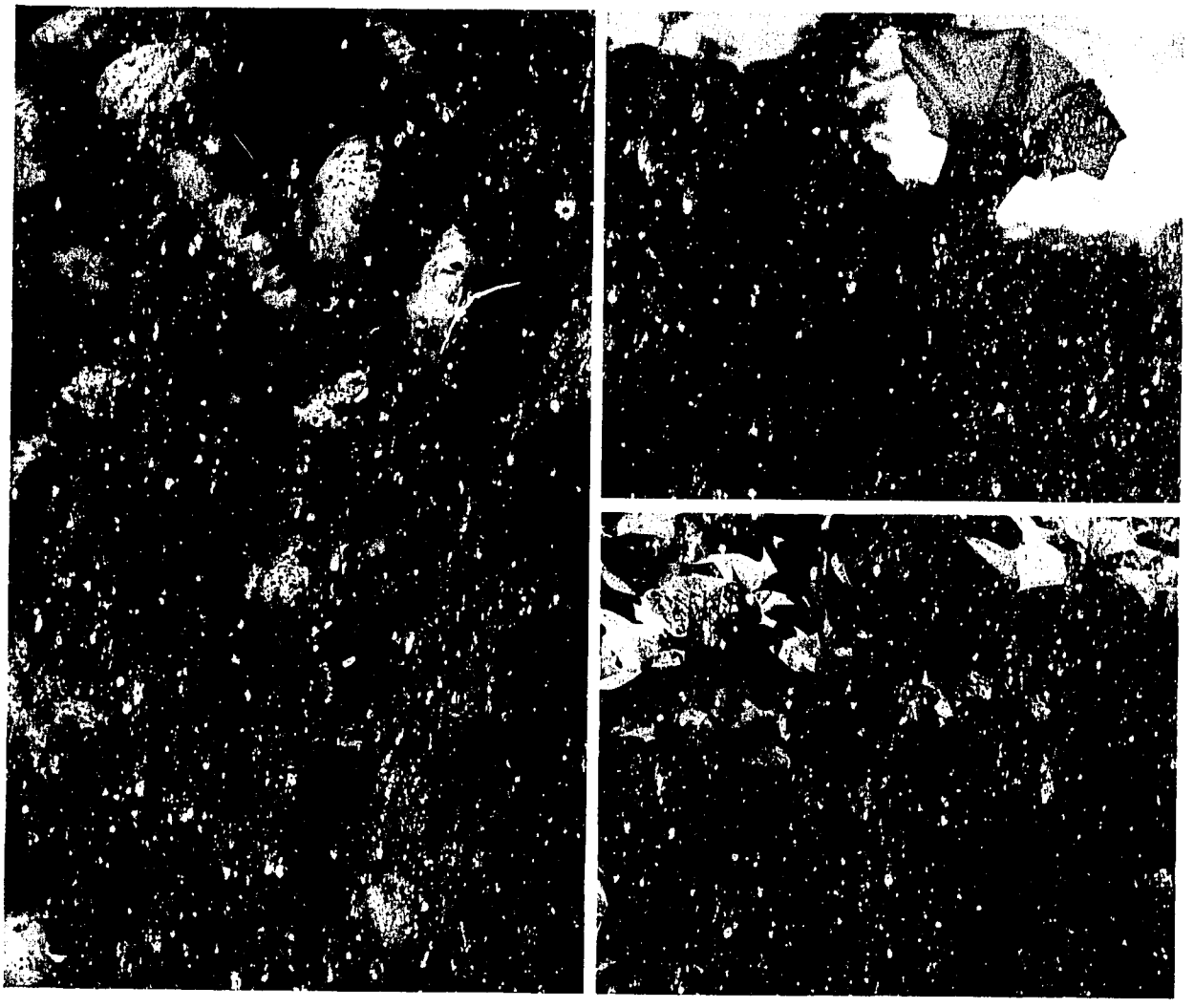
EXPLORATION, MAINTENANCE, AND UTILIZATION OF SWEET POTATO GENETIC RESOURCES

Report of the First Sweet Potato Planning Conference 1987



INTERNATIONAL POTATO CENTER (CIP)

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Report of the First Sweet Potato Planning Conference 1987

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PREFACE

This volume contains 31 documents by "the best minds of the world working with sweet potatoes" presented in the first CIP Planning Conference on this crop held at CIP headquarters from February 23 to 27, 1987.

CIP planning conferences are strategies to plan and evaluate research. During its 15 years of existence, CIP has celebrated 29 of these conferences on potato and related topics. The present Conference is the 30th in total and the first on sweet potatoes. The planning conferences bring together outstanding scientists from different parts of the world, to help CIP evaluate research in process and plan the lines of action.

The sweet potato has been recently added to CIP's mandate. Research and transfer on this crop will benefit from the network and the strategies CIP has developed around the world for exchange of knowledge and technology on the potato.

The objectives of this 30th Planning Conference call for priorities, strategies, guidelines and definitions on collection, evaluation, and utilization of sweet potatoes. The results are presented in the following pages.

C O N T E N T

Page

PLANNING CONFERENCE

ON

EXPLORATION, MAINTENANCE AND UTILIZATION OF

SWEET POTATO GENETIC RESOURCES

February 23-27, 1987

OBJECTIVES

The first planning conference on the exploration, maintenance and utilization of sweet potato genetic resources will be oriented to the following objectives:

1. To review the priorities for sweet potato germ plasm exploration and collection.

2. To determine the best strategies for sweet potato germ plasm conservation.

3. To establish guidelines for evaluations in the sweet potato collection.

4. To set out strategies for utilizing these genetic resources and establish CIP's breeding priorities.

5. To determine CIP's comparative advantage for research amongst what other institutions are already accomplishing.

OPENING SWEET POTATO PLANNING CONFERENCE

R. L. Sawyer

Welcome to this 1st Sweet Potato Planning Conference at CIP. This is the 30th Planning Conference held by CIP during the past 15 years, a strategy whereby we ask the best scientists across the world working on the specific problem to give us their time and mental energies to help us plan our work for the next five years.

You gathered in this room are representative of the best minds in the world working with sweet potatoes. And I wish to thank you for taking the time from your busy schedules to help us this week. I wish to particularly thank the representatives from IITA and AVRDC for their participation in this conference. Those two institutions have already been working on sweet potato improvement for the developing world for many years. We at CIP are newcomers with this crop. Let me briefly explain how CIP became involved with sweet potatoes and then explain what I feel should be the common denominator for the discussions and planning to take place this week.

CIP started to emerge long before there was any idea of a Consultative Group for International Agricultural Research. In fact, I came to Peru in 1966 with the hidden agenda of developing an international center while coleading a national potato program through a USAID funded North Carolina State University contract. The agreement signed in 1971 by the Minister of Foreign Affairs of Peru and the Chancellor of North Carolina State University was for a tuber and root crop international center. However, since the time we joined the newly formed CGIAR system in 1972 we have only received funding for potato research until recently. In 1972 only four other centers existed, IRRI, CIMMYT, CIAT and IITA. Although we received requests over the years for sweet potato help our answers were the same, we only work with the tuber bearing solanums.

Recently the Technical Advisory Committee for the CGIAR centers produced a study on priorities for the system. In the balance of investments amongst food commodities, the study indicated that sweet potatoes were considerably underfunded. At the same time an impact study of the CGIAR centers inferred that the most successful centers were the commodity centers and those working with only a few commodities.

Shortly after the early drafts of these two studies emerged several members of TAC and several major donors to the system asked us at CIP if we had ever considered including sweet potatoes. Since that time serious consideration was given by staff and the Board of Trustees with formal and informal meetings held with the Directors of the Centers already working with sweet potatoes.

The Board of Trustees formally approved the move in 1985 and gave permission to utilize up to 5% of present funding for sweet potatoes.

Special project funding was received for some work and IBPGR has helped us build a sizable collection. A special budget for sweet potatoes was provided to TAC for 1986 and again in 1987. Let me briefly quote the official blessing of TAC and the CGIAR to CIP's move into sweet potatoes in TAC's annual Centers Week report to the group last year from which we received some funding for this year.

CIP's move into sweet potatoes is to complement what others are already doing as together we address the priority problems of sweet potato production and use in the developing world. In my opinion the sweet potato has a greater potential than any other major world food for much of the world's land and people in the future. As population increases, more marginally productive land will come into use by farmers with scarce investment resources Under such conditions, the sweet potato has a greater potential than any other commodity in the CGIAR system.

The common denominator at all discussions this week should be the priority needs of developing countries for sweet potato improvement and not what specific institutions would like to do and be funded to do.

Secondly, we should be discussing what is presently being done by staff in existing facilities. This will probably lead to the identification of gaps where priorities are not being attended or are being under attended. Together I would hope that we could come up with strong proposals intelligently prepared which would lead to the funding of work at all of our institutions for those priority needs for which there was a comparative advantage.

CIP's program of research and transfer of technology with potatoes has been more diversified than any of the other CGIAR centers. Each year we fund over 40 research contracts at other institution from core funds. Our approach to priority sweet potato work is similar and if a priority area of work can best be done at another institution we prefer to help fund the other institution or help them get funds for the work. We do not want the needs of developing countries directly or indirectly through helping others serve to get bigger at CIP, we just want to get better; better to serve the needs of developing countries directly or indirectly through helping others serve.

You are here this week to help us identify the work for which we have a comparative advantage and plan our activities around those comparative advantages for the next five years. We are not here to plan the work of the other institutions involved in sweet potato research, but we must take their work into consideration as you plan what CIP should do. We want our work and plans to be complementary to what others are doing around their comparative advantages.

RECOMMENDATIONS

I. Conservation

The following recommendations are suggested for conservation of different types of Ipomoea genetic resources.

1. Species of Ipomoea section batatas, excluding Ipomoea batatas. When material is received, either as plants or seeds, a sample should be grown to verify species, ploidy level and self or cross compatibility. The remainder of the original seed will be preserved. Individual plants should be placed in subgroups of the accession on the basis of ploidy differences if necessary.

   If the accession is self-compatible and sets seed freely, sufficient seed from each plant should be maintained to provide an initial supply of 1000 seed.

   If the accession is self-incompatible, a larger group of individual plants should be used to develop the initial seed supply. These plants should be crossed by hand or by insects in an isolated location to provide an initial supply of 1000 seed.

   Seed viability should be observed, and seed supply should be renewed following IBPGR guidelines.

2. When seeds of Ipomoea batatas are received they should be maintained and generated as necessary.

3. Seed Handling

   All seed received should be immediately placed in a plastic bag with vapona strip for one week (or more if necessary).

Low specific gravity seed should be floated off in water with a surfactant. Seed that sink should be saved, dried, packaged in foil and stored at constant temperature and low humidity.

4. Clonal Accessions of Ipomoea batatas

   Clonal material should be initially grouped by geographical origin and field polycrosses established. Seed should be harvested and maintained by identification of female parent. Techniques for flower induction should be used if necessary. Characterization and evaluation should begin immediately so that duplicates can be identified and eliminated. Depending on final size of the clonal collection, elite clones will be

permanently maintained either in field collections or tissue culture or both. Remaining clonal materials will not be preserved as clones but as seed pools.

II. Utilization of Sweet Potato Genetic Resources

Utilization of sweet potato genetic resources was discussed in terms of priorities and methods of breeding. The following areas were recommended as areas of highest priority and areas in which CIP has a comparative advantage.

1. Insect and Nematode Resistance

Weevils (Cylas, Euscepes)
Diabrotica
Stem borer
Root-knot nematodes

CIP's comparative advantage in utilization of germplasm for insect and nematode resistance lies in the germplasm collection and in the presence of these pests in Peru. However, AVRDC has a comparative advantage of having the African Cylas spp. for evaluation purposes. It is therefore, recommended that CIP, AVRDC, and IITA work very closely in the evaluation and utilization of CIP's germplasm collection for weevil resistance. A close cooperation with AVRDC for work on stem borer is also recommended. CIP has the comparative advantage of having Meloidogyne spp. for evaluation purposes. Evaluation and utilization of CIP germplasm collection for resistance to root-knot nematodes and the interacting Fusarium spp. is recommended.

2. Environmental Stress

- Excess moisture
- Drought
- Heat
- Salt
- Shade
- Cold

CIP's advantage lies in being able to screen in the above environments within the country and in the germplasm collection.

3. Agronomic Characteristics

- Yield potential
- Earliness

4. Food Quality Attributes

- Dry matter/starch
- Protein
- Carotenoid compounds
- Flavor
- α and β amylases
- Processing characters
- Potential of foliage use as a vegetable

5. Storage Attributes

- Diseases and insects specifically related to perishability in short or long-term storage
- Sprouting in storage

6. Diseases

CIP has a comparative advantage in the germplasm collection and in its high level of expertise in virology. It is recommended that work continue on elucidation of virus diseases and, simultaneously, the search for resistant or tolerant clones to specific viruses.

III. Quarantine

1. We recommend that CIP establish phytosanitary standards for pest and pathogens for the distribution of true sweet potato seed and in vitro cultures. Until such time, as official standards have been established, we recommend that research be emphasized which will elucidate the identity, importance and detectability of sweet potato pests and pathogens for materials designated as having the greatest export potential.

2. In the case of clonal material, the Committee recommends that clonal material be pathogen tested as per guidelines that will be established in the forthcoming position paper.

   Included in this position paper will be a review of ongoing research efforts provided in part by the members of the conference to help CIP's management define institutions comparative advantages for execution of this research.

3. True sweet potato seed derived from pathogen tested material can be distributed. Small amounts of true sweet potato seed imported to CIP will be planted out under quarantine conditions and pathogen tested as individual clones. Non pathogen tested true sweet potato seed can be distributed for research purposes to those institutions with appropriate quarantine, and virus and viroid testing capabilities.

Large scale seed lots cannot be pathogen tested by present technology as populations. Testing of these materials must await the results of recommended research designed to provide these techniques.

4. Non pathogen tested *in vitro* plantlets can be distributed for conservation and/or pathogen elimination to those institutions with appropriate quarantine, and virus and viroid testing capabilities.

5. Distribution of non pathogen tested materials from CIP should be made only after receiving an official document from the importing country stating the acceptance of the risks involved. A CIP phytosanitary statement should clearly indicate the unknown health status of the material.

6. It is recommended that resources be made available for priority research for virus identification and virus elimination.

7. It is also recommended that resources be made available for research into population testing of large seed lots.

IV. Taxonomy, Exploration, Collection and Maintenance

1. It is recommended that CIP be established as the central gene bank for sweet potato and related species for the Americas.

2. Biosystematic research on section Batatas and evolution of the sweet potato is strongly recommended.

3. It is recommended that equal priority should be given to the collection of sweet potato cultivars and to wild species of section Batatas. Whenever possible, species of other sections should be collected for potential use as virus indicators, root stocks, and other purposes.

   Priorities for collecting activities during fruiting periods should be conducted as shown in Tables A and B.

4. Research on sampling techniques, collection methods, seed regeneration for wild species, and seed storage is essential.

5. Duplication of well documented national and institutional cultivated collections is encouraged.

6. High priority should be given to duplicate identification in the cultivated collection using data collected from morphological, biochemical, self incompatibility, and other evaluation criteria.

7. For security purposes, seed stocks should be duplicated in other *Ipomoea* gene banks.

8. Adequate measures to minimize the spread of pathogens and insects within the cultivated collection should be taken. Contaminated materials, when identified, should be isolated.

9. It is recommended that clonal accessions be transferred to in vitro conditions to ensure germplasm safety and improve phytosanitary status.

A. In the cultivated species further exploration and collection is needed according to the following priorities:

Country	Priority
Mexico	H
Nicaragua	H
Honduras	H
El Salvador	H
Guatemala	M
Belize	M
Panama	M
Cuba	M
Haiti and Dominican Republic	M
Antillas	M
Colombia and Venezuela	M
Brazil	M
Costa Rica	L
Peru	L
Ecuador	L
Bolivia	L
Argentina	L
Chile	L
Paraguay	L
Uruguay	L

H = High, M = Medium, L = Low

B. In the wild species further exploration and collection is needed according to the following priorities.

Ipomoea Species	Priority	Region
cynanchifolia	U	Brazil, Paraguay, Argentina
grandifolia	U	Brazil, Paraguay, Argentina
gracilis*	U	Australia
costata*	U	Australia
muelleri*	U	Australia
peruviana	U	Peru, Ecuador
trifida	U	Mexico to Colombia
tenuissima	H	Florida, The Caribbean
littoralis*	H	Indian and Pacific ocean
cordatotriloba (trichocarpa)	M	Argentina
ramossisima	M	Central America and Bolivia
lacunosa**	L	U.S.A.
leucantha**	L	U.S.A.
tiliacea	L	The Caribbean
triloba	L	The Caribbean

To be collected by:

* AVRDC
** USDA

U = Urgent
H = High
M = Medium
L = Low

SWEET POTATO RESEARCH AT CIP

Peter Gregory

1. Introduction

CIP is already very active in several areas of sweet potato research. The addition of sweet potatoes to our mandate was a natural step in CIP's development. Much of our experience with potatoes is highly relevant to the study of sweet potato, and our research organization needed no major changes in order to facilitate work on this additional crop.

In this presentation I will outline some elements of our research organization and philosophy, I will give an overview of our current sweet potato research and how it fits into our organization, and discuss the ways in which we intend to plan and implement future sweet potato research at CIP.

2. CIP's Research Organization and Philosophy

Our organization was designed to remove priority constraints in global potato agriculture when CIP has a comparative advantage to do so. Our organizational structure and philosophy is highly suited to achieve the same purpose in sweet potato agriculture.

