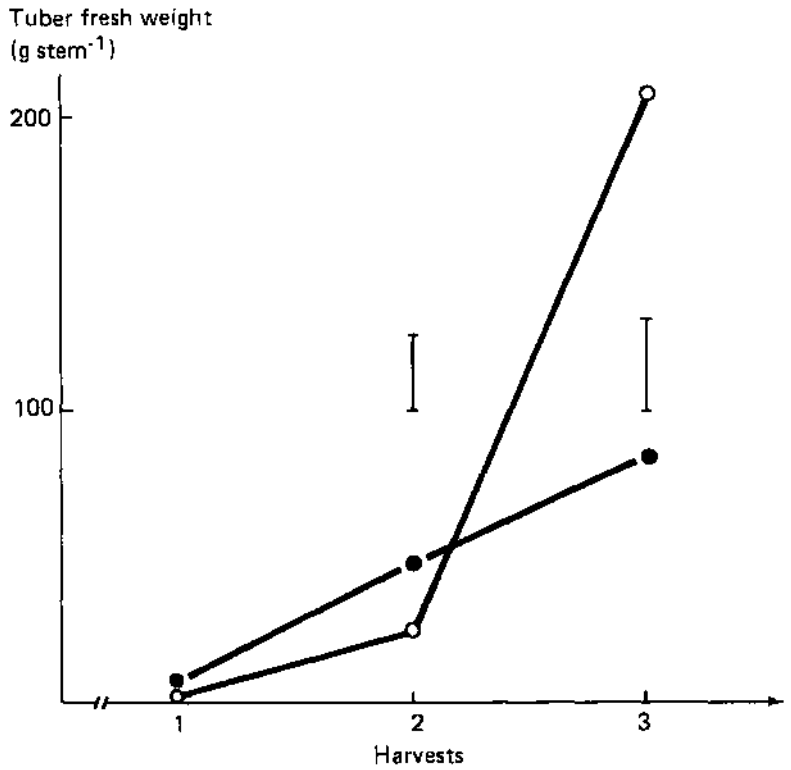


Figure 2. Tuber fresh weight of progenies of seedlings selected for onset of tuberization at high temperatures (●——● early tuberizing, ○——○ late tuberizing clones) grown in the field in Yurimaguas.

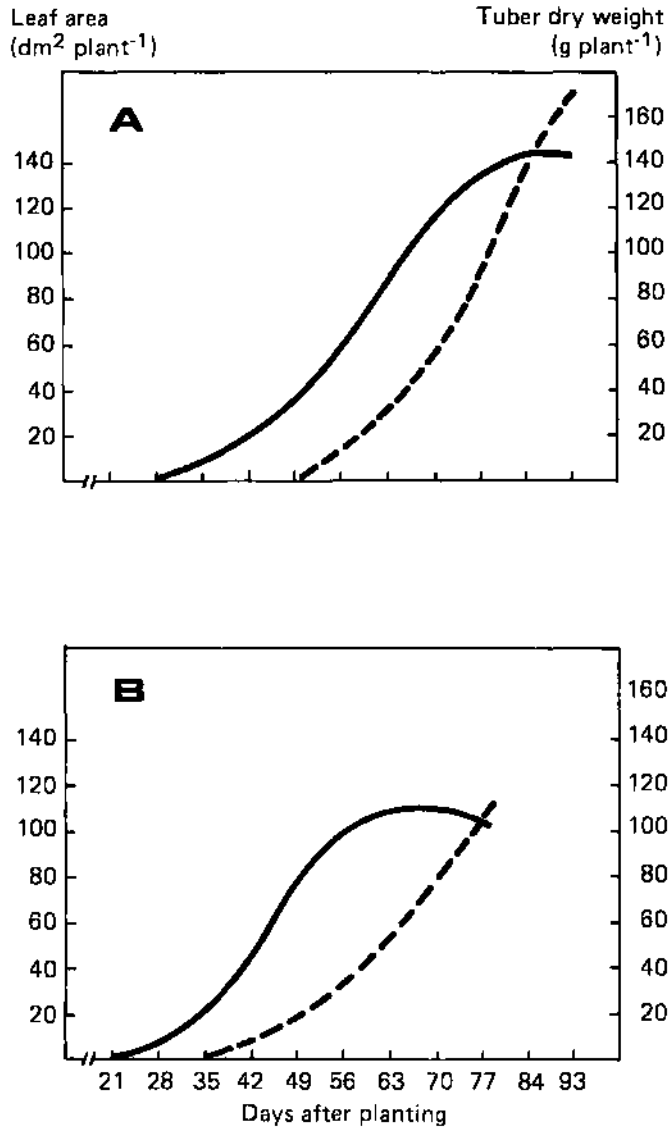


Figure 3. Leaf area development and tuber dry weight increment of an early (A) and a late (B) tuberizing clone. Graphs were drawn from computer fitted data.

Both high temperatures and early tuberization have adverse effects on root growth. The combination of both factors probably lead to particularly poor root development. This could be one factor responsible for observed earlier senescence (Figure 3). It is suggested that root growth must be a major point of attention in any approach to adapt the potato to high temperatures, especially in areas where temporary drought and adverse soil conditions, like low fertility, are common.

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## Seed Tuber Potato Production in Argentina

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ABSTRACT

Problems affecting good quality seed tuber production in Argentina are discussed. Special attention is focused on diseases and weather conditions in regions where production takes place. Suggestions are offered for improvement.

Research work is carried out in production areas to improve the crop. In the southeast area of the Buenos Aires province, which is the most important, studies are done on seed behavior according to different planting dates and storage systems. National and imported cultivars are used for seed production, and applied to other areas at a later date.

## Potato Performance in Soil Families of the Benchmark Soils Project

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ABSTRACT

Potato experiments were conducted in three agroenvironments as part of a program to determine crop production potential and land capabilities of a network of tropical soil families. Good tuber yields resulted from matching requirements of the potato crop to land characteristics. Average yield was 32,000 kg/ha in the thixotropic, isothermic soil family of Hydric Dystrandepts in Hawaii. Results indicate that year-round potato production is possible in Hydric Dystrandepts under rainfed conditions.

Yields of irrigated plots in the clayey, kaolinitic, isohyperthermic soil family of Tropeptic Eutrustox were 36,000 kg/ha in the winter and 25,000 kg/ha in the summer. Results indicate that winter temperatures are nearly isothermic, and are thus suitable for potato production, in an isohyperthermic Tropeptic Eutrustox of Hawaii. No yields were obtained from plantings in the clayey, kaolinitic, isohyperthermic soil family of Typic Paleudults in Indonesia and the Philippines. The warm and moist environment of the Typic Paleudults was not conducive for tuberization. Vegetative performance was also poor.

# Estimation of Outcrossing Rates in Andigena Cultivars: Implications in Breeding TPS Cultivars

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## ABSTRACT

Studies were carried out to determine the outcrossing rate of four Andean potato cultivars, Solanum tuberosum ssp. andigena. An anthocyanin spot on the embryo (seed-spot) was used as a morphological marker. Clearly distinguishable markers which can be scored early in the life cycle of seedling progenies are most suitable for outcrossing studies. The use of seed spot represents a tremendous savings in time and resources needed to determine the outcrossing rate.

Single inflorescences of the test varieties were place in an apiary paired with the seed spot donors. The estimates therefore, represent outcrossing between inflorescences. The lowest rates observed were 5% and the highest 100%.

The effects of mixed selfing and random-mating on heterozygosity in autotetraploid populations will be discussed.

## Introduction

In the Andean Cordillera, the place of origin of the cultivated potato, cultivars exist in a polyploid series ranging from diploid (2n = 24) to pentaploid (2n = 60). Cultivated diploids are hemaphroditic and self-incompatible, while tetraploids, Andigena, (2n = 48) are self-compatible. Although different forms of gynodioecy are especially frequent in long-day adapted Tuberosum cultivars, that evolved from Andigena originally, Andigena cultivars are mostly male and female fertile.

There is abundant observation that bumblebees are the predominant agents of pollination (Glendinning, 1976). Berry set is rare without some kind of manipulation if plants are protected from bumblebees, such as in a greenhouse situation (Plaisted, 1980).

The floral morphology suggests that the proportion of fertilizations arising from selfing could be high due to the close juxtaposition of dehisced anther pores and receptive stigma in the flower.

The purpose of this paper is to present estimates of outcrossing rates of several Andigena cultivars obtained by use of a seedspot genetic marker. The importance of outcrossing rate will be discussed in terms of the effects on inbreeding levels in autotetraploid populations. Application of this relationship

to an alternative scheme for breeding potato populations for utilization as true seed cultivars will be explored.

## Materials and Methods

Genetic Stocks: Two cultivars of *Solanum tuberosum* ssp. *andigena* possessing "seedspot" phenotype, i.e. anthocyanin pigmentation visible on the hypocotyl region of the embryo, were selected as a "donors" of the genetic marker. Three Andigena cultivars whose true seed was free of this marker were selected as "recipients."

Experimental set-up: Inflorescences were cut from field grown plants when one to three flowers had anthesed. Recipient inflorescences were paired with donor inflorescenses and placed in milk bottles. The milk bottles were placed at a distance of five meters apart in an apiary of honeybees *Apis mellifera* L. at 3,300 m elevation in the Mantaro Valley of the Departament of Junin in Peru. The distance between the recipient and donor inflorescences in each bottle was approximately 5 cm.

Scoring: The presence or absence of seedspot was scored by observing at 10x magnification with flourescent light transmitted from below, through the translucent seed coat. Before scoring a careful screening of seed was carried out to insure that only seeds with fully developed embryos were scored. This prevented overestimation of the proportion of spotless individuals through scoring of apparently normal seeds, lacking embryos, as spotless phenotype. Deformed and opaque, usually dark brown, seed coats were naturally not considered for scoring.

Controlled pollinations, including all combinations of donor and recipients and self-pollination of recipients, were made to provide estimates of the proportion of the progeny expected to show seedspot upon 100% outcrossing. All pistillate parents were emasculated first and pollinated in an insect-free screenhouse to prevent accidental selfing or outcrossing to unknown genotypes.

The percent outcrossing, t, was calculated by:

$$\%t = \frac{D_i}{P_i} \times 100$$

where $D_i$ is the proportion of individuals with seedspot phenotype in the progenies of recipient i from the outcrossing experiment and $P_i$ is the proportion of individuals with seedspot in the progenies of recipient i from the controlled crosses. This is a modification of the dominant-recessive technique upon which Jain (1979) commented. The donors are not homozygous dominant as will be reported below. Thus, $P_i$ represents the phenotypic proportions expected with full outcrossing. The estimates of standard deviation were calculated as indicated by Jain (1979).

## Results: Controlled Crosses

The proportions of progenies from controlled crosses with seedspot is shown in Table 1. The progenies of crosses between unpigmented recipients and pigmented donors showed seedspot in differing proportions. Donor clone OCH 6579 when crossed with OCH 7525 produced progenies with 46.2% seedspot. When crossed with 702316 and CUP 183 the progenies showed 41.2 and 41.4%, respectively. The donor clone 702156 showed a much lower proportion of expression than OCH 6579, producing

32.5, and 26.2% embryos with seedspot when crossed with OCH 7525 and 702316, respectively. In addition, the utility of OCH 6579 as a marker clone is greater because the spotted phenotype is much more clearly defined with a darker, larger spot. The cultivar 702156 produces a less distinct, fainter purple spot which is difficult to score. The percent seedspot shown in Table 1 was converted to a proportion by dividing by 100. The resulting $P_i$ values were used to calculate outcrossing rates for each combination of donor and recipient.

## Results: Outcrossing Estimates

Pollinators: Although the inflorescences were placed in a honeybee apiary, effective extraction of pollen or transfer of pollen to the stigma of flowers by honeybees, was never observed. This agrees with the observations of Sanford and Hanneman (1981) that honeybees appear to be totally unadapted for pollination of flowers of cultivated potato. Occasionally worker bees would land on flowers but did not demonstrate any organized pollination activity. An unidentified "bumblebee" did enter the apiary and worked the flowers as is typically seen in potato fields of male fertile cultivars in the area. The area immediately surrounding the apiary was planted for table stock with two different male sterile Peruvian Tuberosum-Andigena hybrid cultivars (cv. Revolucion and cv. Mariva).

Table 1. Percent seedspot in progenies of controlled crosses between donors and recipients.

| | % Seedspot | N |
|---|---|---|
| OCH 7525 x | 0 | 100 |
| OCH 7525 x OCH 6579 | 46.2 | 186 |
| OCH 7525 x 702156 | 32.5 | 166 |
| 702316 x | 0 | 100 |
| 702316 x OCH 6579 | 41.2 | 223 |
| 702316 x 702156 | 26.2 | 221 |
| CUP 183 x | 0 | 100 |
| CUP 183 x OCH 6579 | 41.4 | 244 |

The estimates range from 13.2 to 44.9% (see Table 2). There is some difference between the two donors but the estimates for recipient 702316 are very close.

## Discussion

The question of whether cultivated tetraploid potato is a predominantly self-pollinated crop is essentially a point requiring quantitative answers. Glendinning (1976) reported estimates ranging from 14 to 30% with a mean of 20% in Neo-tuberosum. Peloquin reported a range of from 10 to 40% in breeding clones of cultivated potato (CIP, 1980). In tetraploid and hexaploid wild species, Camadro and Peloquin (1982) reported maximum estimates of 50 and 65% outcrossing, respectively.

Table 2. Estimates of outcrossing rates in Andigena cultivars.

| | Outcrossing Rate $\hat{\%t}$ | ± | $\hat{\sigma}_{\hat{\%t}}$ | N |
|---|---|---|---|---|
| OCH 7525 x 702156 | 27.3 | ± | 7.6 | 304 |
| OCH 7525 x OCH 6579 | 44.9 | ± | 3.9 | 751 |
| 702316 x 702156 | 13.2 | ± | 9.9 | 145 |
| 702316 x OCH 6579 | 15.2 | ± | 4.4 | 272 |
| CUP 183 x OCH 6579 | 41.0 | ± | 7.4 | 259 |

The outcrossing estimates presented here range from 13 to 45%. Taking an average value of 36% for cultivar OCH 7525, of 14% for 702316 and the single estimate of 41% for cultivar CUP 183, the average over three clones is 31%. This lies within the range of all three above mentioned reports. Based on the very small sample, these estimates should only be regarded as preliminary.

Considering the present estimates and those available from the cited literature, it is not strictly correct to call the cultivated potato a selfing species in regards to its sexually reproductive phase. The effect of a mixture of selfing and random-mating in hemaphroditic plant species is a reduction of heterozygocity below that which would exist in a random mating population assuming no selective advantage of heterozygotes. However, as long as some random-mating occurs, the population will not become completely homozygous. Wrights inbreeding coefficient, F, the probability that two alleles taken at random are identical by descent, is a useful parameter for comparing the equilibrium levels of inbreeding with different rates of outcrossing. Bennet (1968) derived an equation for the coefficient of inbreeding at equilibrium for partial selfing, $F_\infty = (S + 2\alpha)/4 - 3S + 2\alpha$, for autotetraploid species where $\alpha$ is the coefficient of double reduction and S is the probability of selfing. Assuming $\alpha = 0$ the result is $F_\infty = S/4-3S$. In Table 3 the values of the inbreeding coefficient at equilibrium are shown for a range of outcrossing percentage, $\%t = 100 \times (1-S)$. If 30% is taken as a benchmark value for potato, it can be seen that $F_\infty$ is .368. This is certainly less inbreeding than would be expected from full selfing, and in fact, on a population basis this value would allow for considerable heterozygosity and thereby genetic variability. The progenies of certain crosses of present day North American cultivars would have coefficients of inbreeding close to this value: Cobbler x Earlaine, F = .344; and Triumph x La Soda, F = .313 (Mendoza and Haynes, 1974).

## Implications of Present Data for Breeding Potato for Cultivation from True Seed

Starting in the People's Republic of China 20 years ago and now under intensive study at the International Potato Center, the culture of potato as a crop established from seedlings derived from true seed is of great interest. While previously potato cultivars were single clones, already at this writing several true seed cultivars are available from private seed firms. The genetic impact of mating system now takes on increasingly significant role because the breeding of potato cultivars can be conducted by several new alternative routes.

There are essentially three approaches at first glance. First, seed lots obtained from open-pollinated berries may be used as cultivars. Regardless of

outcrossing rate seed balls obtained from large fields of a single clone are genetically selfed.

A partial polycross system might be imagined where cultivars consist of open-pollinated seed lots obtained from single clones where pollen from other clones would have been available. In this case, OP seed would consist of a mixture of progenies from selfing and outcrossing to various clones. The actual amount of inbreeding would be highly dependent on the actual arrangement of parental clones in the field and the outcrossing rate.

Table 3. Values of inbreeding coefficient at equilibrium, $F_\infty$, on autotetraploid population with mixed selfing and random mating (outcrossing), $0 \leq \% t \leq 100$, $0 \leq F_\infty \leq 1$.

| %t | $F_\infty$ |
|---|---|
| 0 | 1.000 |
| 1 | 0.96 |
| 5 | 0.83 |
| 10 | 0.69 |
| 20 | 0.50 |
| 30 | 0.37 |
| 40 | 0.27 |
| 50 | 0.20 |
| 60 | 0.14 |
| 70 | 0.10 |
| 80 | 0.06 |
| 90 | 0.03 |
| 95 | 0.01 |
| 100 | 0 |

Second, simple hybrids derived from controlled crossing of two clones or a simple bulk produced by crossing a single pistillate parent with a composite pollen from two or more staminate parents may be developed as cultivars. This approach could take advantage of pretested superior progenies and would maximize heterozygosity.

A third approach, that of a synthetic, would allow a small farmer to propagate TPS cultivars through true seed for a number of generations. A synthetic is a cultivar consisting of two or more parents comprising an $S_0$ generation which are randomly mated to form the $S_1$ generation. Subsequent generations are produced through natural pollination means. The population size is very small in the $S_0$ and virtually infinite in size in the $S_1$ and future generations. The quantity of true seed available is rapidly increased in the $S_2$ and $S_3$ generations and further, if necessary. Seed increase is inexpensive as hand pollination is not needed. The performance of the successive S generations may change. A specific generation may be used as a cultivar or all generations after which sufficient seed is available. For example, successive generations may be planted in successive crop years: crop year $1 \rightarrow S_1$, crop year $2 \rightarrow S_2$, crop year $3 \rightarrow S_3$. Busbice (1969) described the progress of inbreeding, expressed as Wright's inbreeding coefficient, F, in autotetraploid synthetic varieties where the mating system is mixed selfing and random mating.

The key initial variables are $F_o$, the average level of inbreeding in the initial parents, $r_o$, the average level of coancestry, and n, the number of parents. From these, $F_1$, and $r_1$, are calculated for the $S_1$ generation.

$$r_1 = \frac{1}{n} \frac{1 + 3 F_o}{4} + \frac{n - 1}{n} r_o$$

$$F_1 = \frac{1}{3} 2 r_o + F_o$$

A recurrence equation for $F_t$ in succeeding generations was derived

$$F_t = \frac{s}{6} \frac{2 (1 - s)}{3} r_1 \frac{1 - \frac{s}{2} + \frac{1}{3}^{t-1}}{1 - \frac{s}{2} + \frac{1}{3}} + \frac{s}{2} + \frac{1}{3}^{t-1} F_1$$

where s is the probability of selfing. From this relation the equilibrium inbreeding coefficient is:

$$F_\infty = r_1 + s(1 - r_1) \;/\; s + 4 (1 - s)$$

(Busbice, 1969).

Table 4 shows the relationship of outcrossing to the equilibrium value of F for synthetics originating from two, four, eight, and sixteen parental clones. The assumptions here are that the parental clones are not inbred ($F_o = 0$) and they are unrelated ($r_o = 0$). Outcrossing rates shown cover the range of 0 to 50% only.

For a given value of outcrossing, the inbreeding coefficients decrease as the number of parents increase. For a given number of parents, the inbreeding coefficient decreases with increasing outcrossing rate. An eightfold increase in the number of parents results in a 16% decrease in inbreeding coefficient at equilibrium for 30% outcrossing. But, a 20% percent decrease in the inbreeding coefficient at equilibrium is achieved for a synthetic originating from just two parents if the outcrossing is raised from 30 to 40%, an increase of one-third.

It is difficult to choose large numbers of parents with high general combining abilities. The reduction in inbreeding is not as dramatic with an increase in the number of parents as with an increase of outcrossing rate.

The nature of genetic variability in outcrossing rates remains as yet undefined. The goal of selecting for higher outcrossing appears possible based on the variability in estimates already reported in the literature and those presented here. Continued selection in a breeding program may be impractical owing to the difficulty of rapidly screening clonal lines for outcrossing rate. The seedspot marker could alleviate this problem, however.

The present discussion of inbreeding coefficient suggests that synthetics based on as few as two non-inbred, unrelated clones will accumulate relatively little inbreeding if the outcrossing rates are maintained between 30 and 40%. Therefore, it would seem that the objective of providing TPS cultivars which can be multiplied sexually for a number of generations without deleterious accumulation of inbreeding can be achieved in synthetics originating from as few as two parents as long as outcrossing rates are maintained higher than 30%. This value is well within the range of the heretofore reported estimates. More attention should be placed on outcrossing rate if it is contemplated that TPS cultivars will be multiplied by small farmers to provide an inexpensive continuous nondegenerating seed supply.

It is likely that certain agroecosystems would require that farmers be capable of producing their own true seed in successive seasons. Purchase of hybrid seed could increase costs too much. Only acceptable levels of inbreeding will accumulate if the outcrossing rates are sufficiently high. This may also provide a means of increasing quantities of seed available from simple hybrids (two parents) where seed quantity may be the main factor limiting commercial exploitation of superior progenies.

The increase in the inbreeding coefficient over successive cycles of multiplication with natural pollination is shown in Figure 1. Starting with a cross of two unrelated noninbred clones how much seed could be produced in two further cycles of multiplication? If the multiplication rate is 1,000 seeds/plant in the field, then 1,000 $S_1$ seeds would yield 100,000,000 seeds in the $S_3$. If an outcrossing rate of 30% had been maintained during these two cycles, the inbreeding coefficient would have reached 0.3. If we assume that 150,000 seeds/ha are required then enough seed would be available to plant 67,000 hectares. If we had started with 100,000 seeds we could plant 6,700,000 hectares with the $S_3$ seed. The decline in performance of TPS populations that is expected to occur with inbreeding will be less with higher outcrossing rates. Efforts to select for and maintain the highest possible outcrossing rate are therefore justified. At the present time the difficulty of producing sufficient quantities of TPS appears to be a serious obstacle to wider applications of this new technique for growing the potato crop.

Table 4. Coefficient of inbreeding at equilibrium in autotetraploid synthetic with differing numbers of noninbred, unrelated parental clones in relation to percent outcrossing (%t) during successive sexual multiplication.

| | Number of initial parental clones | | | |
|---|---|---|---|---|
| %t | 2 | 4 | 8 | 16 |
| 0 | 1.00 | 1.00 | 1.00 | 1.00 |
| 10 | .73 | .71 | .70 | .70 |
| 20 | .56 | .53 | .52 | .51 |
| 30 | .45 | .41 | .39 | .38 |
| 40 | .36 | .32 | .30 | .28 |
| 50 | .30 | .25 | .22 | .21 |

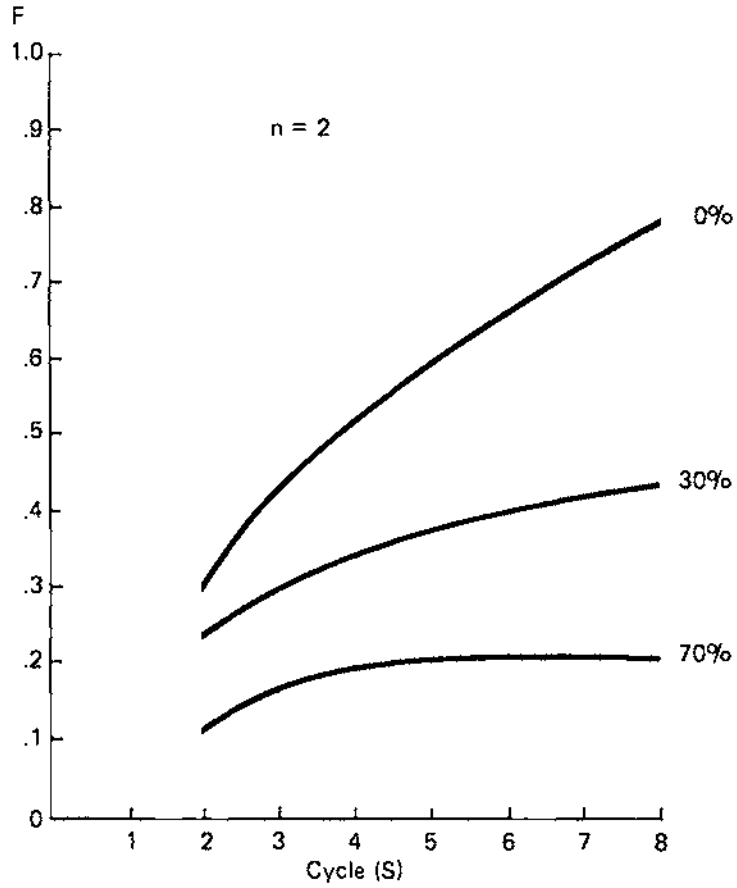


Figure 1. Inbreeding coefficient over cycles of multiplication for different outcrossing rates (%). The $S_0$ consists of two nonimbred, unrelated parents.

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Potato Breeding for Combined Resistance to Tropical Pests by the Ploidy Level Manipulation Approach: Progress in Extraction of Haploids with Male Fertility and 2n Pollen

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ABSTRACT

The present approach is aimed at combining multiple resistance to important pests of tropical zones working at the 2x level. This permits an efficient breeding work using disomic inheritance. Three steps are involved: (1) extraction of haploids from selected tetraploids; (2) population breeding at the 2x level for multiple resistance, agronomic characteristics, adaptation and 2n-pollen production in wide genetic backgrounds; and (3) transfer of the improved 2x germplasm into the 4x level via First Division Restitution (FDR) 2n-pollen.

The following progress has been attained for the first step. A large number of haploids were extracted from selected tetraploids by 4x - 2x crosses using the diploid Phureja clone 1vP 35 as a haploid inducer. More than 400 haploids coming from late blight-resistant tetraploids were evaluated for resistance in a greenhouse. Cytological finding of male fertility and 2n-pollen production in these haploids is encouraging, because the male fertility of the haploids is useful for crossing with other valuable diploids, and the 2n-pollen can be utilized to transfer the resistance of the haploids into 4x progeny through 4x - 2x crosses. Many PVX/PVY-resistant haploids were extracted from resistant tetraploids, and 45 haploids were selected for good agronomic characters. A total of 242 haploids obtained from cyst-nematode-resistant Andigena clones is being evaluated for resistance. Finally, further extraction of haploids from tetraploids with resistance to PVX/PVY, PLRV, cyst nematode, late blight, or heat is being done.

## Introduction

The control of pest and disease by resistant cultivars of potato is important since the average farmer in developing countries has limited access to chemical control. Moreover, use of certified seed is limited in some countries and is not available in others. These facts, and the greater severity of pest and disease in the tropics, justify a strong emphasis on breeding for multiple pest and disease resistance.

The great majority of cultivated potatoes are autotetraploids ($2n = 4x = 48$) and have tetrasomic inheritance. Tetrasomic inheritance is a disadvantage for combining resistances, especially when resistances are polygenically controlled.

The present approach aims to combine multiple resistance to important pests of tropical zones working at the 2x level. This permits efficient breeding work using disomic inheritance (Hougas and Peloquin, 1958). Three steps are involved: (1) extraction of haploids from selected tetraploids; (2) population breeding at the 2x level for multiple resistance, agronomic characteristics, adaptation, and 2n pollen production in wide genetic backgrounds; the population breeding approach applies recurrent selection which increases desirable gene frequencies and stimulates their recombination so that a higher frequency of multiple resistant progenies can be obtained; and (3) transfer of the improved 2x germ plasm into the 4x level via First Division Restitution (FDR) 2n pollen.

Three conditions should be satisfied before full potential of the approach using haploids and 2n pollen can be exploited. First, a large number of haploids with wide genetic background should be obtained since intensive use of particular haploids results in narrowing the genetic bases. This might lead to coancestry and inbreeding which is highly undesirable, particularly for yield. Second, a good number of male fertile haploids should be utilized so that male sterility caused by interactions between tuberosum cytoplasm and nuclear genes of related germ plasm can be avoided. This is important to achieve efficient crossing work during the advancing generations of population improvement. Finally, identification of the parallel spindle (ps) gene in haploids extracted from tetraploids is crucial, since the use of FDR 2n pollen by ps is essential to transfer improved 2x germ plasm into the 4x level. This paper reports progress of production of a large number of male fertile haploids with FRD 2n pollen production.

## Materials and Methods

Two different ecological zones within the tropics are considered. These are highland tropics and lowland tropics. The resistances or tolerances considered important for each zone are:

highland tropics - PVX, PVY, cyst nematode, late blight and frost.
lowland tropics - PVX, PVY, PLRV, bacterial wilt, root-knot nematode, late blight, potato tuber moth and heat.

Selected tetraploids were used as sources of resistance to PVX, PVY, PLRV, cyst nematode, late blight, frost and heat and, thus, haploid extraction from the selected tetraploid was needed.

Extraction of haploids from selected tetraploids was done by 4x - 2x crosses by using a diploid clone IvP 35, which was reported to be a good haploid inducer with embryo-spot marker (Hermsen and Verdenius, 1973). Seeds from the crosses were checked for embryo spot. Observation of general morphology and count of chloroplast number of stomata were used to eliminate triploid or tetraploid plants grown from embryo spotless seeds.

Pollen stainability and 2n pollen production were studied in haploids from which pollen samples were available. The mechanism of 2n pollen production was determined by cytological observation of meiosis in floral buds.

## Results and Discussion

### Extraction of large number of haploids

A sample of 2,379 haploids with different attributes and genetic background was obtained from 76 tetraploids (Table 1). Extraction of a large number of haploids from late blight resistant tetraploids was emphasized, since only a small proportion of the haploids were expected to be highly resistant. Since the haploids were from many tetraploids having tuberosum, andigena and phureja in their genetic background, it is expected that use of the haploids will not lead to inbreeding unless the number of useful clones becomes very small making mating between relatives difficult to avoid. The haploids are being evaluated for resistance.

Table 1. Numbers of haploids extracted from selected tetraploid.

| Resistance of tetraploid parent | Number of resistant parents | Genetic background | Number of extracted haploids |
|---|---|---|---|
| Late blight | 21 | tbr, adg | 1,726 |
| PLRV | 10 | tbr, adg | 180 |
| PVX/PVY | 16 | tbr, adg | 210 |
| Cyst nematode | 17 | adg | 118 |
| Heat | 12 | tbr, adg, phu | 145 |
| | 76 | | 2,379 |

The haploid inducer IvP 35 was relatively efficient in terms of number of haploids obtained after pollination, although the number of haploids per pollination varied much depending on the female parents. Thus, it would be advisable to test many cultivars as a source of haploids and then concentrate haploid extraction work on some selected tetraploids based on their ability to produce many haploids. Some portion of seedlings from spotless embryo seeds turned out to be triploids or tetraploids. This was probably due to incomplete expression of embryo-spot marker genes and/or involvement of modifying genes of female parents which inhibit the expression of the genes.

### Male fertility of the extracted haploids

A sample of 501 haploids has been studied for pollen stainability. The haploids were classified into four groups according to pollen stainability. About a third of the haploids had less than 5% of pollen stainability and were considered to be male sterile and 29% of the haploids had 5% to 30% of pollen stainability and were expected to have only low level of male fertility (Table 2). On the other hand, 14% of the haploids had 30% to 50% of stainability and were expected to have good level of male fertility and the rest, 22% of the haploids, had more than 50% of the stainability and were considered highly male fertile. Thus, 36% of the haploids are expected to have an adequate level of pollen fertility. Since pollen stainability is an indirect estimate of pollen fertility, real fertility value should be obtained from the amount of seed produced in 2x - 2x crosses. Some of the haploids with more than 30% of stainability were used for 2x - 2x crosses as male parents and high seed sets were obtained. The results are

encouraging, since use of haploids as male parents makes it possible to circumvent cytoplasmic-genic male sterility in hybrids with other 2x germ plasm and to keep good level of male fertility during population improvement at the 2x level.

Table 2. Distribution of pollen stainability values in extracted haploids.

| Pollen stainability (%) | <5 | 5-30 | 30-50 | >50 | Total |
|---|---|---|---|---|---|
| Number of haploids | 179 (36%) | 144 (29%) | 70 (14%) | 108 (22%) | 501 |

Several genetic factors are supposedly involved in determining level of male fertility of extracted haploids. They are: (1) cytoplasmic factors (Koopmans, 1959; Grun et al., 1962); (2) gene(s) which interact with sensitive cytoplasm causing cytoplasmic-genic male sterility (Grun et al., 1966, 1979); (3) restorer gene(s) which restore male fertility in plants which otherwise have cytoplasmic-genic male sterility (Hanneman and Peloquin, 1979; Peloquin and Iwanaga, 1981); (4) male sterile gene(s); (5) minor gene(s) which reduce level of male fertility.

Male sterility is common in haploids extracted from North American or European varieties (Ross et al., 1964). Carroll and Low (1976) reported that about 70% of their extracted haploids from four varieties had less than 10% of pollen stainability. The present study shows higher level of stainability in the haploids compared with those of Carroll and Low (1976). Use of many hybrids between tuberosum x andigena as a source of haploids was probably one of the reasons for the high stainability since chance of exposure of male sterile recessive genes is minimum from such heterozygous hybrids. Landeo and Hanneman (1979) attributed high level of male fertility of haploids from andigena clones to their heterozygosity. Another possibility is that many tuberosum parents utilized might have demissum cytoplasm, but not tuberosum cytoplasm which results in male sterility interacting with nuclear genes. Since most of the tuberosum parents resistant to late blight have demissum in their genetic background, identification of cytoplasm donor for the tuberosum parents is important to know to avoid accumulation of an increasing frequency of male sterility over several crossing and selection cycles. This is true, especially where modern day varieties and advanced clones stem from interspecific crosses, e.g. involving demissum, acaule, stoloniferum, chacoense, vernei. If the hypothesis is true, late blight resistant tetraploids which have demissum cytoplasm would be an excellent source of male fertile haploids.

## Identification of FDR 2n pollen production in the extracted haploids

Screening work for 2n pollen production in 322 haploids with more than 5% of pollen stainability from 19 tetraploids resulted in finding 151 haploids with 2n pollen (Table 3). Thus, about half of the haploids were 2n pollen producers. Gene frequency of ps was estimated for the haploids from cv. Atzimba and for the haploids from other 18 tetraploids, assuming that ps was the only 2n-pollen production mechanism involved in the haploids. High ps frequencies were obtained in both populations, 0.71 and 0.77, respectively. This is in accordance with the high frequency of ps in tuberosum cultivars reported by Iwanaga and Peloquin (1982). Based on the segregation rate for 2n pollen production, genotype of

Atzimba for ps was determined as Pspspsps. The present results clearly show that ps gene is common in haploids and extracted haploids are a good source of ps gene.

Table 3. 2n pollen production of haploids extracted from Atzimba and 18 other tetraploid and estimated ps frequencies.

| Tetraploid parents | No. of haploids studied | Without 2n pollen | With 2n pollen | ps frequency |
|---|---|---|---|---|
| Atzimba | 213 | 106 | 107 | 0.71 |
| 18 tetraploids | 109 | 45 | 64 | 0.77 |
| | 322 | 151 | 171 | |

Meiosis study of some Atzimba haploids unveiled that about half of the haploids had synaptic abnormalities which were due to one recessive gene sy4 (synaptic mutant No. 4). The existence of mainly univalents at Metaphase I strongly indicates inhibited chromosome pairing (detailed cytological study of mutant will be published elsewhere). Usually, synaptic abnormalities result in male sterility due to abnormal chromosome distribution. However, when the mutant is combined with ps gene, fertile FDR 2n pollen with inhibited genetic recombination can be produced. The genetic significance of this combination of the mutants is that it makes possible the transmission of 100% of heterozygosity and epistasis of the parent into the 4x offspring (Okwuagwu and Peloquin, 1981). Therefore, the finding of sy4 mutant along with ps in Atzimba haploids is extremely valuable for the present breeding approach, since desirable gene combinations bred at the 2x level can be transferred intact into the 4x offspring. The progenies can be used in a clonal selection program or can be evaluated for possible utilization as True Potato Seed (TPS) cultivars. Moreover, the combined mutants will be especially useful for utilization of TPS for commercial potato production. The TPS cultivars produced by using the mutants would have minimum segregation thanks to genetically uniform pollen and desirable multiple resistances which are uniformly transmitted by FDR 2n pollen.

It seems that synaptic mutants are relatively common in potatoes. Iwanaga and Peloquin (1979) reported sy1 and emphasized the importance of further search of meiotic mutants for potato breeding. Since then, three synaptic mutants, sy2 (Johnston et al., 1981), sy3 (Okwuagwu and Peloquin, 1981), and sy4 (present report) were found. Therefore, a careful search for useful meiotic mutant in different breeding materials might lead to the discovery of more mutants. Moreover, it is likely that such mutants, if any, will be found together with ps which is very common in haploids, permitting the use of the combination of ps and sy with relative ease.

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# Intervarietal Hybridization for Potato Production from True Potato Seed (TPS)

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## ABSTRACT

Different breeding methods were used to generate TPS progenies having the necessary characteristics for the production of good tuber yield with acceptable phenotypic uniformity in color, size, shape, and maturity. Based on combining ability studies involving several clones and cultivars from the CIP lowland tropic populations and other sources, a number of good progenitors were identified. These parental lines were further intercrossed to obtain different groups of TPS families, which were evaluated in a replicated trial for their yield and agronomic performance at CIP's experimental stations in Lima and San Ramon. The results showed that there were several TPS families which gave a marketable tuber yield of more than 1 kg per plant and uniformity rating ranging from acceptable to excellent. The yield and uniformity of some of the TPS families were as good as that of commercial varieties produced from seed tubers.

## Introduction

The traditional method of propagating potatoes involves the utilization of tubers. Normally it takes about 2 tons of seed tubers to plant one hectare of land. According to Accatino and Malagamba (1982), this represents 40% to 70% of the cost of production of potatoes, especially in the developing countries of the world. Another economic factor in the use of tuber seed is its high cost and the inconveniences of storage and transportation. Furthermore, the method of vegetative propagation has the disadvantages of promoting the transfer of viruses and other tuber-borne pathogens from season to season.

An alternative method of potato propagation which has the potential of minimizing most of the problems associated with seed tubers is the use of true potato seed (TPS). The International Potato Center (CIP) has undertaken an overall research effort to exploit the potential of this technology and thus make potato a low cost food crop in many of the developing countries.

Basically, there are two types of TPS populations which can be utilized for the commercial propagation of potato: (1) open-pollinated populations, and (2) hybrid populations. In general, the hybrid TPS populations appear to be superior in yield and uniformity of tubers than the open-pollinated populations. Comparing hybrid and open-pollinated TPS progenies, Accatino (1980) and Bedi (1979) observed that most hybrid TPS progenies gave significantly higher marketable tuber yields

and uniformity than the open-pollinated progenies. Haverkort (1982) obtained similar results in Rwanda.

Although seed production aspects of open-pollinated TPS progenies are less expensive and more convenient to the farmer, the hybrid TPS progenies are more appealing especially in countries where labor cost is not high. Use of TPS derived from controlled hybridization provides the possibility of improving and incorporating desirable characteristics in TPS populations.

This study was undertaken to develop high yielding and uniform TPS progenies through hybridization of tetraploid cultivars and advanced clones.

## Materials and Methods

A total of 48 hybrid TPS progenies were developed from advanced tetraploid clones adapted to lowland tropic conditions. This involved crossing of each of the 12 male parents to each of the four different female clones, resulting in 48 TPS families. These TPS progenies were evaluated in two replications at La Molina, Peru, during the winter season of 1981.

Another group of 100 TPS progenies were derived by crossing selected tetraploid advanced clones from both the highland tropic and lowland tropic projects of CIP. These progenies were evaluated in 1982 in a replicated trial at La Molina (240 masl) and San Ramon (800 masl).

In all the trials the botanical seeds were first sown in flats and germinated seedlings were transferred into jiffy-7 pots after about 15 days. After 4 weeks of growth, the seedlings were transplanted into the field in jiffy pots at a spacing of 35 cm between plants in the row and 75 cm between rows. A total of 40 seedlings per family in each replication was used in all the trials. Crops were harvested in 90 and 100 days in San Ramon and La Molina, respectively.

Field observations on plant survival, vegetative vigor of uniformity, and maturity were made at different intervals during the growing period. At the time of harvest, the yield on a per hill basis and uniformity with respect to color, size, and shape of tubers were recorded.

## Results and Discussion

### Tuber Yield

Results on yield and uniformity of tubers of portions of the TPS progenies evaluated in La Molina in 1981 are summarized in Table 1. It is evident from this table that there were large differences between TPS families in yield of tubers. In this trial, 12 TPS families gave an average marketable tuber yield of more than 1.0 kg per plant and about 0.2 kg of unmarketable smaller size tubers which may be satisfactory for further planting. Marketability was mainly based on the size of the tubers. In general, tuber sizes of about 50 grams or more were considered marketable. Some of the yields in the range of 1.0 kg per plant will be equivalent to about 40.0 tons per hectare, assuming a stand of about 40,000 seedlings on one hectare of land. This result is quite comparable to other TPS yield results reported by Bedi (1979), Martin (1982), and Mendoza (1981).

Table 1. Tuber yield and uniformity traits of true potato seed (TPS) families obtained from crosses of lowland tropic adapted tetraploid parental lines, La Molina, winter 1981.

| Pedigree of TPS Family | Tuber Yield (kg/plant) Marketable | Tuber Yield (kg/plant) Unmarketable | Tuber Uniformity* |
|---|---|---|---|
| 1. 377964.3 x 378017.2 | 1.17 | .01 | 4 |
| 2. 377891.19 x " | 1.31 | .08 | 5 |
| 3. 377885.15 x " | 1.03 | .10 | 4 |
| 4. 377257.1 x " | 0.84 | .23 | 3 |
| 5. 377887.59 x 377904.1 | 1.31 | .15 | 4 |
| 6. 378015.7 x " | 1.52 | .10 | 3 |
| 7. 377933.13 x " | 1.33 | .20 | 3 |
| 8. 377950.14 x " | 0.96 | .15 | 2 |
| 9. 377922.15 x 377964.5 | 1.12 | .11 | 4 |
| 10. 377935.27 x " | 1.16 | .07 | 5 |
| 11. 377887.17 x " | 1.11 | .07 | 3 |
| 12. 377939.5 x " | 0.78 | .11 | 2 |
| 13. 377887.74 x 377920.37 | 1.05 | .20 | 4 |
| 14. 377883.8 x " | 0.82 | .16 | 3 |
| 15. 377885.15 x " | 1.12 | .12 | 3 |
| 16. 377887.17 x " | 0.85 | .13 | 3 |
| 17. 377835.3 x 377877.6 | 0.60 | .16 | 1 |
| 18. 377877.19 x " | 0.74 | .17 | 2 |
| 19. 377887.25 x " | 1.11 | .08 | 3 |
| 20. 377871.22 x " | 0.59 | .02 | 2 |
| $\bar{X}$ | 1.03 | .12 | |

* Based on scale of 1 = least uniform to 5 = highly uniform.

In the 1982 trial of 100 TPS families, the majority gave satisfactory tuber yields and had acceptable uniformity. Table 2 shows 56% of TPS families in La Molina and 30% in San Ramon gave a tuber yield of 0.5 kg or more per plant. As compared to the four open-pollinated TPS families, 72% of the hybrid TPS families in La Molina and 59% in San Ramon gave higher tuber yields (Tables 2 and 3).

On the basis of the yield data obtained from the two locations, a strong family-environment interaction for yield became evident. There were only a few TPS families which gave high yields in both locations.

Tuber Uniformity

At time of harvest, tubers from each TPS family were evaluated for uniformity in skin color, size, and shape. As shown in Tables 1 and 3, several TPS families had the necessary phenotypic uniformity of color of skin, size, and shape of the tubers. Some TPS families had tubers almost as uniform as standard varieties propagated from seed tubers. Similar results were obtained by Mendoza (1979) who has shown that TPS progenies with adequate phenotypic uniformity can be obtained from intervarietal mating of selected tetraploid parents.