As the top priority problems are solved we move on to the next priority. This implies the need for a research organization with the flexibility to address changing issues. It also implies the need for practically - oriented interdisciplinary research.

These needs are satisfied by a simple organization based on Departments (each with a Department Head) which provide disciplinary strength and have staffing and budgetary responsibilities, and Thrusts (each with a Thrust Leader) which are interdisciplinary units each containing projects designed to address specific priority issues.

These projects change with changing needs, but the Thrusts and Departments tend to remain the same.

Research at CIP facilities in Peru is integrated through the Thrust system, with activities in the 8 Regions of our Regional Research Program. This research integration plus CIP's Training and Communication activities facilitates the efficient transfer and testing of technologies under developing country conditions. But the key to any of CIP's successes is that transfer and testing of technologies is done in close collaboration with National Program scientists.

CIP's research and technology transfer is strongly supported by contract research, and by Regional Networks. As Dr. Sawyer emphasized, CIP gives contracts from its core funding to institutions where special expertise and facilities are available, in developed and developing countries. This has been a cost-effective way of augmenting CIP research, making available equipment and techniques otherwise unavailable to us. I anticipate that Contracts will play an extremely important role in our sweet potato research. Some contracts are already active.

In addition to contract research CIP is involved in many productive research collaborations funded by external sources. I urge each of you to consider new contracts and collaborations during this conference.

Research Networks such as PRECODEPA and SAPPRAD have greatly expanded potato technology transfer through cooperative assistance among countries in a geographical region. We expect the same for sweet potatoes. Common problems are identified and responsibility for research to solve the problems is assigned to institutes in member countries of a network. CIP provides a coordinating role in the development of a network, as well as funding for travel and supplies.

3. Current Sweet Potato Research at CIP

The breadth of our current or pending sweet potato research, and how it fits into the Thrusts, is shown in Table 1.

This list is illustrative and is not meant to be comprehensive.

Most institutional emphasis is currently being given to (1) germplasm collection, maintenance and taxonomy, (2) techniques for the distribution of pathogen-tested germplasm and (3) the gathering of socio-economic data on a global scale. Let us consider each of these areas of little more closely:

3.1 Germplasm collection, maintenance and taxonomy

The heart of CIP's work on potatoes has been (and will continue to be) the development, maintenance and utilization of the World Potato Germplasm collection. Our activities with sweet potatoes will also be based on the development, maintenance and utilization of a germplasm bank.

CIP, which is in and adjacent to the centers of origin of sweet potato, has already assembled one of the largest collections of sweet potatoes in the world. Possibly the largest. Descriptors are being developed and an International Computerized Data Bank is being organized.

Table 1

Some Current and Pending Research on Sweet Potatoes at CIP		
Thrust I	:	Germplasm collection and maintenance. Taxonomy, cytology and crossability.
Thrust II	:	Field plot techniques. Biochemical basis of consumer acceptability.
Thrust IV	:	Virus identification and detection.
Thrust V	:	Yield loss relationships to insect damage. Resistance to weevils. Resistance to nematodes.
Thrust VI	:	Tolerance to flooding, aluminium toxicity, salinity and drought.
Thrust IX	:	Flower induction physiology.
Thrust X	:	World patterns and trends in production and use.

Also, the experimental basis for biochemical identification of duplicates is being made through collaboration with Dr. Stegemann of the Institute for Resistance Genetics, Braunschweig, West Germany. Elimination of duplicates (already achieved in the potato collection) will make the maintenance of the sweet potato collection more efficient, and less costly.

Research on *in vitro* maintenance techniques for sweet potato has started well and the culturing of meristems was accomplished with ease.

3.2 Germplasm Distribution

CIP is using its experience in distribution of pathogen-tested potato germplasm to develop for sweet potatoes a closely integrated '*in vitro* plus virology' program to facilitate global distribution of pathogen-tested germplasm.

The major problem is to identify the sweet potato viruses, and to develop methods for their detection. We are fortunate to have a contractual arrangement with Dr. Moyer at North Carolina State University which will be of enormous help in this difficult area.

When we are at a stage to distribute the pathogen-tested material, the impact of such distribution will be maximized by the experience gained with potatoes. CIP's Regional

Research operations and the Networks are expert in receiving, multiplying and evaluating potato materials: In many ways potato agriculture and sweet potato agriculture are similar.

Our extensive experience in Training and Communications will also be extremely valuable.

CIP is already working in most of the major sweet potato producing countries. We have associations in 14 countries (including China). These account for 95% of the world production of sweet potato.

3.3 Socioeconomic studies

Integration of social science into our biological research has been (and will continue to be) an extremely important part of CIP's strategy. As you will hear in the next presentation, CIP's social scientists have already focused on world patterns in sweet potato production and use. There will be socioeconomic research on farmer adoption of varieties, development of country files, mapping, plus research on marketing, consumption and nutritional considerations. All of this will be essential in helping us to pursue biological research in the appropriate context - the needs and wants of people. Social scientists are already active in researching 'house gardens' and 'roles of women in agriculture'. Both areas are relevant to sweet potato research.

4. Planning Future Work

One of the first steps in planning our sweet potato research was taken by Dr. Orville Page, the previous Director of Research. His 'Position Paper on the Sweet Potato' is a valuable resource. Future planning will, as before, be based on determining priority global constraints that CIP has a comparative advantage to work on.

How shall we do this? We will continue to have CIP Regional Staff determine the priority problems in their geographical areas of activity. In this matter, a continuation of our excellent collaborations with National Program staff involved in sweet potato research and extension will be essential.

Consideration of the socioeconomic science input will be critical, as mentioned earlier.

Our Annual Internal/External Review in which all CIP staff, Directors and Board Members plus visitors evaluate and change aspects of our program, will be important in guiding the sweet potato research. The Annual Regional Meetings will also be valuable. In these, regional staff members meet with headquarters-based scientists to plant research and other activities.

Planning Conferences, such as this first one on sweet potatoes, will play an extremely important role in evaluating and planning our sweet potato research.

The previous 29 Planning Conferences have had a major impact on our potato research.

Two general objectives of these Planning Conferences have been to (1) provide CIP with an objective external review and guidance by international experts and (2) to stimulate participating scientists to re-orient their own research to help solve key problems identified at the conferences.

The specific objectives of this Planning Conference are shown in Table 2.

Table 2

PLANNING CONFERENCE OBJECTIVES	
1.	To review the priorities for sweet potato germ plasm exploration and collection.
2.	To determine the best strategies for sweet potato germ plasm conservation.
3.	To establish guidelines for evaluations in the sweet potato collection.
4.	To set out strategies for utilizing these genetic resources and establish CIP's breeding priorities.
5.	To determine CIP's comparative advantage for research amongst what other institutions are already accomplishing.

Of course, achieving each of these objectives is of major importance to CIP and to each of you from other institutions who share the common goal of improving sweet potato agriculture in developing countries.

But there is a 6th unwritten objective for this Planning Conference, namely that new informal associations between the participants will be made, and that existing associations will be strengthened.

Based on our experience with Potato Research Planning Conferences such associations will yield tremendous benefit for years to come.

WORLD PATTERNS AND TRENDS IN SWEET POTATO PRODUCTION AND USE

Douglas E. Horton

Introduction

This paper presents some findings of a CIP research project, "Patterns and Trends in Root Crop Production and Use." The project's goals are: (1) establish a computerized data base of root crops statistics provided to CIP by the Food and Agriculture Organization (FAO) of the United Nations and make it available to all interested parties; (2) conduct various types of analysis of these figures; (3) lay the groundwork for periodicals on potatoes, sweet potatoes, and root crops; and (4) improve the FAO data base.

We have stored in our computer the FAO data on harvested area, yield, production and utilization of all root crops in all countries for the period 1961 through 1985. We have also entered farm-gate prices for 25 commodities in 1981— the most recent year these prices are available for most countries. Utilization data have also been entered.

Two editions of the Potato Atlas have been published, in 1977 and in 1985. Potato Statistics 1986 and Sweet Potato Statistics 1986 are now being printed. Winrock International plans to issue the first Root Crop Atlas in late 1987. The Atlases are to be issued every three to five years. Potato Statistics and Sweet Potato Statistics will be issued yearly.

The FAO Data

This paper is based on FAO data. After I gave a presentation at the 1981 symposium of the International Society for Tropical Root Crops, the eminent root crop specialist D.G. Coursey remarked, "We all know how worthless these numbers are, but it is a contribution of sorts to put them all together in one place." The FAO data do have many shortcomings, but it is easier to criticize them than to improve on them.

Every year the FAO estimates all the variables listed in the second paragraph of this paper, and many more, for every crop grown or used in every country of the world. FAO's estimates are based primarily on official country statistics.

The following "Food Balance Sheet Equation" provides the framework for much data gathering and analysis. The top line in the equation shows sources of domestic supply. The bottom line shows uses.

Food Balance Sheet Equation

Production + Import - Export - Change in Stocks
= Total Domestic Availability =
Seed + Feed + Manufacturing + Waste + Food

The estimation process begins with area, yield and production. Imports are added and exports substracted. In the case of cereal grains and traditional export crops, retatively easily documented, trade flows provide statisticians with a basis for checking their production estimates. However, root crops are generally not traded. Moreover, since most root crops are grown in small, irregular fields (many of which are intercropped), field surveys and censuses often overlook or grossly underestimate root crop production.

On the uses side of the food balance sheet equation, estimation problems are perhaps ever worse. Who knows what part of the crop is fed to livestock, processed, or wasted ? For example, numerous studies (Werge, 1979; Christiansen, 1967; Yamamoto, 1987) have documented the importance of Andean potato processing. Yet Peru's official statistics include no processed potatoes.

Keeping in mind the shortcomings of the FAO data, this paper deals briefly with four subjects:

- global distribution of root crops
- major producing countries
- production trends
- prospects for the future

The emphasis is on general patterns and trends rather than specific estimates for individual countries.

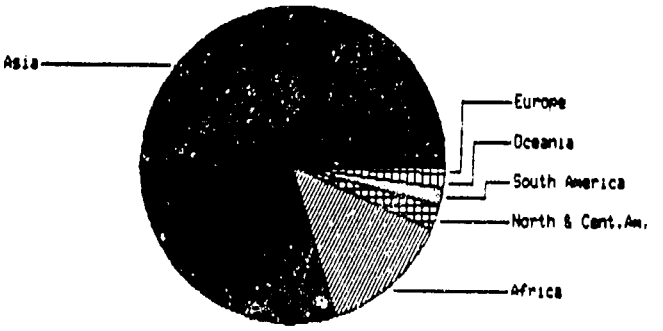
Global Distribution

Roughly 80% of the world's sweet potatoes are grown in Asia, just under 15% in Africa, and only about 5% in the rest of the world (Figure 1). Europe grows virtually no sweet potatoes and North American production is small. This pattern contrasts sharply with that of

potatoes, many of which are grown in Europe and North America. Because the northern latitude industrial countries neither grow nor import sweet potatoes, they have traditionally done very little sweet potato research. For this reason, the base of research knowledge for sweet

potatoes is much thinner than it was for potatoes when CIP began work on this crop in the early 1970s.

Figure 1. Distribution of world sweet potato area.



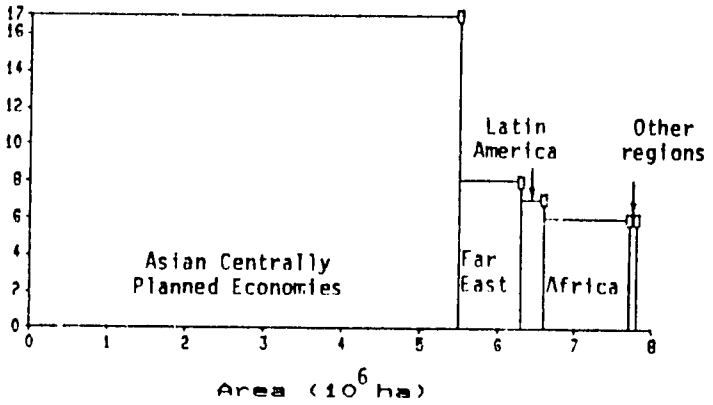
Developing countries grow nearly all of the world's sweet potatoes, and China accounts for about 80% (Table 1 and Figure 2). China also has much higher sweet potato yields and production per head than any other world region. Yields in China are double those of other regions and production per head is several times higher.

Table 1. World sweet potato production and yield, average 1983/85.

	Prodn (10^6 t)	Yield (t/ha)	Prodn per capita (kg)
Asian CPE*	96	17	85
Far East	7	8	5
Africa	6	6	14
Latin America	2	7	6
Near East & others	1	6	3
All developing countries	112	14	32

Source: FAO Basic Data Unit (unpublished).
* Centrally planned economies.

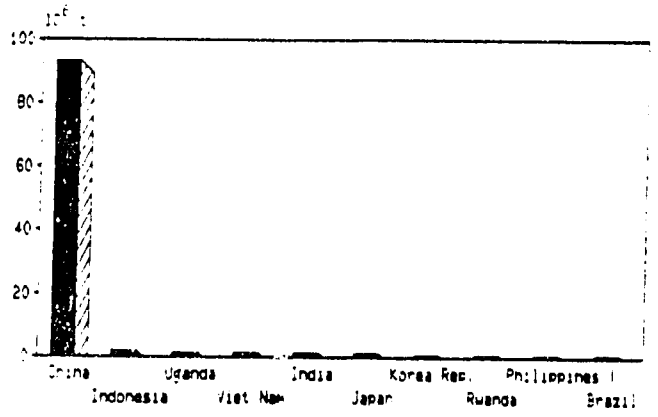
Figure 2. Regional sweet potato production, area and yield.



Major Producing Countries

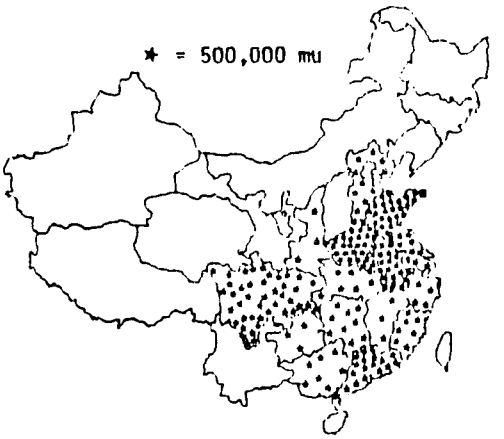
With about 90 million tons of sweet potatoes, China is by far the world's largest producer (Figure 3). Indonesia, the second largest, produces only about 2.5 million tons.

Figure 3. Major sweet potato producing countries.



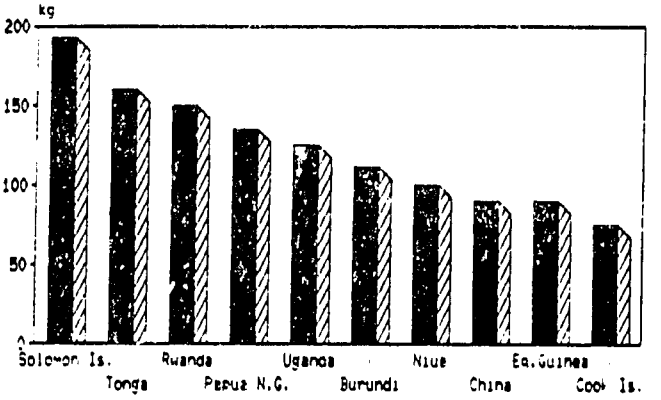
Given the large size and importance of China, it is useful to note the distribution of production within the country. We are presently negotiating with the International Food Policy Research Institute to have their China expert, Bruce Stone, work with Chinese authorities in the analysis of regional production patterns and trends. Each star in the accompanying map (Figure 4) is equivalent to 500,000 mu. The original Chinese source reports in units of 10,000 mu. Since 15 mu equal 1 ha, each star represents approximately 33,000 ha. These conversions illustrate just the simplest of problems of interpreting China's statistics. In Chinese statistical yearbooks, root crops are classified as "grains" and production estimates are in grain -equivalent units. Root crops grown in vegetable gardens --a very significant volume-- are not included in the official estimates.

Figure 4. China's major sweet potato growing areas.



While China is the largest sweet potato producer, some other countries have higher average levels of per capita production (Figure 5). According to FAO, the first five countries in this respect are the Solomon Islands, Tonga, Rwanda, Papua New Guinea and Uganda.

Figure 5. Sweet potato production per capita.

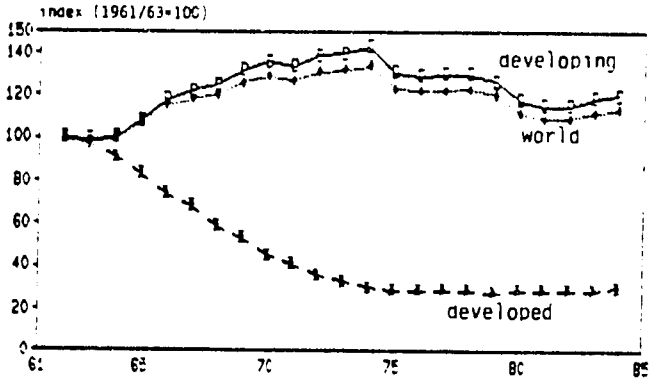


Production Trend

World sweet potato production increased from 1960 to about 1975 and then declined again (Figure 6). Given the overwhelming importance of

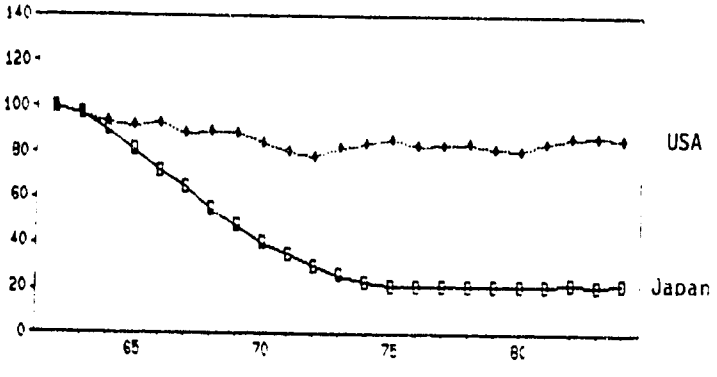
China, the world trend practically mirrors the trend for that country and for all developing countries as a group.

Figure 6. World sweet potato production trends.



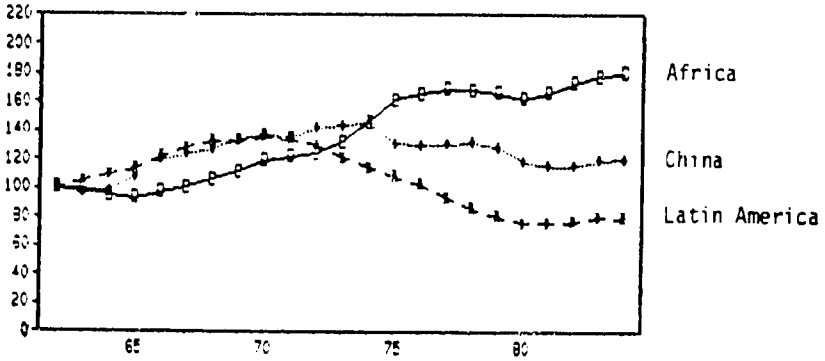
Japan and the USA are the only industrial nations that grow significant amounts of sweet potatoes. Production has fallen dramatically in Japan (Figure 7). It is generally believed that this has occurred because as income levels rose, consumption of sweet potato --considered to be an inferior food-- fell. In my view, this should be considered a research hypothesis rather than a fact, since the effects of production costs, marketing problems, and other factors have never been carefully examined. In the USA where sweet potato production has also fallen little empirical research has addressed the question, "why"?

Figure 7. Sweet potato production trends in Japan and USA.



In Latin America, sweet potato production rose in the 1960's, fell in the 1970s and then stabilized (Figure 8). In China and the rest of the Far East, production followed a similar but less pronounced trend. nly in Africa has production tended to increase throughout the entire period since 1960.

Figure 8. Sweet potato production trends in Latin America, China and Africa.



In summary, available statistics indicate that sweet potato production has fallen rather sharply in the developed countries (mainly in Japan) and increased modestly and rather erratically in the developing countries (mainly in China).

Prospects for the Future

What can we expect in the future? The past trends are not terribly encouraging. However, sweet potato improvement programs could help change the trends by increasing supply, improving quality or expanding demand (Table 2).

Table 2. Potential problems of sweet potato production and their solutions.

Problem	Solution
Supply	- Raise yields - Lower production costs - Expand environmental adaptability
Marketing	- Reduce perishability - Reduce losses - Improve market information
Demand	- Improve quality - Diversify uses - Overcome prejudices

When CIP first set its research priorities for potatoes, the main factors limiting production and use in developing countries were believed to be the potato's limited supply and high price. People wanted more potatoes but low yields, high costs and restricted environmental adaptation limited production and use. Is this the case for sweet potatoes? Some studies (Lin et al, 1985; Martin, 1983) indicate that marketing and demand problems may be of greater importance than production constraints per se. Due to the perishability of sweet potatoes and the rather primitive transportation and marketing systems in many developing areas, marketing and distribution problems certainly deserve careful research attention.

Beyond problems in the marketing system, demand factors may limit sweet potato production and use. Who wants sweet potatoes? What kinds do they want? How will sweet potatoes be used? And what are people willing to pay for them? Several authorities state that sweet potato consumption is limited by quality factors. If so, studies should attempt to define precisely what traits need improvement so that breeders can focus on these.

It is often said that prejudices limit sweet potato consumption. For example, South Koreans say they don't like sweet potatoes because during the Second World War they had to live on them. I'm not entirely convinced of this, since both Parmentier in the eighteenth century and R.L. Sawyer (CIP's Director General) in the Second World War had to live on white potatoes, and they both became potato fanatics. In short, we simple do not know very much about why people do or do not like a particular food.

A promising avenue for expanding demand may be to diversify sweet potato uses. In Taiwan many sweet potatoes are used for feeding livestock, and in Korea many have been used for starch. Why can't more sweet potatoes be fed to hogs and cattle or converted into starch, alcohol or ethanol? Such uses could indirectly expand the food supply, increase employment and raise real incomes. In establishing breeding priorities, the end uses of sweet potatoes need to be carefully target.

Conclusion

National and regional statistics help set the stage for sweet potato improvement by providing basic information on production patterns and trends. However, we need to complement these rather cold and shakey official statistics with other sources of information, including literature reviews and questionaire-type surveys of knowledgable individuals. Visits to important producing areas and on-farm research is also essential for understanding the trends in sweet potato production and use and how research and public sector policies might be used to influence them.

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THE TAXONOMY, EVOLUTION AND GENETIC DIVERSITY OF SWEET POTATOES AND RELATED WILD SPECIES

Daniel F. Austin

S U M A R I O

Se hace un resumen de la taxonomía de Ipomoea sección Batatas , con la conclusión que la alianza se compone de doce especies con nombre, dos híbridos con nombre y un híbrido sin nombre. Se presenta una interpretación de evolución dentro de la sección mediante el uso de datos provenientes de morfología, ecología, citología, híbridos y análisis de conglomerados. Se discute diversidad genética en relación con datos sobre la fitogeografía de la sección. Se da una hipóthesis sobre el origen del camote con la conclusión que I. triloba e I. trifida son sus parientes vivientes mas cercanos. Se agrega como apéndice un nomenclátor de importantes binomios y de sus disposicciones actuales.

A B S T R A C T

The taxonomy of Ipomoea section Batatas is summarized with the conclusion that the alliance is composed of twelve named species, two named hybrids and one unnamed hybrid. An interpretation of evolution within the section is presented by using data from morphology, ecology, cytology, hybrids, and cluster analyses. Genetic diversity is discussed in relation to data on the phytogeography of the section. An hypothesis of the origin of the sweet potato is given with the conclusion that I. triloba and I. trifida are its closest extant relatives. A nomenclator of important binomials and their current disposition is appended.

I. I N T R O D U C T I O N

The sweet potato [Ipomoea batatas (L.) Lamarck] was one of the first root crops introduced into Europe after Columbus landed in the Caribbean islands (72). Today, the plant remains one of the three most important root crops in the world, following the potato (Solanum tuberosum) and manioc (Manihot esculenta). In spite of both of these important aspects, less research has been

done on sweet potato evolution than on the other two crops. The other two major root crops, for example, have had ongoing systematic studies for decades. The systematics of the sweet potato allies was not really examined until 1978 (5). Only recently have we learned enough about the genus Ipomoea to begin to have a realistic idea of what wild species are the closest allies of the sweet potato.

The following discussion is little more than a superficial examination of the data on several aspects of the sweet potato allies. For about a decade and a half I have been involved with this species alliance; the ideas presented are an outline of what I currently believe to be the best interpretation of available data. Areas where more research is needed are pointed out, and a limited number of references are presented to lead the reader into a tangle of literature.

II. TAXONOMY

Taxonomically, the species allied with sweet potatoes have been poorly known and understood. It was not until S.J. van Ooststroom (69) studied the Malasian species that an understanding of the section began. This study was followed by that of B. Verdcourt (79) on African plants, and more recently with the sectional revision by Austin (5, 10). It is now thought that most, or perhaps all, of the closely related species in Ipomoea section Batatas have been identified.

While there is an "aspect" to the plants related to the sweet potato that allows one to recognize a member of the group, it is not easily communicated in words. Indeed, after some months of study of this species alliance, an unknown and unrelated species may seem to belong. Species are difficult to distinguish morphologically because of the homologous variation of most traits. Several types of leaves, for example, as illustrated by Yen (83), may occur on individuals of most species.

One of the important characteristics for recognizing the section is rounded, glabrous seeds. Since many plants rarely have seeds when studied this is not always a practical trait. Sepal characteristics, on the other hand, are important and consistent criteria for identifying the various species (Fig. 1). These and other aspects of morphology and taxonomy have been discussed elsewhere (3, 5).

Based on studies in 1983-1984 it was found that the various allied species may be distinguished with the classical traits (5) and by a number of others. Analysis of the data reinforces the original conclusion for all except one of the names applied by Austin (5). That

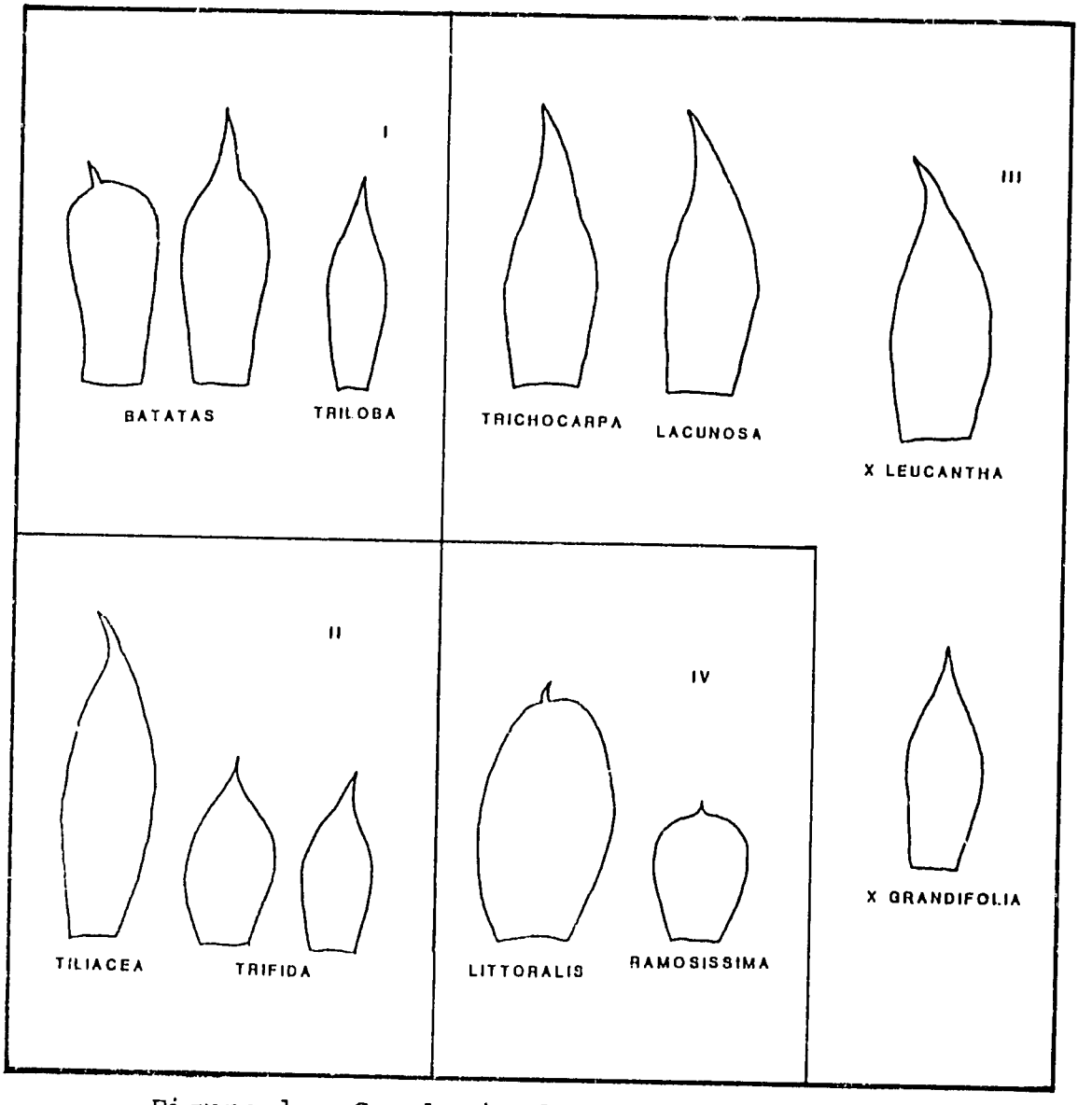

Figure 1. Sepals in four basic shape groups.
G R O U P I. Sepals oblong to obovate and caudate, including *I. batatas*, *I. peruviana*, *I. tenuissima*, *I. gracilis* and *I. triloba*.
G R O U P I I. Sepals ovate to elliptic and typically acuminate-mucronate but not caudate, including *I. tiliacea* and *I. trifida*.
G R O U P I I I. Sepals ovate and lanceolate, mucronate but not caudate, including *I. lacunosa*, *I. cordatotriloba*, *I.* X *leucantha* and *I.* X *grandifolia*.
G R O U P I V. Sepals oval, obtuse and mucronate, including *I. littoralis*, *I. cynanchifolia* and *I. ramosissima*. Sepals all drawn to same scale with a camera-lucida.

exception was the taxon called I. X leucantha, which may contain two races or may be of dual origin.

Ipomoea section Batatas contains both annual and perennial plants. Most of the species are perennial, although some live for barely two years. There is an annual herb in the southeastern U.S.A. (I. lacunosa), on the border of the range of the section, and another that came originally from the islands of the Caribbean. This Caribbean species (I. triloba) is now pantropical, at least partially because of being spread as a contaminant in rice (7). The sweet potato (I. batatas) is perennial and produces storage roots in most strains. Some plants grown from seed have only slightly thickened roots and bear no "potatoes." There are also supposed to be storage roots of another type in I. tiliacea. Most of the other species have root systems that are either incompletely known, or are only thickened without the "potato" storage structures.

Two species were originally North American (I. cordatotriloba, I. lacunosa); three were Caribbean (I. tenuisissima, I. tiliacea, I. triloba). Most of the other related species (5) are Central and South American in distribution (I. cynanchifolia, I. X grandifolia, I. peruviana, I. ramosissima and I. trifida).

Ipomoea littoralis is an Asian species, being found in the Pacific and Indian Ocean regions. Australia has three named taxa that are either allied with the Batatas complex or synonymous with some of the known members. These taxa are Ipomoea gracilis R. Brown (Prodr. 484. 1810) from Carpentaria Island off Queensland, I. costata F. Muell. ex Bentham (Fl. Austral. 4: 419. 1863-1878) and I. muelleri Bentham (Fl. Austral. 4: 423. 1863-1878). These and other members of the genus used by Aborigines have been discussed previously by Golson (20) and Yen (84). More recent study of I. gracilis suggests that it may actually be a synonym of I. batatas. The status of the other taxa remains unknown, and they will temporarily be excluded, pending future investigation.

In summary, there are twelve species, two named hybrids, and an unnamed hybrid in the section. The species are I. batatas, I. cordatotriloba, I. cynanchifolia, I. gracilis, I. lacunosa, I. littoralis, I. peruviana, I. ramosissima, I. tenuissima, I. trifida, I. tiliacea, and I. triloba. One of these, I. cordatotriloba, has three named varieties. The two named hybrids are I. X grandifolia and I. X leucantha. Sweet potato is hypothetically one of the parents in the unnamed hybrid, but the other parent is as yet undetermined.

III. E V O L U T I O N

Although important data are still lacking on several of the recognized species within section Batatas, it is possible to make evaluations of those for which data are available. For simplicity, these examinations will be placed in three categories.

A. Cytology : In spite of a series of excellent cytological studies made over the past two and one half decades (26, 34, 35, 58, 62, 70, 71, 77, 78, 80, 82, 83, inter alia) chromosome counts exist for only five species and two hybrids (3, 4). Seven species and one proposed hybrid (5) remain unexamined. Data presently available show that there are three ploidy levels within the section. The cultivated sweet potato is a hexaploid with 2n = 90, although there are plants morphologically most similar to I. batatas with 2n = 60 (4). These tetraploid plants have been masquerading in the literature under a variety of binomials (4, 10). To date the only verifiable species with 2n = 60 is I. tiliacea (35), and the other tetraploids reported under whatever name are all hybrids with I. batatas (4). As Jones (26) and Yen (82) have previously pointed out, some of the "I. trifida" called progenitors of sweet potato are feral I. batatas.

Three species are known to be diploids, I. cordatotriloba, I. lacunosa and I. triloba. North American hybrids of the last two species, which have been called I. X leucantha, are also diploid (5).

Since efforts to obtain seeds from the real I. trifida were unsuccessful, a study of stomatal lengths was undertaken to determine the feasibility for inference of ploidy levels. The following summarizes the findings of the research period of 1983-1984 in an annotated list comparing results of my study with those of past investigations.

1. Diploid plants may be distinguished from polyploids by measurements of stomatal length (15).

2. Tetraploid plants may be distinguished from hexaploids only with statistical analysis of stomatal length.

3. Ipomoea triloba is diploid (stomatal length). Verification by chromosome counts (21, 22, 27, 35).

4. Ipomoea tiliacea is tetraploid (stomatal length). Verification by chromosome counts (21, 22, 27, 35).

5. Ipomoea batatas is hexaploid (stomatal length). Verification by chromosome counts (21, 22, 27, 35).

6. Ipomoea ramosissima is diploid (stomatal length). Not verified by chromosome counts.

7. In terms of ploidy levels, Ipomoea trifida does not equal Ipomoea batatas (stomatal length). Verification of the interpretation published by Austin (5, 10).