Table 2. Distribution of TPS families according to their tuber yields per plant in two locations, winter 1982.

| Yield Group (kg/plant) | No. of TPS families | |
|---|---|---|
| | La Molina | San Ramon |
| < 0.2 | 8 | 7 |
| ≥ 0.2 | 11 | 10 |
| ≥ 0.3 | 9 | 24 |
| ≥ 0.4 | 16 | 29 |
| ≥ 0.5 | 17 | 23 |
| ≥ 0.6 | 13 | 5 |
| ≥ 0.7 | 16 | 1 |
| ≥ 0.8 | 4 | 1 |
| ≥ 0.9 | 1 | - |
| ≥ 1.0 | 5 | - |
| Total | 100 | 100 |

Plant Survival, Foliage Uniformity Vigor, and Maturity

Maintaining optimum stands in TPS progenies appeared to be one of the major problems, especially at lower altitudes. As can be seen in Table 4, the percentage of seedling survival in the field ranged from 45% to 85% under La Molina winter conditions. However, the majority of the TPS families had a plant stand of about 75%. According to Elango (personal communication, 1982) the significant reduction of plant stand in TPS families may be mainly attributed to the post-emergence damping-off disease complex caused by a combination of biological and environmental factors such as *Rhizoctonia solani* and high soil temperature.

In terms of foliage vigor and uniformity in the field, the TPS families showed considerable variations. In most TPS families, vegetative growth was uniform with satisfactory vigor (Table 4).

It is worth mentioning, however, that there was always some degree of segregation for flower color within any given TPS family. This is to be expected in a segregating population of potatoes. The difference in seedling vigor was also evident in the screenhouse. Seedlings from some TPS families were considerably more vigorous and became ready much earlier, than other families. It is reasonable to expect that seedlings with high vigor will have a better chance of survival in the field than less vigorous seedlings.

Early maturity is one of the important attributes in the use of TPS for the commercial propagation of potatoes. In general, TPS progenies derived from tropically adapted clones appear to be earlier in maturity than others. On the basis of maturity data obtained from various types of TPS families under San Ramon and

La Molina conditions, it appears that the development of TPS progenies, which can mature in less than 100 days from transplanting, is possible.

Table 3. Tuber yield (kg/plant) and uniformity of TPS families evaluated in La Molina (LM) and San Ramon (SR), winter 1982.

| Pedigree of TPS Family | Yield (kg/plant) | | Uniformity* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Color | | Size | | Shape | |
| | LM | SR | LM | SR | LM | SR | LM | SR |
| 1. Serrana x India 832 | 0.52 | 0.47 | 3 | 4 | 2 | 2 | 2 | 3 |
| 2. Atzimba x Katahdin | 0.40 | 0.34 | 4 | 3 | 2 | 2 | 2 | 2 |
| 3. Atzimba x DTO-33 | 0.30 | 0.45 | 2 | 3 | 1 | 2 | 1 | 2 |
| 4. DTO-2 x India 1058 | 0.41 | 0.43 | 4 | 3 | 2 | 2 | 2 | 2 |
| 5. AL-204 x 378017.2 | 0.75 | 0.39 | 4 | 4 | 3 | 2 | 3 | 3 |
| 6. CFK-69-1 x 378017.2 | 0.72 | 0.45 | 4 | 4 | 3 | 3 | 2 | 3 |
| 7. AL-204 x R 128.6 | 0.76 | 0.33 | 3 | 2 | 3 | 2 | 2 | 2 |
| 8. BR 63.65 x R 128.6 | 1.10 | 0.37 | 3 | 3 | 2 | 3 | 3 | 2 |
| 9. CFK-69-1 x 7XY.1 | 0.40 | 0.60 | 4 | 3 | 1 | 2 | 2 | 2 |
| 10. 376932.6 x 7XY.1 | 0.60 | 0.59 | 4 | 4 | 1 | 2 | 2 | 2 |
| 11. India 832 x 7XY.1 | 0.55 | 0.59 | 3 | 4 | 2 | 2 | 3 | 3 |
| 12. CFK-69-1 x AL-204 | 0.41 | 0.51 | 3 | 3 | 2 | 2 | 2 | 2 |
| 13. PSP-30-10 x Trop. bulk | 1.09 | 0.41 | 4 | 4 | 3 | 3 | 3 | 2 |
| 14. MS-35-22 x 377904.10 | 1.06 | 0.97 | 3 | 3 | 3 | 3 | 3 | 2 |
| 15. BR 69.84 x 377904.10 | 0.79 | 0.84 | 2 | 3 | 2 | 2 | 2 | 2 |
| 16. 377427.1 x 377904.10 | 1.04 | 0.44 | 3 | 3 | 3 | 2 | 3 | 2 |
| 17. 377904.10 x 377427.1 | 1.06 | 0.54 | 2 | 3 | 3 | 2 | 3 | 2 |
| 18. DTO-28 x Trop. bulk | 0.80 | 0.53 | 3 | 3 | 3 | 3 | 2 | 2 |
| 19. Atzimba x R 128.6 | 0.71 | 0.27 | 4 | 2 | 3 | 2 | 3 | 2 |
| 20. Atzimba x DTO-28 | 0.49 | 0.42 | 3 | 3 | 3 | 2 | 3 | 2 |
| 21. DTO-28 x R 128.6 | 0.78 | 0.42 | 3 | 2 | 3 | 3 | 2 | 2 |
| 22. DTO-33 OP | 0.27 | 0.29 | 2 | 2 | 2 | 1 | 1 | 1 |
| 23. DTO-28 OP | 0.33 | 0.23 | 2 | 1 | 2 | 1 | 1 | 1 |
| 24. Atzimba OP | 0.29 | 0.37 | 2 | 2 | 1 | 1 | 1 | 2 |
| 25. 7XY.1 OP | 0.15 | 0.19 | 1 | 1 | 1 | 1 | 1 | 1 |
| $\bar{X}$ | 0.63 | 0.45 | | | | | | |

*Based on scale of 1 = least uniform 5 = highly uniform.

Table 4. Field survival, foliage vigor and uniformity, and maturity of TPS families evaluated in La Molina during winter 1982.

| Pedigree of TPS Families | Average No. of Seedlings | | Vigor and Uniformity* | | Maturity† |
|---|---|---|---|---|---|
| | Planted | Harvested | 40 days | 70 days | |
| 1. Serrana x India 832 | 40 | 28 | 3 | 3 | L |
| 2. Atzimba x Katahdin | 40 | 22 | 2 | 3 | MS |
| 3. DTO-2 x India 1058 | 40 | 35 | 3 | 4 | MS |
| 4. AL-204 x 378017.2 | 40 | 29 | 4 | 5 | E |
| 5. AL-204 x R 128.6 | 40 | 32 | 4 | 5 | MS |
| 6. CFK-69-1 x 7X1.1 | 40 | 30 | 3 | 3 | MS |
| 7. CFK-69-1 x AL-204 | 40 | 25 | 3 | 4 | MS |
| 8. PSP-30.10 x Trop. bk. | 40 | 35 | 5 | 5 | L |
| 9. MS-35-22 x 377904.10 | 40 | 32 | 5 | 5 | MS |
| 10. 377904.10 x 377427.1 | 40 | 33 | 5 | 5 | L |
| 11. Atzimba x R 128.6 | 40 | 34 | 4 | 4 | L |
| 12. Atzimba x DTO-28 | 40 | 29 | 3 | 3 | L |
| 13. DTO-28 x R 128.6 | 40 | 31 | 4 | 4 | MS |
| 14. 7XY.1 OP | 40 | 24 | 1 | 2 | MS |
| 15. Atzimba OP | 40 | 18 | 2 | 3 | L |
| 16. DTO-33 OP | 40 | 30 | 2 | 3 | E |

*Based on scale of 1 = least vigorous and uniform to 5 = highly vigorous and uniform.

†E = early; MS = mid-season; L = late.

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# Preliminary Evaluation of True Potato Seed Progenies for their Resistance to *Phytophthora infestans* (Mont de Bary), Productivity and Uniformity in Colombia

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## ABSTRACT

Forty true potato seed (TPS) progenies produced at the Instituto Colombiano Agropecuario (ICA) and the International Potato Center (CIP) originated from crosses among 40 parents of several Latin American potato breeding programs were evaluated during two years for their productivity, uniformity, vigor and resistance to late blight (*P. infestans*, Mont de Bary).

The trials were at ICA Regional Research Center "La Selva," in Rionegro, Colombia, under semi-tropical climatic conditions.

Botanical seed of the progenies was sown in trays in a substrate of natural forest litter, sand and chicken manure. Seedlings were kept in a greenhouse for 30 days, exposed to natural environment for 10 days and then transplanted to the field where conditions for late blight infection were quite severe. Some replicates were not sprayed with fungicide.

Data on late blight resistance during plant growth, plant vigor, earliness, tuber uniformity, and yield were recorded. TPS progenies showed significant differences in resistance to late blight, yield and tuber uniformity. A market acceptability study showed only a 20% lower price for TPS-originated tubers as compared to tubers of a common potato cultivar.

## Introduction

Commercial potato production in developing countries using true potato seed (TPS) seems a promising alternative for many areas. Main advantages of TPS compared to traditional potato production methods: simpler storage and transportation of seed and considerably reduced costs; eliminating losses related to storage of seed tubers; tuber seed-transmitted diseases, especially virus, minimized and therefore, a healthier and cheaper planting material would be available; the crop could be expanded to many areas where potatoes could not be introduced before due to limitations of conventional propagation methods.

Research is now taking place at several Agricultural Research Centers in different countries where improved genetic materials and agronomic practices are being developed and evaluated (1, 2, 3, 5).

In certain semi-tropical regions of Colombia, climatic conditions do not permit production and maintenance of healthy seed tubers. Therefore, total production costs are high due to transport from seed tuber producing areas. In those regions, consumers do not have strong preferences for specific tuber quality as in traditional potato areas.

Therefore, some phenotypic variability in the production of a crop from TPS could be acceptable. Information here is preliminary results of research at ICA's Regional Research Center "La Selva," Rionegro, Antioquia, Colombia. Main objective was to assess whether or not TPS progenies could advantageously compare with plants from seed tubers in productivity, disease resistance, earliness, and market acceptability.

## Materials and Methods

Experiments were during the 1981-82 growing seasons. The Regional Research Center "La Selva" is at 6°20' latitude north, with an elevation of 2,130 m. Average minimum and maximum temperatures range between 11.3°C to 22.4°C, respectively. Average rainfall for the period 1979-82 was 1,841 m. Soil is a black clay silt loam with a pH of 4.5.

In the 1981 trial, TPS of nine progenies, originated from 5 open pollinated and 4 out cross pollinated (hybrids) were produced by the ICA/CIP cooperative program. The local cultivar Pan de Azúcar was used as a seed tuber propagated control.

Seedlings were produced in plastic trays using a 1:1:1 mix by volume of natural forest-litter (humus), soil, and sand. During nursery stage seedlings received weekly applications of a fertilizer solution. Seedlings were first transplanted to small plastic containers 44 days after sowing and to the field 18 days later. Seedlings were spaced in the field at 1 m between rows and 0.30 m between hills.

A randomized block experimental design with 4 replicates, using 3 rows per plot and 60 plants per replicate, was used. Periodic applications of fungicides and insecticides were made to control diseases and pests. Fertilizer (NPK 10-30-10) at the rate of 1.2 t/ha and chicken manure were applied in the field.

During plant development, late blight (*Phytophthora infestans*) incidence was recorded four times.

Plants were harvested 133 days after transplanting. Data on tuber uniformity (shape, size, and skin color), total weight of tubers per plot and specific gravity, measured on a random sample per plot were taken at harvest.

A total of 31 progenies from out crosses (hybrids) made at either CIP or ICA was tested in 1982.

In an non-replicated set of 31 progenies, no fungicide against late blight was applied to the plants. Thirteen other progenies in a 3-replications trial were sprayed with fungicides. Planting distances and fertilizer applications were

similar to the 1981 trial. Seedlings were grown in a mix of natural forest litter (humus), sand, and commercial chicken manure preparation at a 1:1:1 volume proportion.

Seedlings were transplanted directly to the field, bare-rooted, 51 days after growing. Planting distances were similar to the 1981 experiment. Plants were harvested 123 days after transplanting.

A marketing study observed the acceptability of potato tubers obtained from TPS progenies. A 100 kg sample of medium-size tubers classified in three skin color types (white, pink and purple) from high yielding progenies but highly segregated for color, was sent to two market sites in Medellín for sale. Tubers of the local cultivar were also sent as control.

Parental materials used in the controlled pollinations were mainly selected for resistance to late blight. In the 1982 experiment, some specific crosses for tuber shape and color uniformity were included.

## Results and Discussion

Results in the 1981 trial are in Table 1. The values represent an average of four replicates. Results showed that late blight incidence was lower in all progenies than in the cultivar used as control.

Table 1. Late blight incidence, tuber characteristics and yield of 10 progenies and a local cultivar in the 1981 experiments.

| | Late blight Incidence* | Tuber Uniformity (Shape, Size, Skin Color) | Specific Gravity of Tubers | Yield (t/ha) |
|---|---|---|---|---|
| 1. | 2.8 | poor | 1.080 | 17.8 |
| 2. | 2.2 | fair | 1.082 | 28.5 |
| 3. | 2.3 | poor | 1.084 | 27.8 |
| 4. | 3.2 | poor | 1.082 | 19.4 |
| 5. | 2.6 | poor | 1.084 | 18.8 |
| 6. | 2.5 | uniform | 1.085 | 25.8 |
| 7. | 3.0 | fair | 1.089 | 16.1 |
| 8. | 2.8 | poor | 1.095 | 27.1 |
| 9. | 2.7 | fair | 1.096 | 31.3 |
| 10. (check) | 3.4 | uniform | 1.077 | 27.6 |

*Average of 4 readings. Rate 1 to 9; 1 = no attack; 9 = plant dead.

When comparing tuber uniformity, only hybrid progeny 6 was as uniform as the control. Other three progenies, 2, 7, and 9, had fair uniformity, while it was poor in the others.

Specific gravity of tubers, an indicator of total soil content, and cooking and processing quality, was higher in all progenies than in the cultivar.

When total yield was considered, progeny 9 was higher than the control and progenies 2, 3, 6 and 8 were not significantly different from it. Progenies 1, 4, 5 and 7 had considerably lower yields. In general, open pollinated and hybrid progenies did not show considerable yield differences.

Table 2 indicates basic observations for the 1982 trial. Unfortunately, no local cultivar was included in this experiment as control. Seven progenies (4, 5, 6, 8, 11, 12 and 22) showed satisfactory levels of field resistance to late blight, uniform tubers and earliness. Best performance, in terms of yield, uniformity and resistance to late blight, was by the progeny Serrana x 378044.7.

In replicates with fungicide application, higher yields resulted. Yields above 20 t/ha were from hybrids, 65ZA-5 x Pana Blanca and DTO-28 x 378198.5. This former progeny showed also high resistance to late blight in the plot without fungicide treatment and fair tuber uniformity.

Relative low yield in the 1982 experiment, especially in the plots without fungicide control, when compared with 1981 experiment was probably due to transplanting the seedlings in the center of high ridges which may have caused drought stress.

Four progenies, 4, 8, 12, and 22, had acceptable tuber uniformity as a consequence of proper parental combinations. Also, important differences in earliness and plant vigor were observed among progenies.

Market study results indicate an average price of US$0.30 per kilo of consumption size tubers from TPS progenies as compared with US$0.38 per kilo of tubers from the local variety Capiro. This is considered favorable implication for TPS potential, even in a country with high market standards for tuber quality and uniformity.

Therefore, considering rather strict preferences in the Colombian potato market, results of this preliminary study indicate that TPS tubers, except for a relatively small reduction in their retail price, could have adequate market acceptance. Probably the price reduction would be minimal when compared to lower production costs of a TPS potato crop.

## Conclusions

Considerable differences among TPS progenies were obtained for late blight resistance, earliness, tuber uniformity, plant vigor, total yield, and tuber cooking quality. Some families were able to tolerate and produce well without fungicide applications for late blight control.

Seedlings exposed to direct sunlight by placing them in flats in the open for about 10 days before transplanting, had markedly improved plant survival if adequate moisture is provided immediately after transplanting.

Yields of TPS progeny can be as high as those obtained by normal cultivars. The range for different progenies was from 15 to 25 t/ha. Yields could be considerably increased by using proper genetic combinations selected for this particular trait.

Table 2. Late blight incidence, and some vegetative and productive characteristics of different progenies evaluated in 1982 at "La Selva" Research Center.

| | Late Blight Incidence* | Plant vigor | Earliness | Tuber uniformity | Yield(t/ha) |
|---|---|---|---|---|---|
| 1. | 2.6 | Medium | Early | Poor | 7.2 |
| 2. | 2.6 | Medium | Medium | Poor | 8.5 |
| 3. | 2.0 | Medium | Medium | Poor | 8.9 |
| 4. | 2.3 | Medium | Early | Uniform | 14.2 |
| 5. | 2.0 | Medium | Early | Fair | 8.7 |
| 6. | 2.6 | Medium | Early | Fair | 6.6 |
| 7. | 2.6 | Medium | Early | Poor | 9.5 |
| 8. | 3.0 | Medium | Medium | Uniform | 9.5 |
| 9. | 2.0 | Medium | Early | Poor | 8.9 |
| 10. | 2.0 | Medium | Medium | Poor | 7.3 |
| 11. | 2.3 | Medium | Early | Fair | 9.8 |
| 12. | 3.6 | Low | Early | Uniform | 6.2 |
| 13. | 2.6 | High | Late | Fair | 14.2 |
| 14. | 2.3 | High | Medium | Fair | 12.2 |
| 15. | 1.6 | High | Medium | Fair | 16.4 |
| 16. | 3.0 | Medium | Early | Fair | 6.9 |
| 17. | 3.1 | Low | Early | Poor | 5.3 |
| 18. | 2.0 | High | Medium | Poor | 9.9 |
| 19. | 3.6 | High | Medium | Fair | 9.7 |
| 20. | 3.6 | High | Late | Fair | 10.3 |
| 21. | 4.3 | Medium | Late | Fair | 8.8 |
| 22. | 3.6 | Medium | Medium | Uniform | 7.4 |
| 23. | 4.0 | Medium | Medium | Fair | 11.3 |
| 24. | 3.0 | Medium | Medium | Fair | 10.6 |
| 25. | 3.0 | Medium | Medium | Fair | 8.9 |
| 26. | 3.0 | High | Late | Fair | 7.8 |
| 27. | 2.6 | High | Late | Fair | 15.8 |
| 28. | 2.6 | High | Late | Fair | 12.6 |
| 29. | 6.0 | Low | Early | Fair | 5.6 |
| 30. | 5.0 | Low | Early | Fair | 12.4 |
| 31. | 2.1 | Medium | Medium | Fair | 12.4 |

*Average of 3 readings. Rate 1 to 9. 1 = no attack; 9 = plant dead.

Preliminary marketing studies indicate favorable acceptance for tubers even from non-uniform progenies, showing a good potential for the economic utilization of TPS progenies in commercial operations.

The preliminary study indicated substantial potential for TPS technology including selection of high yielding progenies with resistance to late blight and uniformity.

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# Food Quality and Chemical Composition

Dry Matter Content, Total Protein and Consumer Acceptability of Potatoes (Solanum spp.) Produced Under Hot Tropical Conditions

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ABSTRACT

The influence of a range of tropical growing conditions, the dry matter and protein contents and consumer acceptability of potatoes was studied in Peru. Dry matter decreased at hotter sites. Agronomic treatments to reduce soil temperature marginally improved percentage of tuber dry matter. Protein, expressed as a percentage of dry matter, increased at the hotter sites but on fresh weight basis, protein remained similar at each site. Although there was no direct relationship between taste and dry matter for samples within a site, dry matter was related to texture. Qualitative assessments of tuber taste from Peruvian testers are included. Implications of these results for breeding potatoes for hot climates are discussed.

Dry matter content is the most commonly used criteria to determine culinary quality in potatoes. In Peru, native potatoes are traditionally grown in highland production zones (> 3,000 m.a.s.l.) and are prized for high dry matter content. These native and other highland-grown potatoes are preferred by most Peruvian consumers over potatoes with a lower dry matter content produced in the irrigated valleys of the coastal desert. Potatoes from both production zones are consumed by people in Lima, the capital city.

Potatoes with optimum qualities of taste and texture are referred to as arenosa or harinosa (sandy or floury) (Brush et al., 1980; Poats, 1982), and usually have dry matter content above 24%. In Peruvian markets, arenosa potatoes normally are higher priced than those judged to be low in dry matter content. Due to these consumer preferences, dry matter and protein contents and consumer acceptability were also examined of potatoes grown experimentally in Peru's eastern lowland and mid-elevation humid tropical forest zones.

## Background

Relatively little work has been reported regarding the effects of agronomic manipulations and novel production environments on dry matter content, nutritional quality and acceptability of potatoes. Studies of Wurr and Allen (1974) and Ifenkwe, Allen and Wurr (1974) showed that percent dry matter is directly related to tuber size. Dry matter at a given tuber size can also be increased by planting either at closer spacings or delaying harvest (Bleasedale and Thompson, 1968). Maris (1969) and Simmonds (1974) suggested that a high level of dry matter is associated with late maturity. Reports from India suggest that dry matter content

varies with variety and location (Verma et al, 1975). Similar results have been obtained in the USA (Hoff et al, 1978; Haynes, 1981). Studies in Peru indicate that potatoes respond qualitatively and quantitatively to local environmental and climatological conditions, yet the extent of the response appears to be governed by the tuber's genetic constitution (Moreno, 1973; Poats, 1982).

Since physiological responses of potatoes to climatic features also imply biochemical changes which could affect tuber quality, it is important to measure quality not only by means of dry matter and protein contents but also in terms of consumer acceptability. To date, there appear to be no published studies in which potatoes produced in novel environments, such as under high temperature regimes, have been evaluated on all three criteria of productivity, nutritional composition and quality, and consumer acceptability.

In 1982 a coordinated approach to examine quality of potatoes produced under hot, humid conditions was initiated at the International Potato Center (CIP)[1]. The original objective of the research on potatoes grown under hot conditions was to identify practices and progenies that would provide high yields. Investigation of qualitative aspects began as a by-product. However, the results have encouraged further study and also indicate the route these studies should follow.

## Materials and Methods

Tubers used in these experiments were produced in four distinct ecological zones representing a wide range of growing conditions. At three locations potatoes were produced under warm to hot conditions. Tubers for sampling were from bare soil plots and from plots with agronomic treatments designed to reduce soil temperatures. In Lima and San Ramon, lime and straw mulch, respectively, were used as soil reflectants, and in Yurimaguas partial shading of plants was achieved with adjacent maize plants.

Six heat-tolerant clones: DTO-33, DTO-2, 69-47-2, 374080.5, LT-1, LT-2, and LT-4 were used in the experiments together with the broadly adapted varieties Mariva and Desiree.

Each clone or variety was analyzed for dry matter and total protein as a percentage of total dry matter, and submitted for consumer taste tests. For laboratory analyses (at CIP and at the Department of Nutrition at the Peruvian National Agricultural University, UNA, in La Molina), potatoes of each clone or variety were divided into two groups: one remained raw while the other was boiled for approximately 30 minutes with skins intact. Tubers of both groups were then cut longitudinally into thin slices and freezedried. Samples were weighed before and after dehydration to determine dry matter content. Once dehydrated, the samples were finely ground (60 mesh) and analyzed for total protein by the microkjeldahl method (AOAC, 1970).

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[1]This did not actually begin in an organized, interdisciplinary manner. The antropologist started consumer testing potatoes produced under lowland, hot humid conditions, in early 1980 on-an ad-hoc basis, in response to tentative evidence that potatoes produced in lowland humid zones of Peru were unacceptable to local consumers (Poats, 1982). Meanwhile, the agronomist began experiments to modify the environmental stresses of potatoes produced under hot, humid conditions (Midmore, 1980). In 1981 the biologist began laboratory analysis of Midmore's experimentally-produced potatoes and some consumer tests with volunteers from the International Potato Center.

Consumer acceptability of the potato samples, was evaluated by taste tests at two locations under slightly different procedures. In CIP and UNA laboratories, volunteers rated potato samples in comparison to locally available controls. In these evaluations, potatoes were rated for flavor on a scale of 1 to 5: 1 = bad, 2 = regular, 3 = good, 4 = very good, and 5 = excellent; texture was rated on a scale of 1 to 3: 1 = hard, 2 = watery and 3 = adequate. Another set of samples was rated by a panel of women from a low-income district (Pamplona Alta) of Lima. The panel compared qualitatively the tastes between each sample, and between samples and locally purchased potatoes. Although residents of Lima, all of the women originally came from areas outside Lima and represented a fairly broad sample of the national population.

## Results and Discussion

### Dry Matter

Dry matter in crude samples of Desiree (Table 1) and Mariva (Table 2) decreased with increase in temperature. Yurimaguas, the highest temperature site, dry matter content of Desiree was 12.5% and Mariva 16.6%. In contrast, at medium and cool temperatures dry matter content ranged from 16% to 19% for Desiree and 20% to 28% for Mariva.

Table 1. Dry matter content and total protein on a dry and fresh weight basis in raw and cooked potato samples of var. Desiree from four production sites.

| Site/ Treatment | Raw | | | Cooked | | |
|---|---|---|---|---|---|---|
| | | Total Protein | | | Total Protein | |
| | Dry matter % | Dry weight basis % | Fresh weight basis % | Dry matter % | Dry weight basis % | Fresh weight basis % |
| Huancayo | | | | | | |
| Control | 19.4 | 11.94 | 2.31 | 22.3 | 12.18 | 2.71 |
| La Molina (1981) | | | | | | |
| Control | 15.5 | 11.0 | 1.70 | 19.8 | 14.0 | 2.8 |
| Mulch | 16.7 | 10.2 | 1.70 | 17.7 | 13.6 | 2.4 |
| San Ramon (rain 1981) | | | | | | |
| Control | 15.0 | 16.0 | 2.4 | 15.9 | 16.3 | 2.6 |
| Mulch | 15.3 | 15.7 | 2.4 | 15.5 | 16.1 | 2.5 |
| (dry 1982) | | | | | | |
| Control | 15.0 | 18.0 | 2.7 | 16.2 | 18.5 | 3.0 |
| Mulch | 16.0 | 17.5 | 2.8 | 16.4 | 17.1 | 2.8 |
| Yurimaguas | | | | | | |
| Control pH6 | 14.3 | 19.6 | 2.8 | 14.9 | 18.8 | 2.8 |
| Control pH4 | 12.5 | 18.4 | 2.3 | 13.4 | 16.4 | 2.2 |
| pH4 + Maize | 12.6 | 19.8 | 2.5 | 13.3 | 15.8 | 2.1 |

Besides the direct effect of temperature on tuber dry matter, indirectly the reduction of crop duration at hotter sites led to smaller tuber size, a possible immature harvest, and consequently less total dry matter, in accord with data of Verma et al, (1965).

Table 2. Results of taste tests (women panel) on tubers of var. Mariva from three production sites.

| Production Site | Organoleptic characteristics |
|---|---|
| Huancayo | Sandy (mealy) or floury, good taste, good for making puree or soups. Not good for frying. |
| La Molina | Good taste, slightly sandy (mealy), good for making papa a la huancaina (a cold potato dish), stuffed potatoes or frying. |
| San Ramon | Sweet taste, good only for frying, papa a la huancaina or stuffed potatoes. |

Nevertheless, it should be noted that when Desiree was planted in a less acid (pH 6) soil than normal (pH 4) at Yurimaguas, the dry matter content increased 2%, confirming results reported by Grison (1973) that soil type can affect tuber dry matter content.

There would appear to be little chance for agronomically improving tuber dry matter content either by planting in alternative seasons at hot sites or by implementing agronomic techniques that reduce soil temperature and conserve moisture (Table 1). However, both techniques have successfully improved absolute tuber yields per unit land area (Midmore, 1980). There were some clonal differences in dry matter content within a site indicating a potential to select for higher dry matter content.

Differences in dry matter content were observed between raw and cooked samples of the same potato variety or clone. Dry matter tended to increase per unit weight upon cooking due to the loss of water and water-soluble contents through the skin. Cooked samples (the usual form for consumption) should therefore be used in evaluating nutritional quality.

## Total Protein

Protein values for Desiree are expressed either as percent of total dry matter or percentage of fresh weight for both raw and cooked samples. Comparing raw samples on a fresh weight basis, those produced in La Molina had lowest values (Table 1). When cooked samples were compared, Yurimaguas had the lowest protein values.

Conducting the same comparisons with protein expressed on a dry weight basis, or as a percentage of total dry matter (the most common way of expressing protein), we may erroneously affirm that tubers from hotter areas have higher protein

content than those of cooler areas. Yurimaguas potatoes, in fact, showed 19.8% protein expressed as a percentage of dry matter. In reality, what is being measured here is not the variation in protein quantity, but the variation in carbohydrate; less total dry matter causes relatively the same amount of protein to occupy a larger proportion of the dry matter. For this reason, it is more accurate to compare protein content of potatoes produced under different ecological conditions on a fresh weight rather than a dry weight basis. In addition, as noted above, the protein values for tubers grown in Yurimaguas (Table 1) show that the protein decreased after cooking indicating the loss of soluble nitrogenous constituents, not observed in the samples from the cooler sites. This phenomenon deserves further study.

For Mariva, the percentage of protein expressed on a dry weight basis demonstrated the same tendencies as those of Desiree in moving from one environmental zone to another. The Mariva samples were analyzed in a fresh state which would account for somewhat lower values. Variability between clones for protein content on a fresh weight basis of cooked samples exists and may be further improved upon by conscious selection. Variations of protein content reported here between sites are probably due, as indicated by Moreno (1977), to the effects of climate on the metabolism of the potato plant.

## Consumer Acceptability Tests

All varieties were evaluated for flavor and texture to determine influence of the production environments. With the variety Mariva (Table 2) the taste changed according to production zone with the most desirable taste in the Huancayo (higher elevation) sample and the least in the San Ramon (mid-elevation) sample where a sweet taste was detected.

For Desiree (Table 3), produced on the coast (La Molina) and in both the mid-elevation (San Ramon) and lowland (Yurimaguas) humid tropical zones, several undesirable flavors, such as a metalic taste and bitterness, were detected, depending in some locations on the agronomic treatments and time of planting. These flavors became more marked with increases in the temperatures of the production zone. Many potatoes grown in San Ramon were judged by tasters to be suitable only for frying. Table 4 presents consumer acceptability of other varieties, many of which demonstrated similar taste characteristics.

The relationship between flavor or texture and dry matter content in one variety, Desiree, were measured using numerical codes. Although flavor was only loosely correlated to dry matter, texture was found to have a higher correlation with dry matter content.

In hot regions of the world where the potato is not traditionally consumed, emphasis should be placed on maintenance of acceptable dry matter content so that the potato can compete with locally-adapted carbohydrate sources.

## Conclusions

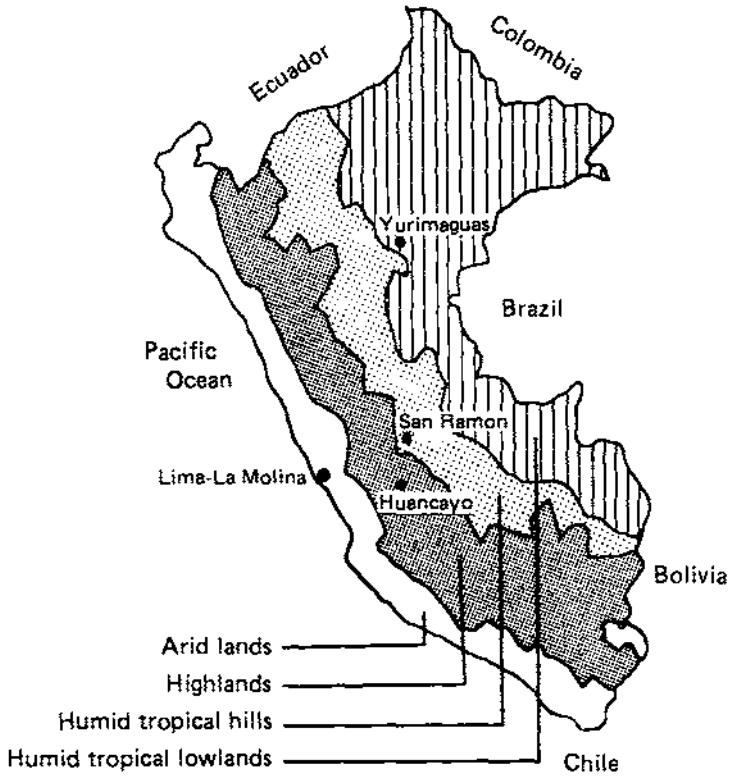
Dry matter, protein, taste, and texture vary in accordance with variations in production environment. There was a tendency for dry matter to decrease with increase in temperature and for flavor and texture quality to diminish. This tendency reached an extreme in the lowland humid tropical zone (Yurimaguas) where the dry matter content of some varieties and clones dropped to 12% and the taste, according to consumer panels, was unacceptable.

Table 3. Results of taste tests at CIP with the variety Desiree, produced at three sites.

| Site/ Treatment | Taste | Texture | Comments |
|---|---|---|---|
| La Molina | | | |
| Control | 2.5 | 2.9 | "Off taste" |
| Soil reflectant | 2.5 | 2.8 | Slightly strange taste |
| San Ramon (rainy season) | | | |
| Control | 2.5 | 2.2 | Metalic taste |
| Mulch | 2.2 | 2.6 | Metalic taste |
| (dry season) | | | |
| Control | 2.3 | 2.6 | Slightly bitter, biting |
| Mulch | 2.1 | 2.7 | Slightly bitter, sticky |
| Yurimaguas | | | |
| pH6 | 1.7 | 2.0 | Watery, acid |
| (alkaline soil treatment) | | | |
| pH4 | - | - | Watery, bitter "Green" taste, biting Suitable for pig feed |
| pH4 + Maize | - | - | Suitable for pig feed |

Table 4. Results of taste tests at CIP with various clones from three production sites.

| Site/ Clone | Taste | Texture | Comments |
|---|---|---|---|
| La Molina | | | |
| Mariva | 3.8 | 3.0 | - |
| DTO-2 | 3.0 | 2.5 | Slightly strange taste |
| DTO-33 | 2.9 | 2.5 | Slightly strange taste |
| San Ramon | | | |
| DTO-2 | 3.0 | 2.9 | Slightly bitter |
| DTO-33 | 2.2 | 2.3 | Slightly bitter |
| 69-47-2 | 2.6 | 2.1 | Slightly bitter |
| 374080.5 | 2.6 | 2.5 | Bitter taste |
| Yurimaguas | | | |
| LT-1 | 2.4 | 2.3 | Biting, slightly hard |
| LT-2 | 2.4 | 2.6 | Slightly acid, sticky |
| LT-4 | - | - | No taste, strange smell, good perhaps for frying |




| | Arid lands | Highlands | Humid Tropical Hills | | Humid Tropical Lowlands |
|---|---|---|---|---|---|
| | <1000m | > 1000m | 500-1000m | | <500m |
| Experimental Station | Lima | Huancayo | San Ramon | | Yurimaguas |
| Growing Season | Jan-Mar | Oct-Mar | Dec-Mar | May-Aug | May-Aug |
| Approximate Season Length (days) | 110 | 150 | 95 | 95 | 70 - 90 |
| Mean Max t°C | 27.9 | 20.6 | 29.0 | 29.7 | 31.4 |
| Mean Min t°C | 19.1 | 6.6 | 18.7 | 17.3 | 19.9 |
| Mean Monthly Rainfall | – | 100 | 235 | 72 | 126 |

Figure 1. Location of CIP experimental stations, and data pertaining to growing seasons.

Agronomic practices to decrease temperature improved dry matter content in some experiments, but differences were not detected by consumers. It is possible that an increase of 1% to 2% in dry matter is not detectable when the total dry matter content remains below 18%.

It is essential to evaluate protein on a fresh weight basis when comparing potatoes produced in different ecological zones because dry matter content varies significantly.

Consumer acceptability is an important part of food production. Consumer acceptance declines with increases in temperature of the production zones. The recommendation is that consumer acceptability tests be made on a selective, rigorous basis at all stages for materials produced in novel production environments such as the hot humid tropics.

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# Integrated Control of Potato Moth in Rustic Potato Stores

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## ABSTRACT

Experiments related to integrated control of Potato Tuber Moth *Phthorimaea operculella* (Zeller) in rustic diffuse light stores at San Ramon, Peru investigated the effect of various traditional practices, the effect of biological control using biological insecticide Dipel a formulation of *Bacillus thuringiensis*, the effect of synthetic pyrethroid Fenvalerate, and the use of water and synthetic sex pheromones consisting of a mixture of trans-4, cis-7-tridicadien-1-ol acetate (PTM 1) and trans-4, cis-7, cis-10-tridecatrien-1-ol acetate (PTM 2). Tuber and sprout damage in potatoes stored for 4 months was significantly reduced in all treatments when tested alone. Promising control components for inclusion in an integrated pest-management program included use of the weed *Lantana* sp., *Bacillus thuringiensis*, water on walls of store and synthetic sex pheromones used in combination with a funnel trap.

## Introduction

The potato tuber moth *Phthorimaea operculella* (Zeller), is a widely distributed pest of solanaceous crops and thrives best in areas with hot dry summers (Foot, 1975). Under field conditions, pest populations become apparent when the average daily temperature reaches 16°C. Population increase is fastest when average temperature is between 20° and 25°C, when the life cycle takes between 3 and 4 weeks to complete (Haines, 1977). Although eggs are reported not to hatch at 10°C and below (Haines, 1977), there are indications that this and related species are becoming increasingly tolerant to cooler conditions.

During growth of host plants, tuber moth larvae live as miners in the foliage and stems. Prior to harvest, tubers may become infested by direct larval attack or by adults laying eggs on exposed tubers. During storage, larvae already present in infested tubers may spread to healthy tubers and reinfestation by adults entering the store occurs.

Damage caused to both growing crops and stored tubers can be extensive. Potatoes planted in the hot dry summer on the coast of Peru suffer heavy attacks when adequate control measures are not followed. Infestation of tubers in the field has been shown to be as high as 50% (Anonymous, 1980). Storage losses are reported to vary from 30% to 70% in country stores in India (Nirula, 1960) and as high as 86% in Tunisia, Algeria and Turkey, despite the use of insecticides such

as malathion dust (Anonymous, 1980). In San Ramon, over 90% tuber infestation has been recorded following 2 months storage (Anonymous, 1981).

Reports of successful pre- and post-harvest pest control using a range of insecticides can be found in the literature. Also reported are high levels of pest resistance to several insecticides in several countries (Haines, 1977). The development of insecticidal resistance by this pest together with frequently inadequate means of monitoring tuber moth populations commonly result in excessive use of insecticides (Kennedy, 1975). The undesirability and potential dangers of applying large and uncontrolled quantities of insecticides to potato tubers which later may be consumed must be recognized.

Although host plant resistance has been reported (Raman and Palacios, 1982) --physical and biological control methods are also to be found in the literature (Haines, 1977)--little use of these data has been made to develop integrated control measures which could reduce the present reliance on toxic insecticides. The sex pheromone of this insect, consisting of a mixture of trans-4, cis-7-tridicadien-1-ol acetate (PTM-1), and trans-4, cis-7, cis-10-tridecatrien-1-ol acetate (PTM-2), has been shown to be highly effective in capturing male tuber moth (Raman, 1982a) and a simple funnel trap for mass trapping in the field has been developed (Raman, 1982b). Insect populations and crop damage in the field are reduced in rainy seasons and where overhead sprinkler irrigation is used (Langford and Cory, 1982; Foot, 1976). Similarly, directly wetting stored tubers has been reported to reduce infestation levels on stored tubers (Haines, 1977; Parker, 1981). Inert mineral dusts have been shown to be an effective means of controlling damage to tubers, but not to growing sprouts, in stores (Helson, 1942).

Present tuber moth research at the International Potato Center (CIP) is aimed at identifying and testing potential components of an integrated potato tuber moth control program, and later to put these together in appropriate combinations that will minimize or even exclude the use of toxic insecticides. This paper reports evaluation of several control components for use in low-cost natural diffused light seed stores.

## Materials and Methods

These studies were at the CIP experiment station in the tropical humid hills at San Ramon, Peru. San Ramon is situated at a latitude of 11°08 S at an altitude of 800 masl. The mean temperature is 24°C, mean minimum temperature 18°C, mean maximum temperature 30°C and the annual rainfall is 2,000 mm. All trials were in simple natural diffused light stores (Anonymus, 1979, 1980, 1981), maintained at ambient temperatures.

In all experiments 50 tubers (variety Revolucion) were stored in small (36x28x18 cm) wooden seed crates. Each crate was considered a replicate and four replicates were used per treatment which were laid out in the form of a randomized block. All treatments were equally exposed to natural tuber moth infestation.

During these studies the following treatments were compared:

1. Traditional practices:
   (a) Dried weeds. Dried foliage of the following common weed plants were chopped and spread on top of the tubers to a depth of 2 cm: *Lantana* sp., a common weed of many tropical countries; Muña

(Minthostachys sp.), a weed of the high Andes, and Cymbopogan citratus a weed occuring in San Ramon and other similar tropical locations.

(b) Lime dust applied at 10-12 g per crate.
(c) Wood ash.
(d) Rice straw.

To avoid possible interference from the repellent effect of weed treatments, these were placed in an isolated corner of the store, well away from other treatments.

2. Use of Dipel. The biological insecticide Dipel, containing active spores of Bacillus thuringiensis, was applied as a single spray containing 0.2% and 0.5% a.i. prior to storage.

3. Use of Fenvalerate. The synthetic pyrethroid, Fenvalerate, at 0.2% a.i. was sprayed on the stored tubers every 15 or 30 days throughout the storage period.

4. Use of sex pheromones and water. Three pheromone traps were placed in one store at the same height as the stacked crates, a second store had no pheromone traps. In a third store, water piped from an irrigation canal was made to fall in a curtain-like manner down the screen walls of the store.

Observations were made following 120 days in store of all tubers stored for (a) number of tubers infested, (b) number of sprouts damaged, and (c) number of tubers rotting due to larval penetration followed by decay by soft rotting organisms.

## Results

During these trials it became apparent that for the particular situation of the storage of seed tubers, the number of sprouts damaged and the percentage of tubers rotting were the most important observations recorded. Total number of tubers infested did not indicate the viability of the tubers as seed and was thus not a useful indicator of effectiveness of treatments for storage of tubers.

Traditional practices. All treatments tested significantly reduced the percentage of sprouts damaged and the three weed species and the lime treatment also significantly reduced tuber rotting (Figure 1). When compared with the inert materials, rice straw, wood ash and lime, only the weed lantana significantly reduced both sprout damage and tuber rotting (Figure 1).

Use of Dipel. The single pre-storage spray of both concentrations of the biological insecticide significantly reduced both sprout damage and tuber rotting (Figure 2). The highest concentration tested resulted in the least damage.

Use of Fenvalerate. Both spray regimes significantly reduced sprout damage and tuber rotting. Spraying every 15 days resulted in significantly less sprout damage than spraying at 30-day intervals (Figure 3). Spraying with 0.2% Fenvalerate every 15 days, which thus required a total of 8 sprays during the 120 day storage period, gave similar levels of tuber moth control as the single pre-storage spray with 0.5% Dipel (Figures 2 and 3).

Use of sex pheromones. A total of 13,800 male moths were caught in the pheromone traps during the storage trial. Sprout damage was reduced to a level similar to that obtained with Dipel and Fenvalerate sprays (Figure 4).

Use of water. Although water on the store screen walls did not reduce the amount of sprout damage to the same degree as following the use of Dipel and Fenvalerate sprays, it did reduce the number of damaged sprouts by more than 50% as compared with the control treatment (Figure 4).

## Discussion

Although none of the treatments gave complete control of the tuber moth, it is nevertheless possible to select several methods which may be combined and tested in an integrated control program depending on specific local conditions.

The results indicate that the weed species tested, and particularly the *Lantana* sp., have tuber moth repellent properties and so reduce sprout damage over and above that obtained from the physical barrier effect resulting from covering stored tubers with inert materials. If these specific plants are not available locally other plants could usefully be screened for tuber moth repellent qualities. The application of such materials as a powder may combine their repellent qualities with the recorded physical barrier effect of inert dusts. Also, and depending on the plant species involved, it might be worth considering planting a small area around the store with such plants if they can also be shown to be repellent in this form.

Results obtained following the use of the biological insecticide, Dipel, are promising and merit further testing of the material both as a curative and protective insecticide for potential incorporation in an integrated control program. Where chemical insecticides have to be used in stores the synthetic pyrethroids, like Fenvalerate, show promise. However, to prolong potential usefulness of such insecticides with low mammalian toxicity their use should be limited and because of the potential development of insect resistance their extensive and indiscriminate use in both fields and stores should be discouraged.

Where water availability and store design permit, the use of water in conjunction with storage structures should be examined as a potential means of reducing tuber moth infestation pressure. In hot dry regions and/or periods, the presence of water through natural evaporative cooling will help reduce the store temperature. Although little or no reduction of store temperature will occur in hot humid areas or periods, the present results together with those of Parker (1981) indicate that the presence of free water on the store walls or on the tubers themselves reduces tuber damage caused by tuber moth. However, the presence of a free water film on tuber surfaces for prolonged periods will greatly enhance the risk of bacterial soft rotting, particularly at elevated storage temperatures.

The use of sex pheromone traps within simple seed stores appears to be a promising and simple means of reducing infestation pressure. The use of simple traps is easily incorporated into an integrated control program.

Thus, it may be concluded that the potential is high for developing an integrated potato tuber moth control program for use in simple diffused light seed stores. Depending on specific local conditions and availability of materials, several components have been identified in the study which merit continued evaluation. However, the control of potato tuber moth in seed tuber stores must not

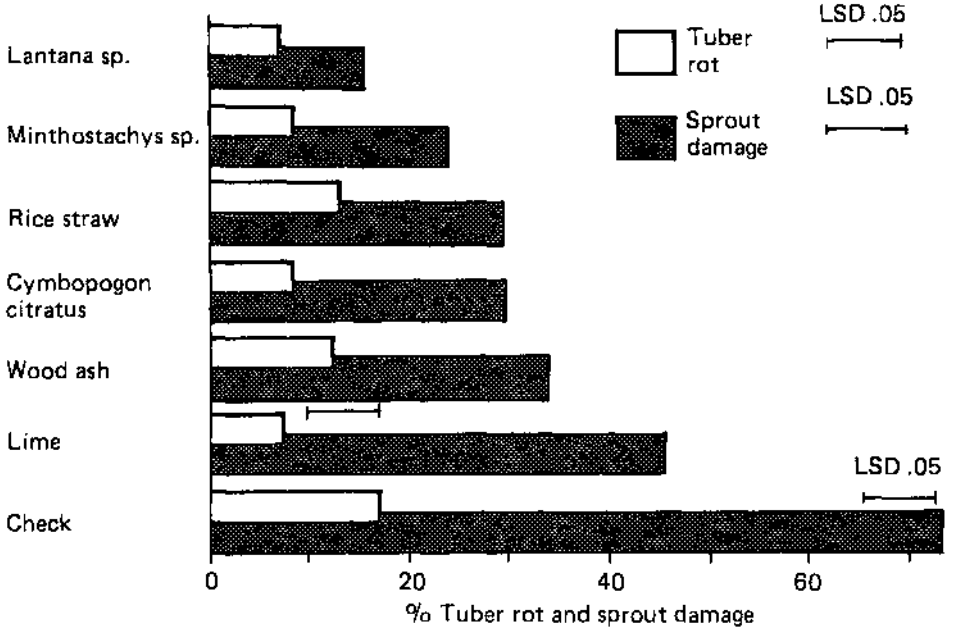


Figure 1. Comparison of some traditional practices for control of P. operculella, San Ramon (1982).

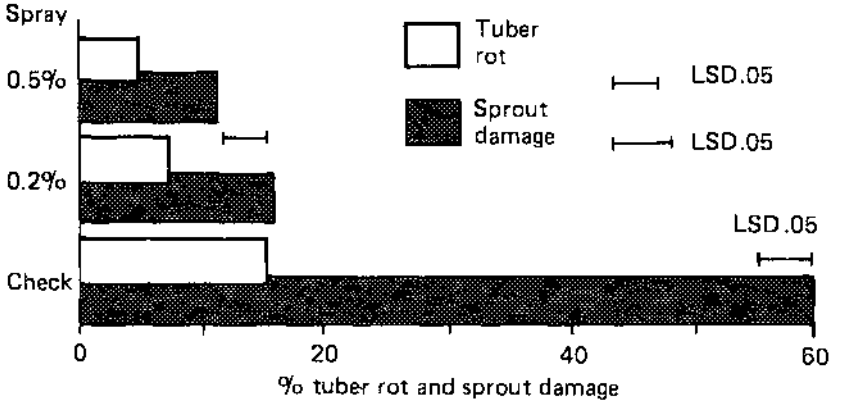


Figure 2. Effect of Bacillus thuringiensis (Dipel) in controlling P. operculella.

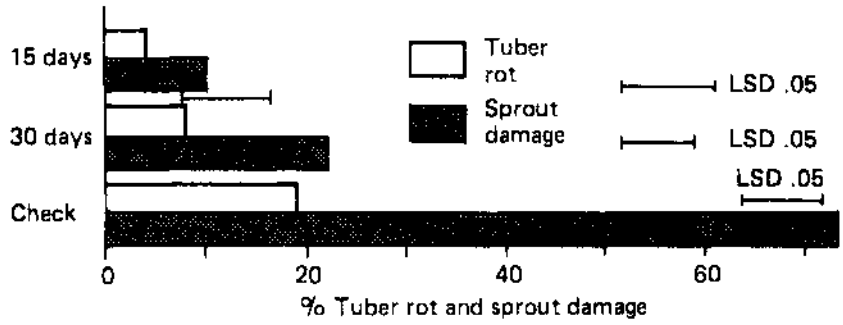


Figure 3. Effect of synthetic pyrethroid (Fenvalerate) at different spray intervals on P. operculella. San Ramon (1982).

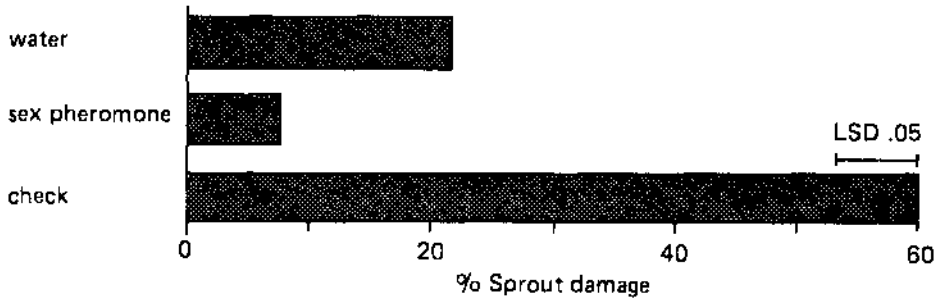


Figure 4. Use of synthetic sex pheromone and water (humidification) for control of P. operculella, San Ramon (1982).

be considered in isolation. The effectiveness of any control system applied during storage is likely to be much greater if the number of already infested tubers coming from the field is reduced through proper selection and the general population of potato tuber moth available to reinfect stores is also reduced. Thus any program aimed at reducing potato tuber moth damage in stores should be closely linked to overall efforts to reduce infestation by this devastating pest.

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Control of Potato Tubermoth (Phthorimaea operculella) Through Crop Association

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ABSTRACT

In studies on effects on crop association on potato tubermoth, leaf and tuber infestations were consistently less in the association plots compared with the sole potato plots. Least damage was found among potato-native tomato and potato-onion associations. Notable differences were found in predator/parasite populations, as well as yields among and between associations and sole potato plots although these were not significant.

The implications of these results and their relevance to overcome threatening pests in lowland tropical (non-traditional) potato environments are offered.

Several investigators have found that certain crop combinations or mixtures affect pest incidence and subsequent damage. In intercropping trials, for instance, it was observed that significantly more diamond backmoth (Plutella xylostella), adults were found on cabbage-tomato intercrop (Buranday and Raros, 1975). Unsprayed cowpeas were observed to be less subject to insect damage when intercropped with sorghum rather than sole cropped (Raheja, 1973). Surayatna and Hardwood (1976) reported significant reduction in corn borer on corn-peanut intercrop compared with plots of pure corn. Potato-sorghum intercrop was found to be more vigorous and less damaged by late blight, Phytophthora infestans compared with sole potato plots (Raymundo and Alcazar, 1982). On the otherhand the disease was very severe in potato-sweet potato plots.

No known published work is known on the effect of crop association on pest infestation on potatoes. This study was undertaken to determine the influence of crop association on the incidence and damage by tubermoth. It is envisaged that results of this study will help identify crop species to be planted along with potato to reduce losses from damaging pests. Data collected could have immense relevance for the lowland humid tropics (non-traditional climates), where mix cropping or polyculture, is popular particularly among small-scale crop growers.

## Materials and Methods

The study was in the summer of 1982 at the Centro Internacional de la Papa (CIP) Experimental Farm, La Molina, Peru. Potato (main crop) was planted in alternate rows with each associated crop. A check plot of sole potato was used for comparison. The potato as well as the associated crops were planted at the same time. The experimental design was randomize block with four replications.

Tubermoth is the most damaging pest of summer-planted potato at the experimental site, hence there was no need for artificial infestation. Various parameters including larva, predator and parasite populations were obtained from time to time. At harvest, data on percent damaged tubers and yields were recorded.

## Results and Discussion

### Leaf infestation

The effects of the various treatments on leaf infestation are shown in Figure 1. Infestation levels were about the same during the first observation (35 days after planting). However, as the season progressed significant differences were found between infestation on sole potato plot compared with some association plots. The potato-native tomato and potato-onion associations consistently registered the lowest infestation level.

### Percent damaged tubers

It is evident that planting potato in association with the crops used significantly reduced pest damage on the tubers (Figure 2). The associated crops are listed in their order of effectiveness: native tomato, onion, Rutjers tomato, *Phaseolus* beans, soybean and corn.

### Predator and Parasite Populations

The associations varied in their effectiveness to attract the predominant parasite, *Apanteles* sp. Similarly, there were differences in their attractiveness to the predominant predatory species, *Chrysopa* sp. (Table 1). Potato-corn and potato-*Phaseoulus* bean plots had more predators per potato plant compared with sole potato plot. Potato-corn registered more parasites per plant compared with sole potato plot. For both predator and parasite population counts, no significant difference between any of the treatments was found.

Table 1. Comparison of predator and parasite population per potato plant on sole-potato plot and in association with other crops.

| | Average predator per plant** | Average parasite per plant* |
|---|---|---|
| Potato alone | 1.4 | 1.9 |
| Potato corn | 1.6 | 2.0 |
| Potato-*Phaseolus* | 1.5 | 1.5 |
| Potato-onion | 1.4 | 1.9 |
| Potato-soybean | 1.3 | 1.9 |
| Potato-tomato (Rutjers) | 1.1 | 1.8 |
| Potato-tomato (native) | 0.9 | 1.5 |

*Predominantly *Apanteles* sp. (Braconidae)

**Predominantly *Chrysopa* sp. (Chrysopidae)

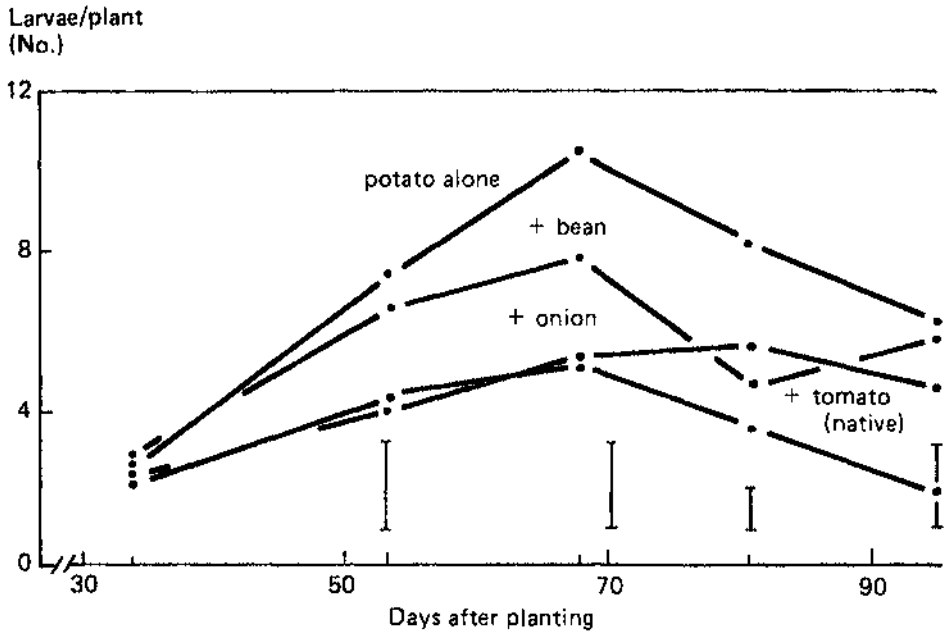


Figure 1. Phthorimaea operculella leaf infestation on potatoes grown in different crop associations. (In total 7 treatments). La Molina, January 1982.

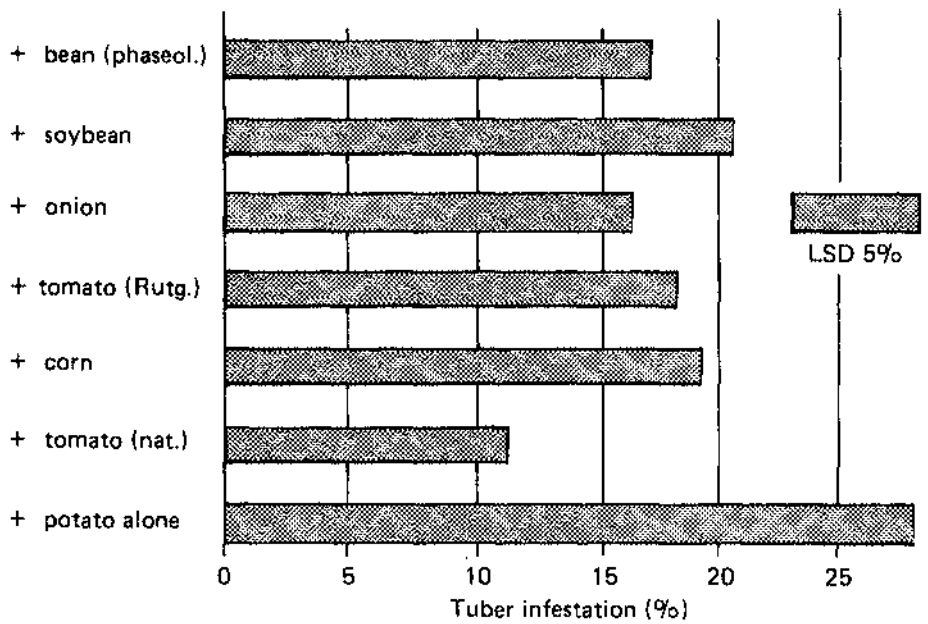


Figure 2. Phthorimaea operculella tuber infestation on potatoes grown in different crop associations. La Molina, January 1982.

## Yields

As shown in yield data (Table 2) potato-soybean, potato-corn and potato-tomato (Rutjers) had higher yields than the sole potato plot; conversely, the potato-native tomato plot gave the lowest yield. No significant difference, however, was found between any of the treatments.

Reduced pest damage in polyculture as opposed to monoculture has been attributed to various factors. The odor of non-hosts in crop mixtures has been found to inhibit pests from feeding on host species (Tahvanaienen and Boot, 1972). Pests sometimes colonize one particular crop in mixtures which then serves as a diversionary host, protecting other possibly more susceptible species (McBeth and Taylor, 1944). One crop may represent a purely physical barrier to the successful establishment of a pest (Pimentel, 1951). Pest control in crop mixtures as influenced by visual effects were reported by Kennedy et al., 1961.

In the foregoing study no attempt was made to identify the mechanism(s) which may explain the pest-reducing effect of the associated crops used. Studies along this line have been initiated.

To be effective as a component of natural control, it is a requisite that predators and parasites be successfully established in the ecosystem where they operate. It is unlikely that a single season was sufficient for the observed predators and parasites to multiply sufficiently and establish themselves. Consequently, no marked differences were found in predator/parasite populations.

Table 2. Yield of potatoes in sole potato plot and in association with other crops.

| | Yield (grams/plant) |
|---|---|
| Potato alone | 495 |
| Potato-soybean | 512 |
| Potato-corn | 506 |
| Potato-tomato (Rutjers) | 499 |
| Potato-onion | 434 |
| Potato-*Phaseolus* | 383 |
| Potato-tomato (native) | 250 |

Physiological factors, such as light and nutrient competition, soil and ambient temperatures, humidity, are likely to explain the differences in yields. For example, it was observed that in the potato-native tomato plot, the potatoes were virtually covered by the creeping stems and branches, and lush foliage of the associated crop (native tomato). Such a situation is certain to have markedly contributed to the resultant low yields. It is extremely important that for meaningful interpretation of yield data and profitability of certain crop associations agronomic requisites such as optimum spacing, time of planting, and other recommended agronomic practices should be taken into account.

The results presented give evidence that planting potato in association with other crops could prove beneficial in reducing tubermoth, a threatening potato pest under warmer environments. In the continuing pursuit of expanding potato cultivation, particularly into the lowland humid tropics, it seems that crop association could have a suitable place in the formulation of uni- or multi-component, sound and viable pest management technologies.

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Interaction of Phosphate Fertilizer and Cyst Nematode Infestation (*Globodera pallida*), in Two Potato Cultivars

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ABSTRACT

Effect of different phosphate fertilizer rates (10, 120, and 240 ppm) on the yield of two potato cultivars, 'Renacimiento' (potato cyst-nematode tolerant) and 'Revolucion' (nontolerant to potato cyst-nematode) inoculated with *Globodera pallida* pathotype P4A was investigated under greenhouse conditions.

Results indicate a significant yield increase in the cyst nematode-inoculated plants treated with phosphate application as compared to those in the treatments receiving either nematodes alone or no phosphate. Although nitrogen or potassium application increased yield, nitrogen effect was more significant than that of potassium application.

## Introduction

The primary effects of potato cyst nematode infection are on root growth and function, with secondary effects on rates of haulm growth and senescence, which in turn affect tuber yield.

Various evidences suggest that nematodes affect, P, K, Mg, and Ca uptake and their translocation to the tops (Sher, 1957; Kirkpatrick, et al., 1964; Oteifa and El-gindi, 1962).

Trudgill et al., (1975) found that nematodes decreased significantly the amount of K in the haulm dry matter. Carpenter (1957) also suggested that heavily infected plants were chronically K-deficient and that the rate of K uptake limited haulm expansion. As nematode numbers increased, the amount of K, Mg, or P, in haulm decreased greatly. Amount of N was unaffected but Ca and Na increased two fold. These changes in concentration probably explain the results of Stelter and Mein (1969), who measured the total ash content of cyst-nematode infected potato plants and concluded that nematodes affected uptake of neither nutrients nor water. Other investigators have reached similar conclusions for different nematode/crop associations (Hunter, 1958; Jenkins and Malek, 1966; Bergeson, 1968).

As potato is the main crop in Peruvian Andean region and most of the soils are acid, poor in P, organic matter and nitrogen, and mostly infested with the potato cyst nematode, information on mineral nutrition related with nematode attack and damage is warranted.

Present study was to determine effect of P on potato cyst-nematode multiplication rate and plant behavior of a non-tolerant cultivar ('Revolucion') and a tolerant cultivar ('Renacimiento').

## Materials and Methods

The experiment was conducted under screenhouse conditions in La Molina, Lima, Peru, during June to September, 1981. Treatments were arranged in completely randomized block design with a factorial disposition.

Fertilizers and cyst inocula (i.e. 20 eggs/g of soil) were incorporated and mixed with soil substrate before planting two tuber buds of the cultivars Renacimiento and Revolucion per pot.

The rates of nitrogen and potassium as potassium sulphate (50% $K_2O$) and amonium nitrate (33% N) were constants (160 ppm of N and $K_2O$). However, levels of phosphorus as simple superphosphate (20% $P_2O_5$) varied (0, 120 and 240 ppm $P_2O_5$). Additional treatments were included only for the nontolerant cultivar Revolucion to cover the addition and/or deficiency of N, P and K. The last two additional treatments were used as potassium magnesium sulphate (32% $K_2O$ + 8% Mg) and potassium sulphate (53% $K_2O$).

Pot moisture was maintained at field capacity. Three and a half months after planting the foliage was cut and tubers and roots removed from soil. Afterwards data on fresh and dry weight of roots, tubers and foliage were taken. Cyst of *G. pallida* were extracted from soil samples of nematode inoculated plants and final nematode density (pf) was determined and nematode multiplication rate (Pf/Pi) was calculated.

## Results and Discussion

Renacimiento had less fresh matter weight in roots and tubers than Revolucion (Table 1). This probably is because Renacimiento is a "late" variety (5 to 6 months); as contrasted to Revolucion (4 months) and the time allowed for its full growth was short. However, compared to the control, reduction of fresh top weight due to nematode damage was higher in Revolucion (35.6%) than in Renacimiento (26.2%) in inoculated plants (Figure 1). This effect was even more dramatic with the tuber yield where Revolucion showed a greater yield reduction (59.0%) than Renacimiento (23.7%), indicating its poor capacity to tolerate root damage caused by nematode invasion.

Estimated nematode multiplication rate for these two cultivars indicate a higher multiplication rate in Revolucion than Renacimiento (29.9x and 23.7x, respectively). These results would reflect on slow development of Renacimiento, which did not allow a proper nematode multiplication. As level of phosphorus per plant was increased (0, 120 and 240 ppm of $P_2O_5$), weight of roots and total fresh weight of both cultivars also increased. However, response of Revolucion was better than Renacimiento (Figure 2a). This could be due to a more rapid root development in Revolucion and consequently higher phosphorus absorption.

Table 1. Effect of two potato cultivars on the fresh weight of haulm, roots and tubers.

| | Fresh matter weight (g/pot) No infested | | | |
|---|---|---|---|---|
| Cultivar | Foliar | Root | Tuber | Total |
| Revolucion | 97.1 | 35.7 | 61.7 | 194.5 |
| Renacimiento | 99.6 | 27.5 | 13.9 | 141.0 |

Similarly, as the level of phosphorus was increased the number of cysts also increased in Revolucion (Figure 2b). However, when 240 ppm of $P_2O_5$ was applied, the final number of larvae per g of soil and nematode multiplication rate (680 and 34.3x) was lower than the application of 120 ppm of $P_2O_5$ (950 and 47.6x). Similar results in final nematode density and nematode multiplication rate were observed with Renacimiento. This reduction in the multiplication rate of the potato cyst nematode at the high rates of phosphorus would indicate either an inhibitory effect on the cyst viability egg content or on the root morphology since the number of cysts and fresh root weight were increased with this rate.

Although inoculated and noninoculated plants showed similar response to phosphorus levels, the fresh roots weights of the inoculated plants were lower than those without nematodes (Figure 3).

Results of additional treatments indicate that the total biomass (foliage, tubers and roots) increased as one of the nutrients was added to the fertilization (Figure 4a).

Tuber weight (Figure 4b) in noninoculated plants was significant, higher than inoculated (with and without nematicide) ones as single nutrients were added. Although infected and nematicide-treated plants showed similar response, yield was higher in the nematicide-treated plants. These results indicate a significant plant response to the three major nutrients, and no significant differences between sources of K.

Although nematode multiplication rate was increased as major nutrients were added, it was lower in nematicide-treated plants as compared to control (Figure 5), indicating a partial control effect.

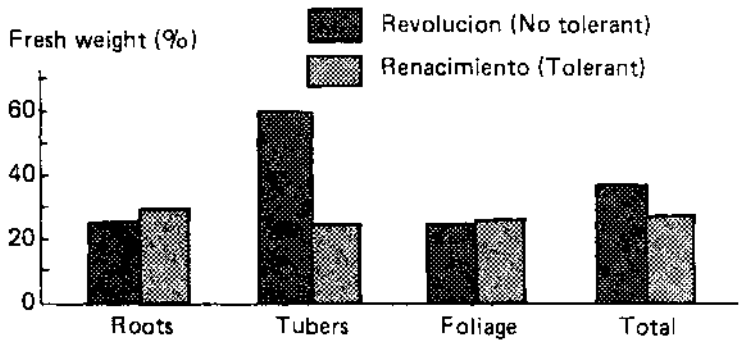


Figure 1. Percentage of reduction in fresh weight of two potato cultivars with different reaction to the potato cyst nematode G. pallida.

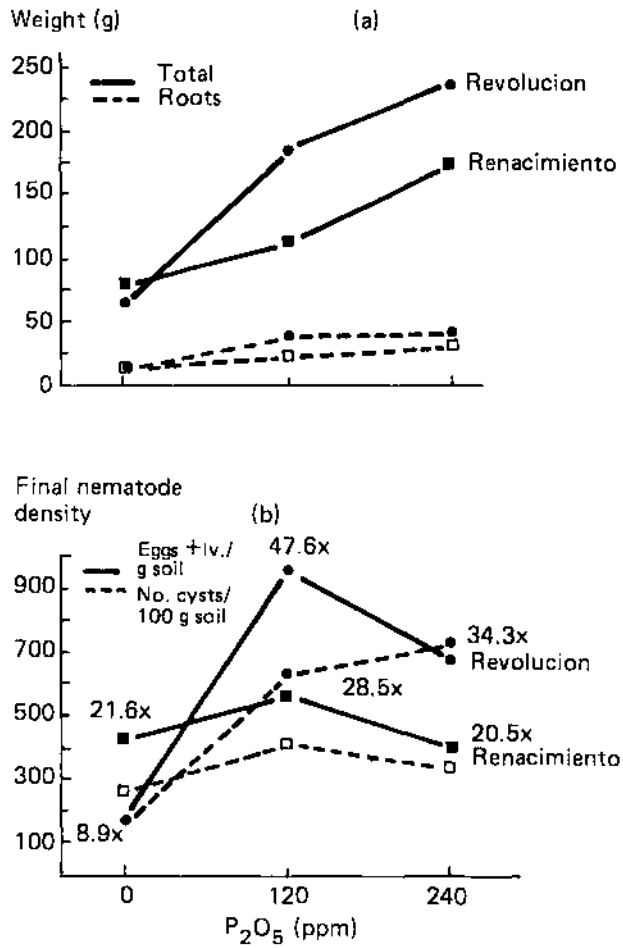


Figure 2. Effect of three phosphorus levels on: (a) the fresh weight and (b) potato cyst nematode multiplication rate in two potato cultivars.

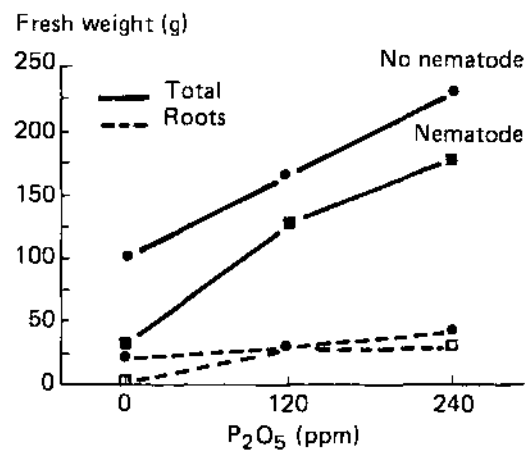


Figure 3. Comparative effect of three phosphorus levels on the fresh weight of potato cyst nematode infected and noninfected potato plants.

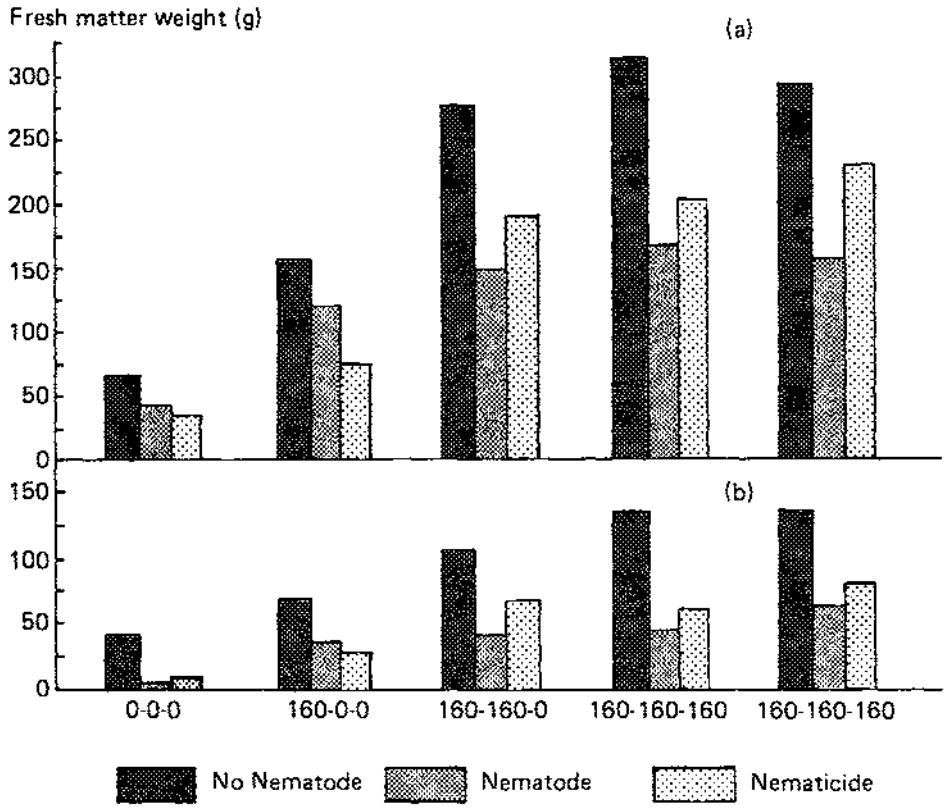


Figure 4. Effect of different rates of fertilizers and nematicide on: (a) total fresh weight and (b) tubers weight of G. pallida-infected and noninfected potato plants.

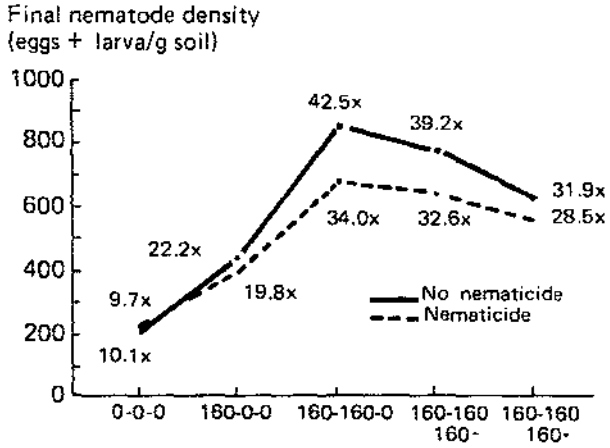


Figure 5. Effect of fertilizers and nematicides on the multiplication of the potato cyst nematode G. pallida.

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Diseases and Pests of the Potato in Sri Lanka: 1975-1982

Authors: Velupillai, M. and French, E. R. Dept. of Agriculture-Sita Eliya, Nuwara Eliya, Sri Lanka; and International Potato, Lima, Peru.

ABSTRACT

Late blight (Phytophthora infestans) was the most damaging disease, though limited to the Central highlands of Ceylon Island. The testing of Mexican cultivars led to the development of resistant varieties Krushi and Sita. Spongospora subterranea was damaging to a very susceptible one of these cultivars. Fusarium oxysporum and F. solani caused dry rot of tubers stored for seed, which when planted in the hot irrigated lowlands at Kalpitiya and Jaffna peninsulas caused poor emergence or wilt. Sclerotium rolfsii was damaging to some tuber families tested for adaptation to Jaffna. Close by at Odduchuddan, Mullaittivu District, Choanephora cucurbitarum and Meloidogyne incognita damaged potatoes suffering drought.

Bacterial wilt (Pseudomonas solanacearum) was constantly present in paddy land of Badulla District and periodically infected potatoes through-out the highlands, from where it occasionally spread latent in tuber seed to the lowlands, not persisting there. Erwinia spp. caused blackleg throughout the potato growing areas, but incidence was very low.

PLRV developed from seed grown during drought years in Europe. Roguing eliminated it from subsequent crops. Mosaic symptoms were rare.

The mite Polyphagotarsonemus latus was most severe in Jaffna. The aphid Rhopalosiphoninus latysiphon was determined feeding underground at the highest elevation potato seed farm, Uda Radella.

# Tissue Culture and Seed Potato Production in Vietnam

Authors: Nguyen Van Uyen, Research Center for Experimental Biology, Ho Chi Minh City, Vietnam.

ABSTRACT

Work was conducted to establish tissue culture methods for the rapid multiplication of potato for seed production. The intensive procedure developed comprises six steps, using sterile *in vitro* conditions in the first and semi-sterile or field conditions in the other steps. Single node cuttings, obtained from healthy clones maintained *in vitro*, were used as starting propagula, and the subsequent steps were carried out using cuttings from test tube cultures and grown on sand, enriched soil mix, and then potted. Potted plants were used for high density field transplanting. In the last step, small tubers from the field were handed to seed production cooperatives for seed production.

Based on the results of this research, a station for Seed Potato Multiplication could handle 10,000 test tube cultures and produce 1500 tons of low virus seed potato every year.

# Fertilizer N Use Efficiency and Associative $N_2$-Fixation of Sweet Potato

Author: W.A. Hill and P. Bacon, Department of Agricultural Sciences, Tuskegee Institute, Alabama 36088, USA.

## ABSTRACT

Experiments evaluated potential mechanisms for minimizing fertilizer N requirements of sweet potato (*Ipomoea batatas*). The response of four sweet potato cultivars to drip 'fertigation' (DF), drip irrigation + granular N (DI) and nonirrigation + granular N (NI) were compared. Method of N application significantly influenced yield, dry matter and N recovery.

Isotopically labeled fertilizer at 18 kg N/ha was applied to 'Jewel' sweet potato at 3-week intervals for 15 weeks. Three weeks after each application, roots and foliage were analyzed for fertilizer N recovered. Fertilizer N recovered in foliage and storage roots was greatest when applied at 6 and 12 weeks after transplanting respectively.

Nitrogenous activity of fibrous roots from six sweet potato cultivars was determined with acetylene reduction assay. Nitrogenous activity of fibrous roots ranged from 66 to 465 nmoles $C_2H_4$/h/g depending on the cultivar. Sixteen $N_2$-fixing bacterial isolates with morphological characteristics similar to *Azospirillum* were isolated in vitro. Nitrogenase activities of single colonies ranged from 32 to 472 nmoles $C_2H_4$ per culture-h.

The recommended rate of fertilizer N for optimum production of sweet potato ranges worldwide from 0 to 146 kg N/ha and depends on soil type, variety, climate, cropping system, product use and availability of fertilizer (Hill, 1982). Time and method of fertilizer N application influence yield, N uptake and quality of sweet potatoes (Alexander et al., 1976; Hammet, 1981; Miller and Covington, 1982) and may influence fertilizer N use efficiency. The fact that only 38% to 50% and 30% to 80% of applied fertilizer N is recovered by sweet potato and other annual crops, respectively, indicates a need to increase fertilizer nitrogen use efficiency in crop production (Hill, 1982; Hauck, 1978; Tucker and Hauck, 1978). Part of the reason for the low fertilizer nitrogen recovery can be attributed to leaching, denitrification, volatilization and immobilization. In 1980, these processes resulted in an estimated loss of 13-35 million metric tons of applied fertilizer throughout the world (Harris and Harre, 1979).

Through sweet potato is drought tolerant, if supplemented by irrigation, yield can be increased (Constantine et al., 1974). Drip irrigation is known for its high water efficiency and it provides a ready source of soil moisture to the 'root sorption zone.' Drip irrigation can supply plants with nutrients

(drip 'fertigation') such as nitrogen, in controlled amounts during the growing season (Bresler, 1977; Jammis, 1980).

An alternate approach to reducing fertilizer nitrogen requirement is to develop plant-bacterial associations that result in biological nitrogen fixation of non-legumes (Neyra and Dobereiner, 1977; van Berkum and Bohlool, 1980).

The objectives of this study were to: evaluate the effect of drip 'fertigation' on yield and N uptake of sweet potato; determine the effect of time of N-15 depleted fertilizer N application on the uptake and distribution of N in sweet potato; and evaluate biological $N_2$-fixation associated with sweet potato roots.

## Materials and Methods

### Drip 'Fertigation' Study

Sweet potato slips of four cultivars ('Jewel', 'Carver', Centennial' and 'Rojo Blanco') were transplanted on May 28, 1981, into Norfolk sandy loam; rows were 1.2 m wide and 4.2 m long. Treatments were drip irrigation + granular N (DI); drip 'fertigation' (DF); and, nonirrigation + granular N (NI). Fertilizer nitrogen was ammonium nitrate ($NH_4NO_3$) applied at 90 kg/ha. For the DI and NI treatments fertilizer N was split applied: half before transplanting and half 6 weeks after. The DF treatment consisted of five applications of fertilizer N applied at 18 kg/ha every 3 weeks through the drip lines. Phosphorus and potassium were applied, based on soil test, by broadcast and incorporation prior to transplanting. The experimental design was a randomized complete block with irrigation treatments as blocks and four replications of each cultivar in each block.

Sweet potato roots and foliage were harvested on October 22, 1981, graded, and analyzed for percent dry matter, and total N content (Bremner, 1965).

### Depleted N-15 Uptake Study

'Jewel' sweet potato slips were transplanted on May 28, 1981, into rows 1.2 m wide and 4.2 m long. Each row represented a different treatment and was replicated three times. The treatments were the times/date of N-15 depleted ammonium nitrate application. Figure 1 shows times/dates of application of labeled and unlabeled ammonium nitrate. Times coded with "X" and without "X" indicate N-15 labeled and unlabeled ammonium nitrate, respectively. At each application time, 18 kg N/ha was dissolved in 23.4 liters of water and 0.6 liters of this solution was injected into the 'root sorption zone' of each plant in the designated rows. The experimental design was a randomized complete block design with three replications.

Three weeks after each application of fertilizer N, two plants from the exterior end of each row were sampled by digging the entire plant. Plants were washed, air dried and separated into leaves, stems, and roots. Storage roots were distinguished from fibrous roots by color and size. Total N was determined and isotope ratio analysis was carried out by mass spectrometry (Bremner, 1965).

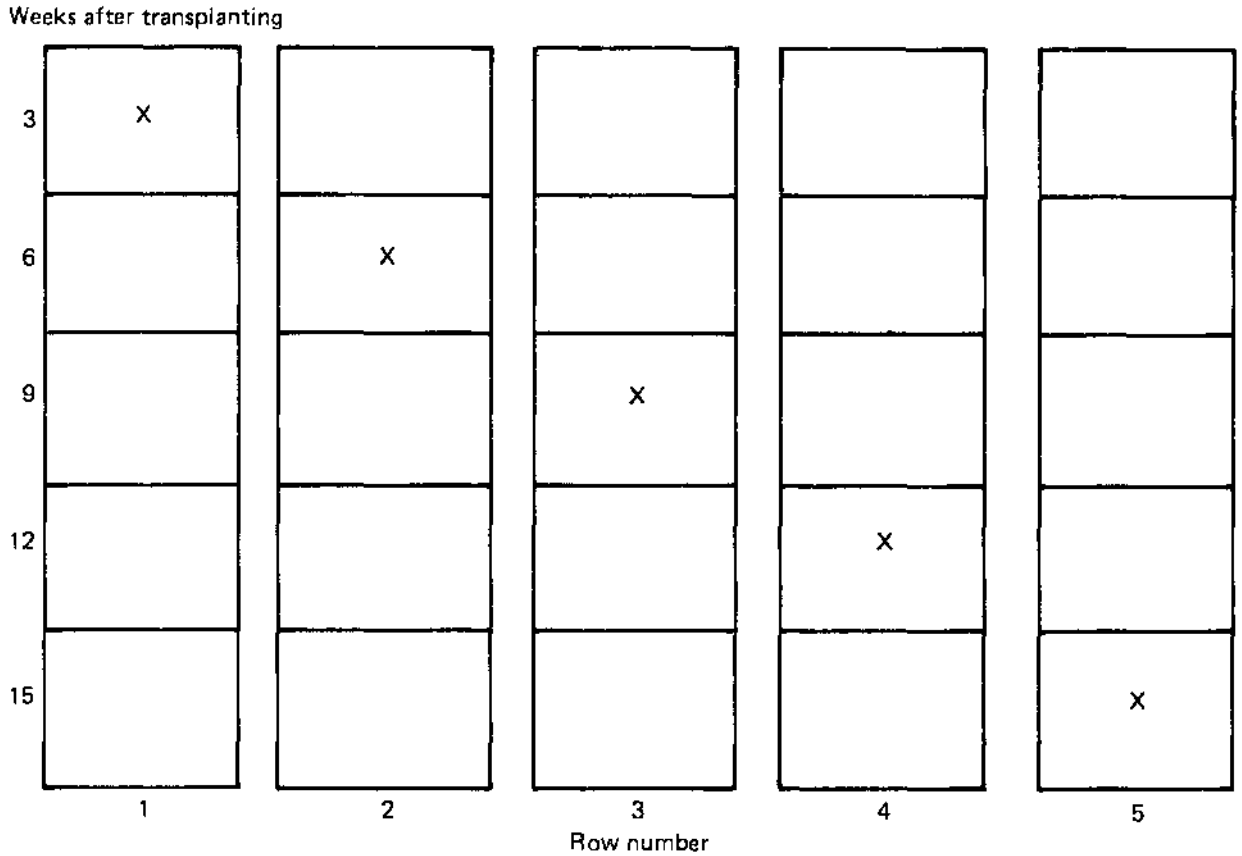


Figure 1. Time of application of N-15 depleted fertilizer N.

## Associative $N_2$-Fixation Potential

A greenhouse experiment was conducted with six sweet potato cultivars ('Jewel', 'Rojo Blanco', 'Southern Queen', 'Haymen Yam', 'Centennial' and 'Carver'). Cuttings of the six cultivars were placed into 10x10 cm and 20x20 cm black plastic pots containing Norfolk sandy loam in a complete randomized design with three replications. After growth for 3 months, soil was taken from the roots and placed into 500 ml Mason jars with rubber ports. Nitrogenase activities of roots were determined using the acetylene reduction assay (van Berkum, 1980).

Washed roots (5 mm in length) were incubated in nitrogen free semisolid malate medium (Dobereiner, 1980). Cultures that yielded greater than 30 nmoles $C_2H_4$ reduction per culture-h were identified as positive. Serial dilutions were

made onto semisolid medium and microscopic examination used to verify the presence of Azospirillum.

## Results and Discussion

Table 1 shows the influence of drip irrigation and fertilizer N application method on yield of sweet potato grades. US #1's and canners tended to be higher for DF and NI than DI. Jumbos and marketable yields were significantly higher for DF and NI than DI. Cracks and nonmarketable yields were significantly higher for DF and DI than NI. Total yields were 25% higher with DF than DI or NI though the difference was not significant at the 5% level. These results show that DI was inferior to DF and NI in production of marketable sweet potatoes. DF was the best method for obtaining optimum yield production, if nonmarketable grades of sweet potatoes are used to produce ethanol for gasohol production or as a supplement in animal rations.

Table 1. Effect of drip irrigation and fertilizer N application method on sweet potato grade categories (US #1's, canners, jumbos, culls and cracks) and total yield.

| Grade | DF (kg/ha) | DI (kg/ha) | DI (kg/ha) |
|---|---|---|---|
| US $1's | 7,084 a* | 5,402 a | 6,627 a |
| Canners | 2,772 a | 1,743 a | 1,839 a |
| Jumbos | 3,545 a | 1,281 b | 5,064 a |
| Culls | 817 a | 1,403 a | 1,069 a |
| Cracks | 6,250 b | 6,696 b | 2,166 a |
| Total marketable | 13,401 a | 8,426 b | 13,531 a |
| Nonmarketable | 7,067 b | 8,099 b | 3,235 a |
| Total | 20,468 a | 16,525 a | 16,166 a |

*Mean separation within rows using Duncan's multiple range test, 5% level.

Data in Table 2 show the effect of drip irrigation and fertilizer N application method on percent dry matter, total N and percent protein of sweet potato. The percent dry matter was higher for NI than DI, and was lowest for DF. These results were similar to those found by Constantine et al., (1974) using sprinkler irrigation. Since the percent dry matter is directly related to storageability, roots grown with DF would be expected to have better storageability than with DI, and poorer storageability than with NI.

A significantly lower ($P < .05$) foliage dry weight was produced with DF than with DI. There was a tendency for lower foliage dry weight with NI than DI. The results in Tables 1 and 2 indicate an inverse relationship between foliage dry weight and marketable yield of sweet potato. The DI treatment apparently increased foliage growth at the expense of marketable roots, when compared to the DF and NI treatments. DF had a significantly lower percentage of protein in roots and foliage and lower total N in foliage compared to DI. The lower N recovery explains the significantly lower foliage growth with DF than DI and possibly resulted from lower N availability and uptake during maximum growth of the foliage. Protein content in roots was highest with NI and highest in foliage with

DI. These findings may prove important if present studies of sweet potato foliage as a vegetable source indicates that protein content influences marketability. Cultivar comparisons (data not shown) indicate that DF may be a beneficial cultural practice for increasing total yields of 'Jewel', 'Rojo Blanco' and 'Centennial' but not of 'Carver'.