8. Ipomoea trifida may have both diploid and tetraploid races (stomatal length). Not verified by chromosome counts.

9. Ipomoea batatas has both tetraploid and hexaploid races (stomatal length). Some of these are believed to be of hybrid origin, others may not be. Past studies have reported the tetraploids under a variety of binomials. (cf. 4, 10 for literature summaries).

10. An exception for the usual method of identifying taxa is the application of the name " Ipomoea X leucantha. " This was delimited to the intermediate hybrids between Ipomoea cordatotriloba and I. lacunosa by Austin (5). Stomatal data have shown that this was used for two ploidy levels, diploids and tetraploids. The diploids studied to date are thought to be derived from the hybrids indicated by Austin (5) and Abel & Austin (1). Those plants from the tropical regions of the world may belong to this taxon or may have been derived from another source. Current data indicate that perhaps the plants in the tropical zones resulted from hybrids, at least in part, between Ipomoea batatas and some other species.

B. Taximetrics : Numerical analysis of characters has been shown to be an indicator of similarities and distinctness with many organisms (cf. 17, 75, 81). Even though only ten populations were used in this analysis, such a study should provide useful information. Several of the traits may be determined only through study of living plants, and therefore it was not possible to include several of the populations.

Complex patterns are often revealed with the use of cluster analyses. Since the algorithms differ with the various types of analysis, different systems will give different results. Information from these methods may be used to construct different phenetic dendrograms. One method used for the dendrograms was the single-link type which joins units at their highest point of similarity (75). Using a completely unweighted method, where all traits were given equal value, one pattern emerged (Fig. 2A). By giving higher weight to sepal length and shape, a pair of characters classically shown to be of high predictive value in the genus Ipomoea , a slightly different dendrogram emerged (Fig. 2B). A UPGMA

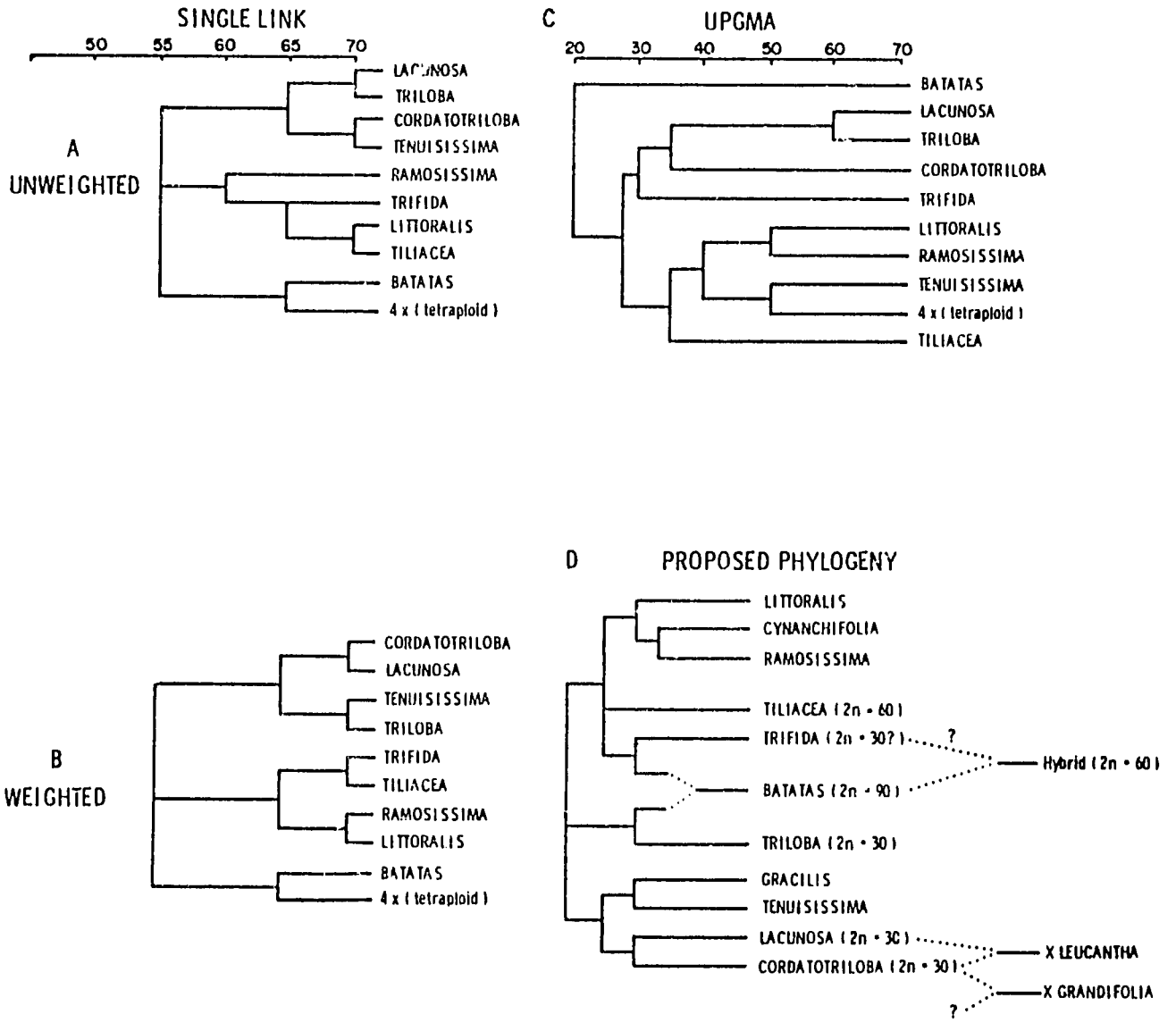

Figure 2. Cladograms generated by cluster analysis and a proposed phylogeny. Fig. 2A. Unweighted single-link analysis. Fig. 2B. Weighted single-link analysis, giving higher weight to sepal length and shape. Fig. 2C. UPGMA analysis. Fig. 2D. Proposed phylogeny. Units are in percent similarity.

(Unweighted Pair Group Method using arithmetic Averages) system written originally by E.E. Schilling (Department of Botany, University of Tennessee, Knoxville) was modified for use in the IBM by C.E. Nauman (Fairchild Tropical Garden, Miami, Florida). The results of this analysis showed another arrangement (Fig. 2C). It will be noted that the single-link diagrams are very similar, while the UPGMA system produced a different pattern.

Apart from some realignment of some of the satellite species, it should be noted that in the single-link dendrogram construction *I. batatas* and the "mystery" tetraploids of Wedderburn (80), Nishiyama (62) and Martin & Jones (58) fall out together. This was the original stimulus that made me suspect that this tetraploid was not a distinctive taxon. After study of the morphology of the plants and the papers that had been published on the cytology of the tetraploids, I concluded that it was a hybrid with the sweet potato (4). My conclusion that it is of hybrid origin does not detract from the value previously placed on the plants by all the others who have studied them; instead, the plants may be even more important than formerly thought.

As for the satellite species in these dendrograms, the weighted process probably more nearly reflects the actual relationships. For example, the weighted dendrogram placed *I. cordatotriloba* with *I. lacunosa*, while the unweighted dendrogram separates these two species. Studies by Jones & Deonier (34) and Able & Austin (1) have shown that these two species not only may be crossed artificially, but they have been undergoing natural introgressive hybridization. Crosses with either of these species with *I. triloba*, the taxon with which *I. lacunosa* is paired in the unweighted dendrogram, are either totally unsuccessful or extremely difficult. This difficulty with crossing *I. triloba* and *I. lacunosa* suggests to me that they are more distantly related than are *I. lacunosa* and *I. cordatotriloba*. Crosses with other taxa involved have not all been made, but the data lead me to conclude that the weighted dendrogram is a better representation of genetic similarity. Further crosses are needed to test this interpretation.

The UPGMA arrangement was somewhat unexpected after the results of the single-link type. Analysis by UPGMA does show that *I. tenuissima*, *I. littoralis*, *I. ramosissima*, and the unnamed tetraploid belong to the same major clade as the known tetraploid *I. tiliacea*. Also, the known diploids *I. lacunosa*, *I. triloba*, and *I. cordatotriloba* are linked with the probable diploid *I. trifida*. Perhaps the most important result with this technique is that the sweet potato is linked more closely

with the I. triloba / I. trifida complex than it is with I. tiliacea or any other species.

This last analysis does not support the hypothesis that the unnamed tetraploid is a hybrid between I. batatas and some unknown diploid; however, it does not negate that possibility. The UPGMA analysis does, however, suggest the hypothesis that I. triloba and I. trifida are closely allied with I. batatas. These data indicate that these two species should be investigated much more thoroughly to determine their possible role in the origin of the sweet potato.

C. Hybrids : Sweet potato is the best known hybrid in the section Batatas. This hexaploid has been examined by a number of people, including Nishiyama (62), Martin & Jones (58) and Yen (83), and it has been agreed that the species arose through alloploidy. Nishiyama (62) has given a good discussion of two methods how this alloploid may have originated and the cytological studies by others (21-36, 44, 59) substantiate the hypotheses presented by Nishiyama. One of the difficulties in this theory is that the lines most closely related to sweet potato had not been identified, Nishiyama's claims to the contrary not withstanding. Nishiyama (62) has been proposing I. trifida as a species very closely allied to the sweet potato for over two decades. In spite of the fact that he misidentified his material (5, 10, 26, 83), he did choose the specific name of a plant that was probably directly involved with the sweet potato. The nomenclatural and identification complications have been discussed elsewhere (5, 10), and no details will be given here. Let it be sufficient to say that I. trifida , in its original sense (cf. 6-9), is a prime candidate as a close relative of the sweet potato.

Morphology and cluster analyses lead me to believe that the second prime candidate for a genome involved in the sweet potato is I. triloba. Even though this species is an autogamous annual that never produces enlarged roots, its sepal shape and pubescence suggest to me that it is the best possibility of taxa now existing. Note that I. triloba is Caribbean, and that I. trifida is Circum-Caribbean. More study of these species as potential donors of genes to the sweet potato needs to be done.

For many years it was stated that I. tiliacea was very closely allied with sweet potatoes. While I cannot deny that this may be true, most past workers thought the two species were related only because they could not tell them apart. Ipomoea tiliacea is said to produce storage roots, and even though they seem to be of a

different type from those in sweet potato, the species may have been involved with the origin of the cultivated species. Jones & Kobayashi (35) made the I. tiliacea and I. triloba cross, but they did not carry the triploid on to the hexaploid stage. If they had done this and attempted crosses with the sweet potato more positive statements might be made about the role of both in the production of the hexaploid. This combination of genomes needs further study.

Over the past few decades there have been several papers dealing with tetraploids in the section. Of the four or more names used for the plants, only I. tiliacea is clearly and verifiably a tetraploid species. This does not deny that there are other tetraploid plants in the neotropical zones. In fact, reports by Wedderburn (80), Jones (29), Nishiyama (62), Martin & Jones (58) and Yen (83) all recorded plants that are undoubtedly tetraploid. These tetraploids that have received so much study are thought to be hybrids with I. batatas (4, 6, 10). The other parent remains uncertain.

Studies by Jones & Kobayashi (35) and Abel & Austin (1) have established that certain plants are hybrids between I. lacunosa and I. cordatotriloba. There has certainly been a long period of introgression between these two diploids, and the array of morphological traits almost spans the gap between the parental species. We have duplicated the cross experimentally and made backcrosses (1). There are comparatively few barriers between the hybrids and the parents. Although we have not been able to document the situation to our satisfaction, we suspect that the introduced Old World honey bee (Apis mellifera) is responsible for the original crossing and subsequent backcrossing between these plants in the wild.

It has been hypothesized (5) that a South American taxon (I. X grandifolia) is of hybrid origin. This conclusion was based on the morphological similarity of these plants to I. cordatotriloba , which grows near them in South America (3). Little is yet known of this proposed hybrid except the data that may be obtained from herbarium materials and floristic literature. The other parent may be I. batatas , but more study is required.

IV. GENETIC DIVERSITY

Breeding programs for sweet potatoes have existed in user countries for decades, yet the original material, and the current genomes of these breeding programs is incredibly limited. A major center in the southeastern U.S.A. until recently maintained between 50 and 60 lines of sweet potato; in contrast, Douglas E. Yen collected 30

types in a single garden in northwestern Peru in the late 1950's (P. Duke & D.E. Yen, personal communication). Data are available suggesting that "wild" genes are continually being introduced into the sweet potato in Central and South America (4), so that the potential of the crop has barely been sampled. Moreover, Yen (83) has shown that the sweet potato germ plasm outside the Americas is little more than a sample of the American variability. These facts have not been fully appreciated even though they have been known for over a decade.

The data now available indicate that the highest diversity of sweet potato germ plasm is in northwestern South America and parts of Central America. These are the same geographic regions where *I. trifida* is also abundant. Two of the other species that may be close relatives (*I. triloba* , *I. tiliacea*) are mostly the Caribbean islands, but are often found in the Circum-Caribbean region as well.

As reported before (10), the countries of Guatemala, Colombia, Ecuador and Peru have great diversity in sweet potato germ plasm. Since 1983 it has been possible to examine about 3,000 museum specimens; most of these are cited in the tables (Tables 1-8). Numerous living specimens have also been studied. The formerly reported trends continue in this larger data set. While museum specimens are not usually considered the best samples of cultivated plants, they may give us the best suggestion available to date of the high diversity of this crop and the species with which it is allied.

TABLE 1. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN SWEET POTATO VARIBILITY.

COUNTRY	NO. VARS	COUNTRY	NO. VARS.
Bahamas	7	Panama	67
Cuba	12	Colombia	115
Hispaniola	36	Venezuela	32
Jamaica	6	Ecuador	104
Puerto Rico & Virgin I.	7	Peru	172
Mexico	78	Brazil	81
Guatemala	160	Guianas	24
Nicaragua	42	Total	943

TABLE 2. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA TRIFIDA* VARIBILITY.

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
Bahamas	0	Panama	52
Cuba	20	Colombia	38
Hispaniola	0	Venezuela	95
Jamaica	0	Ecuador	0
Puerto Rico & Virgin I.	0	Peru	0
Mexico	44	Brazil	0
Guatemala	50	Guianas	0
Nicaragua	81	Total	380

TABLE 3. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA LACUNOSA* VARIBILITY.

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
United States	307		
Bahamas	0	Panama	0
Cuba	0	Colombia	1
Hispaniola	0	Venezuela	0
Jamaica	3	Ecuador	0
Puerto Rico & Virgin I.	0	Peru	0
Mexico	0	Brazil	0
Guatemala	0	Guianas	0
Nicaragua	0	Total	311

TABLE 4. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA CORDATOTRILOBA* VARIBILITY (including *I. X leucantha*).

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
United States	233		
Bahamas	0	Panama	0
Cuba	0	Colombia	1
Hispaniola	0	Venezuela	1
Jamaica	1	Ecuador	0
Puerto Rico & Virgin I.	0	Peru	0
Mexico	45	Brazil	0
Guatemala	2	Guianas	0
Nicaragua	7	Total	290

TABLE 5. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA TILIACEA* VARIBILITY.

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
Bahamas	3	Panama	52
Cuba	28	Colombia	3
Hispaniola	13	Venezuela	15
Jamaica	37	Ecuador	0
Puerto Rico & Virgin I.	17	Peru	0
Mexico	8	Brazil	5
Guatemala	5	Guianas	23
Nicaragua	2	Total	211

TABLE 6. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA TRILOBA* VARIBILITY.

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
Bahamas	22	Panama	0
Cuba	30	Colombia	6
Hispaniola	1	Venezuela	0
Jamaica	23	Ecuador	2
Puerto Rico & Virgin I.	21	Peru	0
Mexico	18	Brazil	0
Guatemala	0	Guianas	0
Nicaragua	0	Total	123

TABLE 7. SELECTED LIST OF COUNTRIES IN THE AMERICAS SHOWING TRENDS IN *IPOMOEA RAMOSISSIMA* VARIBILITY.

COUNTRY	NO. VARS.	COUNTRY	NO. VARS.
Bahamas	0	Panama	1
Cuba	0	Colombia	0
Hispaniola	0	Venezuela	0
Jamaica	0	Ecuador	3
Puerto Rico & Virgin I.	0	Peru	14
Mexico	1	Brazil	6
Guatemala	1	Guianas	0
Nicaragua	7	Total	33

TABLE 8. OTHER SPECIES IN THE *IPOMOEA* section *BATATAS*

I. *tenuisissima*	- Florida = 3
I. *cynanchifolia*	- Brazil = 8
I. X *grandifolia*	- Brazil = 8; Paraguay = 5; Argentina = 3
I. *gracilis*	- Australia = 1
I. *littoralis*	- Asia = 36

Grand Total = 2355

For their size, Ecuador and most of the Central American countries have greater diversity than might be expected from larger countries nearby. This may in part be explained by somewhat biased collecting patterns, but that hardly seems sufficient to account for all the differences. The possibility of the high diversity level being associated with abandonment of cultigens should be examined.

It has not been pointed out before that there are about three specimens of sweet potato for any one of the wild species. This marked abundance of the sweet potato, mostly representing plants outside cultivation, belies the literature statements that say the species does not occur in the wild. These data and my own experience indicate that the sweet potato is indeed abundant in some areas in the wild. Many of the plants in the wild represent discarded cultigen fragments that have established new colonies, but many are also plants grown from seed.