Table 2. Effect of drip irrigation and fertilizer N application method on dry matter, % dry matter, total N and % protein of sweet potato.

| | DF | DI | NI |
|---|---|---|---|
| % Dry matter | 32.1 b* | 30.8 a | 32.6 c |
| Foliage dry matter | 2,788 a | 4,337 b | 3,459 ab |
| Total N/ha | | | |
| Roots | 26.0 a | 31.2 a | 46.0 b |
| Foliage | 31.0 a | 47.7 b | 57.4 b |
| % Protein | | | |
| Roots | 2.6 a | 3.9 b | 5.2 c |
| Foliage | 6.9 a | 9.8 b | 7.4 a |

*Mean separation within rows using Duncan's multiple range test, 5% level.

Percent labeled N recovered by sweet potato foliage and roots at different times showed highest nitrogen recovery occurred when nitrogen was applied at 6 and 12 weeks after transplanting for foliage and roots, respectively. There was a substantial decrease in percent fertilizer N recovered in foliage for N applied at 9 to 12 weeks after transplanting, while nitrogen recovered in storage roots increased during this period. The decrease in N recovered in leaves and fairly uniform recovery in storage roots after 9 weeks most likely is related to the fact that storage root initiation begins roughly 9 weeks after transplanting for many sweet potato cultivars (Onwueme, 1978) and once initiation begins the storage roots become the major sink for nutrients.

The percent labeled N recovered from N applied at 12 and 15 weeks decreased in leaves, tended to level off in fibrous and storage roots, and tended to increase in stems. The latter result most probably occurred because stems can act as an intermediate sink for temporary storage of nutrients required in other plant parts during periods of stress or maximum demand. Greatest percent of labeled N (29%) recovered by roots plus foliage occurred for N applied at 6 weeks after transplanting. These results suggest that sweet potato utilizes most of the fertilizer N when applied between 3 and 9 weeks after transplanting.

The rates of nitrogenase activity of fibrous roots of five sweet potato cultivars are in Table 4. Rates range from 66-465 nmoles $C_2H_4$/h per g dry root depending on cultivar and pot size used to measure the rate of acetylene reduction. The rates of acetylene reduction are comparable to results reported from grasses. Endogenous ethylene production and ethylene oxidation by excised roots were found to be negligible.

Table 3. Storage root weight and nitrogenase activity of excised fibrous roots of six sweet potato cultivars grown in 10x10 vs 20x20 cm pots. The rate of acetylene reduction was determined from gas samples taken at 1-8 h after injection of acetylene. The results are means of three replications ± standard error.

| | 10x10 cm pots | | 20x20 cm pots | |
|---|---|---|---|---|
| Cultivar | Nitrogenase activity nmoles $C_2H_4$/g dry root-h | Fresh weight of storage root (g) | Nitrogenase activity nmoles $C_2H_4$/g dry root-h | Fresh weight of storage root (g) |
| Carver | 287 ± 44 | 4.2 ± 1.1 | 465 ± 290 | 15.5 ± 7.2 |
| Jewel | 185 ± 0 | 0.0 ± 0.0 | 322 ± 0 | 6.2 ± 2.6 |
| Centennial | 71 ± 12 | 0.0 ± 0.0 | 68 ± 25 | 21.3 ± 7.0 |
| Rojo Blanco | 155 ± 10 | 7.2 ± 1.2 | 86 ± 10 | 66.1 ± 9.1 |
| Haymen Yam | 311 ± 55 | 8.2 ± 2.8 | 426 ± 146 | 25.0 ± 11.2 |
| Southern Queen | 205 ± 53 | 4.7 ± 4.7 | 66 ± 11 | 34.7 ± 3.7 |

Table 4. Acetylene reduction of $N_2$ fixing isolates from five sweet potato varieties.

| Variety Isolates | nmoles $C_2H_4$ per culture-h ± S. E. |
|---|---|
| Jewel | |
| TI-sp-1 | 137 ± 17 |
| TI-sp-2 | 32 ± 2 |
| TI-sp-3 | 191 ± 49 |
| Centennial | |
| TI-sp-4 | 44 ± 18 |
| TI-sp-5 | 309 ± 120 |
| TI-sp-6 | 198 ± 128 |
| *TI-sp-16 | 472 ± 232 |
| Rojo Blanco | |
| TI-sp-7 | 146 ± 8 |
| TI-sp-8 | 274 ± 189 |
| TI-sp-9 | 214 ± 8 |
| TI-sp-10 | 66 ± 40 |
| Southern Queen | |
| TI-sp-11 | 231 ± 42 |
| TI-sp-12 | 94 ± 52 |
| TI-sp-13 | 163 ± 60 |
| Carver | |
| TI-sp-14 | 180 ± 8 |
| TI-sp-15 | 403 ± 43 |

*TI-sp-16 was isolated from the skin of the storage root. All other isolates were from fibrous roots.

All enrichment cultures contained dense white pellicles 1 mm below the N-free malate medium surface, which is a characteristic of Azospirillum. Microscopic examination of pure cultures revealed organisms similar in morphology and motility to Azospirillum spp. (Tarrand et al., 1978). Nitrogenase activity of isolates ranged from 32 to 472 nmoles $C_2H_4$ per culture-h (Table 4). TI-sp-15, TI-sp-5 and TI-sp-8 resulted in highest nitrogenase activities. Biochemical characterization of the 16 isolates (Hill et al., 1983) suggests that A. brasilense and A. lipoferum associate with sweet potato roots. These results and work by others (Cohen et al., 1980; Dobereiner, 1978) suggest that associative $N_2$-fixation of sweet potato be further explored.

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# Genotype by Environment Interactions of the Yield Components in Sweet Potato

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## SUMMARY

A multilocal trial of sweet potato was set up in six different environments of Rwanda. Yield and its related components were observed. Genotype by environment interaction was important. There was a strong stress between number of tubers per unit area and average tuber weight. The latter trait was environmentally controlled. Under low-yielding conditions, translocation limitation seems to be more important than sink limitation. Yield related traits arise from parallel ontogenesis, though with relayed emphasis. No relation could be found between yield stability and stability of the yield components. Survival ability may shadow yield stability.

## Introduction

Sweet potato growing in the Central African Highlands has to match a tremendous variability of ecological conditions. Traditional agriculture has met these variable requirements with a wealth of different local varieties. The breeder must know if breeding of new clones should be directed toward obtaining new cultivars with high environmental adaptability, and, if so, which characters are likely to contribute most to the achievement of yield stability across different environments. Among the many proposed stability parameters the "ecovalenz" parameter of Wricke (1962) is usually satisfactory. Grafius (1965), Institut des Sciences Agronomiques du Burundi (ISABU) B.P. 795, Bujumbura - Burundi pointed out that to be stable, a variety should have the longest edge of its yield parallelepiped subject to the stronger GXE interactions. GXE interactions were found to be stronger the more remote the concerned characters was in the ontogenetic sequence (Thomas et al. 1971), e.g. grain weight was more subject to GXE interaction than number of heads. Jong (1974), Lowe and Wilson (1975), Pushkaran et al (1976), Mahungu (1979), Janssens (1980), all indicated the overwhelming importance of number of tubers per unit area as yield contributor. Significant clone by environment interactions have been mentioned in sweet potato (Jong, 1974; Jong and Park, 1975; Shukla, 1976; Mahungu, 1979; Li, 1979; Saladaga, 1980; Baert, 1982). The clone by season interaction variance components for tuber yield and for average tuber size were found to be larger than the respective clone variance components (Jong, 1974).

## Materials and Methods

A multilocal trial of 27 sweet potato clones was established in Rwanda (Central African Highlands). The trial was repeated across six different environ-

ments, comprising three different locations (Karama, Rubona, and Rwerere), as well as two different sites within each location, once on the hill and once in the swamp. Within each environment, the 27 clones were repeated over two randomized blocks. Plots were 4 $m^2$ in size in a 2 x 2 m square configuration. Each plot consisted of four 1 $m^2$ hills, and planting density was 8 cuttings per hill. No provision was made for guard rows, as sweet potato in the Central Highlands of Africa is grown in varietal mixtures. Hence, clones should be identified which combine a good yield potential with a strong intergenotypic competitivity (Janssens, 1980). Growing period was about six and a half months and coincided for the three hill sites with the 1981-B season (March-September), and with the 1981-C season (May-November) for the three swamp sites. The dry season spans July to September, inclusive.

In each environment, observations were made on the following traits: total number of tubers per plot (X), fresh tuber yield per plot, and fresh vine (i.e. stems + leaves) yield per plot (S). A random sample of two or three tubers was taken for each of the 27 clones, within each environment, and analyzed for dry matter content (Z). Two secondary traits were deduced: average fresh tuber weight (Y), and dry tuber yield (W). The latter trait corresponds to the yield parallelepiped according to Grafius (1965) and Mahungu (1979). Dry matter content (X) was unweighted such that the product X.Y.Z. does not always amount to W.

Classical multi-environmental analysis of variance was performed on all traits, assuming fixed effects both for environments and genotypes.

The stress matrix was established and the standardized partial regression coefficients on yield (W) were calculated for each of the six environments according to Hamid and Grafius (1978). Environmental stability (ecovalence) was estimated for each trait and for each clone, using the V-values of Wricke (1962). Each V-value is defined as the specific contribution of a given clone to the total sums of squares for GXE interaction. The correlation matrix of the V-values among the different traits was calculated to identify which yield components contributed most to yield (W) stability.

The 27 clones are a mixture of local varieties, selections from the breeding work of Dr. Hahn at IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria), accessions and selections made by the former INEAC (Institut des Sciences Agronomiques du Congo Belge) before 1960 (Lemarchand, 1956), and 15 of the author's selections. The standard variety was cv. Rusenya, a local variety originating from the border of Lake Kivu.

## Results and Discussion

### Environmental characterization

For each trait the environmental mean is given in Table 2. If Rubona was best for number of tubers, Karama was better for average tuber weight. Dry matter content was best in Rubona. Swamp conditions did not decrease dry matter content (28.2% vs. 27.7% on the hill), as would be expected (Ton and Hernandez, 1978). The shorter photoperiod and the drier conditions of season C are favorable for tuberization (Hahn, 1977) and have largely compensated for the moisture stress of the swamp conditions. Karama 81-C and Rubona 81-C have comparable dry weight yields although achieved through different ways. The former environment is conducive of large average tuber weight and vine yield, whereas the latter compensates its low Y by above average number of tubers (X) and dry matter content (Z)

(Table 2). In the high elevation of Rwerere (Table 1), three components are below average: X, Y and to a lesser degree, S (vine yield).

Table 1. Location characteristics.

| | | Karama | Rubona | Rwerere |
|---|---|---|---|---|
| Elevation (m) | | 1,347 | 1,650 | 2,060 |
| Aver. Yearly Temp.(°C) | | 21.3 | 19.9 | 14.3 |
| Aver. Yearly Max. Temp. | | 28.4 | 25.1 | 22.6 |
| Aver. Yearly Min. Temp. | | 14.3 | 14.6 | 5.9 |
| Aver. Yearly Precip. (mm) | | 899 | 1,171 | 1,096 |
| Aver. Nr. of Sun Hours/Year | | 22,869 | 21,817 | 17,852 |
| Aver. Yearly Evaporation (mm) | | 1,440 | 1,380 | 836 |
| Polar Coordinates | | 30°17'E;02°16'S | 29°46'E;02°29'S | 29°53'E;01°30'S |
| Soil Type | 81-B | Xero-Kaolisoil | Humic Kaolisoil | Kaolisoil |
| | 81-C | Hygro-Xero Kaolisoils | Grey Hydromorphic Soils | Grey Hydromorphic Soils |

Table 2. Environmental performances.

| Trait | Karama 1981-B | Karama 1981-C | Rubona 1981-B | Rubona 1981-C | Rwerere 1981-B | Rwerere 1981-C | Global Analysis |
|---|---|---|---|---|---|---|---|
| Number of tubers/$m^2$ | 7.7 | 13.0 | 21.9 | 18.9 | 6.7 | 6.8 | 12.5 |
| Average tuber weight(g) | 73.7 | 145.0 | 60.9 | 62.4 | 47.1 | 31.1 | 70.0 |
| Fresh weight yield ($g/m^2$) | 353.2 | 1701.0 | 1346.7 | 1161.0 | 346.0 | 215.0 | 854.0 |
| Dry matter content (%) | 25.9 | 26.3 | 30.1 | 34.1 | 27.2 | 24.1 | 27.9 |
| Dry weight yield ($g/m^2$) | 92.2 | 441.0 | 391.0 | 398.0 | 94.7 | 52.7 | 245.0 |
| Fresh vine yield ($g/m^2$) | 745.7 | 2520.2 | 1179.0 | 1015.2 | 904.7 | 420.2 | 1131.0 |

Sequence and genetic importance of the respective components

From the analysis of variance it appears that Y (average tuber weight) was not under significant genetic control, but mainly under environmental control, suggesting that sink limitation (Hahn, 1977) is less important, if not absent, under low yielding situations, and that component compensation (Adams, 1967) will alleviate, if necessary, insufficient sink size. The X and Y yield components had GXE interaction variance components which were larger than the respective genotype variance components viz. 22.4% vs. 13.1% and 11.1% vs. 2.0% in accordance with Jong (1974). Dry matter content (Z) and fresh vine yield (S) had their respective

GXE and genotype variance components of similar size, 32.6% vs. 31.9% and 20.7% vs. 23.1%. Dry tuber yield (W) had intermediate variance components, respectively 11.2% and 7.1%.

Genetic control decreased along the following component sequence: Z (31.9%), S (23.1%), X (13.1%), and Y (2.0%). According to Grafius and Thomas (1971), and Hamid and Grafius (1978), genetic determination of the yield components is the stronger when ontogenetically closer in the sequence development of the components. Grafius (1978) stated that "plasticity is inversely proportional to ontogenetic proximity." In sweet potato, however, the corresponding decreasing Z, S, X, and Y sequence is questionable from a morphogenetic and physiological point of view. Dry matter content of the tubers (Z) is built up only after tuber initiation. Even if the dry matter content of the other plant parts is high previous to tuber initiation, it does not imply that translocation to the tubers will be efficient. Moreover, all four components tend to vary during the growing process. Z and Y will increase gradually during growing process, S will peak at about 4 months, and X will plateau at about 3 months. One could speak of parallel ontogenesis with relayed emphasis for each of the components along the following sequence: S, X, Y, Z. The fact that the last component in the sequence, Z, is under strong genetic control can be explained by a smaller number of genes governing this trait.

## The yield parallelipiped

For each of the 27 clones, the X, Y, Z components necessary to construct the yield parallelipiped (W) according to Grafius (1965), as well as the S component, are given in Table 3. The best yielder, cv. Rusenya (W = 1.61), is characterized by a below avergage tuber weight (Y = .93), all other components being above average viz.; X = 1.35, Z = 1.10, and S = 1.66. However, it was outyielded in four out of six environments. It is concluded that in low-input agriculture, selection should aim at identifying environment specific genotypes, rather than attempting to breed for widely adapted genotypes.

## The stress matrix

Simple, partial, and multiple correlations were calculated among the different traits, using the overall genotype means (Table 4). Only number of tubers (X) was significantly correlated with dry tuber yield ($r = .45^{+}$). However, most partial correlations were highly significant. Components X, Y, Z, and S, all contributed signficantly to the final dry tuber yield viz. $.73^{++}$, $.72^{++}$, $.57^{++}$, and $.42^{+}$ (Table 4). The multiple determination coefficient of W was very high ($R^2 = .88$). All yield components (X, Y, Z, and S) were negatively related among themselves giving further evidence to the stress theory of Grafius (1970). Stress (or competition) was strongest between X and Y ($r = -.65^{++}$), supporting the view that "number and size tend to have an inverse relationship" (Grafius, 1978). Determination was average for Z ($R^2 = .59$), and least for vine yield ($R^2 = .40$). The latter lack of determination may be attributable to an uncompleted growing cyclus at 6.5 months under Central African Highland conditions, and/or to a possible limitation of the translocation process for most clones.

## Relative importance of the yield components in different environments

It has been suggested that stress is more important in higher yielding locations as well as within higher yielding varieties (Adams, 1967; Thomas et al, 1971; Hamid, 1980). The multiple determination coefficient of W as a function of

X, Y, Z, and S gives an immediate estimate of overall stress. Two low yielding environments, Rwerere 81-B and Rwerere 81-C (Table 2), had nevertheless strong stress conditions ($R^2$ = .88 and .94, respectively). Hence, high yield per se does not seem the prime cause of stress, but rather the competition between the components to tap the available environmental resources. In Rwerere, the average yearly temperature is 14.3°C, and the average yearly minimum temperatura is only 5.9°C (Table 1). Below 15°C, tuberization process is strongly inhibited (Hahn, 1977). Hence, the strong competition between the yield components may result from strong cold stress imposed simultaneously on all components. Henceforth, it can be deduced that low yielding environments will generate a small stress factor ($R^2$) in so far at least one of the components is not subject to environmental stress.

Table 3. Number of tubers/$m^2$ (X), average tuber weight (Y), dry matter content (Z) dry tuber yield (W), and fresh vine yield (S) expressed as a fraction of the respective overall mean.

| | Genotype | Number of tubers X | Average tuber weight Y | Dry matter content Z* | Dry tuber yield W | Fresh vine yield S |
|---|---|---|---|---|---|---|
| 1 | Gahungezi 1435 | .74 | 1.51 | 1.12 | 1.10 | .66 |
| 2 | RUB 204 | 1.08 | 1.12 | .97 | 1.24 | .97 |
| 3 | CL 1663 | .79 | .94 | 1.21 | 1.01 | .59 |
| 4 | TIS 2498 | .98 | 1.06 | .98 | 1.19 | .43 |
| 5 | No. 1142 | .74 | 1.24 | .85 | .71 | .40 |
| 6 | RUB 205 | .99 | 1.03 | 1.13 | 1.42 | 1.11 |
| 7 | RJ 1609 | .81 | 1.17 | 1.00 | .98 | .79 |
| 8 | CL 1658 | 1.25 | .85 | 1.14 | 1.09 | 1.28 |
| 9 | Nyirak. 1636 | .74 | .89 | 1.04 | .73 | .60 |
| 10 | RUB 202 | .81 | .94 | 1.09 | .85 | 1.13 |
| 11 | Mugenda 1603 | .88 | .63 | .90 | .60 | 1.59 |
| 12 | Rusenya | 1.35 | .93 | 1.10 | 1.61 | 1.66 |
| 13 | Nyiranjyojyo | .96 | .83 | 1.19 | 1.05 | .93 |
| 14 | RJ 1612 | 1.46 | .70 | 1.07 | .89 | .64 |
| 15 | TIS 2534 | 1.28 | .91 | .76 | .96 | .76 |
| 16 | 2 - 4 - 2 | 1.16 | .97 | .69 | .86 | .62 |
| 17 | Anne-Marie | 1.20 | 1.16 | 1.07 | 1.33 | 1.84 |
| 18 | Nyiramujuna 352 | 1.02 | .87 | 1.06 | .94 | 1.03 |
| 19 | Bukarasa 1581 | .73 | 1.11 | 1.04 | .67 | .73 |
| 20 | TIS 2544 | 1.16 | 1.26 | .88 | 1.20 | .82 |
| 21 | RUB 201 | .87 | 1.11 | .75 | .77 | .59 |
| 22 | Bukarasa | .96 | .95 | 1.09 | 1.09 | 1.26 |
| 23 | Nkondoyigisabo | .83 | .87 | .97 | .64 | 1.57 |
| 24 | Caroline Lee | 1.11 | 1.29 | .97 | 1.37 | 1.05 |
| 25 | RUB 203 | 1.60 | .82 | .98 | 1.02 | 1.04 |
| 26 | RUB 203 | .86 | .84 | .99 | .74 | .98 |
| 27 | Cordes Rouges | .62 | 1.01 | .95 | .96 | 1.93 |
| (6 | Mean environments) | 12.5/$m^2$ | 70.0 g | 27.9% * | 245 g/$m^2$ | 1.131 g/$m^2$ |

*unweighted mean

Table 4. Matrix of simple (lower triangle) and partial (upper triangle) correlations between yield and related components.

| Simple Corr. \ Partial Corr. | Number of tubers X | Average tuber weight Y | Dry matter content Z | Dry tuber yield W | Fresh vine yield S | $R^2$ | R |
|---|---|---|---|---|---|---|---|
| NR of tubers (X) | | -.65** | -.48* | .73** | -.29 | .81 | .90** |
| Average tuber weight (Y) | -.27 | | -.46* | .72** | -.44* | .83 | .91** |
| Dry matter content (Z) | -.07 | -.11 | | .57** | -.10 | .59 | .77** |
| Dry tuber yield (W) | .45* | .34 | .34 | | .42 | .88 | .94** |
| Fresh vine yield (S) | .09 | -.25 | .21 | .25 | | .40 | .63* |

*, ** = respectively significant at p = .05 and p = .01.

$R^2$ = multiple determination coefficient.

R = multiple correlation coefficient.

For each environment, the relative importance of each component is given by the standardized partial regression coefficients (Table 5). Within each environment, number of tubers is generally the best yield contributor and average tuber weight, second best, although both traits contribute equally in the global analysis (Table 5). Dry matter content is the third best yield contributor in the global analysis, but has only significant contributions in the three highest yielding environments, Karama 81-C, Rubona 81-B, and Rubona 81-C (Table 5). This supports the view that Z is ontogenetically the last trait in the component sequence. Its contribution will only be of significant importance there where environmental resources will be large enough (Grafius and Thomas, 1971) to support further dry matter buildup. Vine yield is an overall poor yield contributor (b = .27+), and becomes negligible within each environment except in Rwerere 81-B. This is an apparent contradiction, as the breeder does know that good top growth is essential to ensure good yield. The four best yielders (Rub 205, Rusenya, Anne-Marie, and Caroline Lee) all happen to have above-average top growth (Table 4). Hence, high top growth should be combined with good translocation of the photosyntates to the tuber sink. Henceforth, translocation limitation seems to be more important than sink limitation under the low yielding conditions of the Central African Highlands.

Relative contribution of the yield components to environmental yield stability

The V-values (Wricke, 1962) of the different traits were calculated for each clone. As expected, there was a positive correlation between V-values and corresponding trait performances for dry tuber yield (r = .48++), vine yield (r = .54++) and number of tubers (r = .37), in accordance with Thomas et al, (1971).

Unexpectedly, no significant simple or partial correlation among V-values of different traits could be found. Hence, dry tuber yield stability cannot be explained by the stability of any of the components.

Yield stability of cv. Rub 204 (V = .103) corresponds with environmental stability for all yield components, whereas cv. Anne-Marie achieves yield stability (V = .271) in spite of high V-values, i.e. low ecovalence, for its components.

The shortest side of the yield parallelipiped of cv. Anne-Marie is dry matter content (Table 4) and yet it has a high V-value for dry matter (V = 79), which in turn should result in a low yield stability according to Grafius (1965). Component complementation does not explain yield stability of each of the genotypes, nor does the shortest edge of the yield parallelepiped. This leads to the suggestion that each of the four components has separate and specific physiological adaptation mechanisms towards changing environments. The interrelation of these mechanisms is survival oriented, rather than yield oriented. Hence, survival stability is shadowing stability of yield and its components, especially under low yield conditions. Each trait possesses several defense mechanisms against stress stimuli, more or less pronounced according to the particular genotype. For instance, drought adaptation can initiate either leaf drop or stomatal closure.

Table 5. Standardized partial regression coefficients of the four components w.r.t. dry tuber yield (W) in each environment, and respective multiple determination coeficients of W.

| | Karama | | Rubona | | Rwerere | | Global |
|---|---|---|---|---|---|---|---|
| | 1981-B | 1981-C | 1981-B | 1981-C | 1981-B | 1981-C | Analysis |
| Number of tubers (X) | .38 | .95** | .97** | .78** | .60** | .59** | .62** |
| Average tuber weight (Y) | .45* | .79** | .99** | .67** | .34** | .56** | .62** |
| Dry matter content (Z) | .36 | .50** | .70** | .42** | .12 | .13 | .39** |
| Fresh vine yield (S) | .11 | .09 | -.13 | .15 | .22* | .08 | .27* |
| $R^2$ | .44 | .94 | 1.00 | .98 | .88 | .94 | .88 |

*, ** = respectively, significant at p = .05 and p = .01.

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# Sweet Potato Seed Improvement on the Farm

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## ABSTRACT

A sweet potato seed improvement program sponsored by the Agricultural Extension Service has resulted in better quality. The purpose of this statewide campaign, called "Yam Alert", has been to dray farmer's attention to the problems of mutations and diseases which occur as a result of poor on-farm seed management. The multi-media approach focuses on an illustrated pamphlet which concisely describes the problem and presents realistic solutions. The pamphlets was mailed to every sweet potato grower in North Carolina. The cover letter accompanying the pamphlet, and other timely grower correspondences, are on a specially designed "Yam Alert" stationery. Growers' meetings feature an eight, two or one projector narrated slide presentation which is entertaining but educational. The "Yam Alert" message is reinforced at meetings by a colorful, table top display. Further reinforcement is provided by radio and television presentations plus timely articles in newspapers and magazines. On-farm tests demonstrate seed improvement principles, especially the importance of careful selection for orange flesh color. Results of grower seed source surveys reveal strengths and deficiencies of individual grower seed management systems.

Sweet potato (*Ipomoea batata*) production in the United States is limited commercially to the coastal and southern states due to growing season requirements. All sweet potatoes in the United States are produced as annuals, storing seedstock between successive crops.

North Carolina has in the past two decades become the leading sweet potato state, producing more than 40% of the total US production of approximately 500,000 metric tons in 1982. This is possible because of good climatic conditions and excellent soils. However, the competitive edge was due to grower commitment to quality production and good salesmanship. Growers simultaneously extended their shipping seasons by constructing modern storage facilities which provided proper temperature and humidity control and ventilation. North Carolina State University research and extension personnel worked closely with growers in the production and maintenance of quality of sweet potatoes.

Although some white-fleshed sweet potatoes are grown, the most popular varieties in the United States today are the orange-fleshed "yam type," such as Jewel and Centennial. Centennial was developed and released by the Louisiana Agricultural Experiment Station in 1960. Jewel was developed and released by the

North Carolina Agricultural Research Service in 1970. These varieties are widely accepted in the fresh market and for processing. More than 90% of the commercial acreage in North Carolina is Jewel.

Jewel produces high yields of moderately short, chunky roots which keep well in storage, but it is susceptible to flooding damage and flesh and skin mutations. These spontaneous changes in genetic material occur at much higher rates in sweet potatoes than in many other crops because they are genetically unstable. Growers know this as "running out" and are constantly in search of that "perfect variety" to replace jewel.

The sweet potato breeding programs at North Carolina State University have produced more improved varieties, but not a "stable Jewel." Improved techniques and tests have been incorporated into the breeder's seed program. This has resulted in improved Foundation, Registered and Certified Jewel (and other varieties) seedstock being made available to growers. However, the ultimate responsibility for good seed is in the hands of the growers. They cannot save seed from the grade-outs and unmarketable roots of this vegetatively reproduced crop and expect to consistently harvest good yields of high quality sweet potatoes. Growers should have their own sweet potato seed programs and should only utilize seedstock which is free from flesh and skin mutations and has no disease problems.

Because of worsening sweet potato quality situation, a statewide seed improvement campaign was initiated. The "Yam Alert" campaign was to educate farmers on importance of establishing and maintaining their own good seed programs. Farmers are encouraged to use Certified seed. They are urged to select the best seed they can get to produce their annual sweet potato crop. They are reminded that the crop they harvest in the fall can be no better than the seedstock they start with in the spring.

Starting in 1980 farmers were made more aware of their responsibility in maintaining their own good on-farm seed programs through many avenues which reinforce the "back to the basics" message:

1. The Yam Alert Newsletter is sent directly to every sweet potato grower in North Carolina. Two or three letters each spring and one or two letters in the fall provide timely reminders of important factors in the production of quality sweet potatoes. These letters are on specially designed, distinctive stationery.

2. The Yam Alert pamphlet (North Carolina Agric. Exten. Svce. Bull. AG-196) briefly states (and illustrates) the problem. It also provides realistic solutions that can be implemented at the farm level. A copy of this pamphlet was mailed to every grower with an appropriate "Yam Alert" cover letter at the start of this campaign in early 1980.

3. Growers' meetings have featured narrated slide presentations which entertain while they educate:

   a. Multiprojector (8 projectors, 3 screens), or
   b. Single projector -- using the same cued narration on cassette.

4. An attention getting table top display reinforces the message of the Yam Alert pamphlet with brief, straightforward statements and large color photographs. This is used effectively at grower meetings and trade fairs; serving also as a focal point for distribution of Yam Alert pamphlet and other timely publications.

5. Yam Alert on-farm demonstrations in several locations provide real life, visual evidence of the results of using "good" seedstock or "bad" seed stock. Local farmers witness the plot harvests and see for themselves that careful seed selection can result in improvement of orange flesh color in Jewel.

6. Timely articles in newspapers, grower magazines and other periodicals provide further reinforcement. Radio and television are also used whenever appropriate.

Professionals in many disciplines have been involved in this campaign; state sweet potato extension specialist, sweet potato breeder, extension vegetable pathologist, North Carolina Department of Agriculture Pesticide and Plant Protection Division specialists and County Agents with horticultural crops responsibilities. County personnel are critically important since they have more frequent contact with growers and can constantly reinforce the basic Yam Alert theme.

For many years North Carolina farmers have been admonished to accept the responsibility for their own sweet potato seed programs. Some do a good job, but many do not. The Yam Alert campaign has been designed to get their attention and sell the concept of on-farm seed management. Many misconceptions have been dealt with directly and positively. For instance, many farmers believe that cutting vines for transplants (or cutting transplants from beds) improves sweet potato quality (including flesh and skin color). Cutting is strongly recomended because it minimizes the transfer of soilborne diseases and insects to the field. Proper selection of seed is the only way to maintain desired flesh and skin color.

Growers are repeatedly reminded that knowing the source of their sweet potato seed is the only way to be sure of quality. Buying plants from other growers is risky and one must always bear in mind that the quality of transplants is not better than the confidence one has in the plant grower.

On-farm Yam Alert demonstrations have been used effectively to demonstrate to farmers that seedstock could be improved through careful selection to eliminate mutations. Grading seedstock eliminates roots of unacceptable orange flesh color and results in production of a high percentage of desirable roots at harvest. Field run seedstock started out with 85% acceptable orange flesh color, but roots produced by plants from this seedstock only had 74% and 43% acceptable orange flesh color, respectively, in the two demonstrations. White mutants used for seedstock clearly resulted in the production of white fleshed sweet potatoes.

Such locally conducted on-farm demonstrations have high impact on the cooperating farmer and his neighbors. The benefits of using good seed and careful selection are reinforced and farmers gain confidence in extension recommendations. Even though it is not always possible or practical to produce statistically significant data from such on-farm demonstrations the farmers personal involvement and reaction is important. Farmers will respond to seed management recommendations more readily if they observe results and differences for themselves. It is, therefore, imperative that such demonstrations be simple, straight-forward and clearly labeled for easy interpretation of results. Using on-farm demonstration

results in local, county and state meetings is useful and important, but less meaningful than getting farmers to visit the demonstration plots at harvest.

In 1982 a Seed Improvement Survey was conducted. Basically, the survey consisted of random collections of 100 transplants from each participating grower's beds. Source of seedstock was identified whenever possible. Transplants were grown on a commercial sweet potato grower's farm. Each grower was assigned a code number for his transplants. At harvest all the roots produced were cut in half and evaluated for flesh color. The coded results were sent to all participants so they could compare their seedstock performance with that of other growers.

Grower interest in this survey aspect of the Yam Alert campaign was good. Several volunteered readily because they were proud of their seed program and confident that their seedstock would compare favorably with that of other growers. Others were not so anxious to subject their seedstock to testing. These were the growers that County Agents focused on because they were likely to benefit the most from knowing more realistically how good (or bad) their seed program was. County Agents used the survey as a tool to introduce good sweet potato seed management concepts and techniques.

The results of the 1982 Yam Alert Seed Improvement Survey indicate that using better seedstock and selecting for orange color pays off. These data reinforce the recommendations to use good seed (Certified if possible) and select for good orange color. Old, unselected seed (Certified 1980 and 1979 and unknown) results in production of a much higher percentage of unacceptable-colored roots. Observe that the range of acceptable orange flesh color is much broader with older and unknown seedstock.

Table 1. Flesh color of harvested sweet potatoes as influenced by source of seedstock. Yam Alert seed improvement survey, North Carolina, 1982.

| Source | No. Samples | Percentage roots with acceptable orange color[1] Range | Average |
|---|---|---|---|
| Selected | 3 | 97.2 - 99.4 | 98.1 |
| Foundation, 1981 | 3 | 95.6 - 100 | 97.5 |
| Registered, 1981 | 11 | 96.1 - 100 | 98.5 |
| Registered, 1980 | 1 | - | 92.9 |
| Certified, 1981 | 12 | 91.8 - 100 | 97.2 |
| Certified, 1980 | 5 | 75.6 - 100 | 91.4 |
| Certified, 1979 | 5 | 82.3 - 96 | 91.3 |
| Unknown | 9 | 88 - 99.6 | 94.9 |
| Overall | 49 | 75.6 - 100 | 95.8 |

[1]Acceptable orange flesh color is determined using a scale of 0 to 5; (0 = no orange color, 5 = intense orange color); 0-2 = unacceptable; 3-5 = acceptable.

## Conclusions

Acceptable orange flesh color of sweet potatoes can be improved through good seed management, especially selection for this character. Growers can and should perform this task annually. Since the Yam Alert campaign began, North Carolina sweet potato processors have observed generally improved orange flesh color of sweet potatoes, especially from growers who select for color. During the same period some growers' sweet potatoes have continued to deteriorate with regard to orange flesh color. Good on-farm seed management programs compliment the breeder's seed programs and result in improved orange flesh colored sweet potatoes for both fresh markets and processing.

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Effect of Depth of Planting on the Development and Yield of Sweet Potato Using Different Types of Cuttings

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ABSTRACT

The effect of depth of planting on the development and yield of sweet potato var. Japonés, using different types of cuttings (upper, middle, and lower), was studied.

When upper and middle cuttings were used, 98% and 90% rooting was achieved. Upper cuttings, however, grew more vigorously and yielded 13 t/ha as compared to 9 t/ha from middle cuttings. On the other hand, plants that originated from middle cuttings produced 24 t/ha of foliage vs 19 t/ha from upper cuttings.

# The *Ipomoea trifida* Complex Closely Related to Sweet Potato

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SUMMARY

The concept of the "*Ipomoea trifida* complex" is proposed after field, herbarium and experimental studies on Ipomoea species belonging to the section Batatas. All wild plants that can be crossed with cultivated sweet potato belong to this complex.

Morphological and cytological observations were carried out using newly introduced Ipomoea species from tropical America in 1979 and 1980. Diploids, tetraploids and hexaploids were recognized by studying the somatic chromosome numbers. It was impossible to detect accurately the ploidy level only on the basis of the morphological characteristics.

Most diploid plants of the complex bear no tuberous roots but some accessions produced somewhat thickened roots. This thickness of roots strongly suggests that diploid forms have the potential to produce tuberous roots.

In 1955, Nishiyama collected in Fortin, Mexico a wild hexaploid (6x, 2n=90) that could be crossed with sweet potato. This observation contributed to the initiation and promotion of sweet potato breeding in Japan using wild species. Thus, two varieties, including the wild germplasm, were developed along with several promising strains which are now being tested for adaptability to various areas. Phylogenetic studies of sweet potato have also been progressing using wild related species. With the progress of breeding experiments using wild species and phylogenetic research, some problems were likely to arise and interfere with international exchange of research information, such as the taxonomic confusion and discrepancy in identification of the wild species relating to sweet potato.

Although researchers in this field are combining increasingly aware of the problem, a satisfactory solution has not yet been found. The purpose of this paper is to offer precisely some solutions to this problem, chiefly on the basis of experimental results obtained in Japan and observations made in tropical America.

## Taxonomic situation of the wild relatives of sweet potato

Discrepancies in species names have been associated with the studies on wild plants resembling morphologically sweet potato. Difficulty in species identification of plants closely related to sweet potato can be ascribed to the existence of an inadequate taxonomic system and subjective interpretation of taxonomic

data by each researcher. In general, the following three factors have contributed to these discrepancies: (1) the species are not well defined morphologically, (2) morphological characteristics which were used to distinguish one species from another by taxonomists show continuous variations, and (3) some species can be easily crossed with others, producing intermediate types between them.

Many taxonomists, as reviewed recently by Austin (1978), have attempted to establish a taxonomic system of Ipomoea species from each viewpoint. Reports from Van Ooststroom (1953), Verdcourt (1963) and Austin (1978) appear to be most useful since these authors investigated the interrelationship and geographical distribution of wild relatives closely related to sweet potato. Van Ooststroom recognized the existence of an interrelationship among I. triloba, I. trifida, I. tiliacea, I. gracilis, and I. batatas species, and he included these five species in the section Batatas. Austin adopted the concept of Ipomoea batatas complex at the section level of taxonomy, and included 11 species and 3 natural hybrids into this complex.

Austin studied the taxonomic literature, the geographical distribution and herbarium specimens extensively, and attempted to analyse the interrelationships among species belonging to the complex. However, he did not interpret correctly the experimental results which had been obtained for the past twenty years presumably due to the taxonomic confusion of Ipomoea species closely related to sweet potato. Nishiyama (1961) designated the wild plant, K123, as I. trifida (H.B.K.) G. Don, and he claimed that this hexaploid species might possibly be the ancestor of sweet potato. The fact that this wild plant had the same number of chromosomes as sweet potato was both and advantage and a shortcoming. The advantage was that K123 could be used readily for varietal improvement of sweet potato. Many researchers focussed their attention on the utilization of wild plants, and several wild Ipomoea species could be introduced thereafter. On the other hand, the incomplete identification of this wild plant made the taxonomic confusion even more conspicuous, and the experimental results thereafter were not highly evaluated by some researchers. In any case, the greatest achievement of Nishiyama was to have initiated research work in this field and promoted breeding studies for the utilization of wild plants as the gene source in Japan.

Nishiyama's report stating that the progenitor of sweet potato had been identified gained the attention of researchers worldwide. Jones (1967) pointed out that Nishiyama's identification was incomplete morphologically and cytologically. Jones believed that K123 was not a separate species but a weedy feral derivative of cultivated Ipomoea batatas, i.e. sweet potato. Jones' assumption has been accepted by many researchers for a long time. If the wild plant first collected had been a diploid plant instead of a hexaploid, the situation would have been different and a great deal of confusion thereafter could have been avoided. The diploid species was collected in Acapulco, Mexico in 1960 by Tamari and Kobayashi. This Ipomoea species was identified as I. leucantha Jacq. by Teramura who was a co-worker of Nishiyama (Teramura et al., 1967). The misconception that K123 could be identified as I. trifida (H.B.K.) G. Don and inaccurate definition of the species by taxonomists certainly contributed to perpetuate the confusion. The plant identified as I. leucantha resembled I. trichocarpa described by Martin and Jones (1972) except for the following two characters: (1) the absence of a pigmented substance at the bottom of the flower tube, making a white asterisk pattern as shown in Figure 1, and (2) the existence of self-incompatibility and several incompatibility groups among plants. At present, it is believed that this diploid species was not I. leucantha but a typical I. trifida.

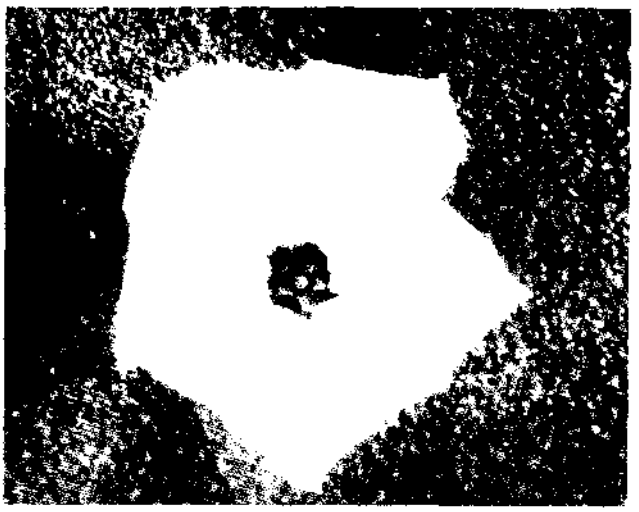

Figure 1. Asterisk pattern at the bottom of the flower tube.

Figure 2. Diploid I. trifida specimens growing near Santa Marta, Colombia.

Triploid Ipomoea seeds were also collected in the same are in Acapulco where the diploid species had been collected. All eight seeds from a single plant were found to be triploid, having a somatic chromosomal number of 45. It was interesting to note that triploid plants could occur naturally, and further, that hybridization among triploids produced several hexaploids. Natural triploid seeds were also collected by Shiotani in Mexico in 1974 (Shiotani and Kawase, 1980).

Since the original triploids and hexaploids derived from the triploids resembled morphologically K123 which had been designated as I. trifida, these triploid plants were called tentatively triploid I. trifida. Collection of natural triploid plants suggested: (1) diploid and tetraploid species must be growing near the area where the triploid seeds were collected, and (2) natural hexaploids must occur naturally and K123 was thus presumed to have originated from such hexaploid plants.

A tetraploid plant was collected in Veracruz, Mexico by Muramatsu in 1962. The leaves of this plant were rather small and appeared thickened. Since the morphological characters seemed to differ considerably from those of I. trifida

(6x) or I. leucantha (2x), the tetraploid plant was considered to be a different species, and was identified as I. littoralis Blume presumably due to its adaptability to the environment of coastal areas (Teramura, 1979). Based on the crossing experiments and cytological observations made be several workers in Japan, Nishiyama (1971) described the genetic origin of sweet potato. A tetraploid species originating from a collection made in Mexico by G. Chapman was supplied to our laboratory by A. Jones. This tetraploid species had been designated as I. gracilis R. Br. (Jones, 1970). This plant belonged definitely to the same species as the tetraploid called I. littoralis in Japan. Austin (1977) believed that this tetraploid plant was neither I. littoralis nor I. gracilis, but resulted from the hybridization of I. batatas and a diploid species, probably I. trifida (H.B.K.) G. Don. The assumption made by Austin seems to be plausible both morphologically or genetically. However, we have some reservations and we would like to suggest that this tetraploid may be an ecotype of I. trifida derived from an autotetraploid originating from the diploid I. trifida as described later in more detail. Tetraploid Ipomoeas closely resembling sweet potato were also collected in Colombia and Ecuador in the 1970s (Martin et al., 1974; Kobayashi, 1978). Furthermore, specimens resembling these tetraploids were collected in Mexico and Guatemala (Muramatsu and Shiotani, 1974). Those tetraploid plants were considered to be closely related to sweet potato, but could not be given any species name due to the taxonomic confusion prevailing at that time. Austin (1977) also postulated that these tetraploid plants had the same origin as I. littoralis or I. gracilis mentioned above. We considered that those tetraploids observed from the Andes to Mexico were derived from the autopolyploid of diploid I. trifida. With the promotion of Ipomoea collections, ecological and genetic information on these plants has accumulated. A plant group which shows the ability of being crossed with sweet potatoes should have a common genome though the ploidy level may be different. Since this group was recognized to be a Mendelian population, Nishiyama (1971) proposed the name of Ipomoea batatas to this plant group including diploids, tetraploids and hexaploids. On the other hand, Austin described 14 kinds of plants belonging to the Ipomoea batatas complex. Species characterization or definition by austin was much more accurate than those of the previous taxonomists. It is, however, still impossible to identify all our collections according to his descriptions. The main reason for this difficulty lies in the continuous variations including sepal characters which Austin considered as being an important taxonomical key to identification.

Ipomoea trifida (H.B.K.) G. Don is the species in which we have been very much interested because it was thought that the complexity of the situation might be alleviated by observing "true" or "standard" I. trifida specimens. As well known, the taxonomic origin of this species dates back to the plants collected on the banks on the Orinoco River by Humboldt and Bonpland at the time of their expedition to tropical America during 1799 to 1804. The plant identified as I. trifida (H.B.K.) G. Don by Van Ooststroom is preserved at the Rijks Herbarium, Leiden. This specimen was collected in Santa Marta, Colombia according to Muramatsu who once compared this herbarium specimen with Nishiyama's K123 wild plant. On the basis of this information, we visited Venezuela and Colombia in 1979, and other regions of Central America and the northern part of South America including seven countries in 1980, with a view to gaining more information and collecting typical I. trifida.

## Distribution of plants which can be crossed with sweet potato

It is comparatively easy to determine if a plant can be crossed with sweet potato by simply observing the floral characteristics as reported earlier (Kobayashi and Miyazaki, 1976). Several communities of I. trifida were observed

along the coast of Santa Marta, Colombia. This specimen was considered to be the same plant as that identified by Van Ooststroom as I. trifida (H.B.K.) G. Don. The plants occurred profusely in places at elevations of 5 to 20 m. above sea level (Figure 2). We could observe this plant even in areas at elevations of about 1,000 m above sea level.

Seed setting was not high compared to flowering number, pointing to allogamous characteristics. Plants occurring at higher elevations can produce tuberous roots (Figure 3). This species is propagated vegetatively naturally as well as by seeds. Similar plants occurring in the vicinity of Santa Marta were observed widely in Maracay, Venezuela, and we reconfirmed its identification by comparing it with I. trifida preserved at the Venezuela National Herbarium in Caracas. Austin also considered that this specimen was a typical I. trifida (H.B.K.) G. Don (Austin, personal communication).

Observations were made after growing specimens of I. trifida collected in Santa Marta and Maracay the following year from seeds under the same environmental conditions. Wide genetic variations including flowering time were recognized. All plants were diploid (2n=30), and allogamous with at least six incompatible groups. Mexican diploid species were also considered to be I. trifida though these species had long been identified as I. leucantha Jacq. in Japan. Figure 4 indicates the itinerary of the trip we made in 1980 and the areas where I. trifida specimens were observed. Specimens collected in Santa Marta and Maracay were all diploid, but tetraploid and hexaploid individuals were also included in the plants identified as I. trifida on the basis of their morphological characteristics and distribution. It can be said in general that larger leaves, thicker vines and fewer flowers were produced as the ploidy level became higher. However, the

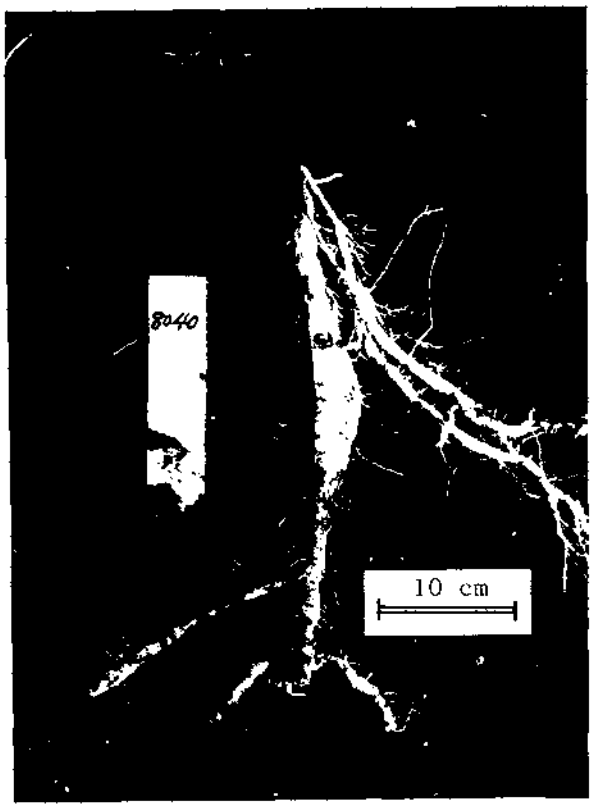


Figure 3. Tuberous root produced by diploid I. trifida.



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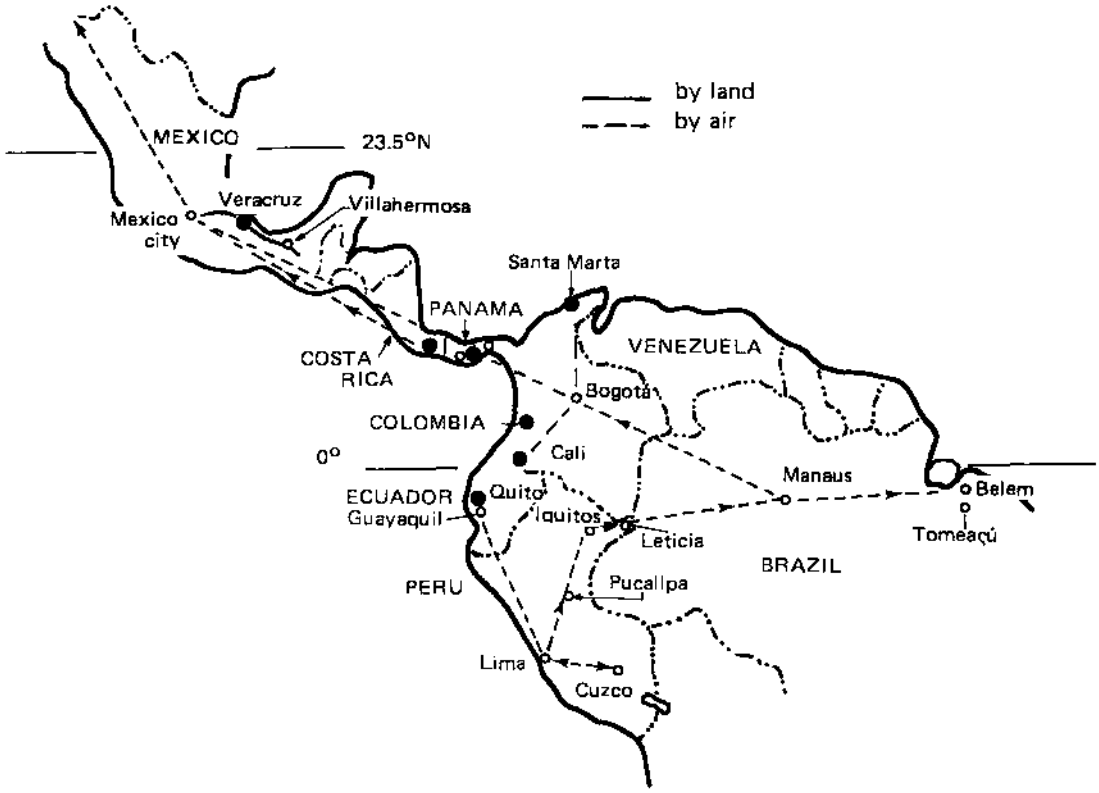


Figure 4. Route map and locations (solid dots) of I. trifida specimens collected in 1980.

ploidy level could not be accurately deduced by only observing morphological characters in the field. Species regarded as hexaploid I. trifida could not actually be distinguished from some plants that were probably derived from cultivated sweet potatoes. Intermediate plants between I. trifida (H.B.K.) G. Don and I. batatas (L.) Lam. were observed profusely in Cali - Buenaventura (1,500 - 2,000 m.a.s.l.), Colombia, San Jose - Turrialba (600 - 1,800), Costa Rica, and around Veracruz (5 - 10), Mexico. Many tetraploid plants identified as I. trifida were observed in the vicinity of Cali, Colombia and along the coast of the Caribbean Sea near Veracruz, Mexico. Many intermediate types between the typical I. trifida and plants called I. littoralis or I. gracilis were observed along with plants of the so-called I. littoralis type that were adapted well to the coastal environment as reported previously by other researchers. Since we observed several intermediate types and no sexual isolation system was recognized, it was eventually concluded that these tetraploid plants represent one of the ecotypes of tetraploid I. trifida and it is believed that these tetraploid plants are neither a separate species nor natural hybrids.

## Concept of the Ipomoea trifida complex

It was considered that the various specimens collected could be distinguished by giving a name to each species based on the discontinuity of morphogenetical variations that had occurred at an earlier time. However, it was recognized after field observation and comparison of the materials grown under the same environmental conditions that the name given to a species did not necessarily correspond to the plant group that could be crossed with sweet potatoes.

By now, many intermediate types between known plants which have different species names and some variant forms of I. trifida (Table 1) have been recognized. It is comparatively easy to connect the links of the chain of the respective germplasms within the group in spite of differences in ploidy level. In nature also, exchange of germplasm is presumed to occur due to the existence of incompatibility that is common to this group. The assumption made by Jones concerning the Mexican hexaploid, and Austin's interpretation on the tetraploid plants as being hybrids cannot be refuted theoretically or experimentally. However, such interpretations could be modified on the basis of the following aspects: natural occurrence of triploid plants is not rare; hexaploid plants can be produced easily from triploid plants; various types of diploid and tetraploid plants occur in tropical America; plant density of this ecological group is far higher than that of sweet potato.

Table 1. Variant forms belonging to I. trifida complex.

| Acc. No. | 2n | Origin | Specific characteristics |
|---|---|---|---|
| 7915 | 30 | Colombia | Blooms freely without seasonal influence |
| 8040 | 30 | Colombia | Tuberization of roots |
| 8043 | | | |
| 8051 | 30 | Panama | Miniature plant type with normal flowers |
| 7948 | 60 | Colombia | Intermediate plant type between typical I. trifida and I. littoralis type |

After observing the species occurring in tropical America environment and considering the evolutionary trend of polyploidy based on the experimental results, it was eventually concluded that both the hexaploid and tetraploid plants could have been derived from diploid I. trifida originally.

To gain a proper insight into the ecological genetics of the wild plants closely related to sweet potato, the concept of the "Ipomoea trifida complex" was proposed, as shown in Figure 5. This complex refers to an ecological group including plants with different ploidy levels ranging from diploids to hexaploids and different ecotypes presumably adapted to the special environments.

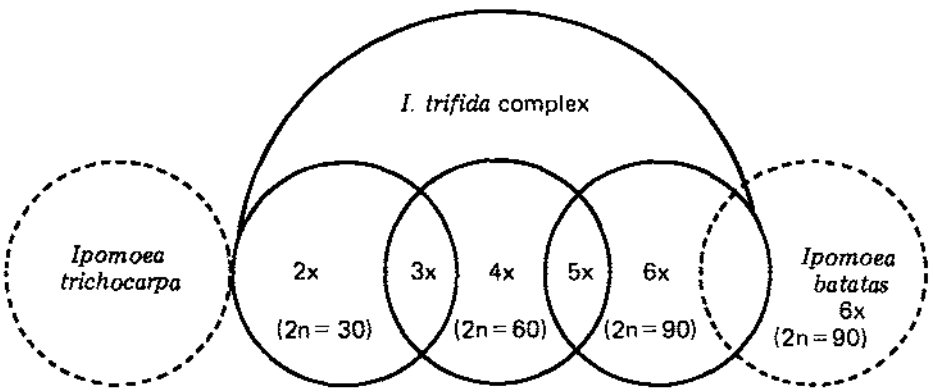


Figure 5. Concept of the Ipomea trifida complex.

The main problems relating to the taxonomy of the wild relatives of sweet potato could be solved through this concept, in particular the phylogenetic relationships of sweet potato. To corroborate the validity of the concept of I. trifida complex, the following aspects can be considered: (1) plants belonging to the I. trifida complex and sweet potato have a common genome (Shiotani and Kawase, 1980); (2) the sphere of adaptability widens as the ploidy level becomes higher; (3) such important characteristics for sweet potato evolution as the presence of tuberous roots and root pigmentation can be observed even in diploid I. trifida (Shiotani, unpublished).

Acknowledgement

Particular thanks to Mr. H. Sato of Kyushu Nat. Agr. Exp. Sta. who travelled with me in 1979 and to Mr. Y. Umemura of TARC who accompanied me in 1980. I wish also to express appreciation to all the scientists, government officials and residents we met in each country for their kind cooperation and help during these trips in tropical America.

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A Clustering Technique for the Classification of Sweet Potato Incompatibility Groups

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ABSTRACT

A computer program was developed using an agglomerative hierarchical cluster analysis procedure to classify sweet potato clones into groups based on similarity of compatibilities. Several measures of compatibility were tested, with frequency of success (FS = pollinations successful/pollinations attempted) and ln (1/FS) proving most useful. Groupings obtained by these procedures can provide breeders with an indication of the crosses most likely to succeed.

# Progress in Developing Sweet Potato (*Ipomoea batatas* (L.) Lam.) Cultivars for Fuel Alcohol Production

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## ABSTRACT

The potential use of sweet potatoes for fuel alcohol production in the United States and the development of cultivars specifically for that purpose are discussed. Field and laboratory studies were conducted in 1981 on yield of dry matter and protein per hectare and on yield of 100% ethanol per hectare after fermentation. Selection for dry matter and protein content in early stages of a breeding program was also evaluated.

'Pelican Processor', one of the older cultivars tested, produced the largest amounts of dry matter and protein per ha. Root yield ranged from 29.3 mt/ha to 54.7 mt/ha. Protein content was highest in the experimental clone WJ2 (6.9% dry weight basis) but because of the high dry matter content (30.7%) and high root yield, 'Pelican Processor' yielded more protein per ha (0.3 mt/ha).

Determination of dry matter content and protein content in seedlings were considered unreliable for estimating these values in mature plants. Correlations between seedlings and mature plants for these characters were significant but low and would not be useful unless severe selection pressure were used.


Production of fuel alcohol from agricultural crops as an alternate source of energy has received much attention in the United States. Although sweet potatoes have the potential to produce more ethanol/hectare than any starch or sugar crops now being used for this purpose (Fike, 1980; Jump et al., 1944), the price per liter of ethanol from sweet potatoes has generally been prohibitive (Fike, 1980). Since this is based on market prices that reflect sales of sweet potatoes as a fresh product to consumers rather than on a crop grown specifically for alcohol production, the cost/liter is perhaps misleading. A goal of breeding programs should be development of cultivars which possess those characteristics most suitable for use as a fuel alcohol source with no emphasis on fresh product consumption.

Several researchers have investigated the potential for using sweet potatoes for fuel alcohol production. Keitt (1909) tested 14 clones and concluded that yield was the most important factor influencing ethanol production/ha since starch

percentage did not vary considerably between clones. When clones with different levels of starch were tested (Boswell, 1944), both plant yield and starch content contributed significantly to the total yield of ethanol. Jump et al. (1944) found that a quantity of dehydrated sweet potatoes yielded 15% to 20% more alcohol than an equal quantity of high-grade corn. However, they questioned the value of the distillage by-product of sweet potatoes as an animal food supplement since it was much lower in protein than the corn distillage.

The objectives of this study were to evaluate sweet potato seedlings and selected cultivars and experimental clones for traits desirable for fuel alcohol production.

## Materials and Methods

### Evaluation of experimental clones and selected cultivars

Nine sweet potato clones were chosen based on preliminary dry matter and yield data. Uniform-size plants from bedded roots were transplanted to a Norfolk sandy loam soil at the Horticultural Crops Research Station, Clinton, North Carolina. A randomized complete block design with four replications was used. Rows were spaced 1.2 m apart with plants 0.3 m apart within the row. Each plot consisted of 30 plants. Cultural practices recommended by the North Carolina Agricultural Extension Service (1980) were followed.

Roots were harvested 161 days after transplanting and total yield was measured for each plot. Samples were collected from each plot for evaluation of dry matter, protein and alcohol production. Dry matter was measured by drying a composite, preweighed sample of 2 roots for 48 hr in a forced air drying oven and reweighing. Protein was measured on a composite sample of 6 roots by analyzing for nitrogen content using a semi-micro Kjeldahl using 6.25 as a conversion factor for calculation of protein nitrogen. Ethanol was prepared from a 1,200-1,700 g sample of root tissue which was weighed and ground in a food mill for 2 minutes. An equivalent weight of water was mixed with 5 g of α-amylase and then added to the ground sweet potatoes to form a slurry. The slurry was brought to the boiling point with moderate stirring and boiled for 30 minutes. The slurry was cooled naturally to 77°C in the cooker. When the temperature reached the 77°C to 80°C level, another 5 g of α-amylase was added and stirred to assure mixing of the additional enzyme. The slurry was cooled to room temperature. Five g of glucoamylase (Biocon) was added to the slurry along with 5 g of distiller's yeast (Biocon). The yeast-containing mixture was then placed in a constant temperature box at 27° to 32°C for 7 days.

Polyethylene milk bottles prewashed with a sulfite solution were used as fermentation chambers. After 7 days the fermented mash was placed in an air-cooled stripping still and boiled slowly until the mash temperature reached 100°C (about 3 hours). The alcohol was collected in a graduated cylinder, the volume and specific gravity were measured at 15.6°C and the results converted to the volume of 100% ethanol. All results are reported on that basis. The hot mash with the alcohol removed was then filtered on a large Buchner funnel to separate the distillage from the water. The filtration was carried out at 51 mm of HG vacuum long enough to remove the excess liquid. Samples of the distillage were frozen for later analysis of protein (by the method previously described) and total sugar.

## Evaluation of seedlings

One hundred seedlings with white root flesh were selected from the 1981 seedling population at North Carolina State University. The seedling root of each of the 100 plants was removed for dry matter and protein analysis as described previously. A terminal cutting approximately 150 mm in length was taken from each of the 100 plants and transplanted to the field in rows 1.2 m apart with plants spaced 0.3 m in the row. After 135 days roots from each of these one hundred plants were harvested. Half the roots on each of the 100 hills were removed for protein and dry matter analysis; the other half were placed in paper bags, cured (95% RH, 30°C) for 1 week and stored (16°C) for future use.

## Results and Discussion

### Experimental clones and selected cultivars

The 9 sweet potato clones differed significantly in yield, dry matter, and protein content. Yields ranged from 31.4 mt/ha to 58.6 mt/ha. 'Jewel' yielded 50.2 mt/ha, not significantly different from 'Pelican Processor' which yielded 58.6 mt/ha. Therefore, none of the lines used in this study surpassed 'Jewel' in total yield. 'Jewel' is the cultivar which is now most widely grown in the United States as a fresh market product. However, 'Pelican Processor' had one of the highest dry matter contents (31.4%) and consequently the highest dry matter yield (18.3 mt/ha) of all lines tested in this study. 'Whitestar' was comparable to 'Pelican Processor' in dry matter content (29.4%) but had lower total dry matter production (14.3 mt/ha) due to lower total yield. Protein content ranged from 4.3% to 6.8% (dry weight basis) with the highest dry matter types ('Pelican Processor' and 'Whitestar') having the lowest percent protein. However, actual protein production (ranging from 0.43 to 0.80 mt/ha) was high in these two lines because of high total yield.

These results indicate that although percentage dry matter is an important genotype characteristic in selecting lines with high potential for fuel alcohol production, total yield is more important and should be used as the primary characteristic for selection. Clones with high dry matter content ('Potojam', 'Vogel White') may have low actual yields (mt/ha) of dry matter due to this low yield characteristic. The same was true of percentage protein as a selection characteristic.

Alcohol yield differed significantly among the 9 clones tested. 'Pelican Processor' yielded 0.1467 l/kg of ethanol compared to only 0.0684 l/kg by NC 835. Residue analysis indicated that protein content in the fermentation products of these 9 clones was considerably lower than optimal for extraction as a human food supplement (corn distillers' grains average 30% protein). The residue contained from 0.70% to 2.17% total sugar which indicated that the fermentation procedure was relatively efficient for all clones.

Correlation coefficients were determined for all traits measured (Table 1). Protein content (%) was inversely correlated with dry matter content. However, this will have little significance in selecting for types that yield high amounts of dry matter and high amounts of protein since protein yield (mt/ha) was more dependent on total yield than on actual percent protein; 'Pelican Processor' had low percent protein but high total yield and therefore it had a higher actual yield of protein.

Table 1. Correlation coefficient of screening characters in mature sweet potato clones and cultivars.

| | Protein (%) | Dry matter (%) | Yield | Alcohol yield | Residue protein | Residue sugar |
|---|---|---|---|---|---|---|
| Protein (%) | - | -0.66* | 0.21 | -0.57 | 0.47 | 0.73* |
| Dry matter (%) | | - | 0.08 | 0.96** | 0.31 | 0.63 |
| Yield | | | - | -0.23 | -0.56 | 0.46 |
| Alcohol yield | | | | - | 0.30 | 0.52 |
| Residue protein | | | | | - | -0.37 |
| Residue sugar | | | | | | - |

*,** Significant at the 1% and 5% levels, respectively, (seven degrees of freedom).

Alcohol yield was significantly and positively correlated with percent dry matter. Although the dry matter in sweet potatoes contains materials other than fermentable carbohydrates, this correlation indicated that percent dry matter can be confidently used as the selection criterion for alcohol yield.

Residue sugar was negatively and significantly correlated with percent protein. This correlation probably is a reflection of the high negative correlation between percent protein and percent dry matter (the correlation coefficient between residue sugar and percent dry matter was very high although not significant). Residue protein was not significantly correlated with any other screening character. Therefore, residue protein itself must be evaluated in all lines unless it can be shown that no genetic factor is responsible for the level of residue protein (i.e., all lines tested may be similar in residue protein even though they differ in other characters). It is possible that the method of alcohol production may greatly influence the level of protein in the residue in all clones.

Seedling evaluations

In general, dry matter content changed minimally between seedling roots and clone samples. The correlation coefficient between the two types of samples was significant although fairly low. Protein content (dry weight basis and fresh weight basis) was generally higher when measured after one growing season (clone sample) than when measured in the seedling root. The mean, when measured on DWB or FWB, doubled from seedling evaluation to clonal evaluation. The correlation between seedling root samples and clonal samples, although low, was significant, indicating that rankings might still be accurate in the seedling population but that actual protein content must be determined after one growing season.

The correlation between percent dry matter and percent protein (DWB) was negative and significant in the seedlings as it was in the experimental selections and cultivars.

These results indicate that determination of dry matter and protein content in seedlings will be unreliable for estimating these values in mature plants. The efficiency of selecting for total yield in seedlings is questionable since seed-

ling yield and clonal yield have not been shown to be well correlated (Kamalam et al., 1976). In addition, high yield and high starch content have been shown to be negatively correlated in some sweet potato populations although highly productive, high starch types were obtained using suitable crosses (Zhang, et al., 1981).

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# Food Quality and Chemical Composition

## A Comparison of the Volatile Constituents and Sugars of Representative Asian, Central American, and North American Sweet Potatoes

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ABSTRACT

The volatile profiles and sugars of three cultivars of baked sweet potatoes representing an Asian, Central American, and North American center of selection were compared. Aromatic compounds were analyzed and identified by gas-liquid chromatograph-mass spectrometry.

Volatile components were identified from the North American cultivar Jewel and from the Central American cultivar Morado.

The volatile profiles between the three cultivars were distinctly different as were the aromatic properties, measured subjectively.

There were no qualitative differences in sugars between the cultivars. Maltose, sucrose, glucose, and fructose is decreasing order of concentration were isolated and identified by high pressure liquid chromatography. Significant quantitative differences were found in the concentration of total sugars (Jewel>Tainung> Morado) and in the concentration of free hexose sugars (Jewel> Morado>Tainung 57) between the cultivars tested.

We have proposed that the limited use of sweet potatoes as a preferred staple food for human consumption is due to a large extent to the intensity and dominance of the flavor (aromatic and taste) of the cooked product which minimizes its flexibility for use in cuisines. Based upon the significant variation in both the volatile compounds and concentration of sugars that appear to be present in the sweet potato gene pool, the integration of an analytical measure of flavor into future sweet potato breeding programs would be a highly desirable research approach.

The world's population of more than 4,000 million increases by up to 80 million people every year (Population Reference Bureau, 1976). At this rate the world's inhabitants will double in about 38 years and the demand for food will increase correspondingly. Consequently, increases in food production are needed to meet the growing caloric demand of our expanding population.

Greater food production can be attained through two primary means: by increasing yields per hectare, and/or by increasing the amount of land mass in

production. For example, replacement of part of the acreage currently allocated to less efficient crops with higher yielding species is one readily accessible way to increase the per hectare yield. The sweet potato is a crop which is a likely candidate for increasing food production in this way. Along with high yields, it has the advantage of having both a relatively short growing season and a wide ecological range in which it can be successfully cultured. Sweet potatoes are grown from the tropics through the subtropics and into many areas of the temperate zone. It is currently one of the leading food crops in the world, ranking sixth in total yield (107,254,000 MT/year, 1980).

A persistent problem of the sweet potato in many of the major production areas, for example in the People's Republic of China which produces 81% of the world's sweet potatoes (FAO, 1981), is that one of its primary uses is for livestock feed rather than direct human consumption. This conversion of carbohydrate to animal protein (principally pork) results in an approximate 3.3 fold decrease in caloric value before consumption. Direct utilization of sweet potatoes would therefore elevate the net caloric yield of human food.

One may ask then, why are sweet potatoes not more widely consumed directly as a food? We propose that the primary reason is that the flavor of the cooked product is extremely dominant and as a consequence cannot be readily altered. The majority of the existing staple crops (rice, wheat, cassava, white potato, for example) act to a large degree as flavor carriers (products with low flavor impact) to which flavor is added during or after preparation. This both increases the flexibility of the product for preparation and increases its potential for introduction into new geographical areas, since distinctive "flavor principles" of the culture can be successfully added to increase its acceptability.

In a survey of sweet potato purchase and use in northeastern United States, it was shown that while 82.8% of the households surveyed were classed as users of sweet potatoes, only 10.4% purchased the product more than once a month (Law, 1977). A conclusion that emerges from the data is that the majority of the people like sweet potatoes, however, not sufficiently well to consume them with any regularity. In addition, upon making a cursory survey of selected North American cookbooks in the University of Georgia Library, we found that white potatoes have on the average six times as many recipes as sweet potatoes and a more diverse array of potential dishes. Both examples point toward the intensity, distinctness, and lack of flexibility of the flavor of sweet potatoes, characteristics not commonly associated with common staple foods.

Humans exhibit distinct patterns in the foods which they select to consume and flavor is known to be a primary criterium in this selection. Most flavors are comprised of a combination of both taste and odor. Our perception of taste is generally thought to be limited to four basic tastes: sweet, salty, sour, and bitter. This is contrasted with the potential perception of up to 10,000 distinct odors by the olfactory epithelium. This difference in potential perception is also seen in the number of taste receptors for an individual which are in the thousands, versus odor receptors which are thought to be in the millions. Characteristic combinations of flavors (called "flavor principles") are often added to many foods in most of the worlds cuisines (Rozin, E., 1973). Thus the ability to manipulate the flavor of a food product can greatly enhance a new product's acceptance into a cuisine (Rozin, P., 1977).

Foods can be classed into four general groups based on their characteristic flavor volatiles (Nursten, 1978).

1. Those whose aroma is composed primarily of one character impact compound (CIC).
2. Those whose aroma is due to a mixture of a small number of compounds, of which one may be a character impact compound.
3. Those whose aroma is due to a large number of compounds, none of which are character impact compounds and with a careful combination of these components the odor can be reproduced.
4. Those whose aroma is made up of an unreproducible complex mixture of compounds.

Examples of character impact compounds would be 2-isopropyl-3-methoxypyrazine in raw white potato tubers or isopentyl acetate in banana fruit. Examples of foods whose aroma is made up of a small number of compounds are boiled white potatoes [2-ethyl-3-methoxypyrazine (CIC) and methional], apple [ethyl-2-methylbutyrate (CIC), hexanal and trans-2-hexenal] and boiled cabbage [dimethyl disulfide (CIC) and 2-propenylisothiocyanate].

Little is known about the flavor of sweet potatoes. The aromatic flavor components of cooked sweet potatoes have not been identified although part of the volatile constituents of one North American cultivar have been described (Purcell et al., 1980). The principal taste sensation is sweetness and appears to be due primarily to maltose (Sistrunk et al., 1954) and sucrose. The degree of variation in these parameters between local cultivars and cultivars from diverse centers of selection has not been measured.

The development of the sweet potato into a staple for human consumption appears to be in part dependent upon the integration of an analytical measure of flavor (aroma and taste) into breeding programs for new cultivars. As a preliminary step in this process we describe the volatile profiles of three diverse cultivars of sweet potatoes from different centers of selection, and identify a number of the volatile and sugar constituents.

## Materials and Methods

Three sweet potato cultivars (Jewel, Morado and Tainung 57) representing North American, Central American, and Asian centers of selection were used in our investigation to characterize the volatile compounds and sugars from baked storage roots. The cultivars selected differed significantly in both the physical and aromatic properties of the baked roots (Table 1). Morado, a dry white fleshed type, had very little aroma which was described as a starchy odor. The flavor was often described as similar to a baked dry fleshed white potato (*Solanum tuberosum* L.) that was sweet. Tainung 57, a yellow dry fleshed type, had a slightly stronger aroma than Morado which was also characterized as principally starchy in nature. The flavor was described as somewhat similar to roasted chestnuts (*Castanea sativa*, Mill). Jewel, a moist orange fleshed cultivar, exhibited a strong sweet, caramel aroma. The aromatic properties of this cultivar were much more pronounced than those of either Morado or Tainung 57.

The cultivars were grown at the University of Georgia Horticultural farm, near Athens, Georgia, on a Cecil sandy loam soil. After harvest, the roots were cured at 29.4°C, 98% RH for 7 days and stored until use at 12.8°C, 85% RH. Seven individual roots, 7 to 9 cm in diameter, of each cultivar were baked in an electric oven for 60 minutes at 204°C. The skin was removed and the individual roots of each cultivar composited and mashed. A 300 gm aliquot was removed and blended in a Waring blender with 300 ml of distilled water. The resulting slurry

was placed in a 3-l round bottomed flask with an additional 300 ml of distilled water added. The flask was then connected to a steam distillation, continuous pentane extraction apparatus (Nickerson and Likens, 1966) and the pentane and sweet potato macerate boiled for 8 hours. After cooling, the flask containing the 120 ml of pentane was removed, cooled to ca 40°C, and concentrated to 0.5 ml with a gentle stream of high purity nitrogen.

Table 1. Description and origin of the sweet potato cultivars used to characterize the aromatic components and sugars of the baked roots.

| | Cultivar | | |
|---|---|---|---|
| | Morado | Tainung 57 | Jewel |
| Geographical origin | Central America | Asia (Republic of China) | North America (United States) |
| Skin color* | | | |
| Description | red | yellowish beige | copper |
| L | 40.5 | 55.5 | 44.7 |
| a | 17.9 | 11.6 | 14.7 |
| b | 11.5 | 22.9 | 17.5 |
| Flesh color* | | | |
| Description | white | yellow | orange |
| L | 85.9 | 76.7 | 65.4 |
| a | -1.7 | 12.8 | 32.5 |
| b | 17.9 | 31.8 | 29.7 |
| Description of baked flesh texture | dry | dry | moist |
| Description of aroma of baked roots | little aroma, starchy | weak aroma, starchy | strong aroma, sweet, caramel |
| % dry matter of baked roots | 32.02 | 32.21 | 29.05 |

*Uncooked

GLC-MS Volatile Analyses

Analyses were performed with a Perkin-Elmer Model 900 gas-liquid chromatograph (GLC) on samples ranging from 1.0 to 1.7 µl in volume. The chromatograph was connected by means of an effluent splitter to a DuPont 21-490B mass spectrometer equipped with differential pumping on the analyzer section. Separations were made on a 50 m x 0.05 cm glass capillary column coated with Superox 4 (Alltech Associates). GLC conditions were: carrier gas inlet pressures, 0.6 kg/cm$^2$; injector and manifold temperature at 250°C; and column held at 55° for 6 min then programmed to 200°C at 1.5°/min.

Table 2. The sugar composition of three cultivars of baked sweet potatoes.

| Cultivar | Sugars (% dry weight) | | | | | Total sugars |
|---|---|---|---|---|---|---|
| | Unkown | Fructose | Glucose | Sucrose | Maltose | |
| Jewel | 0.46 | 2.68 | 3.02 | 15.96 | 27.12 | 49.24 |
| Morado | 0.53 | 0.91 | 0.97 | 10.25 | 19.05 | 31.71 |
| Tainung 57 | 0.33 | 0.61 | 0.66 | 13.98 | 25.05 | 40.63 |

Mass spectrometer conditions were: ion source temperature, 200°C, scan rate, 10 s per decade; ionizing voltage, 70 ev; and ion source pressure, 2 x $10^{-5}$ Torr. Compounds were identified by comparison of their mass spectra and GLC retention times with those of known standards. Compounds were considered to be positively identified when their mass spectra and GLC retention times agreed with those of a known standard. Compounds identified solely on the basis of comparison of their mass spectra with standards in the literature are designated "tentatively identified."

## HPLC Sugar Analyses

Samples of the baked sweet potatoes were also collected and freeze dried for sugar and dextrin analysis by high pressure liquid chromatography (HPLC). Two gm samples of ground (40 mesh) freeze dried sweet potatoes were blended in a Virtis mixer for 7 minutes with 25 ml of distilled water. The solution was then vacuum filtered through #2 Whatman filter paper and then through a 0.45 µm Millipore filter. Samples (50 µl) were then separated on an Alltech 600 CH 30 cm x 4.1 mm ID column using either 7:3 or 8:2 ratio of degassed acetonitrile and deionized water as the mobile phase (3 ml/min). The 7:3 ratio was used for separation of the component dextrins, which gave only fair resolution of individual sugars. As a consequence, the 8:2 acetonitrile-water solvent was used on separate samples for more precise sugar analysis. A Whatman CO:Pell pac precolumn was used with an Altex pump, Waters differential refractometer and Hewlett Packard 3380A integrator. Individual peaks were identified and quantified using known standards.

## Raw Product Color

The external and internal color of representative fresh storage roots of each cultivar were measured using a Gardner XL 20 colorimeter against a white chromatic reference standard (L = 92.0, a = -1.2, b = 1.1).

## Results and Discussion

Comparing the chromatographic profiles of the volatile compounds collected from each of the three cultivars indicated distinct differences. These differences were reflected in both the number of volatile compounds present and in the concentration of specific molecules (Figure 1). Jewel had substantially more compounds present and generally a greater concentration when there were similar molecules in either of the other cultivars. We have thus far identified pentene-2, acetone, 2,3-butanedione, hexane, pentane-2-one, methylbenzene, 2-pentanol, methylacetate, dimethylbenzene, pyridine, 2-phenyl-2-methylbutane, furfural, 2-furylmethylketone, benzaldehyde, 2-propenylfuran, 2-methyl-6-ethylpyridine,

α-terpinol, heptylbenzene, hexadecanol, heptadecanol, 1-isopropyl-4-isopropenyl benzene, tetradecanol, a monoterpene and several sesquiterpenes as volatiles of Morado. In Jewel, pentene-2, acetone, acetaldehyde, methanol, hexane, toluene, xylene, pyridine, benzaldehyde, i-butyronitrile, 2-phenyl-2-methylbutane, furfural, 2-acetyl furan, 2-pyrone, n-propylbenzene, limonene, 2,4,6-trimethyl pyridine, β-ionine, several monoterpenes and a number of sesquiterpenes were found. There appear to be a number of alcohols in the higher molecular weight compounds possessing high retention times in the chromatogram (Figure 1). Because of high column bleed at the upper temperatures used, we have not yet been able to get good spectra for these compounds in the Jewel cultivar. A number of these volatiles are known to have distinctive aromatic properties and may therefore be significant components of the characteristic aroma of the respective cultivars. For example, furans, pyridines and pyrones are heterocyclic compounds known to be involved in the aromas of other food products (Figure 2). In addition, terpenes such as the monoterpene limonene and the sesquiterpene cadinene are also distinctive aromatic compounds (Figure 2). We have yet to identify a character impact compound in sweet potatoes. It is probable, however, that if there is a character impact compounds present, it will differ between the moist fleshed highly aromatic Jewel and the weakly aromatic Morado and Tainung 57.

The qualitative composition of specific sugars between the three cultivars was identical, however, the relative amounts and ratios of individual sugars within a cultivar varied considerably between cultivars. The sweet flavor of the sweet potato was found to be due to maltose, sucrose, glucose, fructose and an unknown sugar (possible a pentose) in decreasing order of concentration. The identification of furfural among the volatiles of two types of sweet potato supports the pentose structure for the unknown sugar. Jewel had the greatest concentration of total sugar in the baked product, over one-third greater than Morado which had the lowest concentration. Maltose is believed to be the predominant sugar formed during baking (Sistrunk et al., 1954). Its final concentration is known to vary due to both postharvest factors and cooking technique; both factors which were held constant in this study. The ratio between the concentration of sucrose and maltose was relatively similar between cultivars (1:1.7 - Jewel, 1:1.9 - Morado, 1:1.8 - Tainung 57) which would suggest that differences in the final maltose concentration were due to inherent differences within the respective cultivar rather than any variation in treatment. Differences in free hexose sugars (fructose and glucose) represented a significant point of separation between Jewel and the dry fleshed cultivars. Jewel had 3 to 4.5 times more free hexose sugars than Morado and Tainung 57.

We did not find significant levels of dextrins, although one unidentified peak (Figure 3) probably represents an intermediate chain length dextrin. This would indicate that in the cultivars tested, β-amylase represented the primary active enzyme in the hydrolysis of starch during baking and α-amylase had only a very limited role.

## Summary

We have demonstrated that there is a substantial variation between existing sweet potato cultivars in both the volatile constituents of the baked roots and the concentration and ratios of specific sugars. It is anticipated that a much more extensive range of variation in these parameters will be found in the world sweet potato gene pool and between *Ipomoea batatas*, Lam. and other storage root and tuber forming *Ipomoea* species.

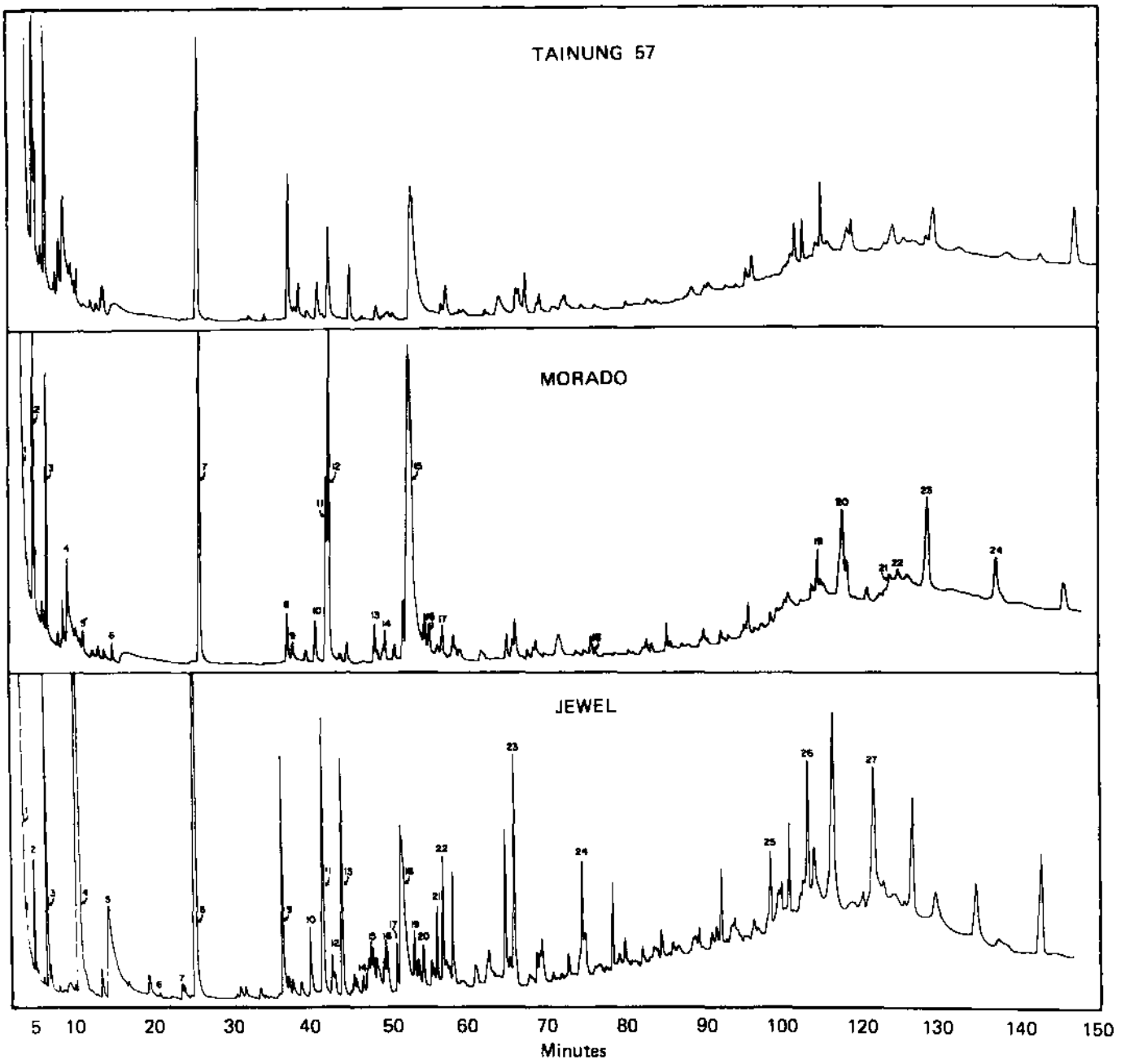
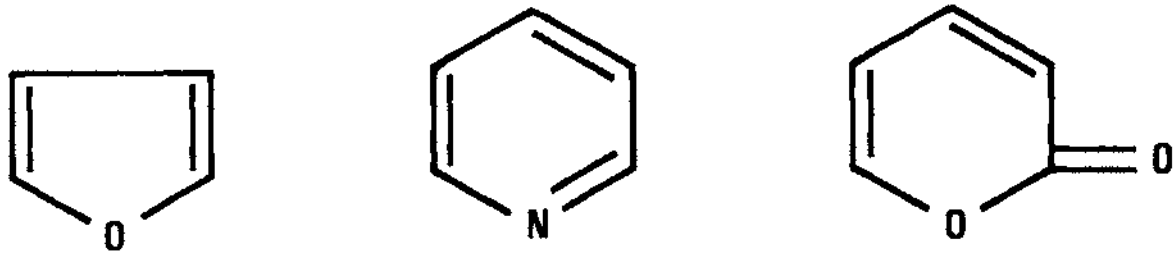


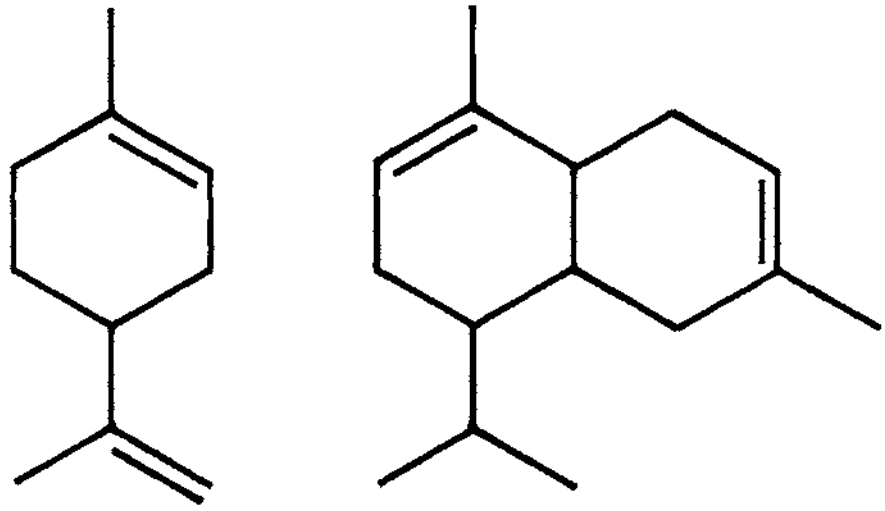

Figure 1. Volatile profile chromatograms of a North American (Jewel), Central American (Morado), and Asian (Tainung 57) cultivar of baked sweet potatoes.

TYPES OF HETEROCYCLIC COMPOUNDS




FURAN PYRIDINE PYRONE

TYPES OF TERPENES



Limonene Cadinene

MONOTERPENE SESQUITERPENE

Figure 2. The basic structure of three general types of heterocyclic compounds and two types of terpenes found in the volatiles of baked sweet potatoes that have been associated with the aromatic flavor of other food products.