A complete analysis of genetic diversity also requires examination of the phytogeography of the taxa involved and some hypothesis concerning the origins of the sweet potato from proposed ancestral species. Distributions of the allied species already have been given so the following will concentrate on the sweet potato.

A. Phytogeography : It is convenient to separate the distribution of the sweet potato into Pre-Columbian and Post-Columbian categories. While such separation is somewhat artificial and there is some overlap, it serves to stress certain pertinent aspects.

1. Pre-Columbian : Before a discussion of the distribution of the plants is given it may be illuminating to map the principal Pre-Columbian cultures of the neotropics. Essentially, these people fall within eight major linguistic groupings (Fig. 3). Chronological

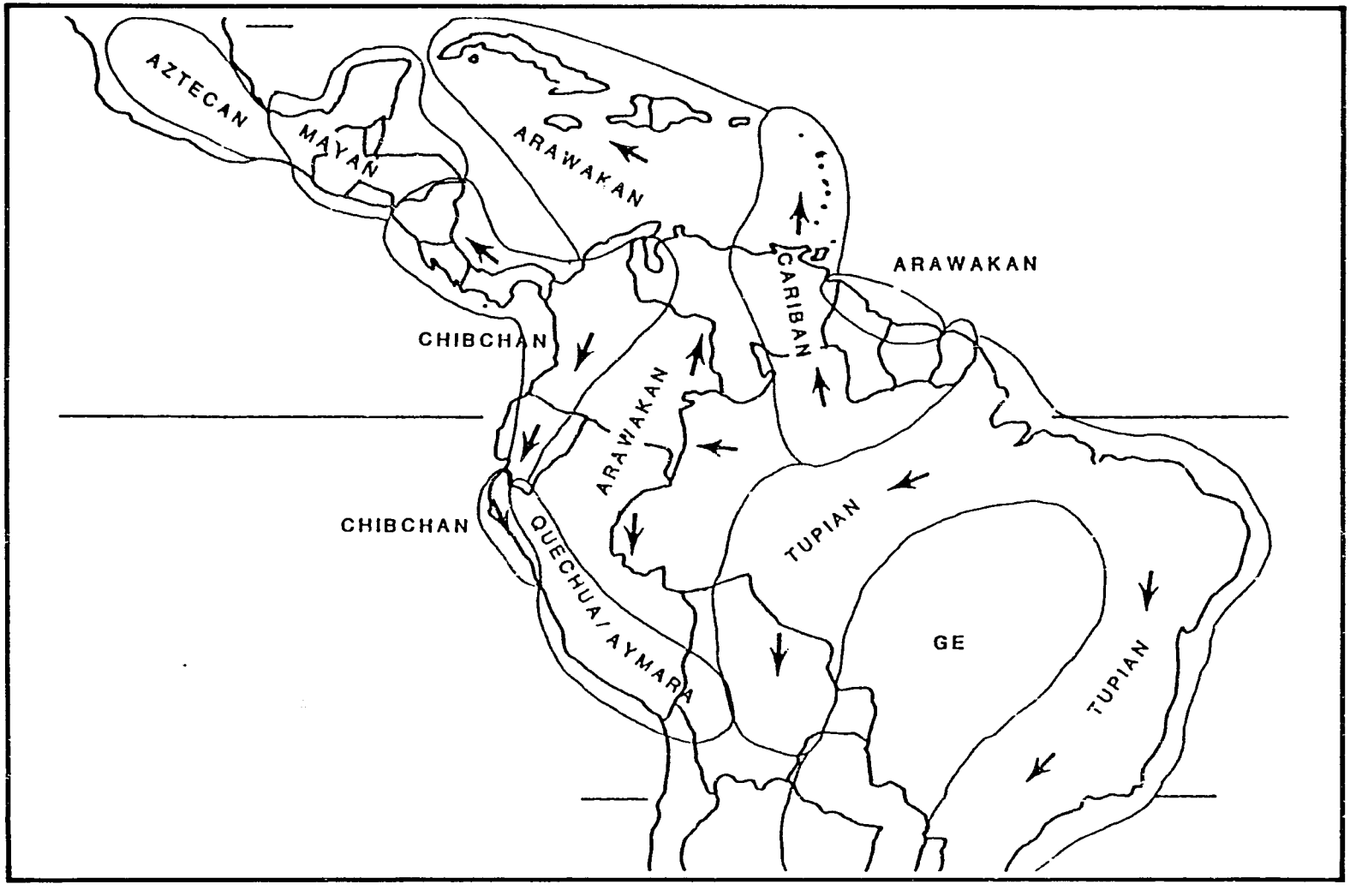

Figure 3. Major linguistic / cultural Indian groups in neotropical zones at the time of European intrusion. Adapted and modified from Steward & Faron (1959) and Lathrop (1970).

sequences are incomplete for these various people, but the latest studies suggest that Chibchan and/or Arawakan are perhaps the oldest. Each of the other cultural/linguistic empires reached their peaks at different times, but at least the Aztecs of Mexico and Incas of Peru/Ecuador were near their peaks at the time of European intrusion. Also, each of these major groupings of people achieved differing levels of sophistication within their civilizations.

Brand (12) has indicated that the sweet potato had reached the limits of the tropics at the time of European contact. Furthermore, O'Brien (68) has summarized the data on linguistic and historical evidence to show that the cultivated root crop had reached southern Peru and southern Mexico by about 2000 to 2500 B.C. This early range was extended little by the time of European contact.

However questionable these dates might be, having been derived from different data bases, one important point has been overlooked by Brand (12), O'Brien (68), and others who have placed the origin of the sweet potato in a 2000 to 2500 B.C. time stratum. A complex species cultivated by a variety of people of totally different historical and ethnic backgrounds does not arise fully formed at the extremes of its range at a single time point. We may certainly double the origin, evolution, and selection of various strains of sweet potatoes chronologically and state with some certainty that by 2000 to 2500 B.C. Ipomoea batatas had been in existence for at least an equivalent amount of time. The discovery of sweet potatoes in a 10,000 to 8,000 B.P. level in Peru supports this conclusion (19, 83). I agree with Yen (83) that the sweet potato may be among the world's earliest domesticates.

Even though our linguistic data are derived from historical sources, many reflect at least some Pre-Columbian events. When the words are involved with Post-Columbian transfer, this is often evident. There exist only two name lists that may be considered reasonably complete, those published by Nordenskiold (67) and Yen (83). By comparing the many names for sweet potato from these lists, and those few from other sources not contained in these papers, two main patterns may be discerned (Fig. 4, 5). Clearly the patterns shown here are oversimplified, but hopefully not to the point of being misleading as were those presented by Brand (12).

One major line follows the "batata" branch of names. While I make no claims to being a linguist, the patterns seem to be real, and those few words that have been studied by etymologists (14, 68) support the present interpretation. In essence, all that has been done in Figs. 4 and 5 is to place the names of Ipomoea batatas in several languages on or near the geographic regions

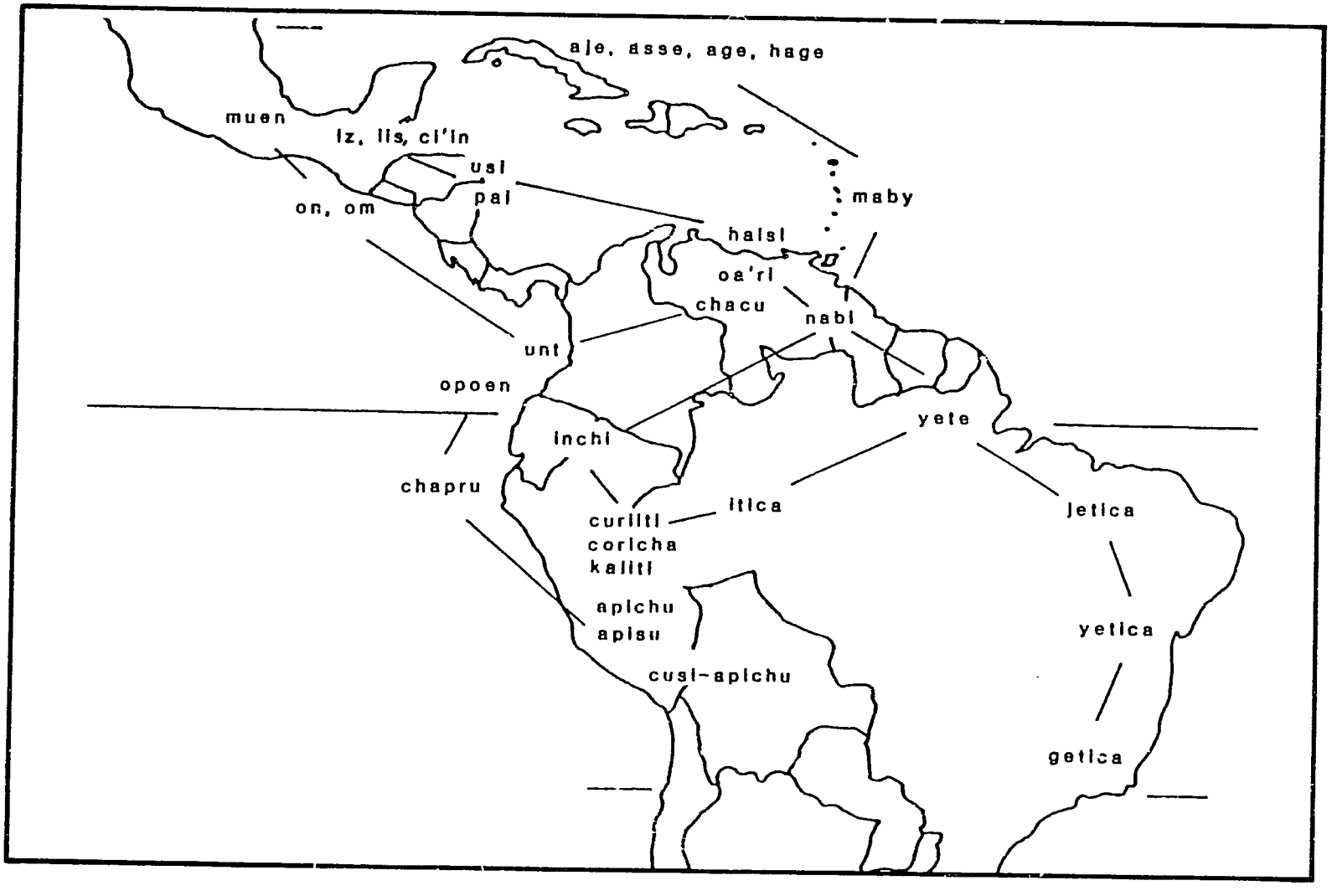

Figure 4. Probable linguistic relationships between some of the Indian names for sweet potato related to the name "aji" or "age" of early literature. "Aji" first appeared in Columbus's log on 21 December 1492 regarding the plants of Haiti.

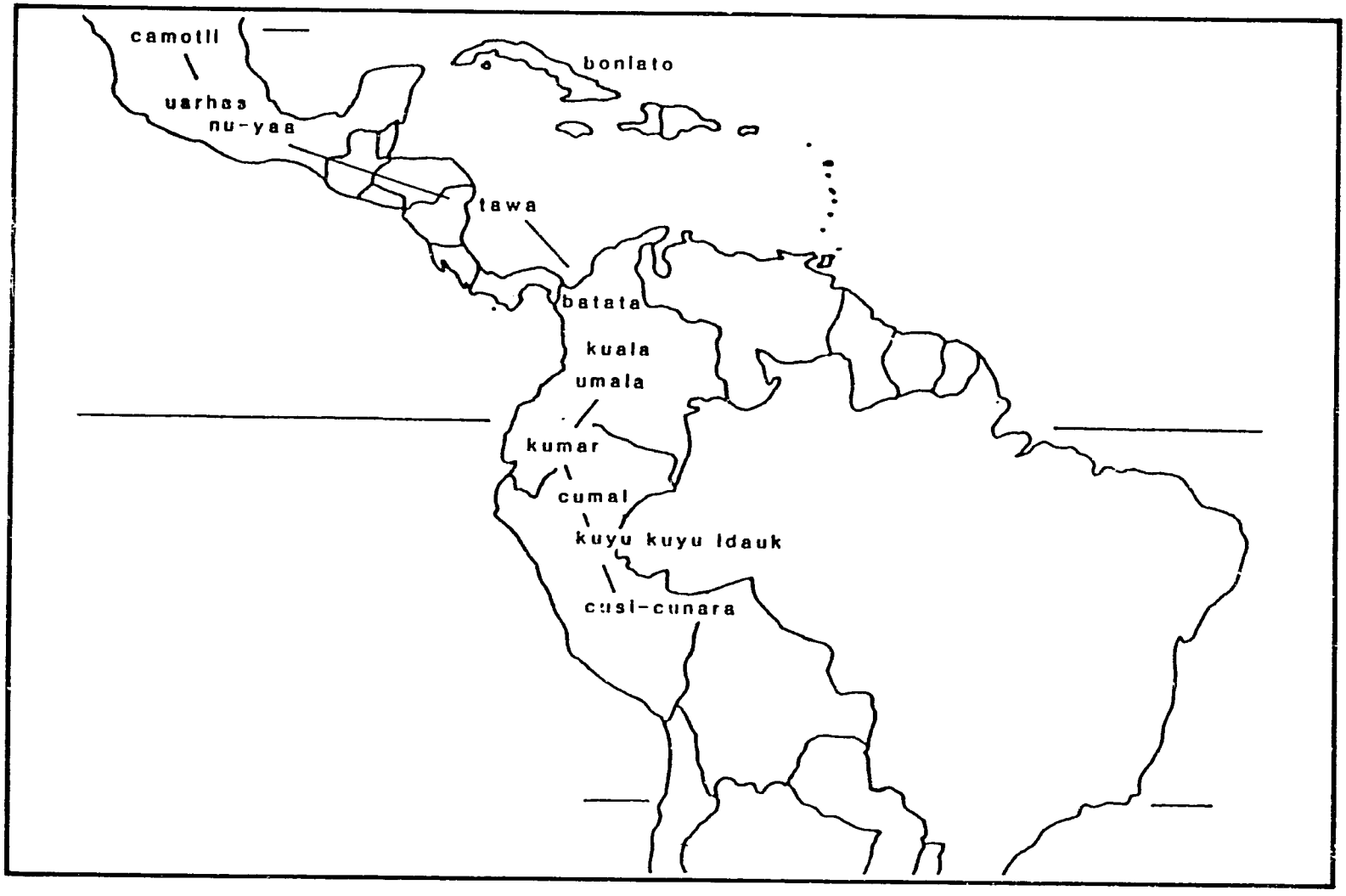

Figure 5. Probable linguistic relationships between some of the Indian names for sweet potato related to the name "batata" of early literature. "Batatas" first appeared in print in 1516 with a publication by Peter Maytyr; the word was from Darien, Panama and not the West Indies.

where they were or are used. When this simple mapping of words is completed it becomes apparent that many are similar, and perhaps represent cognates.

It is my belief that both "camotli" of the Nahuatl and "kumar" of lowland Quechua and Chibchan belong to this line of names. Although O'Brien (68) has argued for a movement of "kumara" from the Polynesian languages, where it exists and would mean something like "soft and sweet" (D.E. Yen, personal communication), her argument is less than convincing. An argument more difficult to dismiss was first presented in the 1960's by Benedict and later reprinted in his book on the Austro-Thai language (11). If contact did indeed occur between the Polynesians and neotropical Indians, it must have been early for such wide dispersal and linguistic changes to have occurred in the Americas by the 1500's.

The second major line may prove to be two lines. Certainly one branch is based on the Arawakan "age" or "hage" and it relatives (Fig. 4). This word is linguistically related to "maby" and "naby" of Cariban (14, 76) and to other terms in Arawakan, Tupi-Guarini and other languages. From the data available, each of these means about the same when literally translated and may be simply "root." Each also implies a useful or edible root as well.

How each of these terms are related, if indeed they are, to the eastern Pacific terms such as "chapru," "opoen," "unt," and "om" is not clear. Perhaps the terminal portion of "chapru" shows some alliance with "apichu" of Quechua. If this proves to be the case, then all are simply a different branch of the same line because "apichu" is related to "sapi" of Cochabamba Quechua (43), a point which Brand (12) overlooked or ignored. Study must be made by someone trained in linguistics to show further relationships, or lack thereof, between these terms.

In summary, the mapping of some of the most prevalent names for sweet potato follows what is currently held to be the migration routes of people in the New World before Columbus arrived. There are two basic lines of names for the sweet potato, one for which we may conveniently use "batata" as a reference point, and another for which "age" or "aje" may serve as a basis of discussion. Early documents from the first 20 to 30 years after Columbus (14, 72) show that there were two "types" of sweet potato during the period, each having several variations or lines. One of these "types" was starchy, having little of the sweet taste, and was the "age" through part or all of its range. The other was also starchy, but markedly sweet in taste: this was the "batata" group in at least Central America and Colombia and perhaps elsewhere as well.