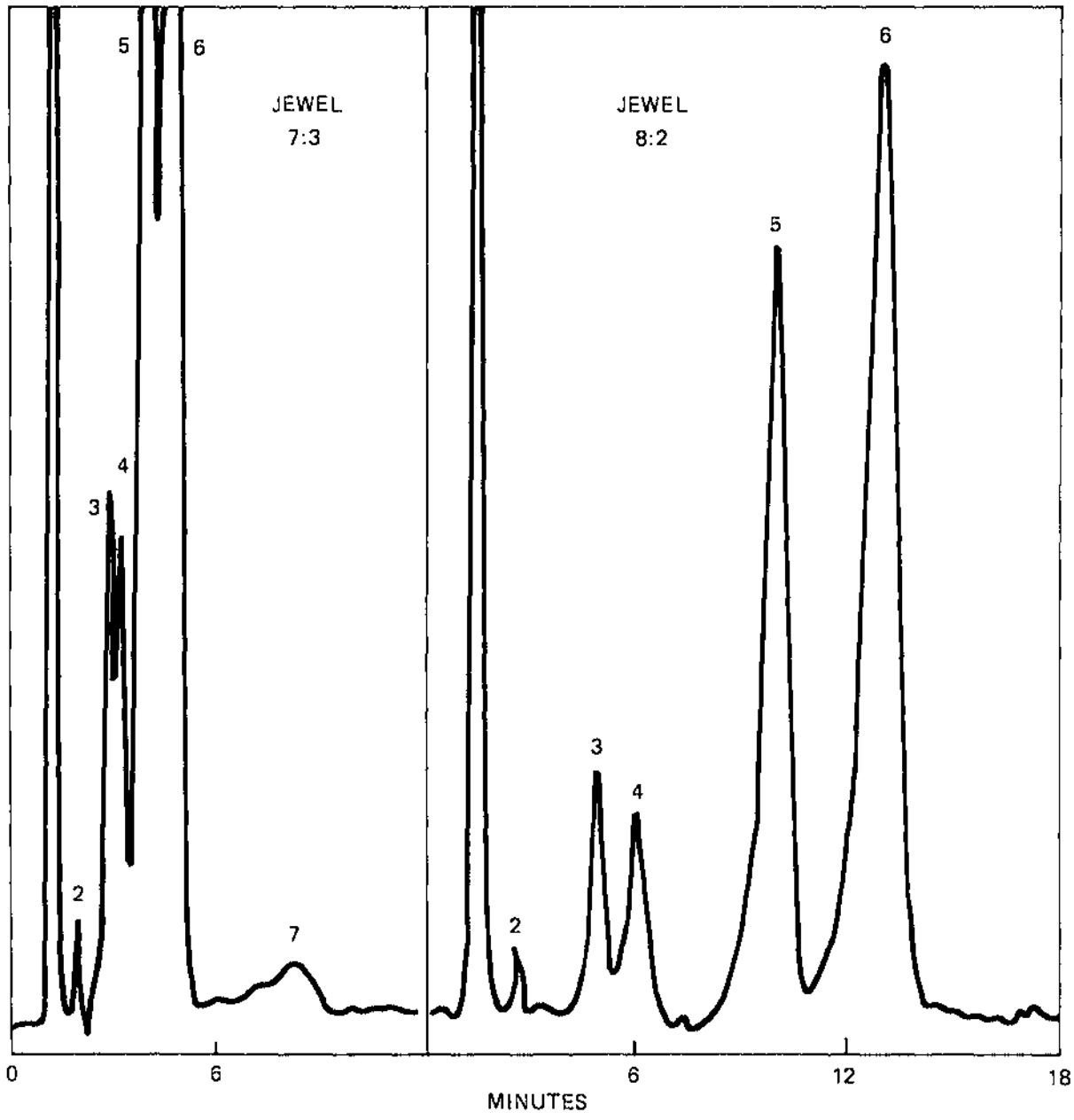



Figure 3. Chromatograms of sugars isolated from baked storage roots of the cultivar Jewel. Solvent ratios of 7:3 and 8:2 (acetonitrile and deionized water) were used to separate component dextrins (7:3) and specific sugars (8:3). Peaks present represent: (1) water, (2) an unknown, possibly a pentose sugar, (3) fructose, (4) glucose, (5) sucrose, (6) maltose, and (7) possibly an intermediate chain length dextrin.

The high yields and ecological flexibility of the sweet potato point toward its potential as a preferred human "staple", i.e. a food which is consumed on a frequent basis in an ethnic or social group's diet, providing a major amount of the nutrition of that group. However, the intensity and distinctness of the flavor of currently existing cultivars appears to decrease the product's flexibility for use and level of acceptance as a preferred staple. With the wide range of variation in the flavor of the sweet potato that appears to be present, the integration of an analytical technique for the rapid screening of genetic crosses for flavor would enhance the rate at which flavor quality could be altered. This could: (1) increase the level of acceptance of sweet potatoes as a human food, (2) increase its potential integration into new geographic areas and social groups, and (3) elevate world food production through its use in preference to lower yielding crop species.

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## Effect of Time of Harvest on Five Sweet Potato Varieties in Root and Flour Yield and Bread-Making

Author: L. Chiappe, H. De la Cruz, R. Zarate, and M. Villagarcia, Department of Fitotecnia, Faculty of Agriculture, National Agrarian Univ., Lima, Peru.

ABSTRACT

Two studies were conducted to determine the most appropriate stage for harvesting five sweet potato varieties (Paramonguino, Lirio, Seedling-50, Chilingano, and Blanco LM) by considering the relationship between root (R) and foliage (F).

Chilingano, Lirio, and Blanco LM were used in the first experiment, and in the second experiment, Lirio, Paramonguino, and Seedling-50. In both experiments, the best results were obtained with a R/F relation around 1.5. The highest flour percentage was obtained with a R/F above 1.5, but decreasing its quality. Both parameters were better with a R/F ranging from 1 to 1.5. Paramonguino and Chilingano gave the highest yields (25 t/ha) and were the best for breadmaking. Blanco LM and Paramonguino had more flour percentage (20%).

## Yield and Flour Production of Twelve White, Sweet Potato Cultivars for Industrial Use

Author: L. Chiappe, P.E. Lopez, and M. Villagarcia, Department of Fitotecnia, Faculty of Agriculture, National Agrarian Univ., Lima, Peru.

ABSTRACT

An experiment was carried out to identify cultivars with high root and foliage yields as well as good quality flour. The best root yields were obtained with Alcala (18 t/ha) and Buen Pobre (16 t/ha); foliage yields were highest in Maleño (30 t/ha) and Ihuanco (20 t/ha); Chilingano, Pierna de Viuda, and Ihuanco gave highest percentage of flour production (34%). In breadmaking, substituting 10% of wheat flour with sweet potato flour gave favorable results in the quality and form of bread.

All cultivars were tolerant to the root-knot nematode (*Meloidogyne incognita*). We believe that white, sweet potato cultivars were tolerant because of their thick skin and periderm, which make it difficult for nematode penetration.

## Technique for Evaluating Resistance of Sweet Potato Accessions to the Weevil, *Cylas formicarius elengantulus* Fabr.

Author: E.N. Bernardo and N.M. Esguerra, Department of Plant Protection, Visayas State College of Agriculture, Visca, Leyte 7127-A, Philippines.

ABSTRACT

The technique developed involves the use of potted plants covered with nylon tulle at the base to produce consistent weevil-free tuberized roots. The plants are provided with trellises for vine support and are kept in an open field. Later, the well-developed, undetatched tuberized roots were exposed by removing some soil from the pot and were then artificially infested with newly emerged adult weevils. The tubers were harvested 20 days later and examined and sliced to record the weevil population present and the extent of damage inflicted. The technique developed was effective in separating resistant from susceptible accessions and in detecting those that escaped weevil infestation in field screening.

## Effect of Type in Histological Differentiation, Precocity, Production, and Susceptibility to Nematodes in Sweet Potato

Author: C. Lopez Ocaña and R.E. Ortiz, Department Fitotecnia, Faculty of Agriculture, National Agrarian Univ., Lima, Peru.

ABSTRACT

Studies were conducted in order to determine the influence of the length and the origin of cuttings (upper, medium, and lower) used as planting on the histological differentiation of the roots, the degree of rooting, crop precocity, root and foliage yields, and susceptibility to root-knot nematode (*Meloidogyne incognita*). In all studies cv. 'Japones' was used.

Rooting and initial vigor were highest with upper (96%) and medium (75%) cuttings. Upper cuttings gave origin to root systems that differentiated earlier because of their simple structure and more efficient hormonal complex. Upper 35-cm cuttings gave the highest yield (23 t/ha) and were significantly better than 25- and 15-cm cuttings. Lower 15-cm cuttings gave the highest foliage yields (22 t/ha). The upper 15-cm cuttings were considered resistant to root-knot nematode, while the lower 25-cm cuttings were tolerant, but at the same time they were the most sensitive.

Preliminary Research on timing of weed control in Yams (Dioscorea rotundata Poir) and Taniers (Xanthosoma sp.)

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ABSTRACT

Preliminary experiments on effects of weed competition at various stages of growth were conducted on yams (Dioscorea rotundata Poir) and taniers (Xanthosoma sp.) at Corozal, in the central hill lands of Puerto Rico. In yams, no response resulted for hand weeding conducted for more than 2.5 months from planting. Weed competition during the first 2.5 months of crop growth did not significantly decrease yields. Data suggests the critical period for maintaining yams weed free is between 2.5 and 4.0 months after planting.

Results of the tanier experiment indicate greater detrimental effect on yield when weed competition is allowed during the first 5.5 months from planting than when allowed only during the later part of the growing season. Highest yields were obtained from hand weeding for 5.5 months or more. However, no significant differences in yield were recorded from weeding throughout the growing season, hand weeding only during the initial 2.5 months of crop growth, and allowing weed competition only during the initial 2.5 months from planting.

The findings in both experiments are preliminary. Additional experiments with both crops are being conducted. Concrete recommendations will be made once the research is completed.

## Introduction

Yams are the most important root and tuber crop grown in Puerto Rico. The island's production, worth $8 million at the farm level during 1980-81, amounted to 14,560 m (Puerto Rico's Dept. Agric., 1981). Price per kg was 55 cents and annual per capita consumption was 4 kg. The amount represents 78% of the per capita consumption during 1955-56.

Taniers are Puerto Rico's second most important root and tuber crop (Dept. Agric., 1981). Worth $ 5.5 million at the farm level during 1980-81, production was 11,113 m with a price per kg of 50 cents. The per capita consumption per year was 6 kg. This amount represents 67% of the per capita consumption during 1955-56.

Yams and taniers are grown mainly in the humid hills of central Puerto Rico. The size of plantings ranges from less than 0.8 to 1.2 ha (González-Villafañe et al, 1980). Mechanization has not been possible because of sloping nature of the land, moist condition of the soil during most of the year, and high costs of machinery for small farm units. Weeds thrive in warm humid conditions under which the crops are grown (Kasasian 1967; Orsenigo 1970; Pacheco et al, 1973). The long growing season of 7 to 10 months for yams and 9 to 12 months for tainers increases the weed competition problem (Doll and Piedrahita, 1976; Kay, 1973; Montaldo, 1972). Use of herbicides in these crops is not permitted in Puerto Rico, because none have been registered with the government. Hand weeding is the only alternative available at present for weed control. However, hand labor is scarce and expensive.

Topography of the terrain and high rainfall in the central mountain region of the island results in soil erosion where protective ground cover is not available. Hand weeding accounts for 27% of the production costs of yams (González-Villafañe and Espinet, 1980). Weeds, although detrimental for crop production, serve as ground cover and prevent erosion. Therefore, it would be desirable to determine the stage(s) of crop growth cycle when weeds have an adverse effect on its production (Kasasian and Seeyave, 1969). If weeds are controlled only at stages when they are detrimental, the cost of production could be lessened and soil erosion reduced. This study is objective to determine growth stages of yam and tanier in which weed competition has a detrimental effect on yield.

## Materials and Methods

A timing-of-weed-control experiment on white-fleshed yam (*Dioscorea rotundata* Poir) cultivar Guinea Negro began at the Agricultural Experiment Substation in Corozal, July 29, 1981. Corozal is in the central hilly region of Puerto Rico at 200 m elevation. The average minimum and maximum temperatures are 19° and 30°C, respectively. The annual average temperature is 25°C with a mean monthly variation of 5°C. The mean annual rainfall is 1,650 mm. The soil is a Corozal clay which is a clayey, mixed isohyperthermic, Aquic Tropudults derived from early tertiary volcanic conglomerates. It has a fine, subangular, very strong blocky structure; the predominant clay minerals are kaolinite and vermiculite.

The soil pH range at planting was 5.0 to 5.4. Soil had been limed at the rate of 2.24 mt/ha 2.5 months before planting. It was limed again 4 weeks after planting with 2.0 mt/ha. The organic matter content at the top 30 cm of the soil ranged from 2.2% to 3.2%. Phosphorus ranged from 0 to 2 ppm (Bray I method), potassium from 178 to 393 ppm, calcium from 1,538 to 1,929, and magnesium from 103 to 149 ppm. Soil texture was 23% sand, 48% clay and 29% silt. Fertilizer was applied twice, at 1 month and at 3 months after planting. A total of 180 ks/ha N, 78 kg/ha P, 300 kg/ha K, and 60 kg/ha Mg were applied. The 8-8-12 analysis applied is the standard fertilizer used for root and tuber crops in Puerto Rico. Sulpo-mag (18.3% K and 10.8% Mg) was the source of Mg and of one-third of the K utilized.

Cut yam tubers were immediately dipped for 15 minutes in a solution of 10 ml of thiabendazole and 10 ml of oxamyl per liter of water. After applying fungicide and nematicide dip, seed pieces were spread in a shaded area and allowed to dry and suberize for 3 days prior to planting.

Seed pieces weighting 112 to 128 g were planted on top of the beds. They were completely covered with soil. Beds were spaced 1.5 m apart and tuber sec-

tions were spaced 30 cm within the row. Each experimental plot included 4 rows 4.6 m long. There were 60 plants per plot. The experimental design followed a partially balanced incomplete block arrangement with 10 treatments replicated 5 times.

A month after planting, yam vines were tied to a wire 1.5 m over the ground level. Aldicarb was applied to the soil at 0.22 g a.i. per m of bed length. Applications of oxamyl and methomyl were made to the foliage in the later part of the season for further control of nematodes and insects.

Treatments included hand weeding for 2.5, 4.0, 5.0, 6.5, or 7.5 months and then allowing weed growth for the remainder of the growing season. In another set of treatments, weeds were allowed to compete for 2.5, 4.0, 5.0, 6.5, or 7.5 months from planting, and from then on the plots were hand weeded until harvest.

The experiment was harvested May 13, 1982, 9.5 months after planting.

A timing-of-weed-control experiment on tanier (*Xanthosoma* sp.) cv. Alers was planted at the Corozal Experiment Substation August 27, 1981. The experiment had the same climatic and edaphic conditions as the one for yams as it was planted in the adjoining field.

Planting material was prepared by taking the main corm, cutting and discarding its distal and proximal ends, and cutting the remainder into 94 g sections. The seed pieces received the same fungicide and nematicide treatments as the yam sections.

Seed pieces were planted on top of the bed and completely covered. Planting distance was 91 cm between the beds and 46 cm within the row. Each plot comprised 4 beds 6.4 m long. There were 12 treatments replicated 5 times in a partially balanced incomplete block design. All the treatments in the yam experiment were included in the tanier experiment. Two additional treatments, hand weeded for the first 9 months, and weed competition for the same period of crop growth, were included in the tanier experiment.

The predominant weed species in both experiments were guinea grass (*Panicum maximum* Jacq.), crabgrass (*Digitaria sanguinalis* (L.) Scop.), caesarweed (*Urena lobata* L.), goosegrass (*Eleusine indica*), spurge (*Euphorbia heterophylla* L.), jungle rice (*Echinochloa colonum* (L.) Link), bermuda grass (*Cynodon dactylon* (L.) Pers.), spreading dayflower (*Commelina diffusa*), and cundeamor (*Momordica charantia* L.). Other weed species in the experimental area included purple nutsedge (*Cyperus rotundus* L.), sensitive plant (*Mimosa pudica* L.), southern sida (*Sida acuta* Burn.f.), *Phaseolus lathyroides*, *Emilia sonchifolia*, pigweed (*Amaranthus dibius* Mart.), and oxalis (*Oxalis martiana*).

## Results and Discussion

In the yams experiment, treatments in which weeds were allowed to compete with the crop during the first 4 months or more from planting yielded significantly less than when weed competition was allowed only during the first 2.5 months from planting, or than any of the other treatments (Table 1). This indicated that weed control must begin during the first 4 months after planting to prevent a yield loss. Significant differences were noted between treatments where weeds competed for the first 4 months, and where they competed for 6.5 or more months. Thus, results show that even if the fields have not been weeded for the

first 4 months, a benefit still results from hand weeding if done no later than 4 months after planting (Table 1).

Table 1. Total yield of white-fleshed yam (Dioscorea rotundata cv. Guinea Negro) at Corozal, Puerto Rico, 1981-82.

| | Treatment | Yield[1] |
|---|---|---|
| | | m/ha |
| 1 | Hand weeded for 2.5 months, free weed growth thereafter | 18.507 a |
| 2 | " " " 4.0 " " " " " " " " | 20.621 a |
| 3 | " " " 5.0 " " " " " " " " | 23.750 a |
| 4 | " " " 6.5 " " " " " " " " | 22.865 a |
| 5 | " " " 7.5 " " " " " " " " | 20.978 a |
| 6 | Weed competition for 2.5 months, hand weeding thereafter | 21.239 a |
| 7 | " " " " 4.0 " " " " " " " | 13.205 b |
| 8 | " " " " 5.0 " " " " " " " | 7.155 bc |
| 9 | " " " " 6.5 " " " " " " " | 5.870 c |
| 10 | " " " " 7.5 " " " " " " " | 6.033 c |
| | C.V. = 16.19% | |

[1]Means followed by one or more letters in common do not differ significantly at the 5% level of probability.

No statistical differences in yield were found for hand weeding only the first 2.5 months (then allowing weed competition), and hand weeding during the whole season. However, yields tended to be lower when hand weeding was done the first 2.5 months, than where plots were weeded for 4 or more months. Results indicate that if the crop is kept weed free during the first 4 months of growth, allowing weed competition thereafter does not affect yield. Statistically, there was no advantage for hand weeding the yam fields for more than 2.5 months from planting.

The results of this experiment are not conclusive. The experiment should be repeated in different locations, but always taking into account the predominant weed species in the yam growing region. However, the experimental data indicates that the critical period for hand weeding is 2.5 months from planting. There was no statistical differences between plots which were weed free at 2.5 months and those hand weeded year long. At the same time, there was no difference in yield between plots in which weed competition was allowed during the first 2.5 months and then hand weeded for the rest of the season and those where hand weeding was done during the whole season. Thus it appears weeds do not adversely affect yield during the first 2.5 months of crop growth. Yams, therefore, should be kept weed free in the period from 2.5 months to 4 month after planting.

In the experiment with taniers, no statistically sifnificant differences were found between the treatments where weeds were controlled year around and where they were controlled for only the first 2.5 or more months from planting (Table 2). However, yields tended to be lower where hand weeding was done only to 4 months from planting vs. where weeds were controlled for a longer time. The tendency indicates that weeds may have a detrimental effect on tanier yield if they are controlled only for less than 4 months from planting.

Plots in which weeds were controlled for 5.5 months or more from planting yielded more than plots in which weeds were allowed to grow during the first 5.5 months or more and weeded thereafter (Table 2). The data clearly supports the hypothesis that weed competition has a greater effect on yield in the early stages of crop growth than during the later stages. Although no statistically significant differences were found between the treatments where weeds were controlled throughout the year and where weed competition was allowed for up to 4 months from planting, there was a tendency for the yield to be lower in all treatments in which initial weed growth was allowed.

Table 2. Total yield of taniers (Xanthosoma sp.) cv. Alers at Corozal, Puerto Rico, 1981-82.

| | Treatment | Yield[1] |
|---|---|---|
| | | m/ha |
| 1 | Hand weeding for 2.5 months, no weed control thereafter | 6.521 abc |
| 2 | " " " 4.0 " " " " " " " | 6.273 abc |
| 3 | " " " 5.5 " " " " " " " | 8.273 ab |
| 4 | " " " 7.5 " " " " " " " | 8.489 a |
| 5 | " " " 9.0 " " " " " " " | 8.444 ab |
| 6 | " " " season long | 7.651 abc |
| 7 | Weed competition for 2.5 months, hand weeding thereafter | 5.847 abc |
| 8 | " " " " 4.0 " " " " " " " | 5.469 bcd |
| 9 | " " " " 5.5 " " " " " " " | 4.556 cde |
| 10 | " " " " 7.5 " " " " " " " | 1.726 de |
| 11 | " " " " 9.0 " " " " " " " | 2.533 e |
| 12 | " " " " season long | 2.094 e |
| | C.V. = 34.77 | |

[1]Means followed by one or more letters in common do not differ significantly at the 5% level of probability.

Yield of taniers in the treatment in which weed competition was allowed only for the first 2.5 months from planting were significantly higher than in treatment in which weed competition was allowed for the first 7.5 months. The results indicate that cormel yield can be increased by hand weeding at 4.0 months from planting, even when initial damage from competition has already been done.

No differences in cormel yield were found between the treatments where weed competition was allowed during the first 5.5 months of crop growth and where weed competition was allowed the year around. However, yields did tend to be higher where weed competition was allowed during the first 5.5 months than where they were allowed for longer periods. The data indicate a substantial decrease in yield when weed competition is allowed for more than 4 months from planting. However, a tendency exists for yields to continue decreasing if weed competition is allowed to continue from 5.5 to 7.5 months or more after planting (Table 2).

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# *Dioscorea nummularia* Lam.: The Primary Edible Yam of Western Samoa

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## ABSTRACT

The authors feel that, in W. Samoa, the importance of *Dioscorea esculenta* and *D. alata* has been overestimated and that of *D. nummularia* underestimated. Thus the literature on the latter is reviewed and observations from village production and a variety collection are reported.

*D. esculenta* is eaten only on the western tip of Savaii island and other Samoans deride people of that district since sweet root crops such as sweet potato are generally disliked. Only *D. alata* "ufi tau" and *D. nummularia* "palai" are marketed. However, even in the June through August *D. alata* season, "palai" is more common in the market. The solid texture and high dry matter of the latter is preferred by Samoans. Four "palai" cultivars are recognized: 'maoi (Samoa)' has a dark spiny stem, 'Niu Kini (New Guinea)' has a thicker less spiny stem and curving tubers, 'ulu' has a large protocorm, and 'lau palai' has lighter stem and leaves.

*D. nummularia* is also the primary marketed yam in Suva, Fiji.

While reading the literature on yams in the Pacific, it appeared to the authors that the importance of *Dioscorea alata* and *D. esculenta* has been overestimated and that of *D. nummularia* greatly underestimated, particularly in Western Samoa. Martin has suggested that systematic studies of the neglected minor species *D. nummularia*, *D. transversa* and *D. pentaphylla* be given priority in yam research. Thus the authors have reviewed the literature on *D. nummularia* and have initiated trials on this species (Chandra, 1979; Yen, 1979; Jackson, 1980; Sivan, 1980; Martin, 1981; personal observations).

*D. nummularia* Lam. originated in South-East Asia. Today it is cultivated in Indonesia and is the most important *Dioscorea* species in parts of New Guinea and some Pacific Islands. Nonetheless, it has been neglected in germplasm collections. In Indonesia only two cultivars from east Java have been collected, in the Solomon Islands the collection has been small until very recently, and the yam collections in Papua New Guinea, Philippines and Fiji presently contain no accessions of *D. nummularia* (Burkill, 1951; Spencer, 1966; Coursey, 1967; Damania and Williams, 1980; Jackson, 1980 and personal communication; Sivan, personal communication).

D. nummularia belongs to the section Enantiophyllym of the family Dioscoreaceae characterized by vines which twine counter-clockwise (twining to the right). Stems are round in cross-section with dense spines and occasionally indistinct ridges at the base. The upper portion of the vine is glabrous. Tubers, which can be as deep as one metre, are large, deeply lobed, almost independent, with each lobe deltoid. Roots are wirey and flesh is white to red. Leaves are large, cordate or elliptic, with the lower ones opposite and upper alternate. Flowers are in racemes, the males in groups of one to four racemes each up to 4 cm long. The females are in groups of one or two racemes each up to 15 cm long (Barrau, 1956; Massal and Barrau, 1956; Coursey, 1967; Martin and Degras, 1978).

D. glabra Koorders non-Roxb., D. palauensis Knuth, D. hebridensis Knuth, D. seemanii Pr. and Burk., and D. pirita Nadeaud are either synonymous with or subspecies of D. nummularia Lam. In addition several other species recognized by Knuth are also synonymous, including D. angulata, D. glaucoidea, D. lufensis and D. raymundii. Likewise D. divaricata Blanco is very similar, differing from D. nummularia only in the straightness of the lamina margin (Burkill, 1951; Barrau, 1956; Coursey, 1967).

## Distribution

D. nummularia on Hai-nan island, China, is locally called "toa tu tang". In Malaysia its name "tali cupang" is derived from the fact that the stem is sometimes used as cordage and in eastern Malaysia, northern Kalimantan and Sulawesi, Indonesia, it has been described as deep growing, low yielding and high in saponin. In Indonesia D. nummularia is called "sounda" in east Java, "marau" in the Hermit islands, and "waro" on Amboina. In contrast to other Dioscorea species which are differentiated by cultivar name, the wild D. nummularia in Sunda, Indonesia, and among the Sambali of Luzon, Philippines, has the same vernacular name as Smilax sp. However, on eastern Luzon wild D. nummularia had more than one series of vernacular names. In the Philippines the typical variety has been called vera, while var. glauca is distinguished by glaucous capsules. Knuth also recognized var. lata with broad leaves. Tagalog name on Luzon is "ubing basol", it has the name "banan" on Mindanao, while in the Republic of Belau in Micronesia to the east it is called "detachel" (Prain and Burkill, 1959; Burkill, 1951).

In Papua New Guinea the names "kiloma", "boku" and "sinngo" have been used in the literature for D. nummularia. It has been reported from the north and south-east of the mainland, and on the islands of Louisade, New Ireland and Bougainville. In Goroka highlands it is a minor cultivated crop in addition to being gathered from the wild and in west New Britain where it is biennial and weedy, the Sengseng often harvest it from wild populations (Prain and Burkill, 1939; Barrau, 1956; Brookfield and Hart, 1971; Yen, 1979; Bourke, 1980).

Although D. nummularia was not recognized in the early literature of New Caledonia, thirty cultivars have now been identified from the country as a whole and fourteen cultivars including two wild ones have been identified in Poya alone. Cultivar 'bwet' was described as being less susceptible to excess soil magnesium and it absorbed relatively less iron, nickel and chromium than the D. alata tested. In addition, 'bwet' had better taste and larger starch grains than D. alata but stored poorly (Barrau, 1958; Bourret, 1973 in Martin and Degras, 1978; Bourret, 1975).

In the Solomon Islands D. nummularia is locally called "karausu" and "puutiko." Eight cultivars from Guadalcanal have been recorded as 'uvi matua', 'uvi vatu', 'uvi chamba' 'chavuli', 'kaipuchi', 'ngoti hila', 'ngoti tambu ni bela' and 'sambina'. These were largely found in the interior but with some in the west and at Longgu. Vines of these cultivars were generally many (10-20), with spines ranging from large and many to very few. Tubers varied in number and shape, some being round in cross-section, others square, generally deeply placed, although one cultivar was reported to produce shallow tubers. One cultivar produced small tubers within the first year but most required three or four years to produce a reasonable yield and most produced tubers with hard flesh although one cultivar typically had soft flesh and tubers rotted easily (Barrau, 1956; Tedder and Tedder, 1974).

On Anuta, a Polynesian outlier island in the Solomon Islands, D. nummularia was mapped in central and eastern parts of agricultural zone III. It was called either "uporoi" or "Taumako", the former after Upolu, W. Samoa and the latter after a neigh-boring outlier. The tubers produced were illustrated as large, round and irregularly shaped. In contrast, D. alata and D. esculenta were mapped in only one area in zone VI with small plants and tubers (Yen and Gordon, 1973.)

In Vanuatu, D. nummularia is called "pango" and "loopitiko", the latter being similar to the "puutiko" name used in the Solomon Islands. On Ponape, Federated states of Micronesia, D. flabellifolia Pr. and Burk. reported in the literature to grow in the mountains and to be used during famine is most probably D. nummularia cultivar "kap nair" or "kapin-air". D. nummularia variety "sep" reported from yap appears to have a corrugated leaf like D. bulbifera (Glassman, 1952; Sasuke, 1953; Barrau, 1956; personal observation.)

In Fiji D. nummularia is called "rauva (-dua)", "tivoli", "tikau" or "san shue" in Cantonese, while in the Lau islands of eastern Fiji it is locally called "tchivoli", a name similar to one from the Solomon Islands. Generally it grows below 500 m elevation. It has been reported to be rare (less than 2%) in Suva home gardens as compared to 2-9% for D. alata, but in the Suva market it is definitely more important than D. alata. In 1975 and 1976 D. nummularia was recorded during 33 of the 35 market surveys with a mean abundance score of nearly 3 out of a maximum of 4 (very abundant). Although it was available year-round, tubers were most abundant in the months April through November. One Saturday in November 1981 the senior author observed that yams in the Suva market were almost exclusively D. nummularia with cultivar "tivoli" dominating. Only one Chinese merchant was selling D. alata "uvi" which was sprouting and spoiling. On Vanuabalavu island in the Lau group, wild "tivoli" and "tikau" yams were reported as common in the 1920s and 1030s, but have almost disappeared today due to extensive clearing of the forests (Barrau, 1956, 1961a; Thaman, 1976/1977, 1978a; Thaman and Ba, 1979; Smith, 1979; personal observations).

In tonga cultivars "ufi fisi", "ngu" and "tuaata" commonly found in cooperative yam gardens on Tongatapu may be D. nummularia but this species has not been reported from Vavau in northern Tonga (Prain and Burkill, 1959; Thaman, 1978b).

"Ufi parai" is the name given to D. nummularia on Rarotonga and on Niue it is called by a similar name "uhi palai". On the latter it has been reported to be scarce and to produce several long, slender, white tubers (Barrau, 1956).

At Fatuhiva, Marquesas Islands, the yam originally identified as the African yam D. cayensis Lam. has now been reidentified as D. nummularia. The two species are similar in appearance and easily confused, but D. nummularia usually forms deeper tubers and required much longer (2-3 years) to produce a reasonable yield. In the Society Islands, including Tahiti, and on some of the Cook Islands, "pilita" or "pirita were names for D. nummularia (Nadeaud, 1873; Brown, 1931; Barrau, 1956, 1961 a,b; Coursey, 1967).

In recent times two cultivars of D. nummularia have been introduced into Puerto Rico and the cultivar "wael" from New Caledonia with a chromosome number of 2n=80 was recently introduced into French West Indies where it has been reclassified as D. transversa R. Brown based on the fact that it had alternate leaves except near the vine apex, sparsely scattered spines near the base, profuse vine growth, triangular glossy leaves, and numerous club-shaped tubers (Bourret, 1973, 1975; Degras et al., 1971; Martin, 1974; Essad et al., 1978 in Degras, 1978).

"Ufi Palai" Cultivars in Samoa

In western Samoa four cultivars of D. nummularia are recognized. "palai maoi" or "palai samoa" has very spiny, dark stems and leaves with primary leaf veins at an acute angle. Flowering may occur after two to three years of growth at the time when it is ready for harvesting. Male flowering is common but three female plants were found in different locations in July.

"Palai niu kini", as indicated by its name, is an introduction from New Guinea. Like "palai maoi" it has a dark stem but it can be distinguished by the fact that the stem is less spiny and the tubers curve upwards towards the soil surface. In addition, its leaf is longer from the petiole junction to the apex with the sinus at an obtuse rather than an acute angle as compared to "palai maoi." The quality of "palai niu kini" is reportedly best when it just begins to resprout but after that time it becomes unpalatable. When harvested in August and immediately replanted sprouting occured at the end of October (Lamauta T., personal communications; personal observations).

"Lau palai" has a light green stem bearing leaves with veins at approximately right angles. The tuber shape is similar to that of "palai "maoi" which grow somewhat horizontally and therefore develop closer to the soil surface. Also it and "tue. has been reported to have broader leaves and shorter tubers than "palai maoi" (Christophersen, 1935; personal observations).

The fourth cultivar, "palai ulu", has a distinctive corm from which the tubers develop and has a bluish-green stem with wide upturned scale-like spines. A possible fifth cultivar "palai vao" has been reported but is probably "palai maoi" which has escaped from cultivation in abandoned plantations. Parham has included Christophersen's record of "ufi vao" with D. nummularia, but "ufi vao" inland of Sapoe, Upolu Island, was observed by the senior author to be D. alata (Christophersen, 1935; Parham, 1972; Onwueme, 1978; personal observations).

Two steamed and one boiled samples of D. nummularia harvested from a home garden in western Samoa averaged 38.6% dry matter and it is this high dry matter which gives the species the hard texture so much preferred by Samoans. In contrast, D. alata "ufi vao" and "ufi tau" ranged from 21% to less than 27% dry matter and D. bulbifera L. "soi" bulbils which are considered poisonous ranged from 23.8 to 27.4% dry matter (Pratt, 1911; Cable, unpublished data).

Data from market surveys conducted in Apia for the first week in each month of 1979 except January indicated that yams are only a minor cash crop in western Samoa. Each week total weight sold of the staple carbohydrates including taro, green bananas, Alocasia sp., breadfruit, yams and husked coconuts ranged from about 110 to 210 tonnes, whereas the maximum sale of yams reached only 0.3 tonnes in the two months August and December. Data for yams included both D. alata and D. nummularia but sale of the former is significant only in August during the cool, dry season when this species becomes dormant and sheds its leaves. At other times of the year D. alata is unpalatable and D. nummularia is the only species in the market. D. esculenta (Lour.) Burk. "ufilei" is not marketed. It is now found only in the driest Falealupo district on the western-most tip of Savaii. Most Samoans deride those from that district for eating the sweet tubers of "ufilei" since sweet tasting root crops such as sweet potato are generally disliked. Likewise D. pentaphylla L. "pilita", also called "lena" on Tutuila, is rare (Pratt, 1911; Setchell, 1924; Christophersen, 1935; Parham, 1972; Economic Analysis and Planning Division, 1979a-d; Leuluai J. W., personal communication; personal observations).

In American as well as western Samoa villages "palai" are normally planted in mounds and trellised on poles to trees 5-6 m away. Each family generally has no more than twenty or so plants of the different "palai" cultivars. Stones often are used to surround the mounds and coconut husks and mulch may cap the top as well. Whole corms with several tuber initials or sections of individual upper tubers may be planted with or without pre-sprouting. Because of the effort in digging the relatively long tubers, harvest is usually delayed until after two years. In lithic soils the corm tops may by that time begin to protrude from the ground. Yield data are not available but one "palai niu kini" plant harvested from a home garden produced a 4-branched tuber weighing 21.2 kg. It descended 63 cm into the soil and the dried remnants of the previous years's 4-branched tuber was attached to the same corm. This indicates that D. nummelaria is not perennial as sometimes reported (Merrick, 1977; Martin and Degras, 1978; personal observations).

There is a Samoan legend concerning the "palai" (tivoli") yam in Fiji. One of the numerous Sina married the king of Fiji. Her brother Pili went to visit her but hid in the bush being evidently doubtful of his brother-in-law's reception. He asked the birds and trees how he could arrange a meeting with his sister and the "palai" yam offered to send out one of his "tolo" vines to Sina's door. As Sina came out, her foot caught in the vine and since at that time there was a shortage of food in Fiji, Sina followed along the vine to find the tuber. There she found her brother. Since "palai" yam is very long, Sina broke off only a piece of it an returned home. Every day she returned to meet her brother and broke off another piece of yam. As she had followed up (tuli) the broken-off tuber (matanau), the tuber was called "tuli matanau". Hence repeated attempts at meetings or consultations to effect unity is referred to as "tuli matanau, le ufi o sina" (Tuli matanau, the yam of Sina) (Hiroa, 1930).

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Yam (Dioscorea spp.) Management for Control of Tuber Decay

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ABSTRACT

Yam tubers appear most susceptible to decay during early stages of sprouting, at late stages of field senescence, and during storage. In Puerto Rico, major organisms associated with tuber decay are: fungi (Penicillium spp., Fusarium oxisporum, F. solani, and Rhizoctonia sp.), nematodes (Pratylenchus coffeae and Scutellonema bradys), soft rot bacteria (Erwinia sp.) and white grubs (Diaprepes abreviatus). Decay results from interaction of organisms related to yam susceptibility, cultural and storage practices, and environment (temperature, humidity, and aeration). Studies are directed toward improvement of tuber quality by reducing decay. Commercial fungicides with thiabendazole, applied before storage, effectively reduced tuber fungi during storage and increased yam field stands and yield. Dioscorea alata cv. Florido and whole tubers showed less rapid and extensive tuber decay in storage than D. rotundada cv. Habanero and seed-pieces, respectively. Storing yams on raised slatted beds of bamboo reduced storage decay compared to commonly used soil surface storage. Pre-plant fungicide treatment of seed-pieces from high quality Habanero tubers increased emergence and yield. Treatment with Captan alone or with captan plus Benomyl or plus thiabendazole resulted in more than 90% emergence compared to 52% for untreated pieces. Field emergence and yam tuber yield were directly related.

## Introduction

Edible yams (Dioscorea spp.) are long season (6 to 12 months) tropical vines cultivated for their starchy tubers (Martin, 1972). Although yams are mostly used for their high content of complex carbohydrates, they have a higher protein content and better balance of amino acids than many other root crops, particularly cassava (Splittstoesser and Rhodes, 1973). Two species of yams, D. alata and D. rotundata are grown comercially in Puerto Rico.

In Puerto Rico yams are grown in humid mountain areas. Because of high labor requirement for staking and hand harvest, most yams are produced in small fields (1 to 3 hectares) as a family operation. Yam farmers generally sell their best quality yams for consumption and use low quality yams for planting. Besides this

practice, continuous monoculture in the same field and crude handling and storage practices allow yams to be heavily attacked by pests.

Dioscorea spp. are easily propagated by tuber-pieces or by whole tubers; in most cases true seeds are lacking. Vegetative propagation assures perpetuation of important agronomic characteristics. However, it also facilitates propagation of various pests. The need to use a large amount of expensive tuber material for planting and sensitivity of tubers to drying and to mechanical damage are other disadvantages of asexual propagation of yams.

Yams tubers may deteriorate from several mechanical or biological causes. Biological causes include yam respiration and action of a variety of microflora and microfauna. Yam tubers may be degraded by insects, nematodes, fungi, and bacteria. Although damage by insects is fairly obvious, symptoms from nematodes, fungi and bacteria are often overlapping.

Tuber deterioration can occur anytime between planting and emergence and during tuber formation through harvest and storage. The types of organisms that attack tubers in the field, in storage, and at planting and their relative importance may differ depending on environmental conditions.

Preservation of yam tuber viability and vigor necessitates a seed tuber management program that includes a variety of cultural and control practices (Mignucci and Cordero, 1981). Of the limited amount of research on yams, most has centered on the control of storage deterioration (Burton, 1970; Coursey, 1967; Ogundana, 1972; Thompson et al., 1977). The major objectives of the present studies were to define components of yam deterioration and to develop control measures.

## Materials and Methods

Farm Survey: Storage Conditions, Tuber Losses, and Tuber Microflora. Observations on handling and storage practices, tuber losses, pest and diseases were obtained by comprehensively surveying 48 farms of D. alata cv. Florido and D. rotundada cv. Habanero in the yam growing zone of Puerto Rico during the 1980 and 1981 harvests. Newly harvested and stored tubers were evaluated for deterioration and associated microflora. Isolations included cortical tissues of the cortex and internal tissues of the tuber. Isolations were made from both healthy-appearing and rotting tubers. Samples from the different tuber areas were either cut into small pieces, soaked for 3 to 5 minutes in 0.5% NaOCl (10% Clorox), plated on sterile potato dextrose agar, and incubated 7 days or more at 27°C until sporulation permitted identification or were placed directly in moist chambers until developing fungi could be identified. Fifteen tissue pieces were plated for each sample. Fungi were identified with the aid of the stereomicroscope (4-40X) and/or the light transmission compound microscope (100-1000 X).

Pre-storage Fungicides: Influence on Field Performance of Yams. D. rotundata cv. Habanero from Corozal were harvested and sound tubers cut into 113 g seed-pieces. Pieces were either dipped in water (check) or fungicide baths for 5 minutes and then stored for 40 days in the yam storage room. Fungicide treatments included three different products including two formulations of thiabendzole (Tecto B and Mertect 340F) and an experimental benzimidazole fungicide (ME-147). Fungicides selected were based on a previous screening of nine commercial formulations of eight active products representing five chemical families of fungicides that included protectants and systemic compounds at several dosages each. Se-

lected products had shown a high degree of efficacy in controlling decay and all were formulated by Merck, Dohme, and Sharp. Each treatment consisted of four replicates of 25 yam pieces each which were randomly arranged in the storage trays. At the end of 40 days storage, yam pieces were rated for the presence of visible fungal growth and the incidence of advanced decay (over 50% of the tuber-piece rotted). The field trial used a randomized complete block design with four replications of 25 tuber-pieces each. The field was in Corozal in a silty clay soil (Ultisol) with a pH of 5.9. Seed-tuber-pieces were planted 8 cm deep every 30 cm in banks which were 90 cm high and with an inter-bank separation of 1.20 cm. Emergence counts were taken at 56 days after planting. Yam plants were counted and harvested at normal maturity and tubers were separated based on marketability.

Types of Yam Storage and Their Influence on Decay. Four types of storage were evaluated for influence on yam decay. Whole sound tubers of *D. alata* cv. Florido and *D. rotundata* cv. Habanero were stored either on (i) soil and covered with dried yam vines; (ii) bamboo tables covered by vines; (iii) as in (ii) but with the bamboo tables having a tin roof 90 cm above the table surface; and (iv) the wooden slats of open boxes in a storage room. The first treatment was to simulate farmer practice and the bamboo tables were designed as possible low technology alternatives. Tables were 90 cm high and built into a slope to conserve building materials and to allow good drainage and aeration. Each storage type was replicated four times with 25 tubers per replicate for each yam cultivar. Every 4 days tubers were individually rated for fungal development and degree of deterioration using the following scale: 1 = no fungi or deterioration, 2 = 1% to 25% fungi or deterioration, 3 = 26% to 50% fungi or deterioration, 4 = 51% to 75% fungi or deterioration, and 5 = 76% to 100% fungi or deterioration.

Pre-plant Treatment of Yam Seed-pieces. On December 15, 1980, Habanero tubers were harvested at the Corozal Substation and stored in trays in the storage house. Three months later, sound tubers of good appearance were selected and cut into sections of 115 g each, treated for one hour in fungicide baths or in water. Fungicide baths at 27°C were agitated by stirring every 10 minutes for a total of five times. Water-treated seed-pieces served as experimental checks. Afterwards, baths were drained and seed-pieces were placed at 35°C and 80% RH for two days to allow wounds to heal. Seed-pieces were planted on 28 March 1981 at the Alzamora Farm of the College of Agriculture at Mayaquez. The experimental site consisted of a silty-clay Ultisol of pH 5.0 typical of many yam production areas in Puerto Rico. The field was cropped in three previous seasons to soybeans and was not planted to yams previously. Samples of soil from the site were analyzed for pathogenic nematodes before planting and after harvesting.

Fungicide treatments were based on commercial formulations of captan alone, captan plus thiabendazole, and captan plus benomyl. For all fungicides 2,000 ppm baths of the captan component were prepared. A randomized complete block design with four replications of 25 seed-pieces each was used for the experiment. Seed-pieces were hand planted 8 cm deep every 20 cm on 50 cm high banks with 67 cm between adjacent banks. Emergence was recorded at 5, 6, 7, 8 and 9 weeks after planting. Yams were harvested at maturity on 14 January 1981. Tubers and plants per plot were counted and weighed. Mean tuber weight was calculated and data was analyzed for variance with treatment mean separation by Fischer's Least Significant Difference (FLSD). Simple linear correlations were used in associating experimental parameters.

## Results and Discussion

In Puerto Rico, planting dates, yam species preference, and selection of seed-tuber size varies considerably especially among distinct yam growing zones. For planting, most farmers use tubers which are not marketable as food because of small size or poor appearance. About 79% of all yam farmers store their tubers by forming large leaf - and vine - covered mounds on the ground or on the floor of existing farm sheds. About 58% of tubers have symptoms of nematode (*Pratylenchus coffeae*) damage. Forty-eight percent of stored tubers showed fungal rot (mostly associated with *Penicillium* spp., *Fusarium okysporum* and *F. solani*) and 44% of tubers showed perforations caused by the larvae of *Diaprepres abbreviatus*.

In order of prevalence, fungi associated with cortical tissues of yams were: *Fusarium oxysporum*, *Penicillium* spp., *F. solani*, *Rhizopus* sp., and *Mucor* sp. In yam tubers stored for prolonged periods bacteria, *Penicillium* spp., *Aspergillus* sp., *Trachysphaera* sp., *F. oxysporum*, and *F. solani* were isolated in that order of prevalence. *Penicillium* spp., *Fusarium* spp., *Rhizoctonia* sp., *Curvularia* sp., and a sterile mycelial basidiomycete were consistently isolated from internal tissues of yam tubers which were with or without rot symptoms.

*D. alata* cv. Florido was more resistant to storage deterioration than *D. rotundata* cv. Habanero. Mechanically injured and cut tubers decayed more rapidly than whole tubers. Visible decay was less on tubers stored on bamboo tables than those stored on field soil or in an enclosed shed. In order of prevalence, *Penicillium* spp., *Fusarium* spp., *Rhizoctonia* sp., and a mycelia basidiomycete resembling *Sclerotium* were associated with tuber rot in these studies of storage facilities.

In pre-storage treatment experiments, non-treated tuber-pieces showed extensive visible fungal colonization after being stored for 40 days at Corozal (Table 1). Although 17% of these emerged in the field, no economic yield resulted due to post-emergence damping-off. Four and eight thousand ppm thiabendazole as Mertect 340 F gave over 90% tuber-piece emergence and less than 10% fungal colonization. This was associated with increased harvested stand and yield. Mean number of tubers per plant and tuber yield per plant were not different among any fungicide treatment. The Tecto B formulation of thiabendazole was less effective than either ME-147 or Mertect 340 in preventing fungal deterioration and stand and yield losses. Control by all formulations increased with increasing dosage.

Several workers (Coursey, 1967; Ogundana, 1972; Thompson et al., 1977) reported storage deterioration of yam tubers. The influence of storage deterioration on yam field performance is not reported. From this study, pre-storage fungicides appear to be a powerful tool for increasing stand and yield of yams.

Fungicide pre-plant seed-piece treatments were highly effective in preventing emergence losses and in increasing yield (Tables 2 and 3). Emergence was 91% to 96% in fungicide-treated seed pieces compared to 52% for the nontreated control. Early emergence (5 weeks after planting) was higher for captan plus thiabendazole than for those treated with captan plus benomyl, captan alone, or nontreated seed-pieces (1% to 2%). From this experiment it appears that even when sound, healthy appearing tubers are used and optimum seedbed conditions are secured, seed-piece decay can almost halve emergence. Yam yields were directly related to field stands ($r=0.94$).

Table 2. Pre-plant fungicide treatments of Habanero yam seed-pieces and their influence on speed and frequency of field emergence at Mayaquez.

| Treatments and rate[1] | Percentage emergence | | | | |
|---|---|---|---|---|---|
| | Weeks after planting | | | | |
| | 5 | 6 | 7 | 8 | 9 |
| Orthocide plus (20 g/1) | 24 **[2] | 54 ** | 73 ** | 73 ** | 96 ** |
| Orthocide 4F (5.4 g/1) | 2 | 23 ** | 71 ** | 85 ** | 95 ** |
| DPX 115B (4.0 g/1) | 1 | 16 ** | 53 ** | 72 ** | 91 ** |
| Check (water) | 1 | 2 | 10 | 36 | 52 |

[1]Fungicide treatments contained 2000 ppm Captan. Pieces were immersed for 1 hour.

[2]Double asterisks below the treatment mean indicates that at that date the difference between that mean and the control is highly significant (P = 0.01) using FLSD.

Table 3. The effect of yam (Dioscorea rotundata cv. Habanero) seed-piece fungicide treatment on the yield of yams and its components in Mayaquez, Puerto Rico.

| Treatment* | Total tuber yield (kg/plot) | Total number of tubers | Per plant yield (kg) | Number of tubers per plant | Mean tuber weight (g) |
|---|---|---|---|---|---|
| Captan plus Thiabendazole, 10% Captan + 0.5% Thiabendazole, Orthocide plus | 27.0** A*** | 28.5 aA | 1.1 a | 1.20 A | 942 aA |
| Captan alone, Orthocide 4F, 36% Captan | 22.0 B | 28.5 aA | 0.9 a | 1.16 A | 770 bAB |
| Captan plus Benomyl, DPX-115B = 50% Captan + 10% Benomyl | 22.5 B | 26.3 aA | 1.0 a | 1.20 A | 858 aBA |
| Nontreated (check) | 12.6 C | 22.5 bA | 1.0 a | 1.64 B | 560 cB |

*Seedpieces were placed in fungicide baths for 1 hour at 27°C. All fungicide baths contained 2000 ppm captan.

**Means based on four replications of 25-seed-pieces each planted in 6.1 m row lengths on 1.1 m centers.

***A common lower or upper case letter signifies no statistical difference between treatment means at P = 0.05 and P = 0.01, respectively, based on Fischer's Least Significant Difference (FLSD).

Table 1. Performance of yam (*Dioscorea rotundata* cv. Habanero) seed-pieces treated with prestorage fungicides.

| Prestorage[a] fungicide and dosage (ppm a.i.) | Tuber pieces with visible fungi | Tuber piece emergence | Plants at harvest | Tubers at Harvest | | | Yield | | | Mean No. of tubers | Tuber yield (g) | Mean tuber weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Market | Non-market | Total | Market | Non-market | Total | | | |
| hiabendazole (Mertect™) | (%)[b] | | (No. x $10^3$/ ha) | | | | (Kg. x $10^3$/ha) | | | (g/plant) | | (g) |
| 2,000 | 61 | 53 | 11.7 | 15.6 | 6.6 | 22.3 | 6.3 | 0.5 | 6.8 | 1.9 | 0.58 | 306 |
| 4,000 | 2 | 96 | 25.8 | 26.6 | 14.1 | 40.6 | 11.9 | 1.4 | 13.3 | 1.6 | 0.52 | 327 |
| 8,000 | 4 | 92 | 29.7 | 38.0 | 14.1 | 52.0 | 17.2 | 1.7 | 18.8 | 1.8 | 0.63 | 362 |
| E - 147 | | | | | | | | | | | | |
| 5,500 | 76 | 29 | 8.3 | 9.1 | 3.6 | 12.7 | 5.3 | 0.4 | 5.6 | 1.5 | 0.68 | 442 |
| 11,000 | 71 | 54 | 16.1 | 17.2 | 5.2 | 22.3 | 7.4 | 8.8 | 8.2 | 1.4 | 0.51 | 368 |
| 22,000 | 32 | 69 | 23.4 | 25.6 | 12.5 | 38.1 | 13.7 | 1.2 | 14.8 | 1.7 | 0.63 | 379 |
| hiabendazole (Tecto B™) | | | | | | | | | | | | |
| 5,500 | 93 | 27 | 6.3 | 9.4 | 2.8 | 12.2 | 4.9 | 0.2 | 5.1 | 2.0 | 0.82 | 416 |
| 11,000 | 92 | 26 | 5.9 | 7.5 | 2.3 | 9.8 | 3.8 | 0.2 | 4.0 | 1.7 | 0.67 | 401 |
| 22,000 | 77 | 29 | 7.8 | 10.9 | 2.8 | 13.8 | 7.0 | 1.0 | 8.0 | 1.8 | 1.02 | 480 |
| o Fungicide | 100 | 17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 000 |

[a]Prestorage fungicides were applied to yam seed-pieces (∿ 110 grams each) by their immersion for 5 minutes in 100 l baths of the test solutions. Seed-pieces were stored 60 days under ambient conditions in Corozal, Puerto Rico.

[b]Treatments consisted of 5 replications of 20 seed-pieces each. Planted in a randomized complete block design in the field after 40 days of storage.

Because of ability to reduce labor costs, decay and mechanical transmission of pathogens, use of small whole potato seed tubers have gained popularity in seed production areas (Hooker, 1981). Specialized production and use of small whole yam tubers for seed may help promote healthier and more vigorous yam seedlings and possibly reduce the need to use pesticides.

Based on this work, a failure to treat yam seed pieces from sound tubers with appropriate fungicides will probably result in significant economic losses to farmers. Yam seed tubers or seed pieces are a significant production expense considering that compared to most seed crops, a tremendous mass is planted on a per area basis. If 10,000 to 20,000 plants per hectare are desired, seed piece costs based on using 117 g pieces at a cost of $0.80 to $1.00 per kg will range from $800 to $2,000 per hectare investment in seed alone. Considering a 50% mortality of non-treated seed pieces, direct losses could amount to from $400 to $1,000 per hectare. Besides the direct loss of seed pieces, the biggest loss is caused by reduction in total yield. In normal practice, farmers use seed pieces and or whole tubers which range from 225 to 900 g in most cases, considerably larger than those used in this experiment (115 g). Therefore, at the farm level, yam losses are probably greater than what we have calculated. Fungicide treatment of seed pieces is a promising practice for increasing yam production with a modest capital outlay.

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Experiments on the Vegetative Cycle and Yield Variation of *Dioscorea alata* by Successive Monthly Plantings and One-Year Aged Seed Tuber Planting

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ABSTRACT

Data from three years of plantings of *D. alata* (cv. Tahiti and Belep) made with tubers harvested in January, and stored at 18°C, 80% relative humidity, lead to the following conclusions.

Germination showed a dormancy response. In storage, bulb formation occurred after 12 months. In the field, it seemed linked to loss of apical dominance. Once a juvenile stage was completed, flowering appeared to be controlled by thermo-photoperiod. Stem number increased with age for one cultivar, but not the other. Tuber number per plant increased with age. Tuber weight was linked with length of the active vegetative cycle, the duration being maximum for the January planting and minimum for the November one. The biological cycle between mother and daughter tuber germination is maximum for the December planting, minimum for the September one.

Year old tubers of *D. alata* cv. Pacala stored under the conditions described above gave greater yields than month-old tubers. Their vegetative development, though initially weaker, benefited earlier from good growth conditions due to rapid tuber germination. Older tubers also produced greater stem and tuber numbers per plant.

Studies on Fertilization of Yam (Dioscorea spp.) and Yam Tuber Storage in Cameroon

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ABSTRACT

Nitrogen-based and potassium-based fertilizers significantly increased yam yields. Nitrogen at 160 units per hectare caused 18%, 25%, and 21% yield increases for Batibo (D. cayenensis), Jakiri (D. dumetorum), and Oshie (D. rotundata), respectively. Potash at 120 and 240 units gave 13.4% and 22.5% increases, respectively, with the Oshie cultivar. There was positive correlation between fertilizer application during the peak growing season (June to July) and economic responses to fertilizers with return/cost ratios varying between 4.8 and 7.6

Yam stored under ambient conditions in slatted wooden trays caused 46.7%, 32%, and 28.7% losses in D. cayenensis, D. dumetorum, and D. rotundata, respectively, after two months' storage. Tubers obtained from fertilized and unfertilized plots showed little difference in storability. Tuber maturity was an important factor in storage. Rapid hardening occurred in D. dumetorum, which rendered the tuber inedible a few days after harvesting. Darkness induced by black polyethylene delayed hardening of this variety by three weeks.

Studies on Yam/Maize Intercropping

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ABSTRACT

Results of three studies on yam/maize intercropping spanning 1976 to 1980 are reviewed. In the 1976 experiment, yam planted sole in March, yam interplanted with maize in March, and yam planted in April through March-planted maize were compared under three yam population densities and three fertilizer levels. Fertilizer application significantly enhanced tuber yields. Intercropping with maize reduced yam yields by 31%, while delayed planting of yam (April) depressed yam yields by 35%. Maize yields were reduced at increasing yam density and enhanced by fertilizer application, but not significantly.

In 1977 and 1978, six yam population densities and five fertilizer levels were evaluated in sole yam and yam intercropped with maize. Higher yam population densities and fertilizer levels significantly increased tuber yield. Grain yield was enhanced significantly by fertilization, but was unaffected by yam density.

In 1979 and 1980, 24 combinations of 5 population densities of yam and maize each as intercrops were compared. Depressions of the yield of each crop at higher population densities of its companion crop were significant. So also were the increases in the yield of each crop as its population density was raised.

Soil Physical and Chemical Properties Suitable for Yam (Dioscorea rotundata) Production in Southeastern Nigeria

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ABSTRACT

For optimum yam (D. rotundata) production, both the physical and chemical conductions of soils must be maintained at favorable levels. A study of soil profiles was carried out at three locations, Anam (derived from Allivium), Abakaliki (underlain by shale), and Umudike (formed from sandstones), to quantify the soil physical and chemical properties suitable for yam production. Anam and Abakaliki are well known for extensive cultivation of yam as a food and cash crop. Umudike is not particularly a yam-growing area but was included as a check. The average yam yields at Anam, Abakaliki, and Umudike were 46.4, 44.6, and 8.8 t/ha, respectively.

Samples from the soil profiles were examined for particle size distribution, bulk density (Bd), particle density, total porosity (Tp), CEC, exchangeable Ca, Mg, and K. Other determinations included organic carbon, total N, and available P. It was found that Anam and Abakaliki soils were fine textured, while Umudike soils were light textured, mainly in the top horizons. The results suggest that the Bd and Tp conducive to yam production lie within 1.10 to 1.36 g/cc and 46% to 56%, respectively. Chemically, the CEC should exceed 18.0 me/100 g and the level of saturation above 25%. Exchangeable K and Mg levels, particularly, should not fall below 0.3 and 2.0 me/100 g.

Guinea Negro: A High Yielding Out of Season Yam Cultivar

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ABSTRACT

Guinea Negro is a yam cultivar introduced from Jamaica. It belongs to the same genus and species as Habanero (Dioscorea rotundata). After various experiments it was found to be high yielding and as to dormancy has a different behavior than Habanero. It can be planted out of season and very high yields are obtained. When planted in October and harvested at 7 May, 8 June, and 9 July during the summer months, yields of 400, 447 and 473 cwt/acre were obtained.

Combining both cultivars, that is, planting Habanero in its regular season, and Guinea Negro, out of season, we are able to have yams in the market all year around.

# Natural Antifungal Compounds from the Peel of Yam Tubers

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## ABSTRACT

Two compounds were isolated from extracts of the peel of yam tubers (*Dioscorea rotundata*) by thin-layer chromatography and were antifungal to the bioassay organism, *Cladosporium cladosporioides*, and pathogens causing storage rot of yams. The toxic compounds were identified with the aid of ultraviolet and infrared spectroscopy, nuclear magnetic resonance and mass spectrometry as 2,5-dihydroxy-4-methoxy-9, 10-dihydrophenanthrene and 7-hydroxy-2, -4, 6-trimethoxyphenanthrene. Both antifungal compounds were absent in the yam flesh.

## Introduction

The resistance of plants to fungus disease has been reported to be due to the presence of chemical substances in the plant. Such compounds may be present in the plant host before attack and prove toxic to the fungus prior to its penetration of living host tissue (2, 9); or may be newly produced in response to infection by pathogens (1, 4, 8, 13, 16). Various antifungal compounds have been isolated from potato tubers (the closest root crop to yam tubers) infected by pathogens (3, 10, 11, 14, 15) but not record exists of any isolation of natural antifungal compounds from yam tubers.

Previous work (12) has shown that the soft rot pathogens of the yam tuber are wound parasites and could not cause infection through the intact peel of the yam tuber. This experiment was therefore undertaken as part of an investigation of the biochemical basis of natural resistance of the yam peel to infection.

## Materials and Methods

### Preliminary extractions

Yam tubers were thoroughly washed with water to remove soil debris on the surface and left to dry. The peel tissue was obtained by removing 1-mm-thick layer from the outer surface of the intact tubers and the innermost (parenchymatous) tissue obtained and used as the flesh. Extracts of the peel and flesh were separately prepared as follows: 50 grams of fresh weight of each tissue was extracted with peroxide-free diethyl ether, 10 ml/g for 30 min and filtered through a sintered funnel. The filtrate was collected and evaporated to dryness under reduced pressure at approximately 40°C. The filtrate residue was finally taken up in 500 ml of cyclohexane ethyl acetate for chromatography. Ten volumes

of each solution were spotted onto thin-layer plates (t.l.c.) in duplicates and developed in equilibrated tanks in the following systems: (a) methanol: chloroform (4:96 v/v); (b) cyclohexane: ethyl acetate (1:1 v/v); or (c) hexane: ether (2:1 v/v). One set of the developed t.l.c. plates was exposed to iodine vapour to locate spots while duplicates were used for the bioassay tests.

Preparation of spore suspension

The test organism used was Cladosporium cladosporioides (fresen.) de Vries (5). The fungus was cultures on potato dextrose agar (PDA) slopes at 25°C for 7 days. Spores were harvested in about 5 ml/slope of glass distilled water (GDW) + 1% Tween 80 to moisten spore surface and filtered twice through two layers of sterile muslin to remove agar and mycelium. The solution was then centrifuged for 10-15 min to make a paste of the spores and the supernatant solution decanted. Spores were washed in two changes of GDW and finally taken up in potato dextrose broth (PDB) before adjusting the concentration to approximately $10^6$/ml.

Bioassay test with spores

The t.l.c. bioassay test employed was similar to that of Homans & Fuchs (7). Developed t.l.c. plates were sprayed with the spore suspensions of C. cladosporioides) ($10^6$ per ml) in PDB, and any excess moisture dried off with a hair dryer. The plates were then incubated in cake boxes lined with moist filter paper for 4 days in darkness at 25°C, to locate antifungal compounds. The bioassary test was repeated for the soft rot pathogens (12) of yam.

Inhibition of germ tube growth

The percentage inhibition of germ tube growth was estimated by comparing the germ tube growth of Aspergillus niger, Botryodiplodia theobromae, Fusarium moniliforme or Penicillium sclerotigenum, the soft rot pathogens and of the test fungus, C. cladosporioides incubated with and without the antifungal compounds under identical conditions. The $ED_{50}$ values were then obtained by plotting percentage inhibition against log. of the concentration and interpolating.

Isolation and purification of antifungal compounds

Approximately 2 kg of yam peel was soaked in two changes of 5 litres of distilled peroxide-free diethyl ether, each time, at 13°C for 3 days and decanted. The combined extracts were filtered through sintered funnel and evaporated to dryness. The extract was dissolved in minimum amount of cyclohexane: ethyl acetate (1:1 v/v) and subjected to column chromatography on silica gel (1 gm extract/100 g silica gel). Fifteen millilitre fractions were collected and evaporated. The fraction residues were separately taken up in the solvent and spotted onto t.l.c. plates and developed in various solvents. The solvents included 4% methanol in chloroform (containing 2% ethanol), cyclohexane: ethyl acetate (various proportions), chloroform: ether (4:1 v/v), Toluene: methanol: acetic acid (10:2:1) and various proportions of petroleum ether: diethyl ether: acetic acid.

Fractions which gave best separations of antifungal compounds were combined and subjected to a second column chromatography with neat chloroform as the solvent. The resulting fractions were evaporated to dryness and separately taken up in chloroform, filtered and streaked across preparative 0.5 mm t.l.c. plates in a narrow band 2 cm from the edge (about 30 mg streaked per plate) and developed

with petroleum ether: diethyl ether: acetic acid (45:50:5) solvent which gave best separation in earlier experiments.

The compounds were detected by spraying the markers at the side of the streak with iodine solution. Antifungal compounds were then separately eluted from unsprayed bands of same RF values as those of the markers with 40 ml of solvent and evaporated to dryness.

## Identification procedures

The spectrum was determined in grade alcohol with a pye unicam S.P. 800 spectrophotometer. The infrared spectrum was obtained on a thin film between NaCl plates using a Perkin Elmer 297 spectrophotometer. For mass spectrometry an A.E.I. MS 902 was employed and the 90 MHZ proton magnetic resonance spectrum in $CDCl_3$ was determined on a Perkin Elmer R.32 instrument.

## Results

### Identifications

No antifungal compounds were detected in the yam flesh. The bioassay of the peel extracts showed three antifungal regions at $R_F$'s 0.30, 0.43 and 0.68 in methanol/chloroform solvent. Only the two $R_F$ components with strong antifungal activity were examined in the present study.

High resolution mass spectomentry of more polar compound 1 ($R_F$ 0.43) showed a molecular ion of m/e 242.0908 indicating the formula $C_{15}H_{14}O_3$. The less polar compound 2 ($R_F$ 0.68) gave a molecular ion at m/e 284.1052 corresponding to the formula $C_{17}H_{16}O_6$.

### Antifungal activity

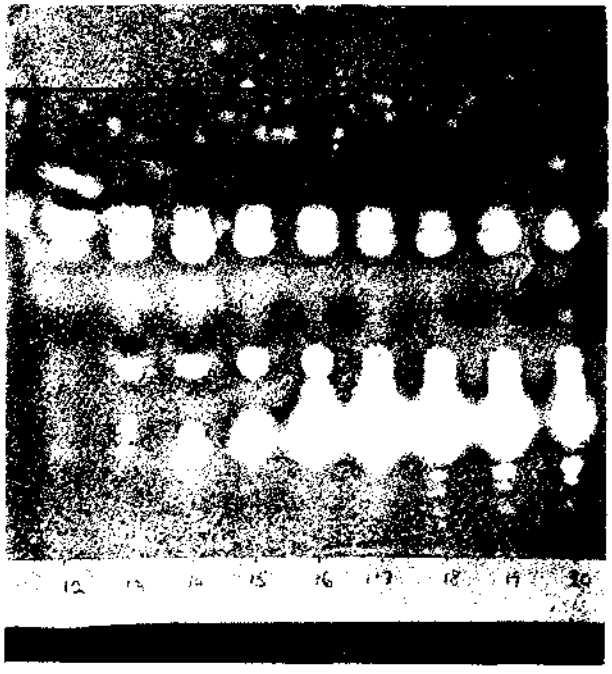
The t.l.c. plates sprayed with spore suspensions of the test fungus and of the soft rot pathogens of yam gave rise to germination inhibition zones. Both compounds affected germ tube growth of all the fungi employed and the $ED_{50}$ values are shown in Table 1.

Table 1. $ED_{50}$ values (ug. $ml^{-1}$) for compounds 1 and 2 against germ tube growth.

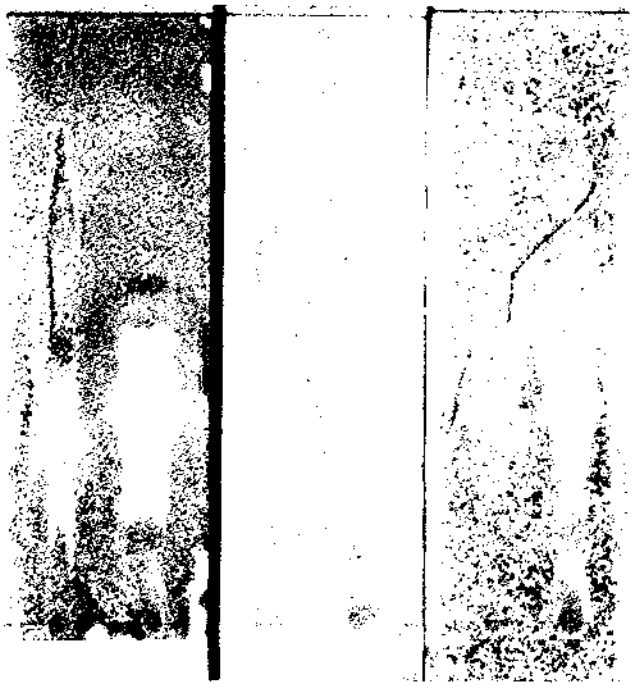
| | A. niger | B. theobromae | F. moniliforme | P. sclerotigenum | C. cladosporioides |
|---|---|---|---|---|---|
| Compound 1 | 42 | 16 | 65 | 41 | 26 |
| Compound 2 | 14 | 79 | 38 | 32 | 59 |

## Discussion

We record here for the first time the presence of naturally occurring antifungal compounds in the peel of yam tubers. The spectrum of our compound 1 (Ca $87_{15}H_{14}O_3$) appeared virtually identical to that reported for hircinol (15), a



TLC plate sprayed with C. cladosporioides.



TLC plate sprayed with spore suspensions of the soft rot pathogens of yam.

well known orchid phytoalexin. Both the uv and mass spectra of compound 2 ($C_{17}H_{16}O_6$) correspond closely with the spectra reported for batatasin 1 (6).

The direct spraying of the thin layer chromatograms with spore suspension is a technique that has been successfully used in detection of fungitoxic compounds against Aspergillus niger, Ascochyta pisi, Botrytis cinera, Colletotrichum lindemuthianum, Fusarium culmorum and Penicillium expansum (7). Hircinol, similar to our compound 1, had been shown to exhibit in vitro antimicrobial activity against a range of microorganisms (15) where it was found that concentrations greater than 500 mg. $ml^{-1}$ were necessary to completely inhibit Aspergillus niger to which our compound 1 became lethal at 42 mg. $ml^{-1}$ (Table 1). Similarly, our compound 2 demonstrated antimicrobial activity against the test fungi employed in present study.

The occurrence of these antifungal compounds is of interest since they occur in the peel ("skin") of the yam tubers where they may function as preformed inhibitors in disease resistance apart from the skin acting as a mechanical barrier. Their isolation and synthesis may ultimately be a break through for the control of yam storage rot. Further studies to determine if the compounds also accumulate in response to infection in yam are in progress.

Acknowledgements

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Phytate Content in Yam, Cooked Yam, and Yam Flour

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ABSTRACT

Six species of edible yams (*Dioscorea* spp.), namely *D. rotundata*, *D. cayenensis*, *D. dumetorum*, *D. alata*, *D. libretsiana*, and *D. schimperiana*, were analyzed for phytate phosphorus, total phosphorus, calcium, magnesium, iron, copper, zinc, manganese, and crude protein. Changes during boiling and the preparation of flour were also studied.

Phytate phosphorus content in yam ranged from 28 to 143 mg/100 g dry weight. *D. dumetorum* and *D. alata* showed the highest values. Although some variation in the ratio of phytate to total phosphorus was observed (0.3 to 0.7), highly significant correlation coefficients were obtained for total and phytate phosphorus contents. The same observation was made for total proteins and phytate phosphorus contents in yam. Phytate retention was important when cooking in boiling water and in the traditional preparation of yam flour. Sun-drying after soaking in water led to a large reduction of the phytate content of flour.

Changes in the Nutritive Value of Two Yam Species (*Dioscorea dumetorum* and *D. rotundata*) during Growth and Storage of the Tubers

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ABSTRACT

Changes in chemical composition were measured on two Cameroun yam cultivars from *Dioscorea dumetorum* and *Dioscorea rotundata* species during the last 6 months of vegetative cycle and 16 weeks of storage.

Dry matter content increased in the early stages of growth and during storage: changes were more important in *D. rotundata* tubers. Mineral content on dry weight basis was higher in immature tubers than in mature ones but did not change during storage. Lipid content did not change markedly. Crude protein content on dry weight basis increased slightly during growth but did not vary with storage period. Amino acid composition of proteins did not vary during growth and storage. Starch content increased until the eighth month of vegetative cycle and decreased during storage. Alcohol-soluble sugar content did not change markedly in *D. dumetorum* tubers, but in *D. rotundata* tubers it decreased strongly during growth and increased during storage. In both species, cell-wall carbohydrate content was higher in immature or stored tubers than in the freshly harvested mature ones.

Neither energy value nor chemical score of protein in the edible dry matter changed appreciably during growth and storage. Water content and storage depreciation (particularly hardening in *D. dumetorum* tubers) are in fact the main restrictive factors of the ability of yams to satisfy a large proportion of human nutritional requirements.

# Selection of D. alata Cultivars of Low Susceptibility to Anthracnose (Colletotrichum gloeosporioides)

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ABSTRACT

A wide range of introductions of D. alata have been evaluated over several years for their low susceptibility to anthracnose (Colletotrichum gloeosporioides). Data are given on their morphological characteristics, cultural behavior, yield performance and culinary grade. The existence of these cultivars underlines the need for a system of description and interchange of germplasm of edible yams.

## Introduction

Although anthracnose has been known on yams, for a long time, it was generally believed to be a disease of relatively low economical importance (Coursey, 1967). Now, in Puerto Rico, for instance yields of Dioscorea alata are reduced from 20% to 100% under anthracnose syndrome over 48 farms (Mignucci and Cordero, 1981); in Guadeloupe between 50% and 100% of D. alata cv. Pacala fields have been thus destroyed in 1978. The disease has been well described by many authors including Baudin (1956) in Ivory Coast; Fournet and al. (1974); Messiaen (1975); Toribio and Jacqua (1978); Lourd and al. (1979); Geiger and al. (1980); Nwankiti and Okpala (1981); Toribio and al. (1981). The following presentation summarizes their findings.

The disease usually begins on old leaves, in normal plantations, with round or irregular necrotic spots, brown at first, then black, with a brown halo, primarily joint to ribs of the ab-axial lamina face. Spots can coalesce. Severe attacks on mature and young leaves and also on vines can lead to a mechanical stunting and branching habit from the repeated dying of each regrowth at the few-leaf stage.

Anthracnose is a disease of D. alata, but it can also be detrimental to D. cayenensis-rotundata (see Benoue athracnose or "Appollo disease", Nwankiti, 1978) and is known on D. bulbifera and even on D. trifida, but rarely.

A problem is the true nature of the fungus complex. Colletotrichum gloeosporioides of which the perfect form is Glomerella cingulata, is always involved in the antharacnose syndrome. But, on one hand, it has so narrow relations with other involved in the Colletotrichum (Gloeosporium musarum of banana tree, C. gloeosporioides of Carica papaya, of Entendophragma, for instance) that its range of hosts may be wide and changing under unknown circumstances. On the other hand, a number of fungi seem to be also involved in anthracnose syndrome, depending from level of intensity and nature of inoculum. Botryodiplodia

theobromae, mainly, Fusarium, often, and Rhizoctonia solani sometimes are associated with it as secondary pathogens, at least. Moreover it seems that the whole "species" C. gloesporioides may be genetically unstable and evolving. All these traits account for the versatility of the epidemies with location, year and cultivars.

Nevertheless the process of contamination is now rather well known. Based on the anthracnose cycle, integrated control of the disease must act at the soil level. If chemicals or cultural protection must be used, the varietal resistance or tolerance remains the more economical and in most cases the more sure of anthracnose control.

## Methods and Techniques

A survey of available local yam cultivars in Guadeloupe and Martinique in 1966-1967 combined with the first phytopathological approach (Bullit, Lefort, unpublished). Lack of adequate resistance level associated with high commercial value leads to wide introduction (1969, from New-Caledonia, 1975 from the world collection of Mayaquez, Puerto Rico, see Martin, 1976) and screening of chemical treatments. From field notation of 120 accessions, a number of cultivars was selected and compared under stastical design in humid and sub-humid locations to local cultivars. Experimental then commercial multiplication was developed with the extension service, professional and governmental aid to promote new cultivar cultivation in both islands and French Guyana.

## Variability in the Collection

More than 100 cultivars have been observed within 11 years (1970-1981) among which 76 remains at the end of this period[1]. Some have died after 1 to 3 years, or are recent introductions. More than 50 have been present for 10 years.

Table 1 sums up the behaviour of consistent samples of the collection including more or less the same cultivars over the 11 years. Changing of the dominant class of disease level shows the variation of its intensity over the years.

Table 1. Percentage levels of anthracnose over several years among a D. alata collection in Guadeloupe.

| Level of Anthracnose* | 1970 | 1971 | 1972 | 1977 | 1979 | 1981 |
|---|---|---|---|---|---|---|
| 0 - 1 | 24 | 48 | 34 | 14 | 28 | 27 |
| 1,5 - 3,0 | 18 | 24 | 40 | 38 | 31 | 52 |
| 3,5 - 5,0 | 58** | 28 | 26 | 48 | 41 | 21 |
| N | 33 | 58 | 62 | 50 | 54 | 52 |

*0 = no disease; 5 = max. disease.

**Underlined: dominant class.

[1]They include 35 West Indian, 18 Neo-Caledonian, 8 West African cultivars. Others are from widely diverse origins.

The behaviour of the remaining 76 cultivars over the years 1979 and 1981 is interesting. They consist of the same cultivars as the samples considered in Table 1, plus others introduced or collected to counterbalance the erosion of the "Pacala" choice group (Degras and al., 1972) after the epidemy of 1978. But the distribution within the three classes of disease level remains the same as in Table 1. What is interesting is the shifting of the cultivars from a class to another. Though on a mean basis the intensity of the disease lowers from 1979 to 1981, cultivars from the class 1.5 - 3 and even from the class 0 - 1 have shifted to the class 3.5 - 5. About half of the cultivars remain in their original class. This shows the importance of the ecology or the fungus population interactions with the host susceptibility.

Varietal Response to Fungicide Treatment

Sixteen cultivars have been submitted to an artificially uniform contamination of Colletotrichum gloeosporioides in a field experimental design. Each plot was split into a treated (Propineb 210 g/hl weekly, plus Benomyl 50 g/hl every fortnight over 6 months) and untreated part. Details of this work have not been published (Fournet and al., 1974). No correlation has been found between anthracnose susceptibility and yield, which means that high yielders may be susceptible or resistant. Goana, for instance which benefits from the treatment, is potentially high yielding and very susceptible. Telemaque while being rather resistant is a low yielder. At least, anthracnose is not involved in its low productivity. On the reverse, a phyto-toxicity effect from the fungicides on some cultivars like Bete-bete seems possible.

An interesting point is the heterogeneity in the response of the so-called Pacala group of cultivars. This gives some encouraging prospects for a clonal selection against anthracnosis susceptibility.

Selected Cultivars of Low Susceptibility

Among the material introduced from New Caledonia two cultivars appeared promising, Belep and Lupias. The next important introduction brings Florido, (Puerto Rico, Pyramid (India), Taniela vulaleka, Binugas, Kinabayo and Kabusah, and Oriental from Barbados.

A series of trials was conducted without a significative level of anthracnose, showing the high productivity of Pacala when at its best.

The behaviour of some of the promising cultivars has also been tested over a range of plantation densities (Arnolin and al., 1973). They seemed to benefit from higher level of density than Pacala, while admitting smaller seed-set.

The cultivars from Puerto Rico have been described by Martin (1975) and Martin and Delpin (1978). Here are brief characteristics of the two neo-caledonian cultivars.

Lupias is a male flowering, rather little-leafed D. alata; its tuber is spheroid to ovo-spheroid, weighing about 1.5 to 2.5 kg in good culture at about 15,000 plant/ha; though the flesh is rather creamy to white except towards the head where it turns brown to reddish, it is often oxidizing under any physical or insect damage; more over at cooking it turns greyish, a factor turning many tasters against it. It is an excellent type for mechanichal planting and harvesting. Care must be taken for a good organic and mineral balance in the soil.

Table 2. Yield of selected cultivars of D. alata without anthracnose attack in Pacala traditional area of cultivation.

| Cultivars | Yield +/ha | Rank |
|---|---|---|
| Pacala | 56.8 | a |
| Sea 190 | 37.8 | b |
| Sea 189 | 36.7 | b |
| Sea 191 | 34.4 | b |
| Belep | 27.6 | bc |
| Florido | 27.3 | bc |
| Sea 144 | 19.5 | c |
| Coconut Lisbon | 13.3 | c |

Table 3. Comparative yield of selected cultivars of D. alata in different ecological areas of Guadeloupe.

| | | Yieldt/ha | | | Yield % |
|---|---|---|---|---|---|
| Cultivars | Origin | Basse Terre | Grande Terre | Moyenne | Pacala mean |
| Temoins | | | | | |
| Tahiti* | Guadeloupe | 48.9 | 40.2 | 44.5 | 281 |
| Pacata St. | Guadeloupe | 21.5 | 10.2 | 15.8 | 100 |
| Oriental | Barbade | 13.5 | 12.3 | 12.9 | 82 |
| Selections | | | | | |
| Lupias | N.Caledonia | 44.0 | 10.4 | 27.2 | 172 |
| Belep | N.Caledonia | 32.3 | 10.5 | 21.4 | 135 |
| Florido | Puerto Rico | 34.6 | 8.1 | 21.3 | 135 |
| Sea | | | | | |
| 144 Taniela-vulaleka | Fiji | 30.0 | 5.5 | 17.7 | 112 |
| 191 Binugas | Philippines | 36.7 | 6.9 | 21.8 | 138 |
| 189 Kinabayo | Philippines | 34.3 | 10.2 | 22.2 | 141 |
| 190 Kabusah | Philippines | 26.6 | 17.7 | 22.1 | 140 |

*About 25% to 50% Tahiti harvested tuber, the head part, is unpalatable and served as seed material. The edible flesh is rather coarse and less appreciated by many people.

Belep has rather wide leaves, its aerial parts being when young somewhat pinkish (stems wings); its tuber is pear shapped to fan-shapped but bearing over light brown skin many fine roots; the flesh is white. When densily planted (25,000 plants/ha or more) its 1 to 2 tubers weighing 0.8 to 1.5 kg are easily mechanically harvested.

Belep and Kinabayo are now the principal cultivars involved in a seed producing scheme incorporating INRA, extension service and a farmer cooperative in Guadeloupe.

Table 4. Result of a cooking and tasting trial with selected cultivars of D. alata.

| Color | Sea 189* | Sea 190 | Sea 191 | Pacala |
|---|---|---|---|---|
| - Whiteness/10 | 4 | 9 | 8 | 8 |
| - Other /10 | 3 | 2.5 | 1.5 | 0.8 |
| Fibrousness/5 | 1.4 | 2.0 | 2.8 | 1.6 |
| Compactness/5 | 3.6 | 2.0 | 1.2 | 2.6 |
| Friability /5 | 1.3 | 3.3 | 3.7 | 2.7 |
| Gum /5 | 2.4 | 1.2 | 1.1 | 1.5 |
| Sweetness /5 | 1.3 | 1.2 | 0.6 | 0.4 |
| Bitterness /5 | 0.2 | 0.6 | 0.9 | 0.5 |

*In other trials this cultivar gives better results.

## Discussion - Conclusion

Anthracnose at least for D. alata, is the most threatening disease over the world, its ability of sudden epidemics causing death of plants in wide areas. Its name of "lighting" in some Pacific islands referred perhaps to its main damaging weather, but may be significant also of its behaviour.

As true breeding of D. alata through flowering is only a recent promise, varietal improvement within the species will be delayed during the search of cultivars of naturally tolerant clones. A knowledge of morphological and/or physiological traits associated with anthracnose resistance-susceptibility would be useful. Roughly it can be said that resistance to the disease seems rather linked with primitive characters; the bulbiferous type (Degras, 1976) is rather tolerant or resistant; four out of the six cultivars of the "choice" group III of Martin and Rhodes (1972), Rhodes and Martin (1973) existing in our collection.

In many countries (Pacific islands, Nigeria, Ivory Coast) efforts are made to select low susceptible anthracnose cultivars. In this direction it seems that the material from the Pacific area and insular South Asia play a great part.

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# Advances in the Study of Anthracnose/Blotch Disease of *Dioscorea alata* in Nigeria

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## ABSTRACT

Water yam (*Dioscorea alata* L.) known to have high nutrient value, is becoming increasingly important in Nigeria as a source of carbohydrate food. However, production is hampered by a disease complex, anthracnose/blotch disease, especially in the rainforest zone of Nigeria. The field appearance most characteristic of the disease is blackening of affected parts and scorching of leaves, especially under high humidity, followed by heavy defoliation of the vines. Tuber yield losses range up to 80%.

The disease may be reduced by planting with the first rains in the year, applying balanced fertilizer or farm yard manure, and staking vines immediately after sprouting.

Field and green-house screening of available cultivars have revealed resistant clones. Techniques for screening and production of enough inoculum of the *Colletotrichum gloeosporioides* for innoculation purposes have been developed. Completed work on the source of resistance is presented and trends of on-going projects on biochemical aspect of resistance are indicated.

Breeding problems as well as difficulties in using fungicides to control the disease are discussed. Suggestions for future work are presented.

## Introduction

Root and tuber crops have important roles in developing countries. Major production problems of yam are high labour requirements, high cost of staking, large quantities of planting material needed, and low yields per hectare. It is propagated vegetatively so diseases are easily transmitted.

*Dioscorea alata*, one of the common yam species grown in Nigeria, originated in the Burma-China area (Burkill 1951). It spread through New Zealand to West India. Some speculations is that Malay sailors may have brought this yam to the coast of Africa and it spread to Central and West Africa. There is also speculation that it first was in Sao Thome and Gambia before spreading to Nigeria (León, 1976).

However, *D. alata* failed, to become important in Nigeria because other native yams were already under cultivation-the Guinean yams (*D. cayenensis* and *D. rotundata*). These Guinean yams were domesticated in 5 000 Bp (Ayensu and Coursey, 1972); while *D. alata* came in years latter. *D. alata* could not displace the na-

tive yams at that time probably because of the morphology of the tubers. Tuber skin of most clones is rough and covered with adventitions roots. It is not as popular as D. rotundata due to its peculiar taste and colour when peeled.

Currently, D. alata is becoming increasingly important in Nigeria as a carbohydrate source. It has high nutrient value, stores well, and has gained a place in the farming systems (Bell and Favier, 1980). It has been popularised in some States of Nigeria (Rivers and Cross River) where special preparations called "Ikwukwo" are made from freshly harvested tubers.

D. alata, generally known as the greater or 10-month yam (Martin, 1972) and commonly called the water yam in Nigeria, is grown in every part of the country and is affected by various diseases, the most serious of which is anthracnose/blotch disease. The disease may cause yield reduction of up to 80%. The terms "yam die back" (Anon, 1974); "leaf and stem blight" (Jackson and Newhook, 1978; Nwankiti and Arene, 1978); "Scorch" (Anon, 1974) and "anthracnose/blotch" (Nwankiti, 1982) are sometimes applied to the disease, while "lightning strike" is erroneously used by laymen.

Waitt (1963) and Coursey (1967) first reported the disease in Nigeria, although it probably existed at a much earlier date. The disease has been recorded from South Pacific (FA'Anunu, 1977); the Carribean (Ferguson et al., 1970); Guyane (Fournet et al., 1975); New Zealand (Jackson and Newhook., 1978) and India (Prasad and Singh, 1960).

It appears the disease occurs in every part of Nigeria with varying intensities. Extreme temperatures of northern Nigeria are not favourable for development of the fungus. It becomes a serious problem in rain forest zones.

## Geographic Distribution

Geographic distribution of crops and plant diseases depends to a large extent upon climatic factors such as rainfall, humidity, and temperature. This is true of most diseases which affect the aerial parts of crops.

Chowdbury (1937) reported that conidia of Colletotrichum are sensitive to atmospheric humidity. Germination could be inhibited below 95 percent humidity. Singh and Prasad (1967) reported that optimum temperature for growth of mycelium of C. gloeosporioides was 26°C while for spore production of the same organism, both 24°C and 26°C had similar effects. Sporulation was good above 22°C but was reduced at 30°C and inhibited at 32°C. In Nigeria, the disease is important in the rain forest and less important in the transitional zone of savannah in the north and swamp forest in the south. These zones correspond to areas with mean annual temperatures of 22°C and 30°C and annual rainfall of about 2000 mm.

## The Disease

Available D. alata clones react in different ways when infected by the casual agents. These reactions led many workers to give different names to the disease.

Generally, infection starts from the lower leaf surface facing the soil. Movement of infection then progresses upwards along the vine. Percent of leaves infected from ground level up to 0.2 metres along the vine of a susceptible cultivar was significantly (P.01) higher than at 0.2-0.4 metres and at 0.4-0.6 metres along the vine.

This indicates the causal agents are probably soil-borne. In some stands, black lesions appear first on the lower part of the main vine just before the first mature leaves.

In severe cases, aerial parts of some susceptible clones may become chlorotic and stunted; while in others the young leaves at the initial infection tend to fold or twist and often become stunted; indicating some toxic effect. Production of toxic principles by Glomerells cingulata pathogenic to other crops has been reported (Koch and Schulz, 1979; Ebenebe, 1982).

Typical anthracnose lesions on leaves and vines of a susceptible clone predominate in an infested field. On most parts of infested leaves, the cuticle is sloughed-off leaving apparently superficial fruitfication. This is an indication of hypostomatic development characteristic of C. gloeosporioides. Young stands are susceptible to the disease and early infection may result in premature death and severe yield losses. The scorch symptoms are noticeable 3 to 4 months after planting and becomes more severe under heavy rains, hence the erroneous use of the term "lightning disease." Scorched leaves show signs of being burned due to toxic effects of some chemicals. The degree of scorching varies with cultivars.

## Techniques for Effective Isolation of the Causal Agent(s)

Isolation of one major causal agents, C. gloeosporioides, may be difficult.

The following isolation procedures may be helpful:
The organism may not be isolated from:

a. Scorched leaves and stems. These are dead tissues.
b. Chlorotic stands. Some stands turn yellow as they emerge from the soil. No necrotic areas are visible.
c. Curled, or slightly folded or twisted leaves. These early symptoms on younger leaves hardly show any necrotic areas which may be useful for isolation studies.