2. Post-Columbian : Columbus took the first sweet potatoes back to Europe with the name "aje." These were starchy plants common throughout the West Indies and had little of the sweet flavor, being compared on several occasions to carrots (72). Subsequent Spanish voyages to mainland Central and South America resulted in a sweeter type of potato called "batata." Although the south Europeans liked the "ajes" they liked the "batatas" even more, and the West Indian Arawak name was soon lost (14). "Batata" and its variant "patata" quickly became the dominant words for these plants throughout much of Europe. With continued exploration, the Spanish soon introduced the Nahuatl "camotl" or "camotli" and changed it to the Hispanized form "camote." Shortly afterward, "apichu" was added to the list in Europe and the situation was incredibly confused by the introduction of the Peruvian potato (Solanum tuberosum). Perhaps not surprisingly, the Quechua word for the Solanum (that was later to become known as the "irish potato" of the U.S.A.) was not adopted. The common Quechua potato name "papa" already existed with a different meaning in several European languages. Some people began to distinguish between the two very different root crops as "potatoes" (derived from "batata") (Solanum tuberosum) and "Spanish potatoes" (Ipomoea batatas). Since the Solanum potato was more adapted to the temperate climates, it became almost a monoculture in northern Europe. The sweet potato, more of a tropical crop, remained dominant in southern Europe for some time (Fig 6).

Sweet potatoes were introduced into Africa in at least two places during the 1500's, and the name was also carried to southeastern Brazil in that time period. In Brazil the plant is now called either "batata" or "batata doce" by the people speaking Portuguese. Following the conquest of the Aztecs in Mexico, the Spanish carried the Hispanized Nahuatl name "camote" to a number of places.

There is no record of the sweet potato in the U.S.A. prior to about 1648 in Virginia (68). It seems likely that the food had been introduced several years, perhaps decades, prior to 1648. By the early 1700's the plants were introduced into the New England region of the U.S.A. Among the Indian languages of the southern U.S.A. the plants came to be called "aha" or "ahe." Whether this appelation reflects early transport by the Spanish from Hispaniola in the 1500's or some other source remains unknown. It is known that among some of the people in the southwestern U.S.A. "aha" or "ahe" is an old word referring to several types of tuberous roots. More study of the linguistics of these regions and languages may clarify the history of the sweet potato introduction.

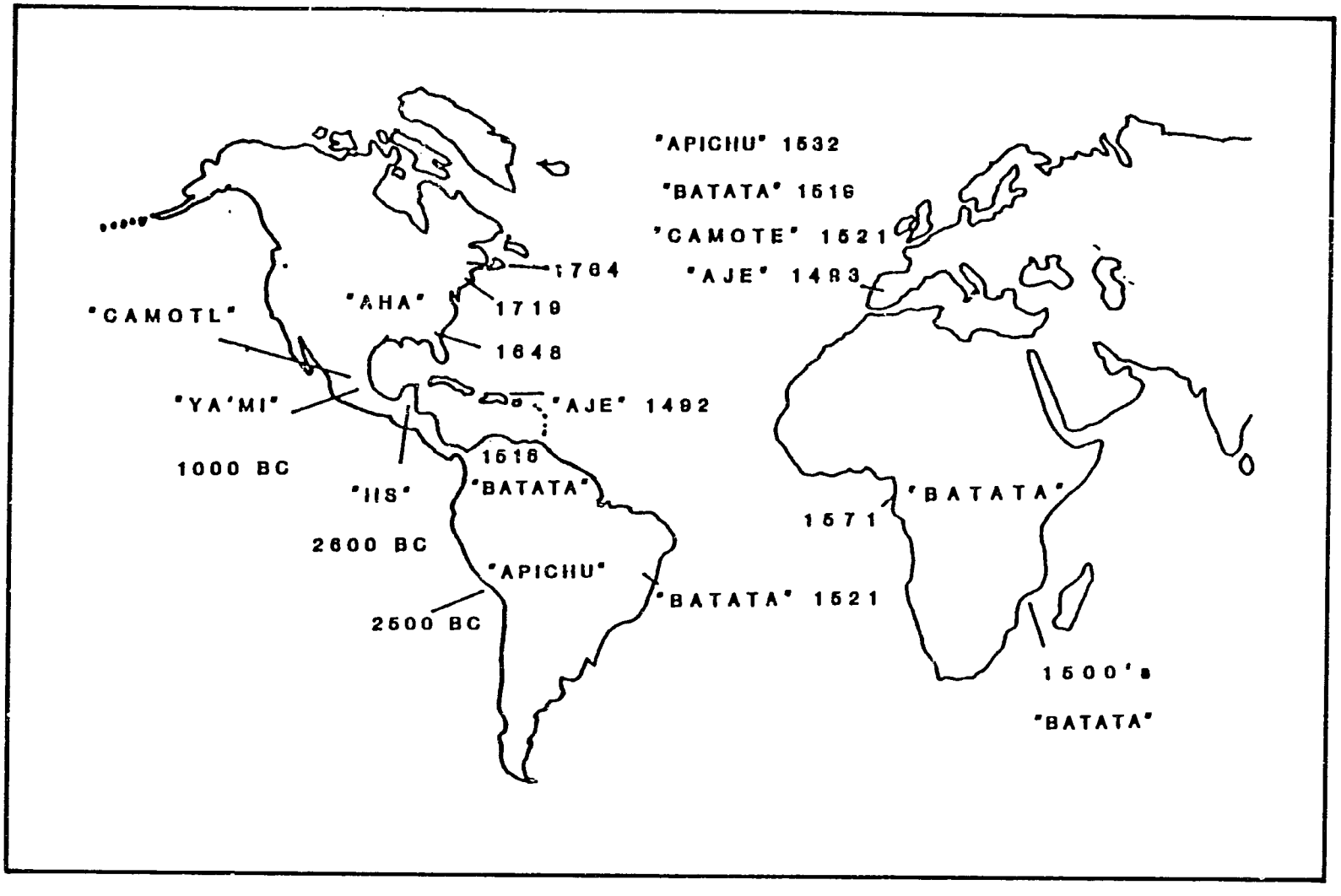

Figure 6. Atlantic Ocean disperal of the sweet potato within historic and near-historic times. Earliest transport was by the Spanish and Portuguese.

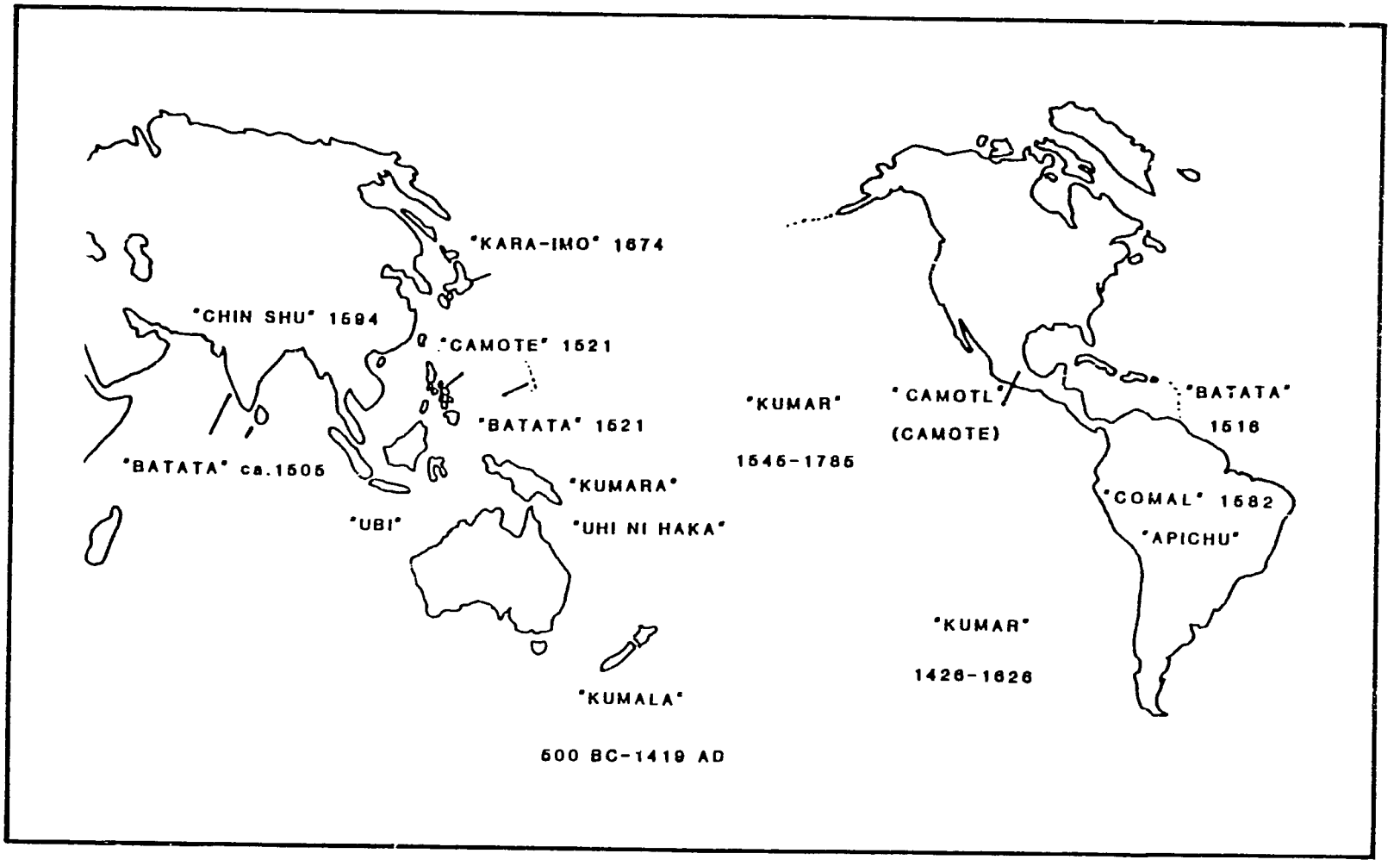

Figure 7. Pacific Ocean dispersal of the sweet potato within historic and near-historic times. Typically the Spanish carried the name "camote" while the Portuguese transported "batata." The crop was in Polynesia, with the name "kumara" in pre-European times.

A similar, but variant, pattern appears in the Pacific (Fig 8). Most notable and most widely publicized and debated among the names is "kumara" and its many variants. Recently Yen (83) has given a detailed analysis and concluded that the sweet potato, if not the name "kumara," was spread to the three points of Polynesia (Easter Island, Hawaiian Islands, New Zealand) when they were discovered by Europeans. There was a long, complex sweet potato history in Hawaii already when the islands were found by Cook in 1778; sweet potato was a basis of the diet in Easter Island already when Rogeween arrived there in 1722. Maoris in New Zealand used the plant extensively in pre-European times, and there is fossil-dating evidence that it arrived there between 500 B.C. and 1419 A.D. (83). Throughout the rest of Asia and Malaysia, the sweet potato is more clearly linked with historic transport.

B. Hypothesis of Origin : Current data suggest that the two species most closely allied with sweet potato are *Ipomoea triloba* and *I. trifida*. Until Post-Columbian times *I. triloba* was mostly an Antillean species although it probably reached the mainland near Yucatan and Trinidad. Conversely, *I. trifida* was a Circum-Caribbean species confined to the mainland. We are unable to document importation of *I. trifida* into Cuba within historic times, but that is probably what happened. The extremes of overlap between these two taxa would be the Yucatan peninsula of Mexico and the mouth of the Orinoco River in Venezuela. It is well documented that people travelled from mainland Venezuela northward into the Lesser Antilles. Perhaps they returned and brought with them *I. triloba* where the cross with *I. trifida* was possible. Although less well documented, there is some indication that people of Yucatan may have visited and traded with Cuba and Jamaica. This is also a feasible route of transportation of one species or the other. Furthermore, translocation of one of the hypothetical parental species from any part of the Caribbean to the mainland may not be excluded. Data are simply lacking.

In the event that *I. triloba* and *I. trifida* are derived from the same lines as the sweet potato, I hypothesized (6) that the ancestors came together in some area unknown, but probably between Yucatan and the mouth of the Orinoco River. Once genetic data are available on both these species, we may be able to support or reject this hypothesis (Fig. 8).

There were two major cultures in the region delimited above during about the correct hypothesized time period. One of these, the proto-Mayans and Mayas of

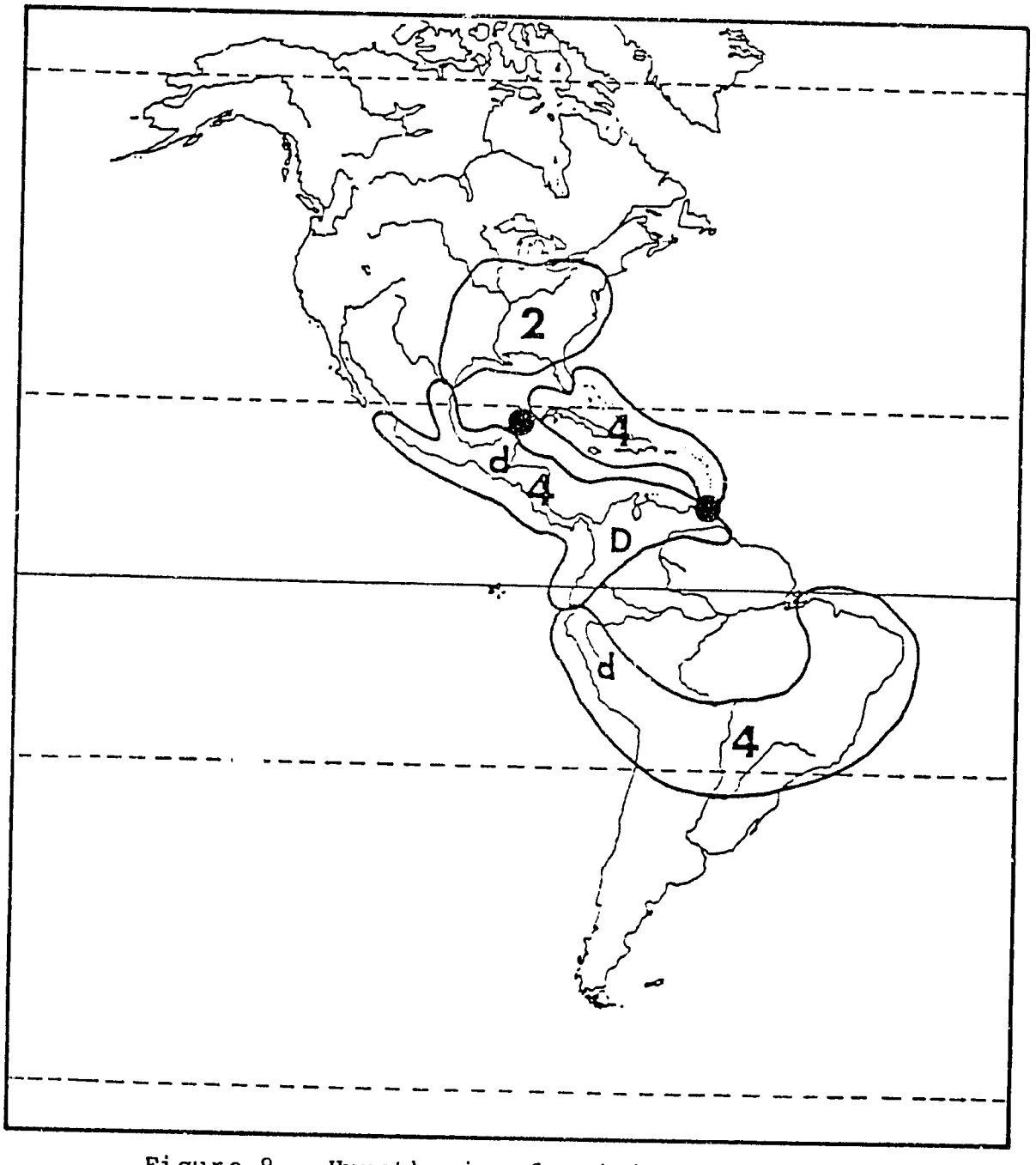

Figure 8. Hypothesis of origin of the sweet potato in the neotropics. Areas outlined contain the current number of allied species known for the sweet potato. The black dots indicate the limits of probable contact between the two hypothesized parental stocks from which the sweet may have arisen, thus the crop perhaps originated between these two points. Capital "D" indicates the geographic region of current greatest diversity of sweet potato variability; lower case "d" shows the two areas of next greatest diversity.

Central America may have brought the crop into domestication, but I doubt that they did. My doubt is based on the relatively late peak of the Mayan culture which was, according to the dates available, too late to have had sufficient time for the dispersal of a sophisticated crop (13). Falling into the correct period, as nearly as we are able to say from existing chronologies, were the proto-Chibchan, Chibchan and Chibchan-influenced people of Colombia and vicinity (2, 85). Little seems to be known about these people, but there are sufficient data currently available to place their rise and peak before the Mayas.

It is my hypothesis that proto-Chibchan, Chibchan, or Chibchan-influenced people discovered the sweet potato and brought it into cultivation. By at least 2500 B.C. the cultigen had been spread to almost the limits in Central and South America that existed at the time when Europeans arrived. Certainly the Mayan and Incan people and their neighbors took the crop and produced new strains better adapted to local conditions. Even at present, the major variability in the species occurs in Guatemala, Colombia, Ecuador and Peru. These geographic regions were those occupied in Pre-Columbian times by the most adept agriculturists. Data from all of these approaches have led to a concept of phylogeny within the section (Fig. 2D).