Specimens most suitable for isolation studies are those with parts of their cuticle sloughed-off and specimens with small dark necrotic lesions which may be surrounded by a yellow halo.

Frequently, other organisms grow on the leaves in association with C. gloeosporioides, especially Botryodiplodia theobromae and Fusarium semitectum (Nwankiti, 1982). These organisms usually grow faster than C. gloeosporioides. Therefore, the following procedure may be necessary for isolation of C. gloeosporioides.

Infected leaf with typical anthracnose necrosis is placed on a piece of damp sterile filter paper in a Petri dish until parts of the acerruli sproulate. These are then cut into small pieces, passed through 25% sodium hypochlorite solution for 1 minute, rinsed in distilled water and placed to dry for 4 hours in covered sterile Petri dishes and them placed in tap water agar. Hyphal tip transfers are then made from all colonies in tap water agar and incubated at 25°C. Subsequent transfers could be made on potato dextrose agar (PDA) or potato carrot agar (PCA). For faster sporulation, all cultures could be submitted to ultra violet/black light irradiation in plastic Petri dishes at 25°C.

## Green House Inoculation Procedures

Successful artificial inoculation of plants with C. gloeosporioides may be difficult. The following experiment describes a suggested procedure for artificial inoculation (Barrus, 1921).

A randomized complete block design experiment including four inoculation treatments with one highly susceptible cultivar was on the floor of a wall-watered greenhouse, (temperature range approximately 20° to 26°C). Treatments, including control, consisted of four plots, each plot consisting of two stands. Each plot was either inoculated with spore concentration of $5.3 \times 10^6$ spores/ml or with a "blank" inoculum of sterile water as control. Two month old potted yam stands of cv "Obunaenyi" were inoculated using either dipping for 5 minutes; leaves of potted stands dusted and rubbed gently with caborundum before dipping for 5 minutes; foliar spray using a 450 ml plastic atomiser spray gun; with leaves dusted and rubbed with carborundum. Inoculum was prepared from pure cultures of C. gloeosporioides obtained from field infections. Each inoculated stand was covered with heavily moistened polythene bags for 4 days. Readings of the percent number of leaves successfully infected were taken 20 days after inoculation.

Anthracnose disease incidence in the greenhouse experiment was more obvious with the foliar sprays. Percent incidence obtained by wounding of leaves followed by foliar spray was significantly higher than any of the dipping methods. But typical anthracnose lesions were obtained with the foliar sprays, though wounding tended to present signs of scorching. The organism was recovered from all treatment except the control. D. alata leaves look glossy and smooth, especially the resistant ones. There are no hairs on the lamins. The leaves of some of the cultivars may contain a lot of waxy substances. It is very pertinent that from these properties of the leaves, the dipping method will be inadequate as shown by our results. The smooth nature of the leaf surface causes easy run-off of water which may result in retention of small amount of inoculum on the leaves. With the foliar spray, several small droplets of the inoculum are left and retained on the leaves, which becomes even more effective when leaves are wounded. This method may be suitable for screening studies.

## Cultural Management

### Time of Planting

Early planting of D. alata cultivars susceptible to anthracnose/blotch disease lowers incidence and severity of disease. Yield of yams planted in March was 65% higher than those planted in May. This early planting gave the crop time to grow vigorously, thereby permitting it to escape serious damage from the disease (Nwankiti, 1982).

### Effect of N Application

The quantity of N (ranging from 0 to 90 kg N/ha as Urea and 0 to 9.6 tons N/ha Farm Manure) applied as separate treatments, significantly lowered apparent infection rates of the anthracnose/blotch disease complex (Nwankiti 1982). Yield response to N applied was higher with increase in quantity of N. Application of N, therefore hastened the bulking rate of the tubers before damage by the disease.

### Time of Staking

Staking vines of D. alata clones immediately after they emerge from the soil reduces chances of the leaves and vines picking up spores of the causal organisms

of anthracnose/blotch disease from the soil. Infection is minimal and yield increases by 35.66% over the unstaked one in cv "Obunaenyi" (susceptible) and by 38.78% for the early staking over the unstaked one in cv "Um 680" (resistant). On the other hand leaf dry matter in cv "Obunaenyi" of the unstaked increased by 14.81% over the leaf dry matter of those early staked, while leaf dry matter in cv "UM 680" of the unstaked increased by 16.66% over the early staked ones.

## Field and Green House Screening for Resistance

Fifty three available clones were subjected to natural infection in a field previously infested with the anthracnose/blotch disease. Eight clones were later selected on the basis of high yield and tolerance to the disease and used for greenhouse screening.

Inoculum for the greenhouse experiment was prepared by seaking rice grains and maize grains separately in tap water for 24 hours in erlenmeyer flasks, decanting off excess water, autoclaving the seeds for 15 minutes at 15 p.a. 1: and inoculating them with mycelial discs out off from the margins of 10-day-old cultures of C. gloeosporioides on potato dextrose agar. Inoculated seeds were incubated for 17 days at 27° to 28°C in the dark. Sterile distilled water was added to the flasks which were shaken vigorously to dislodge conidia from the seeds. Spore concentration was adjusted to give a haemocytometer count of $5.3 \times 10^6$ spores/ml.

For the screening, 2 month-old plants were used. These were rubbed gently with caborundum and then sprayed to wetness with the spore suspensions. They were then covered with wet polythene bags for 5 days.

These susceptible clones - "Um680," "Ominelu," and IITA "13" - were resistant, while "Nvulsogbe" was moderately resistant. These resistant clones had pink colouration on their vines and petioles.

## Source of Resistance

Plant characters investigated to explain the resistance in D. alata included thickness of cuticle, position, and length of stomata and polyphenol content of leaf tissues. The resistant cultivar had thicker cuticle than the susceptible one. The stomata of the resistant cultivar was sunken below the epidermal layers while the stomata of the susceptible clone are even with or slightly raised above other epidermal cells (Nvankiti, 1982). Also resistant clone possessed stomata with longer pore lengths than those of the susceptible clone. Leaf extracts showed higher polyphenol activity against the organism in the resistant clone than in the susceptible clone; as was also shown by the presence of a chemical substance which accumulated around infected areas in the resistant clones. Further work is to investigate what the chemical is and its function.

It is also probable from our investigation that lack of moisture retention on the vaxy leaves of the resistant cultivars reduces or prevents the germination of spores.

## Chemical Control (Foliar Spray)

It may be difficult to control the disease by foliar sprays without proper timing for plant growth and timing for disease outbreak. Height of stakes may also be important. If the crop climbs too high on the stake, spraying becomes

difficult because the upper parts may not be reached. Another problem may be frequency and duration of sprays. Finally, the fungicide must kill the organisms without scorching the leaves.

## Breeding for Resistance

Yam improvement over the years has been by selection of "high quality" tubers by farmers planting new crops (Okoli, 1980). Currently there is renewed interest in the possibilities of improving yams by hybridization, especially in D. rondundata. This has been hampered by poor seed set, low seed viability, small size of tubers produced from true seeds, (Waitt, 1961), and inconsistency in flowering habit. In D. alata flowering may further be hampered by the early devastation of the aerial part of the crop by anthracnose/blotch disease. Among populations of primitive clones of D. alata, some bear only bulbils (cv "Ominaelu") and others only inflorescences. Some susceptible clones to the anthracnose/blotch disease such as cv. "Nvulaogbe", "Obunaenyi", "Bindem", and "Agbo" have desirable characters including high yields. To tap this character, breeding for resistance may be possible if (1) the disease is controlled early (2) high level of vegetative growth necessary for full female expression (Degras, 1976) is realised since generally flowering may be triggered by a certain level of development of the vegetative organs, and (3) early staking of the vines which permits more light (necessary for flowering) to enter the canopy.

These and other cultural management procedures may be necessary to produce healthy crops of the suceptible clones before breeding studies are possible.

## Conclusions

The disease of D. alata, which is worldwide in distribution, is caused primarily by C. gloeosporioides penz, which produces the anthracnose symptoms. Toxic substances which may be produced by the C. gloeosporioides on the leaves or chemical substances leaching out to the leaf surfaces due to wounding of the plant tissues, may cause scorching of leaves. The disease must be effectively studied by:

a. isolating the primary causal agent from infected leaves with peeled off epidermis.
b. wounding healthy plants before inoculation under high relative humidity.
c. producing high inoculum for screening purposes by inoculating rice-grains or maize grains with the C. gloeosporioides isolate.

Farmers and scientists may control the disease in the field and improve yields by:

a. planting clones with the first rains in the year.
b. applying balanced fertilizer.
c. staking vines immediately after they emerge from the soil.
d. using resistant D. alata clones.

It is important to investigate the cause of the curling of leaves in the field and the role of anthocyamin and phytoalexins in resistance. Breeding for resistance should be given a prominent place and causes of non-flowering among D. alata clones should be investigated. More work on cultural control should be initiated and ways of improving chemical control should be sought.

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# *In vitro* Culture, Results and Prospects for Food Yams

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## ABSTRACT

Although *in vitro* culture of yams for pharmaceutical purposes has made great advances, tissue culture techniques for food yams have been advanced less. Data from the literature and original work on *Dioscorea alata*, *D. cayensis-rotundata*, *D. bulbifera*, *D. trifida* and *D. dumetorum* *in vitro* culture are given and discussed in view of strengthening this approach.

Differential species requirements for complete plantlet organogenesis are described. The features of rejuvenation and aging leading to tuberization of in vitro plantlets are emphasized. Problems of obtaining a high multiplication rate in the field from *in vitro* materials, and methods for production of virus-free planting material using *in vitro* thermotherapy of plantlet and meristem tip cultures are also discussed.

## Introduction

In vitro culture of yams dates back as far as 1958, at least, with the experiment by Sawada and al. of the effects of sucrose and peptones on the organogenesis and growth of bulbils from leafless nodes of *Dioscorea opposita*. Bulbil organogenesis again in 1968 (Asahira and Nitsch, 1968) and, then, with *D. bulbifera* in 1970 and 1971 (Uduebo) remains the first approach of the technique, until about 1975 a widest interest begins for in vitro yam culture, applied primarily to the diosgenine producing species.

Most researchers used directly part of the entire leafed or leafless node as material. Some research used other parts of the plant:

- leaf of *D. deltoidea* (Mascarenhas and al., 1976) or *D. floribunda* (Sinha and Chaturvedi, 1979).
- seedling hypocotyl of *D. deltoidea* (Grewal and Atal, 1976).
- tuber of *D. deltoidea* (Mascarenhas and al., 1976, Singh, 1978).
- apical meristem of *D. deltoidea* (Grewal and al., 1977).

Mapes and Urata (1970) could not obtain any proliferation from *Dioscorea* sp. internode.

As in many cases with other plants the medium of Murashige and Skoog (1962) has been the basal one in most research with diosgenine species. Mascarenhas and al. (1976) used also White (1963) or Smith (1967) media in combination with Murashige and Skoog (1962) basal medium. Some less common media have been used by



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some others (Chaturvedi and Chowdhury, 1980, or chinese scientists ,1981, for instance) when callus culture is considered.

The research for the best form and the best ratio of nitrogen compound in shoot and root organogenesis from tuber callus of D. deltoidea has been done by Singh (1978) and by Chaturvedi and Chowdhury (1980) for callus proliferation. But the more frequent research in medium adjustment is the levels and the balance of auxins and cytokinins for shoot and root organogenesis. (Lakshmi Sita and al., 1976, for instance).

A special feature of drug producing plants such as diosgenine Dioscorea species, is their ability to synthesize more drugs with indifferenciated callus or cell suspension cultures than is available from field cultivation. A number of reports bearing on the best techniques for reaching and maintaining this undifferenciated state has been published (Fonin and Voloshina, 1975; Stohs and al., 1975; Chaturvedi and Srivastava, 1976; Marshall and Staba, 1976). What could be useful for food yams in this direction is the investigation of inherent or induced genetic cell variability, in view of selecting new clones, an approach which appears valuable from the variations obtained in number of chromosomes and level of polyploidization with D. deltoidea cells by Karanova and Shamina (1978).

But, before in vitro culture of food yam rises to this level, efforts can be devoted to ensure high ratio of propagation and an easy cleaning of clones from virus.

The first goal of in vitro culture with food yams was an understanding of tuberization through bulbil organogenesis in D. opposita and D. bulbifera. However, the adding of growth substances in the mineral basal medium, which was sufficient for bulbil development, leads Uduebo (1971) to find the parts of the level and the balance of auxin (IAA) and cytokinin (kinetin) in callus, bulbil, shoot and root morphogenesis. Unfortunately, this approach remains a long time useless in its country (Nigeria) and it is only recently that, at IITA (Ibadan), in vitro culture has been again applied to food yams. Fifteen clones of D. alata at least are kept there in germplasm collections in vitro. Indeed, Frison (1981) considers the only important tool or the technique for exchange of free disease material, although he did not indicate if the yam clones were tested for virus cleaning (the explant used is node cuttings and not apical meristem).

Virus cleaning on the contrary has been the main object of the work in Barbados by Haque, Mantell and Whitehall (1978). Mantell and Haque (1979), Mantell and al., (1980). They first established that just as for D. bulbifera (Uduebo, 1970), it was possible to grow D. alata in vitro from node cuttings in the basal mineral medium of Murashige and Skoog only. But this needs plants 4 to 6 month old, no complete organogenesis of shoot and root being obtained from a 2-month-old mother-plant or with auxine and/or cytokinine complement. Apical meristem culture for virus cleaning, however, needs growth substances for successful development. Naphtalene acetic acid and benzyladenine permit within 6 months a normal organogenesis and further micropropagation by node cuttings of the plantlets. As for node in vitro culture mother-plants and plantlets are conducted under 16h daylength. A scheme of virus free D. alata cv. White Lisbon seed is now operating from Barbados with an experimental multiplication net over several West Indian islands (Calixte, 1982). A yield surplus of about 95% can be expected.

Recently Ahoussou (personal communication) began to develop in vitro culture of D. alata and D. cayenensis-rotundata cultivars in the Ivory Coast. Intraclonal variation will be an interesting approach of this new program.

In vitro culture of D. alata has succeeded also in the Laboratories of Y. Demarly and R. Nozeran at the University of Paris-Orsay (Arsene, 1979; Espiand, 1980).

Since 1976 our laboratory began to experiment in vitro culture, first, with the assistance of Dr. Y. Demarly, in direction of androgenesis from D. trifida (Arnolin, 1976). This line of research has been temporarily put aside in favour of development of micropropagation from node cuttings, apidal meristem and callus techniques culture.

## Methods, Technics and Material

These aspects having been extensively presented by one of us (Arnolin, 1980), broad traits only will be given here.

New technical developments:

- All work has been conducted from plantlets obtained in vitro (see Arnolin, 1980 for their advantage over primary explants from field or green house plants). They are lighted over 14 h with 2200 lux at 27 ± 2°C under 45% to 70% relative humidity.

Field transfer of plantlets benefits from:

- Pricking out in rich soil first under continuous, then interrupted, mist for 2 months before effective field growing;

- A 60% shading for the first 3 months in the field. All this for micropropagation.

## Results

### Micropropagation from Node Cuttings

The main result of the quoted work (Arnolin, 1980) was the interest of the N30K medium of Margara (1978) Murashige and Skoog (1962) medium needing a number of complements for a good growth. With N30K however, species differences are remaining:

- rooting ranks first for D. cayenensis-rotundata, less for D. alata and D. trifida, much less for D. dumetorum.

- 60-day old plantlets have between 1 and 2 stems for all species, D. cayenensis-rotundata being somewhat ahead again.

- at the same age, nodes are between 2 and 5, D. alata and D. cayenensis-rotundata being the more advanced species.

New progress in media appraisal obtained:

With a modified MS medium (169) proposed by C. Martin (see Arnolin, 1980), nodes production with D. cayenensis-rotundata cv. V17-2 have been raised to 6,8 at 2 months, that give micropropagation potential of more than 100 000 plantlets over one year.

Intra specific response to MS or N30K medium has been seen with D. trifida.

A position effect of in vitro node cutting level on the growth of subsequent plantlet has been noticed; the more basic level can be less prolific.

The response to different levels and balances of growth substances have been deeply studied.

Table 1 shows differential organogenesis from different balances and nature of growth substance in a 169-based medium. The association of kinetine + ANA raised rooting and depress shooting regarding BA or BA plus ANA plantlets.

Table 1. Action of associations of growth regulators on the plantlet organogenesis of D. cayenensis-rotundata cv. V17.2.

| Characteristics | Associations | | |
|---|---|---|---|
| | BA $10^{-6}$ - | BA $10^{-6}$ + ANA 5 $10^{-5}$ | Kinetine 5 $10^{-7}$ + ANA 5 $10^{-5}$ |
| Average number of roots | 3.96 | 1.58 | 17.00 |
| Average number of stems | 2.50 | 2.22 | 1.31 |
| Average number of nodes/plants | 6.82 | 3.81 | 3.61 |

Table 2 shows in a modified KNOP media other differential organogenesis responses linked to gibberellic acid interactions with ANA and BA. The triple-growth substances together seem to give a better balanced growth, the ANA + GA association giving a higher level of rooting. However, in all cases if rooting is early, roots and stems are thin.

Table 2. Effect of associations of growth regulators on D. cayenensis-rotundata cv. V17.2 and D. trifida cv. INRA 5-20.

| Characteristics | Cultivars | Associations | | | | |
|---|---|---|---|---|---|---|
| | | Modified GRENAN Medium[1] | ANA $10^{-7}$ BA $10^{-6}$ GA $10^{-6}$ | 0 BA 10 GA $10^{-6}$ | ANA $10^{-7}$ 0 GA $10^{-6}$ | ANA $10^{-7}$ BA $10^{-6}$ 0 |
| Root number | V17/2 | - | 3.39 | 6.30 | 8.25 | 1.93 |
| | 5-20 | 2.26 | 1.82 | 1.36 | 4.04 | 1.17 |
| Stem number | V17/2 | - | 2.22 | 1.70 | 2.60 | 1.87 |
| | 5-20 | 1.33 | 2.95 | 1.66 | 2.32 | 1.18 |
| Node number | V17/2 | - | 3.64 | 2.90 | 3.45 | 2.90 |
| | 5-20 | 2.78 | 4.08 | 3.62 | 1.86 | 2.13 |

[1]Modified Knop + Skoog microelements + Fe + sucrose + agar 4,5 g/l.

Preliminary results suggest positive growth response to agar rising from 4,5 to 8 g/l, sucrose rising from 20 to 50 g/l and a timing for different successive media.

Among other media needing further testing, vitamins and amino-acid levels and balances will be introduced in relation with the mineral elements and growth substances which appears determinant for the best adjustment to each species or cultivar.

## Thermotherapy of Plantlets against Virus

Plantlets obtained from field node cuttings of D. trifida have been tested (Miss M. Balagne, personnal communication) over a range of temperature to combine best survival with lethal temperature for virus. Data are soon to be published.

## Gamma Irradiation of Plantlets for Mutation

D. alata and D. trifida plantlets obtained in our laboratory have been submitted to gamma irradiation (varied duration of a weak source) at Montpellier (R. Marie), before pot transfer. They are now in observation in Guadaloupe.

## Apical Meristem Culture

Apical meristem culture of D. alata, D. cayenensis-rotundata and D. trifica are on observation. Full organogenesis has been obtained within 5 months with D. cayenensis-rotundata, and within 6 month with D. alata. However, successes remains low but from the plantlets, as practised in Barbados, node cuttings will be done to grow more plantlets, and to assess their lack of virus.

## Field Transfer of In Vitro Plantlets

Table 3 shows the high differences of behaviour from three cultivars transferred to the field in June 1982 after 2 months in vitro and 3 months under mist. They reached maturity together and were harvested in January 1983. No flowering occurred. The most striking features of these results are:

- the high numbers of stems per plant,
- the narrow association between this number and the tubers one,
- the high level of the D. alata cv. Ti-joseph yield; mean yield of D. alata cv. Belep average the weight of a good experimental seed-set for this cultivar.

## Discussions - Conclusions

This review of results with in vitro culture of food yams confirm the high prospects this technique offers.

Some problems of general interest will be stressed here.

Though rather quick success is obtained in micropropagation, the best ratio of multiplication through the more adequate medium to each cultivar deserves additional attention.

Table 3. Characteristics of plants from vitro culture.

| Characteristics | Cultivars | | |
|---|---|---|---|
| | V17/2 D. cayenensis/rotundata | Belep D. alata | Ti-Joseph D. alata |
| Average number of stems | 1.98 | 6.29 | 9.66 |
| Number of plants with flowers | 0 | 0 | 0 |
| Number of harvested plants | 55 | 50 | 12 |
| Total number of tubers | 90 | 299 | 110 |
| Average number of tubers/plant | 1.63 | 5.98 | 9.16 |
| Total weight of tubers (in g) | 8.92 | 25.740 | 24.015 |
| Average weight per plant (in g) | 16.22 | 514.80 | 2,001.25 |
| Average weight of tuber (in g) | 9.91 | 86.08 | 218.31 |

Attention might be given to the clonal conformity after in vitro culture. A number of data from other plants suggest that in vitro culture could affect the clonal stability if not its definitive functioning. At least, in D. trifida, juvenile stage is clearly carried on with in vitro culture. The plantlet has indefinitely the morphology of a seedling, after a short three-lobed leaf stage when it comes from field node cuttings (see, on Dahlia, Watelet Gonod (1977), for instance). With a modified physiological age of the clone at the plantlet stage, field behaviour could be at variation over some time with normal culture.

The limited field production of D. cayenensis-rotundata as well as the high number of stems and tubers observed are perhaps in relation with physiological plantlets condition or environmental conditions. Relation between stems and tuber number has divergent aspects (see Arnolin and Mathurin this Symposium).

The high tuber yield obtained with D. alata cv TI-Joseph is encouraging although the tuber shape is not attractive (plantlet x field interactions perhaps). But as proved by the Commonwealth West Indian scheme based in Barbados, the use of micropropagation in yams for D. alata cultivars is now at hand for commercial growing.

If D. trifida seems less easy to manage, progress is clear in media and techniques.

Now that in vitro culture of food yam seems to enhance their vegetative multiplication, new efforts are needed to develop its contribution to variation. Gamma irradiation could be an interesting path.

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The Effect of Sett Size, Sett Type and Spacing on Some Aspects of Growth, Development and Yield in White Lisbon Yams (D. alata L.)

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## ABSTRACT

The effect of three sett sizes (85, 170 and 355 g), two sett types (heads and middles), and two spacings (90x30 cm and 90x60 cm) were examined in a factorial experiment with white Lisbon yam (D. alata L.) on a loam soil in Trinidad. Tuber yield increased with increasing size of middle setts but did not increase for head setts, which seem to be more efficient than middle setts. Small head setts yielded as well as large head setts at both close and wide spacings. The overall results suggest an asymptotic response in yield to increasing seed rate in white Lisbon yam. The greater yield of large setts seems to be related to a longer duration of rapid tuber bulking, resulting primarily from earlier and more rapid tuber bulking during the earlier period of tuber development.

## Introduction

A number of workers have shown that in Yams (Dioscorea spp.) sett size affects growth (Enyi, 1972; Onwueme, 1972) and yield (Miege, 1957; Baker, 1964; Afonja, 1967; Enyi, 1972, Onwueme, 1978). In general, yield tends to increase with increasing sett size. Larger setts emerge earlier, produce greater plant dry weights and higher mean tuber bulking rates. Head setts of yams have also outyielded middle and tail setts but some workers have found no difference in yield due to sett type (Waitt, 1959; Gooding and Hoad, 1967). Yield in yams has increased with increasing plant density (Wood, 1933; Baker, 1964; Gooding and Hoad, 1967; Afonja, 1967; Henry, 1967; Caro-Costas and Servando, 1968; Enyi, 1972).

The effect of sett size and spacing can be jointly considered to be one of seed rate, i.e. the total weight of setts material planted per unit area of land. Baker (1964) examined the effect of seed rate on the yield in D. rotundata Poir, and found that an asymptotic curve for yield at increasing seed rates was only obtained when sett weight (size) was constant and seed rate was proportional to population. Afonja (1967) in an experiment with D. rotundata found that yield increased linearly with increasing seed rate but the yields obtained were very low (average 5.3 tons/ha.). Henry (1967), working with D. trifida L. found that sett size had a small effect on yield but spacing had a marked effect.

It is the object of this experiment to study the effect of sett size, sett type and spacing and their interactions on growth, particularly tuber growth, and yield in "White Lisbon" yams (D. alata L.) with a view to understanding some of the crop physiological processes affecting yield.

## Materials and Methods

Three sett sizes, two sett types of *D. alata* in White Lisbon and two plant densities were investigated in factorial combinations in this study. The main treatments were:

| | | |
|---|---|---|
| Sett sizes | (1) | 85 gm (small) |
| | (2) | 170 gm (medium) |
| | (3) | 255 gm (large) |
| Sett types | (1) | Heads (i.e. setts taken from the part of the tuber proximate to the vine) |
| | (2) | Middles (i.e. setts taken from the central portion of the tuber) |
| Spacing | (1) | 90x30 cm - 35880 plants/ha (close) |
| | (2) | 90x60 cm - 17940 plants/ha (wide) |

The experiment was on the University Field Station, Trinidad, on River Estate Loam soil type, which is of moderate fertility. The field was in grass and uncultivated for the previous 4 years was in the form of a low camber. The soil was prepared for planting by ploughing to a depth of 20 cm. It was then rotavated and formed into ridges 90 cm apart.

Setts were planted at a depth of 9 cm on the crest of the ridges. The pre-emergence herbicide, atrazine, was applied at the rate of 3.4 kg per ha on the 28th May. Subsequent weed control was done by hand. Plants were staked one month after planting using individual bamboo poles 1.6 m long. Fertilizer was applied at planting as 373 kg per ha each of muriate of potash and triple super phosphate and 3 months later as 314 kg per ha of sulphate of ammonia. Plants were sprayed alternately with Dithane M45 at 1.5 kg per ha and Miltox at 1.1 kg per ha every 2 weeks for control of an anthracnose disease which attacks leaves and stems.

The number of plants emerging was recorded weekly up to the 8th week after planting. Three complete plants for growth analysis determination were harvested from each plot at three weekly intervals from the 7th to the 19th week after planting.

Analysis of the growth of the foliage was discontinued after the 19th week because of difficulty in recovering the foliage due to entanglement of sample plants with neighbouring guard and other sample plants. Stem number and tuber development were monitored after the 19th week regular samplings at approximately three weeks intervals.

## Results

### Tuber Yield

Tuber yield increased with increasing sett weight (Table 1). However, this increase in yield occurred with middle setts only; small setts of middles produced a significantly lower tuber yield than large setts of middles and all setts of heads. No significant differences were observed among the sett sizes used for heads. At the wide spacing middles produced a significantly lower yield than heads at the wide spacing or middles and heads at the close spacing. Small setts at the close spacing produced a significantly lower yield than large setts at both the wide and close spacing.

Table 1. The mean effect of sett size, sett type and spacing on yield in "White Lisbon" yam (*D. alata* L.).

| | Head Setts | Middle Setts | Close Spacing | Wide Spacing | Mean |
|---|---|---|---|---|---|
| | | | tons/ha | | |
| Small setts | 37.7a | 31.6b | 36.2ab | 33.0b | 34.6b |
| Medium setts | 36.7a | 35.6ab | 37.3ab | 35.0ab | 36.1ab |
| Large setts | 38.1a | 39.2a | 39.0a | 38.3a | 38.7a |
| Close spacing | 37.7a | 37.4a | - | - | 37.5a |
| Wide spacing | 37.3a | 33.6b | - | - | 35.4a |
| Mean | 37.5a | 35.5a | 37.5a | 35.4a | 36.45 |

For heads increasing seed rate above the minimum used (1,525 kg/ha) did not lead to an increase in total yield. As a result net tuber yield (i.e. total tuber yield less the weight of setts planted) declined with increasing seed rate. For middles, however, there was a marked increase in yield with the increase in seed rate and the relationship tended to become asymptotic at higher seed rates. Net tuber yield increased up to about 4,500 kg/ha for middles and declined thereafter.

Sett size and sett type had no significant effects on tuber number per plant. The yield differences resulting from these two varieties were therefore primarily due to differences in tuber size (Table 2). Small setts of middles which were relatively lower yielding produced a larger proportion of small and unmarketable tubers. Plants grown at the wide spacing produced a significantly greater number of tubers per plant and also larger tubers than those grown at the close spacing. Tuber number per unit area was, however, greater for plants at the closer spacing (239 vs 178, $p = 0.01$) resulting in little difference in tuber yield between the close and wide spacings.

## Aerial tubers

The first visible signs of aerial tuber formation were observed between 25 and 28 weeks after planting. Very rapid development of these tubers was noted thereafter. The effects of the various treatments on the production of bulbils are presented in Table 3. Large and medium size setts produced a greater yield of aerial tubers than small setts. Differences between the two sett types and the two spacings were not significant although yields appeared to be higher for heads and at the wide spacing. The higher yield of aerial tubers from large setts was due to both the production of larger and greater numbers of tubers.

## Time to emergence

Plants from head setts emerged earlier than those from middle setts and those from large setts emerged earlier than those from small setts. Plants from large head setts emerged earliest and those from the middle setts latest.

Table 2. The mean effect of sett size, sett type and spacing on tuber number per plant in "White Lisbon" yam (D. alata L.).

| | Head Setts | Middle Setts | Close Spacing | Wide Spacing | Mean |
|---|---|---|---|---|---|
| | tubers/plant SE ± 0.91 | | tubers/plant SE ± 0.91 | | tubers/plant SE ± 0.65 |
| Small setts | 2.67 | 2.84 | 2.20 | 3.30 | 2.75 |
| Medium setts | 2.65 | 2.83 | 2.22 | 3.26 | 2.74 |
| Large setts | 2.84 | 2.66 | 2.20 | 3.30 | 2.75 |
| | SE ± 0.75 | | | | SE ± 0.53 |
| Close spacing | 2.11 | 2.31 | - | - | 2.21 |
| Wide spacing | 3.34 | 3.25 | - | - | 3.29 |
| | SE ± 0.53 | | SE ± 0.53 | | |
| Mean | 2.72 | 2.78 | 2.21 | 3.29 | 2.75 |

CV = 66.2%

Table 3. The mean effect of sett size, sett type and spacing on aerial tuber production in "White Lisbon" yam (D. alata L.)

| | Head Setts | Middle Setts | Close Spacing | Wide Spacing | Mean |
|---|---|---|---|---|---|
| | kg/ha SE ± 0.94 | | kg/ha SE ± 0.94 | | kg/ha SE ± 0.66 |
| Small setts | 242 | 197 | 224 | 215 | 220 |
| Medium setts | 457 | 383 | 388 | 453 | 421 |
| Large setts | 527 | 410 | 422 | 516 | 469 |
| | SE ± 0.77 | | | | SE ± 0.54 |
| Close spacing | 405 | 284 | - | - | 345 |
| Wide spacing | 413 | 376 | - | - | 394 |
| | SE ± 0.54 | | SE ± 0.54 | | |
| Mean | 409 | 330 | 345 | 394 | 370 |

CV = 50.9%

Total dry weight and stem numbers

During the 19-week period when foliage was analysed larger setts produced larger plants than small and medium setts. Plants from head setts had signifi-

cantly greater dry matter than those from middles at 7 and 10 weeks after planting. Differences in total dry weight due to spacing were observed after the 10th week; plants grown at the wider spacing had a greater total dry matter than those at the closer spacing.

Tuber development

Large setts produced greater tuber dry weights at all sampling dates and this resulted in a higher yield for large setts. The relative differences in tuber development between large and small setts were greater during the earlier period of growth. The higher tuber yield of large setts seem to result from higher bulking rates during the period 13th to 22nd. The bulking rate declined rapidly after 32 weeks for all sett sizes. However, the bulking rate for small setts seems to decrease at a slightly slower rate than large setts but this does not appear to have compensated for the slower rate of bulking before the 22nd week. Large setts therefore appear to have a longer period of more rapid tuber bulking than small setts and this may have resulted in the greater yield for large setts.

Plants grown at the wide spacing accumulated dry matter in their tubers at a greater rate and for a slightly longer period than those at the close spacing and this accounted for the higher per plant yield at the wide spacing. Unlike the effect of sett size the differences between spacing treatments were more pronounced during the 22nd and 32nd week.

Plants from large setts produced significantly fewer tubers than other setts during the period of rapid tuber bulking but differences had disappeared by final harvest. Spacing had a large effect on tuber number with plants at the wide spacing producing a significantly greater number of tubers from 16th week onwards.

Discussion

Although tuber yield increased with increasing sett size the effect was confined to middle setts only, particularly at the wide spacing. Head setts seem to be more efficient with small setts yielding as well as large setts at both close and wide spacings.

The results of this experiment indicate an asymptotic response in yield to increasing seed rate for *D. alata* which agrees with the results of Baker (1964) for *D. rotundata*. Very much lower seed rates are required for heads as compared to middles. The results show that the yield response curve was already at its maximum for the lowest seed rate (1,525 kg/ha) used for heads in this experiment with the result that net yield declined with increasing seed rate. For middle setts the biological optimum seed rate as indicated by the maximum net yield is about 4,500 kg/ha which means that at least three times the quantity of middle setts are required to get a yield equivalent to the lowest seed rate used for heads.

In Trinidad the normally recommended seed rate is about 2,500 kg/ha of mixed setts (Haynes, 1967). It is suggested that in commercial cultivation head setts should best be separated from middles and that the seed rate of each adjusted by varying either spacing and/or sett weight.

The higher tuber yield of large setts and head setts seems to be related to the earlier emergence and the more rapid early growth of plants developing from these setts. Large setts will contain a greater quantity of dry matter and nu-

trients than small setts and it has been shown by Ferguson et al. (1980) that head setts contain greater concentration of dry matter, N, P, Ca, and Mg and therefore greater quantities of these nutrients than middle setts. It seems likely that the amount of carbohydrates and nutrients available in the sett for mobilization to the developing plant can affect the growth of these plants and yield. It is also likely that one or more of these factors affect the size of the primary nodal complex which develops directly from the sett and so determine the size of the tuber sink.

The greater yield for large setts seems to be related to a longer duration of rapid tuber bulking resulting primarily from earlier and more rapid tuber bulking during the earlier period of tuber development. Enyi (1972) related the higher yield of large setts in D. esculenta to higher mean bulking rates over the tuber bulking period and Bremner and Taha (1966) found that in the potato the higher yield of large setts resulted from a longer bulking duration because of earlier tuber initiation. The earlier emergence and earlier and longer, more rapid tuber growth of large setts suggest that tubers may be initiated earlier in the large setts of D. alata.

A greater number of tubers was produced and apparently resorbed for small and medium setts than for large setts. Sett size had no effect on the number of tubers produced at final harvest and yield differences were therefore only as a result of differences in tuber size. However, it seems possible that the early formed tubers of large setts were greater sinks than the later formed tubers, thus giving early formed tubers a competitive advantage for bulking assimilates over later formed tubers, the development of which was apparently suppressed.

Unlike the effect of sett size the higher per plant yield at the wide spacing resulted from both an increase in the number and size of tubers. Bulking rate per plant was markedly higher at the wide spacing and was maintained for a slightly longer time. Closer spacing seems to lead to earlier cessation of formation of new tubers and also to earlier resorption of tubers as maximum tuber number was achieved 10 weeks earlier than at the wide spacing.

Aerial tubers in D. alata are secondary sinks and account for a relatively small proportion of the dry matter stored in tubers, in this experiment only one percent. They, however, have agronomic potential for use as planting material because they can be high yielding (Ferguson et al., 1969) and are easy to harvest, simple to prepare for planting, free from cut surfaces that can lead to pathogenic infection and free from pathogenic soil microorganisms. The possibility of developing a system to increase production of aerial tubers needs investigation.

Aerial tubers appeared on vines just after the period of greatest tuber bulking was achieved. Sawada et al (1958), working with D. opposita Thunb. found that high sugar concentration was necessary for the formation and growth of aerial tubers but not for tuberization. A build-up in the concentration of sugars in the stems of yams after the 25th week could have led to the development of aerial tubers. The tuber is a blunt and voluminous organ and Ferguson and Gumbs (1976) have demonstrated that soil compaction can restrict its growth. The tuber grows against existing soil resistances and with the increasing size of the tuber these resistances become greater and restrict the development of the tuber which can result in a build-up in assimilates, mainly sugars, in the translocatory system, which may trigger aerial tuber formation and growth. The higher yield of aerial tubers from large setts could be partly accounted for by the earlier physical restriction of the growth of the larger developing tubers from large setts.

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# Recent Approaches to Seed Yam Production

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## ABSTRACT

Continued production of yam as a crop depends on reducing the production cost. Cost reduction of seed yam, the popular propagule, is seen as a major contribution. Experiments to produce seed of white guinea yam (*Dioscorea rotundata*) using mini setts, herbicide and seed dressing have been conducted.

Cheaper and acceptable seed yam can be produced by the use of mini setts, herbicide and seed dressing. Appreciable reduction in the cost of producing ware yam is thereby affected.

Yams (*Dioscorea* spp.) have one of the highest production costs due primarily to high number of man-days required and cost of the propagule. The traditional propagule in yam production is the tuber. This may be in the form of seed yam, stump regrowth after detuberization or sett. Experience indicates that, all things being equal, higher tuber yields are obtained from larger propagules (Nwoke et al., 1973; Ferguson, 1973). Hence it is usual to use larger seed yams, stump regrowths or setts for the production of ware yams. It has been calculated that the propagule accounts for more than 50% of total production cost of ware yam (Oyolu, 1982).

Studies to establish cheap, rapidly multiplied propagules for yam production indicate that tubers are best. "Milking" (Okigbo and Ibe, 1973) and induction of plantlets sequentially carved out with about 10g segment of the parent tuber (Anon, 1975a) have shown some advantage over the traditional practice but have serious limitations. The minisett technique (Okoli, et al., 1982), a modification of the plantlet technique, appears to have the greatest potential for rapid multiplication of cheap seed yam. This report is part of research progress in the Department of Crop Science, University of Nigeria, Nsukka, Nigeria to find ways of reducing the production cost of yam. Research is supported by University of Nigeria Research Grants Committee.

## Materials and Methods

One hectare field measuring 125x80 m was plowed, harrowed and worked into 125 ridges, 1 m apart and 80 m long.

Seed yams of *D. rotundata* c.v. nwopoko were cut into discs and each disc divided into four minisetts according to Okoli et al., (1982). In addition, ware yams of the same cultivar were also cut into discs some of which were divided into six minisetts and others into eight minisetts depending on the circumference of the disc. Weights of minisetts ranged from 18 - 32 g with a mean of 25 ± 3 g.

Aldrex T (a fungicide/insecticide) was applied by shaking about 30 minisetts in a large tin. The process proved slow, irksome, and uneconomical. Therefore, a seed dressing drum capable of taking 2,000 minisetts at one time was fabricated. As minisetts were loaded, aldrex T was sprinkled on minisetts layers. It took eight packets of 10 g each to dress 2,000 minisetts by rotating the drum for about 15 minutes.

The next morning dressed minisetts were sown at 25 cm spacing along the ridge, providing 40,000 per hectare. Sowing was on 18 June, 1982 about the time farmers in the area normally plant seed yam.

Pre-emergence spraying with gramoxone was done 4 days after sowing.

Sprouting began 21-28 days from sowing and by the 77th day, 82% of the minisetts had sprouted. As the minisetts sprouted, they were staked with slender Indian bamboo branches and the vines trained individually.

The ridges were manually remoulded and weeded between the 70th and 75th days from sowing and 450 kg of 15:15:15 plus 100 kg $MgSO_4$ applied immediately after remoulding ridges. The fertilizer was applied in furrows on both sides of the ridges.

Harvest was during the first week of December 1982. Tuber weights ranged from 75 g to 325 g with over 75% weighing between 195 g and 254 g (Table 1).

Table 1. Frequency of weights of seed yams produced from minisetts, 25 ± 3 g.

| Class (g) | Frequency |
|---|---|
| 75 - 86 | 137 |
| 87 - 98 | 319 |
| 99 - 110 | 376 |
| 111 - 122 | 482 |
| 123 - 134 | 407 |
| 135 - 146 | 512 |
| 147 - 158 | 335 |
| 159 - 170 | 519 |
| 171 - 182 | 614 |
| 183 - 194 | 568 |
| 195 - 206 | 2,989 |
| 207 - 218 | 8,205 |
| 219 - 230 | 7,437 |
| 231 - 242 | 2,942 |
| 243 - 254 | 4,010 |
| 255 - 266 | 1,121 |
| 267 - 278 | 779 |
| 279 - 290 | 395 |
| 291 - 302 | 364 |
| 303 - 314 | 213 |
| 315 - 326 | 76 |

## Results and Discussion

Observations indicate that both seed yams and ware yams, of at least the cultivar studied, can be utilized as minisetts. Whereas 16-24 minisetts were obtained from seed yams, 48-80 were obtained from ware yams but the cost per minisett in either case was between ₦ 0.02 and ₦ 0.03. If it is possible to buy ware yam at less than three times the cost of seed yam, the former may be a better proposal as there is no difference in their performance.

Reproductive co-efficient of minisett averages abut 800 which is at least more than double the reproductive co-efficient of *D. rotundata* under traditional production (Oyolu, 1982).

Dependence of the new yam plant on the reserve nutrients for a considerable period and delayed functioning of leaves and roots (Njoku et al., 1973) appear to be modified in the minisett growth. It also appears that the normal positive correlation between the size of the propagule and the yield of individual plants in *D. rotundata* is altered. These require critical study in the minisett.

The minisett technique presents a rapid and cheap multiplication method for seed yams. Under proper care, it offers a chance to reduce the production cost of yam, especially *Dioscorea rotundata*.

Table 2. Cost of producing one hectare of seed yams from minisetts.

| | Items | | | | Cost (₦)† |
|---|---|---|---|---|---|
| (i) | 6 Tractor hours | | | | 30.00 |
| (ii) | Propagule* | No. | discs | minisetts | |
| | (a) Seed Yam | 900 | 3,600 | 14,400 | 450.00 |
| | | 500 | 3,000 | 12,000 | 250.00 |
| | (b) Ware Yam | 150 | 1,200 | 7,200 | 225.00 |
| | | 80 | 800 | 6,400 | 120.00 |
| (iii) | Cutting minisetts (8 man-days at ₦5.00) | | | | 40.00 |
| (iv) | Dressing minisetts (1 man-day at ₦5) | | | | 5.00 |
| (v) | 160 packets of Aldrex T at ₦0.15 | | | | 24.00 |
| (vi) | 9 liters gramoxone | | | | 90.00 |
| (vii) | Application of herbicide (3 man-days at ₦8) | | | | 24.00 |
| (viii) | Remoulding ridges and weeding (26 man-days at ₦5) | | | | 130.00 |
| (ix) | 550 kg fertilizer at ₦4.25 per 50 kg bag | | | | 46.75‡ |
| (x) | Application of fertilizer at (16 man-days at ₦5) | | | | 80.00 |
| (xi) | Stakes (100 at ₦2.50, usable twice) | | | | 500.00 |
| (xii) | Staking and training vines (90 man-days at ₦5) | | | | 450.00 |
| (xiii) | Harvesting (48 man-days at ₦5) | | | | 240.00 |
| | | | | TOTAL ₦ | 2,704.75 |

*Seed yams were bought at ₦0.5 each and ware yams at ₦1.50
†(₦1) = U.S. $ 1.47
‡at 50% subsidy

Estimated profit may be calculated on 28,531 seed yams of 200 g and above which if sold at ₦0.13 per tuber gives ₦1,004.28 or just over 37% profit. This has not taken into account the 4,269 smaller tubers.

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Contribution to the Study of Vegetative Reproduction of Yam: Plant Weaning and Tuber Pricking with *Dioscorea alata*

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ABSTRACT

Daughter plants of *D. alata* are often separated from the mother tuber, which is pricked out to obtain regrowth. The earliest stage of separation giving acceptable production was determined. The effect of shoot removal on the number of successive flushes of regrowth was also analysed.

More prickings were possible with a whole tuber than a seed piece of the same weight, and with greater tuber weight. At least two prickings were obtained from mother tubers weighing between 100 and 500 g.

The initial weaned plant yielded as much as a normal plant. The cumulative yield from successive plantings was much greater than a normal planting, but individual yields declined over the succession. This decline was also observed with unweaned controls used with the successive plantings, suggesting an effect of tuber aging or ecological evolution.

The cumulative yield of successive weaned plants from a common mother tuber seemed to be lower than the cumulative yield of simultaneous plantings of seed pieces from a mother tuber of equivalent weight.

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