V. NOMENCLATOR

Over the past two decades there has been increased attention given to the sweet potato, its origin, and the species with which the crop might be allied. Numerous papers have been written on cytological and other aspects of the species thought possibly related to *Ipomoea batatas*, many of which suffered from an inadequate taxonomic understanding. In recent years several papers have been presented which should have helped to focus the attention being given potentially close relatives of the sweet potato (1, 3-10, 69). The concepts presented in these studies have not been used or accepted by all parties interested in the origin of this crop plant. At least in part, this reluctance to concur with the systematics presented has been brought about by the close morphological and apparently genetic relationships between the taxa. Even if one is familiar with the various species involved, it is often difficult to determine accurately the identify of a given sample. Unless the samples are flowering or fruiting, the identification must be considered suspect no matter who has offered the name.

As an attempt to rectify and help clarify the apparently critical taxa associated with the sweet potato, the following nomenclator is offered.

IPOMOEA BATATAS (Linnaeus) Lamarck -- The sweet potato, originally from the neotropics, now cultivated world-wide (46-57).

IPOMOEA CORDATOTRILOBA Dennstedt (16) -- Synonym and correct binomial for I. trichocarpa, q.v.

IPOMOEA CYNANCHIFOLIA Meisner in Martius -- A species similar to I. ramosissima in morphological traits, but confined to southern South America.

IPOMOEA GRACILIS R. Brown -- This poorly known Australian form has been confused with a variety of other plants, mostly tetraploids best called Ipomoea batatas (4). Unfortunately, Yen (84) did not discuss this binomial when he discussed some of the known "tuber" producing Ipomoea in Australia. Little is known of the systematic relationships of most of the Ipomoea utilized by natives in Australia.

IPOMOEA X GRANDIFOLIA (Dammer) O'Donell -- Hypothetically a hybrid of natural origin, with the parents possibly being I. batatas and I. cordatotriloba. If this hypothesis is correct, the taxon may have originated within the post-Columbian period.

IPOMOEA LACUNOSA Linnaeus -- Native to the southeastern United States where it hybridizes with I. cordatotriloba producing I. X leucantha.

IPOMOEA LACUNOCILIS Nishiyama (62) -- An illegal nomen nudum referring to a hybrid between I. lacunosa X I. cordatotriloba X I. tiliacea.

IPOMOEA X LEUCANTHA Jacquin -- While Austin (5) has delimited this as the intermediate form of a hybrid between Ipomoea cordatotriloba and I. lacunosa, Kobayashi et al. (37-42) persist in applying the name incorrectly. The plants called this name by Nishiyama appear to truly be hybrids, but not apparently from crosses of these two parents. More recent studies by Austin & Posin (unpublished) indicate that the the tropical samples formerly call by this name may at least partly hybrids of I. batatas.

IPOMOEA LITTOCANTHA Nishiyama (62) -- An illegal nomen nudum referring to a hybrid between I. batatas -hybrid X I. lacunosa X I. cordatotriloba.

IPOMOEA LITTORALIS Blume -- Normally this species is confined to the Indian and Pacific Ocean regions. Occasionally plants are found in eastern Mexico that may belong to this species; whether they are native in Mexico or introduced is unknown. Many of the plants called I. gracilis (cf. 29) were at one time thought to be this species. Now it is believed that they are the product of hybridization between I. batatas and some diploid (4).

IPOMOEA PERUVIANA O'Donell -- This species was known from only two places in Peru until recently. Now several new collections exist for the species in Ecuador. It was hypothesized earlier (10) that this was no more than a large strain of sweet potato. The new collections make this idea seem less likely.

IPOMOEA RAMONII Choisy -- A synonym of *I. triloba*, q.v.

IPOMOEA RAMOSISSIMA Choisy -- Native to Meso-America and South America.

IPOMOEA TENUISSIMA Choisy in DC. -- A narrow endemic to part of the Caribbean region, having been found in Cuba, Hispaniola, Puerto Rico and Florida. The type was collected in Hispaniola and plants are still extant in Florida. No recent specimens have been seen from Puerto Rico and the record is dubious. This species is more closely allied with *I. batatas* than previously suspected and deserves substantially more research to determine its potential in introducing new genes into the sweet potato.

IPOMOEA TRICHOCARPA Elliott (18) -- Properly called *Ipomoea cordatotriloba* Dennstedt (16) by Manitz (45).

IPOMOEA TILIACEA (Willdenow) Choisy -- As currently delimited this is a tetraploid species that is most common in the West Indies; some plants have been introduced into Asia. A problem remains with the disposition of the name and the others that have been considered synonyms. Some of the binomials that have been considered synonyms are clearly *I. batatas*. Since the type of *I. tiliacea* was supposedly collected in eastern Brazil, it too has come under suspicion. The species is not represented in recent collections from that part of Brazil, and either has been misidentified or was collected elsewhere. The microfiche of the type is not enough to determine the identity of the specimen.

IPOMOEA TRIFIDA (Humboldt, Bonpland & Kunth) G. Don -- As I have applied this name, it is completely consistent with Humboldt, Bonpland and Kunth. Ooststroom (69) applied it similarly. Few other people have used this application and several species may be found by examination of the specimens called *I. trifida*. Nishiyama et al. (60-66) have consistently misapplied the name. Their application is both legally and nomenclatorially incorrect.

IPOMOEA TRILOBA Linnaeus -- This annual was formerly endemic to the Caribbean, but is now spread around the world as a weed. It is perhaps one of the closest allies of the sweet potato.

VI. ACKNOWLEDGMENTS

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My wife Sandra helped with various field and laboratory projects during the study. Freda Posin and Penelope N. Honychurch were graduate assistants during the 1983-1984 study.

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GENOMIC STRUCTURE AND THE GENE FLOW IN SWEET POTATO AND RELATED SPECIES

Itaru Shiotani

This presentation consists of three points. The first point is that the cytogenetical study provides evidence of autoploidy of sweet potato and the wild polyploids in the *Ipomoea trifida* complex. The second point concerns the feasibility of the gene flow in a circulating system among sweet potato and its wild relatives. The third point relates to the degrees of heterozygosity of the resynthesized hexaploids by unreduced gametes of triploids.

Preface

The use of gene sources from wild plants in sweet-potato improvement was reviewed by Sakamoto (27) and Kobayashi (11). To efficiently utilize the gene sources from these wild plants, exact knowledge of the genomic structure of hexaploid sweet potato and of the genomic relationship between sweet potato and the wild species are essential.

Many wild plants ranging from diploid to hexaploid were successfully hybridized directly with sweet potato (24 25, 26, 32), and they were grouped into the *Ipomoea trifida* complex by Kobayashi (12).

1. Genomic structure in sweet potato and the polyploids in the *Ipomoea trifida* complex

In order to define the genomic structure of sweet potato, the cytogenetical studies (28, 29) were carried out in the following two steps: the first step was to synthesize hexaploid plants with the diploid and tetraploid forms of *I. trifida*. The next step was to determine the degree of homology between the two basic genomes in sweet potato with the two kinds of hybrids at the tetraploid level. The hybridization process to the tetraploid hybrids is illustrated in Fig. 1.

Meiotic data on the metaphase I of sweet potato showed a complicated pattern with a wide range of univalent to hexavalent, and the frequent multivalents suggested a high degree of genomic duplication (Table 1). The meiotic data

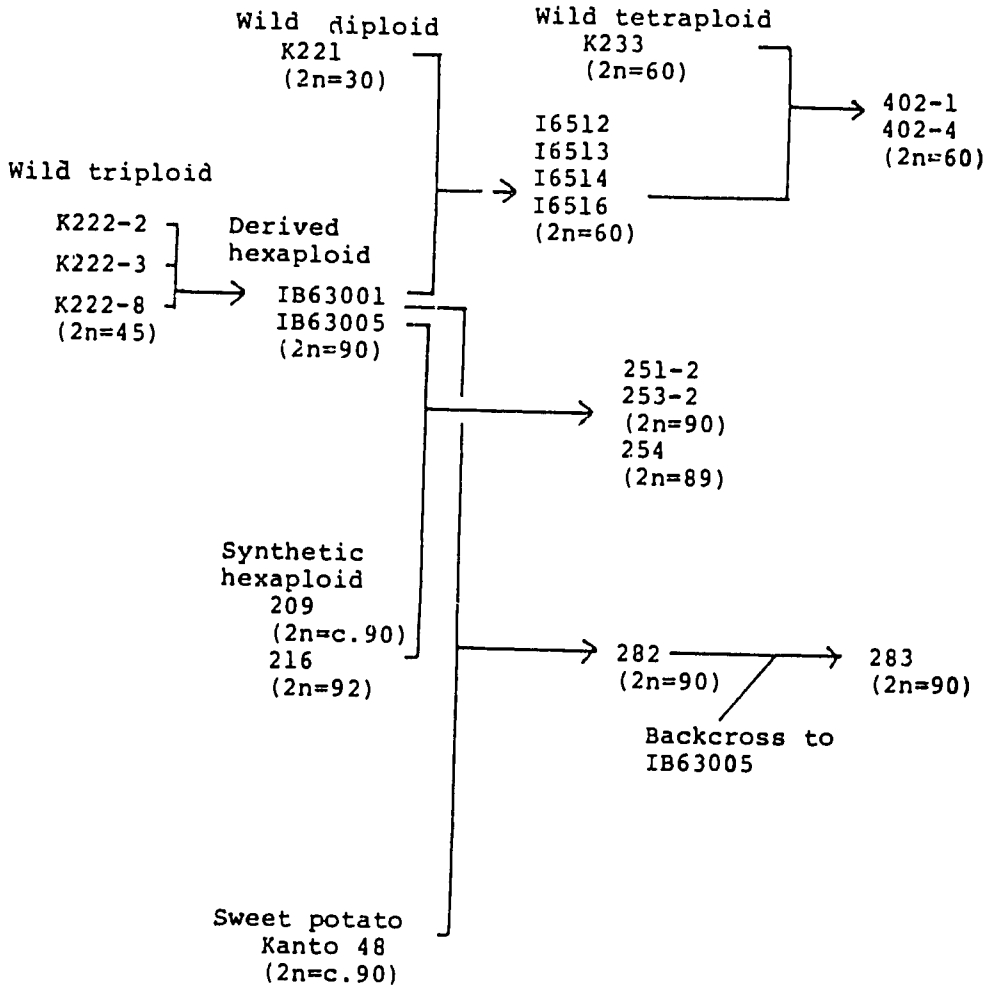

Fig. 1. A schematic representation of the hybrids for identifing the genomes in sweet potato.

Table 1. Chromosome pairing at MI in sweet potato(Kyushu 58)

	I	II	III	IV	V	VI	
2n=94	1.3	26.8	0.9	5.7	0.1	2.2	
		II-EQ 45.9		IV-EQ 8.0			CPM (%) 39.1(42)

II-EQ, bivalent-equivalents; IV-equivalents, tetravalent-equivalents; CPM, chromosomes participating in multivalents.

was rearranged with the bivalent-equivalent (II-EQ) as an indication of the overall amount of chromosome pairing, the trivalent- and tetravalent-equivalent (III-EQ, IV-EQ) and hexavalent each of which represents the degree of genomic repetition, and the number of chromosomes participating in multivalents (CPM).

As shown in Table 2, meiosis of the diploid parent K221 was regular with 15 bivalents. The tetravalent parent K233 was assumed to be an autotetraploid because of almost complete chromosome pairing with the frequent tetravalents. Therefore, the bivalent-equivalents accounting for a genomic pair in the 3x-F_1 hybrids of K221 x K233 were ascribed to an autosyndetic pair of the two genomes from K233. The synthetic hexaploids (SH) exhibited, as expected, chromosome pairing characterized by the frequent tetravalents and some hexavalents. The bivalent-equivalents, about half of the 2n chromosome number, indicated mostly complete chromosome pairing. The hybrid of SH x sweet potato showed a similar meiotic pattern to those of SH. As to seed fertil-

Table 2. Chromosome pairing at MI and the genomic formula of the synthetic hexaploids(SH) induced by chromosome doubling of 3x-F_1 hybrids of K221 x K233.

Parent or hybrid	2n	Mean per cell of					Genomic formula
		II-EQ	III-EQ	IV-EQ	VI	CPM (%)	
Parent							
K221	30	15				0	B_1B_1
K233-1	60	30.0		4.1		16.4(27)	$B_2B_2B_2B_2$
K233-2	60	30.0		4.8		19.3(32)	
3x-F_1 hybrids							
202-1	45	16.0	3.0			9.0(20)	
202-2	45	16.3	3.0			9.1(20)	$B_1B_2B_2$
202-3	45	16.8	2.5			7.5(17)	
Synthetic hexaploids(SH)							
216	92	44.6		9.0	2.6	42.7(46)	$B_1B_1B_2B_2B_2B_2$
220	90	43.8		7.7	2.5	40.0(44)	
SH x Sweet potato(Kanto 48)							
K6843	93	45.3		8.7	3.4	42.6(46)	$B_1B_1B_2B_2B_2B_2$
Sweet potato							
Cultivars	88 90 94	45.9		8.0	3.0	39.1(43)	$B_1B_1B_2B_2B_2B_2$

ity, the synthetic hexaploids and their F_1 hybrids with sweet potato cultivars were fertile in intercrosses and backcrosses with sweet potato. As a result, the synthesis of the hexaploids from K221 x K233 is considered to be resynthesis of sweet potato in regard to the genomic frame. The genomic formula for sweet potato was labelled as $B_1B_1B_2B_2B_2B_2$, in which B_1B_1 was given to K221 and $B_2B_2B_2B_2$ to K233. For a more conclusive genomic structure, however, it was necessary to ascertain the degree of homology between the two basic genomes B_1 and B_2.

The second step started with the natural triploid K222. The derived hexaploids (DH) were the progenies from intercrosses of K222. As shown in Table 3, the derived hexaploids, and their hybrids with SH and sweet potato demonstrated the similar pairing patterns having the frequent tetravalents and some hexavalents. These results suggested that the derived hexaploids have the same genomic structure as those of the synthetic hexaploids and sweet potato. The tetraploid hybrids of DH x K221 may have a genomic struc-

Table 3. Chromosome pairing and the genomic formula of the derived hexaploids(DH) from K222, and of the tetraploid hybrids involving DH.

Parent or hybrid	2n	Mean per cell of					Genomic formula
		II-EQ	III-EQ	IV-EQ	VI	CPM(%)	
K222, the natural triploid							
K222-3	45	16.3	1.6			4.8(11)	$B_1B_2B_2$
K222-8	45	16.6	3.0			9.1(20)	
Derived hexaploids(DH)							
IB63001	90	28.0		6.1	1.5	28.0(31)	$B_1B_1B_2B_2B_2B_2$
IB63005	90	30.3		6.4		30.3(34)	
DH x SH							
251-2	90	42.7		6.7	0.9	29.4(33)	$B_1B_1B_2B_2B_2B_2$
253-2	90	43.1		4.3	1.1	19.9(22)	
DH x Sweet potato(Kanto 48)							
282	90	43.7		9.4	4.1	46.0(51)	$B_1B_1B_2B_2B_2B_2$
DH x K221							
I6513	60	28.5		4.0		18.4(31)	$B_1B_1B_2B_2$
I6516	60	29.8		3.3		13.3(22)	
(DH x K221) x K233							(B_1=B_2)
402-1	60	30.0		3.3		13.3(22)	$B_1B_2B_2B_2$
402-2	60	29.8		4.0		16.0(27)	(B_1=B_2)

ture of $B_1B_1B_2B_2$, that is of amphidiploid if B_1 is nonhomologous to B_2. Further, subsequent hybridization of the above tetraploid hybrids with the natural tetraploid K233 may produce the hybrids of the genomic structure $B_1B_2B_2B_2$, that are expected to be sterile due to considerably irregular meiosis if B_1 is nonhomologous to B_2. The meiotic data on the above two kinds of tetraploid hybrids were mostly regular in having about 30 bivalent-equivalents, and both showed tetravalents as frequent as K233.

Consequently, these observations led to the conclusion that B_1 is homologous to B_2, and that the autotetraploidy for K233 was a proper assumption. In addition, the relatively high fertility in both of the hybrids in intercrosses or in crosses with sweet potato confirmed the functional homology between the two genomes. In conclusion, sweet potato has a genomic structure of autohexaploidy with the B genome, that also exists in the autotetraploid K233 and in the diploid K221 of the I. trifida complex.

The conclusion drawn here is in disagreement with the view of allopolyploid origin in previous cytological studies (7, 33, 34). Based on the analyses of the chromosomes at the pachytene and metaphase stages, Magoon et al. (19) reached the conclusion that three genomes of sweet potato are partly homologous and two of the genomes show closer homology to one another than to the third. However, the results of the present study ruled out such a genomic differentiation with respect to the degree of genomic homology.

2. The gene flow between sweet potato and the *I. trifida* complex

As indicated in Fig. 2, autoploidy enables the recurring gene flow between sweet potato and a polyploid complex of *I. trifida* (29). If any hybrid polyploids have at least 2 nonhomologous genomes, it will result in sterility which will limit the gene flow. There are two pathways through which genes can flow: that of the process of ordinary hybridization between the diploid and the polyploid, and that of the process of exceptional hybridization through the sterile triploid. The percentage of seed fertility shown in the literature (13, 14, 15, 16, 17, 21, 25), although it varied according to the parental lines involved, is proof of the relative value of the efficiency of the flow.

Salient features in the circulating system of the gene flow are summarized as follows:

1) The diploid acts only as a donor of gene sources due to the one-way flow from the diploid gene pool to other polyploids.

2) The sterile triploid plays an important role as a bridge from the diploid to tetraploid gene pool, and as a bridge for the conflux to the hexaploid gene pool.
3) Influx of the gene flow to the tetraploid gene pool undertaken by hybridization diploid x hexaploid is restricted to the cross with the hexaploids as female parent.
4) Frequent gene flow or gene exchange can be expected at a consistent ploidy level, such as that of the flow between sweet potato cultivars and the hexaploid gene pool of *I. trifida*.

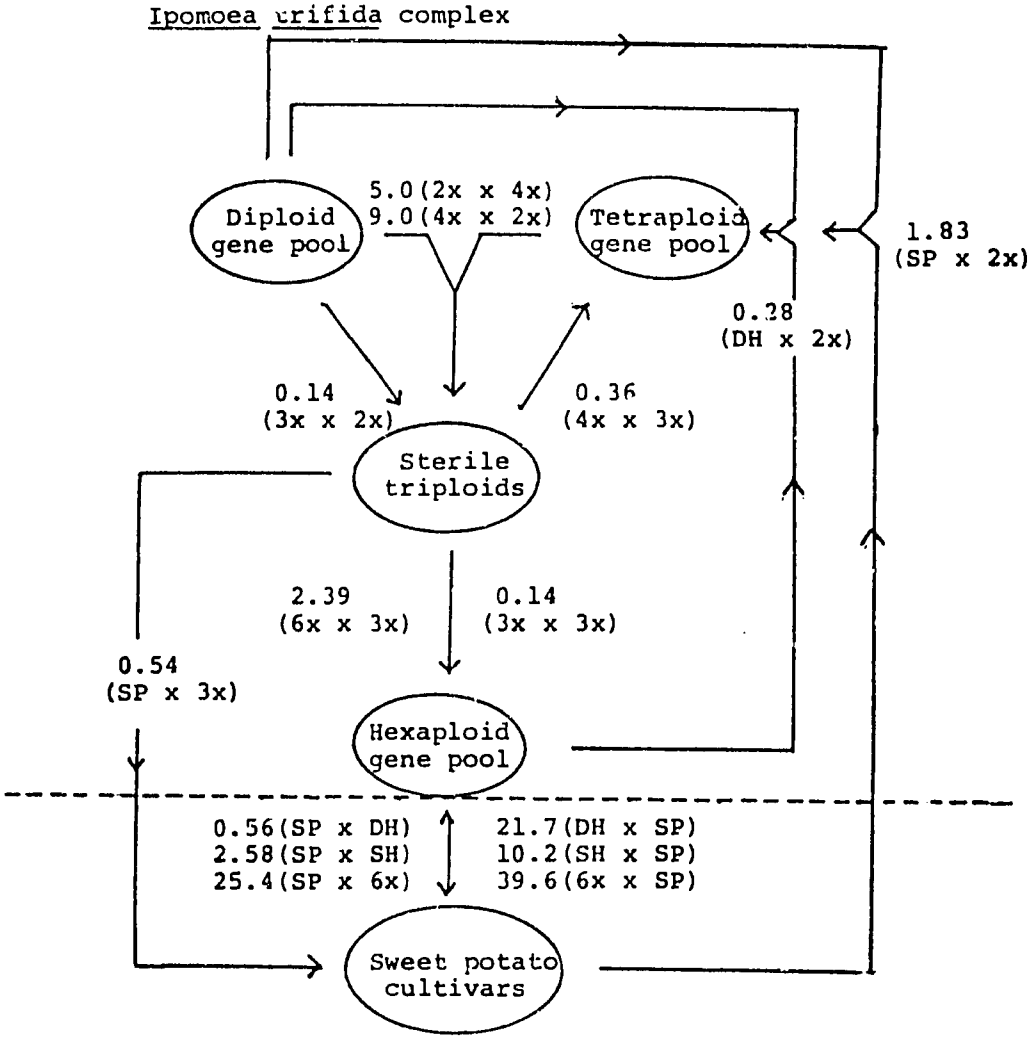

Fig. 2. A circulating system of the gene flow among the diploid and autopolyploids of I.trifida complex and sweet potato. Values along the pathways indicate percentage of seed set of the hybridization. 2x, K221; 3x, K222; 4x, K233; 6x, K123; DH, derived hexaploids; SH, synthetic hexaploids; SP, sweet potato cultivars (13, 14, 15, 16, 17, 21, 25).

In Fig. 2, the gene flow through the sterile triploid is caused by the functional diploid or unreduced triploid gametes. There may be other pathways which have not been demonstrated experimentally, for example, genes could flow from diploidy to tetraploidy, and also through pentaploidy.

Austin in his taxonomical studies (1, 2, 3) was the first to suggest the possible gene flow among sweet potato and its relatives. According to his hypothesis, K233 (24) and other tetraploids (9, 20) are of hybrid origin from the cultivated sweet potato and a diploid species, presumably I. trifida. We, however, believe that most of the plants making up the tetraploid gene pool are spontaneous plants (23, 29, 30), and there is some possibility that the wild gene pool at the tetraploid level contains the gene(s) from the cultivated sweet potato as shown in Fig. 2.

A similar case of interploidy gene flow is seen in the allogamous orchard grass, Dactylis glomerata, that forms an autoploidy series from diploid to hexaploid. Zohary and Nur (35) suggested that the natural triploid hybrids acted as a bridge for the efficient gene flow from the diploid to tetraploid level. Jones and Borrill (10) further discussed the significant role of artificial triploid hybrids through which the genes flow and their value to the breeding of orchard grass.

The gene flow system discussed above is being utilized as a scheme for sweet-potato breeding. The hypothetical scheme of analytic breeding proposed by Chase (5, 6) can be applicable if some modifications are made. Nowadays, reduction of hexaploid sweet potato to the plants of the diploid level is difficult for lack of the influx of gene flow to the diploids.

Regarding the process of resynthesis from the triploid lines, the desirable diploid parents are those selected for a specific trait such as resistance to a pathogen. On the other hand, tetraploid derivatives from cultivars x diploids would be used as parents after selection for root weight, starch content and starch yield.

Recent research of the tetraploid lines (called tetraploid sweet potato), being conducted since 1971 at Kyushu Agricultural Experiment Station, indicates the feasibility of attaining as high root yield at the tetraploid level as sweet potato (18).

3. Resynthesis of the autohexaploids

Last, a problem concerning the resynthesis process of autohexaploids will be discussed. There have been two attempts to induce autohexaploid plants from the diploid material. A single autohexaploid plant from the diploid hy-

brids of I. ramoni - I. lacunosa - I. triloba was so highly sterile that no progeny was obtained in controlled pollination (8). Similarly, "raw" autohexaploids from the diploid K221 were highly sterile, neither intercrosses nor crosses with sweet potato were successful (22).

Raw autoploid plants after colchicine treatment will be homozygous for loci in each genome. Such a homozygous condition seems to have a deleterious effect, just as an inbreeding effect, on fertility and vegetative vigor. To resynthesis, there are two methods for chromosome doubling; by colchicine treatment of the somatic cells, or somatic doubling (S), and by syngamy of the unreduced gametes, or gametic doubling (G). A comparison of the two methods was made in the genic system of the resynthesized hexaploids.

A model with four multiple alleles for a locus in random assortment of chromosomes was used for detecting possible genic systems and their frequencies. The genic system described in this paper is a group of genotypes that have N_1 alleles of the first kind, and N_2 alleles of the second kind, ..., and N_4 alleles of the fourth kind, and then total alleles $N = N_1 + N_2 + N_3 + N_4$. The degree of heterozygosity in a genic system can be expressed as follows: Entropy (En) = $\log ({}^{N!}/_{N_1!N_2!N_3!N_4!})$ as defined by Brillouin (4). Entropy may increase as the degree of heterozygosity becomes larger.

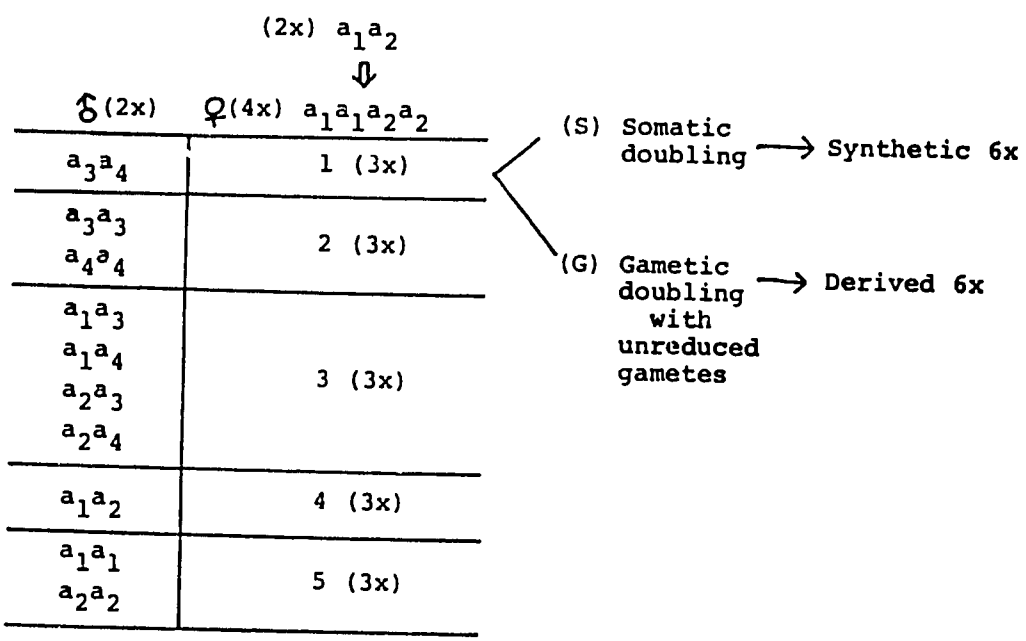

Fig. 3. Types of hybridization between 4x x 2x, and the two ways of inducing 6x. A model with four alleles for a locus.

Table 4. Possible genic systems and the entropy of a genic system in autohexaploids induced by somatic(S) or gametic doubling(G).

No.	Genic system* $N_1N_2N_3N_4$	Entropy of a genic system	Type of hybidization 1 S	1 G	2 S	2 G	3 S	3 G	4 S	4 G	5 S	5 G
1	6 0 0 0	0					1/12	1/144	2/12	2/144	1/6	1/36
2	5 1 0 0	0.778						10/144		20/144		8/36
3	4 2 0 0	1.176	4/12	4/144	2/6	2/36	7/12	42/144	10/12	70/144	5/6	19/36
4	3 3 0 0	1.301						8/144		52/144		8/36
5	4 1 1 0	1.477		4/144				18/144				
6	3 2 1 0	1.778		32/144		16/36		56/144				
7	2 2 2 0	1.954	8/12	36/144	4/6	18/36	4/12	9/144				
8	3 1 1 1	2.079		32/144								
9	2 2 1 1	2.255		36/144								
		Average	1.69	1.98	1.69	1.83	1.34	1.47	0.98	1.15	o.98	1.08

* Genotypes consisting of N_1 alleles of the first kind, N_2 alleles of the second kind, ... , N_4 alleles of the fourth kind. Entropy = $\log(N!/ N_1!N_2!N_3!N_4!)$, where $N = N_1+N_2+N_3+N_4$.

As represented in Fig. 3, an induced autotetraploid from a heterozygous diploid is crossed with a diploid different in genotype. All possible crosses can be classified into 5 types of hybridization. In each of the hybridization types, the genic systems of resulting hexaploids either by somatic or gametic doubling are shown in tabular form (Table 4). Every hybridization type, an array of hexaploids derived by gametic doubling represents the higher mean value of entropy than that by somatic doubling. As a result, the resynthesis by means of gametic doubling is an advantageous way to secure the genic system of higher heterozygosity.

Resynthesis of common wheat by gametic doubling, for example, was suggested to be genotypically controlled because of the extreme range of 0 to 73 percent in seed fertility shown by the different Emmer wheat-*Aegilops* triploid hybrids (31). In allogamous *Ipomoea* plants, chromosome doubling by syngamy of unreduced gametes would be a less frequent event. There may be, however, a possibility that the functioning of unreduced gametes is enhanced by a proper triploid hybrid. The genetic control of unreduced gamete formation, that has of yet to be studied, is of general importance not only to understand a prime cause of polyploidization in Nature, but also to find an effective means to utilize heterozygosis and heterotic effects of the genes in the homologous genomes.

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PROGRESS IN EXPLORATIONS AND COLLECTIONS OF SWEET POTATO GENETIC RESOURCES THE IBPGR/CIP PROJECT

Fermin de la Puente

Introduction

Sweet Potato is an important vegetable crop of the tropics, sub-tropics and temperates regions. It is 6th or 7th position in food production among all food crops of the world (7). However, about 2/3 of the world production is utilized in one country, China (8).

It is generally accepted that the sweet potato, Ipomoea batatas (L) Lam originated in the northwest of South America. Secondary centers of high genetic diversity have also been identified in Guatemala and southern Peru. Austin (2) considered that sweet potatoes germplasm is being lost so rapidly and recommended that expeditions for collection should be mounted immediately. Efforts to preserve sweet potato germplasm are underway at the International Institute of Tropical Agriculture (IITA), Asian Vegetable Research and Development Center (AVRDC), National Institute of Agrobiological Resources (Japan - NIAN), Central Tuber Crops Research Institute (India-CTCRI), U.S. Vegetable Laboratory (Charleston, S.C. U.S.A.) and in some national programs like Argentina, Brazil, Costa Rica, Cuba, Dominican Republic, Guatemala, Peru, etc.

Recognizing the present status of conservation of this germplasm, the International Potato Center (CIP) and the International Board for Plant Genetic Resources (IBPGR), have initiated the development of the Latin-American and Caribbean Sweet Potato Gene Bank in the area of main genetic diversity of this crop.

The first tentative to the development of this gene bank, was initiated at CIP by assembling sweet potato accessions available in several national institutions. Later on, a project for the collection of sweet potato resources in Latin-American and Caribbean regions was signed by CIP and the IBPGR at the begining of 1985. A few references about this project are presented as follows:

Objectives: The main objectives set up are:

- To collect genetic resources of sweet potato in Latin-American and Caribbean region, and

- To maintain this germplasm in an usable form.

Strategy: The strategy to the establishment of this international sweet potato gene bank at CIP was considered by:

- Acquisitions of accessions maintained in some national institutions, and

- To initiate a systematic exploration and collection in areas of high genetic diversity in Latin-American and Caribbean countries.

This report will cover the main activities undertaken in this project since February, 1985 up to date. The pre-collecting, collecting and post-collecting activities will be reported.

Pre-Collecting Activities

The determination of the optimum "Collecting Time", "Collecting Route", "Collecting Areas", "Collecting Sites" and "Species Identification in the Field" were mainly based on:

- Data obtained in literature.
- Checking herbarium material.
- Consulting national and international specialists.
- Identified plant indicators.
- Reports of previous missions
- Phenology of the species.
- Phyto-ecological data of the main localities to be explored.

A full participation of national programs in all phases of this project was considered for the success of the missions. An excellent collaboration of the national institutions were received.

Collecting Activities:

At this phase, the following main considerations were taken:

- Three major sources of genetic variability were chiefly considered for collection in the field and these were: cultivated accessions, feral plants and allied species. Since not major effort was required, other *Ipomoea* species, outside section *Batatas*, have been collected alone with the above

material, for their importance as virus indicators, fodder, binding sand, ornamentals, fendles and for their utilization in the breeding program for flowering stimulation in sweet potatoes, etc.

- Herbarium samples, true seed and/or cuttings were collected from the wild germplasm while from the cultivated one only cuttings were taken.

- The sampling technique for vegetative and true seed samples recommended by Hawkes (1) was followed.

- A duplicate sample of all collected material was left in the national institutions to insure its preservation.

So far, 35 collecting trips were carried out in Bolivia, Colombia, Dominican Republic, Ecuador, Peru and Venezuela. The number of trips, the number of effective field days of exploration and collection and the main collaborator per country are indicated in Table 1.

Table 1. Main References of The Collecting Trips

Country	Number of Trips	Days of Field Work	Main National Collaborators
Bolivia	2	21	R. La Fuente (IBTA)
Colombia	3	50	L. López (ICA)
Dominican R.	1	7	C. Mejìa (M.A.)
Ecuador	4	44	R. Castillo (INIAP)
Perú	24	60	CIP's Personal
Venezuela	1	15	J. Luciani (UCV)
	35	197	

The present status of these explorations and collections (Figure 1) in the above countries, are as follows:

- Collections are mostly completed in: Colombia, Ecuador, and Peru. Some specific areas in these countries will be needed to be explored and reexplored.

- Dominican Republic, Bolivia and Venezuela are partially explored.

As a result of these collections, a total of 2219 accessions of cultivated and wild *Ipomoea* species have been collected in 1112 localities of these five countries. These accessions included:

Figure 1. Present status of the explorations and collections of sweet potato germplasm.

Table 2. Class of the collected material.

Class	Number of Accessions
Wild (Section Batatas)	64
Wild (Other Sections)	317
Wild (Undetermined)	446
Native Cultivars	1392
TOTAL	2219

About 62.7 percent of these 2219 accessions belong to *I. batatas* and the rest to other *Ipomoea* species where are included those of the section batata.

The current status of all collections made to date in each country is as follows:

a) Bolivia.- Route and main locations of the collecting trips are shown in Figure 2. The areas explored comprised 4 departments and 98 main localities. A total of 144 accessions of cultivated and wild species have been collected. These accessions included:

103. *Ipomoea batatas*
2. *I. ramossisima* (section batatas)
5. Other *Ipomoea* species
43. Wild samples undetermined
1. *Merremia* spp.

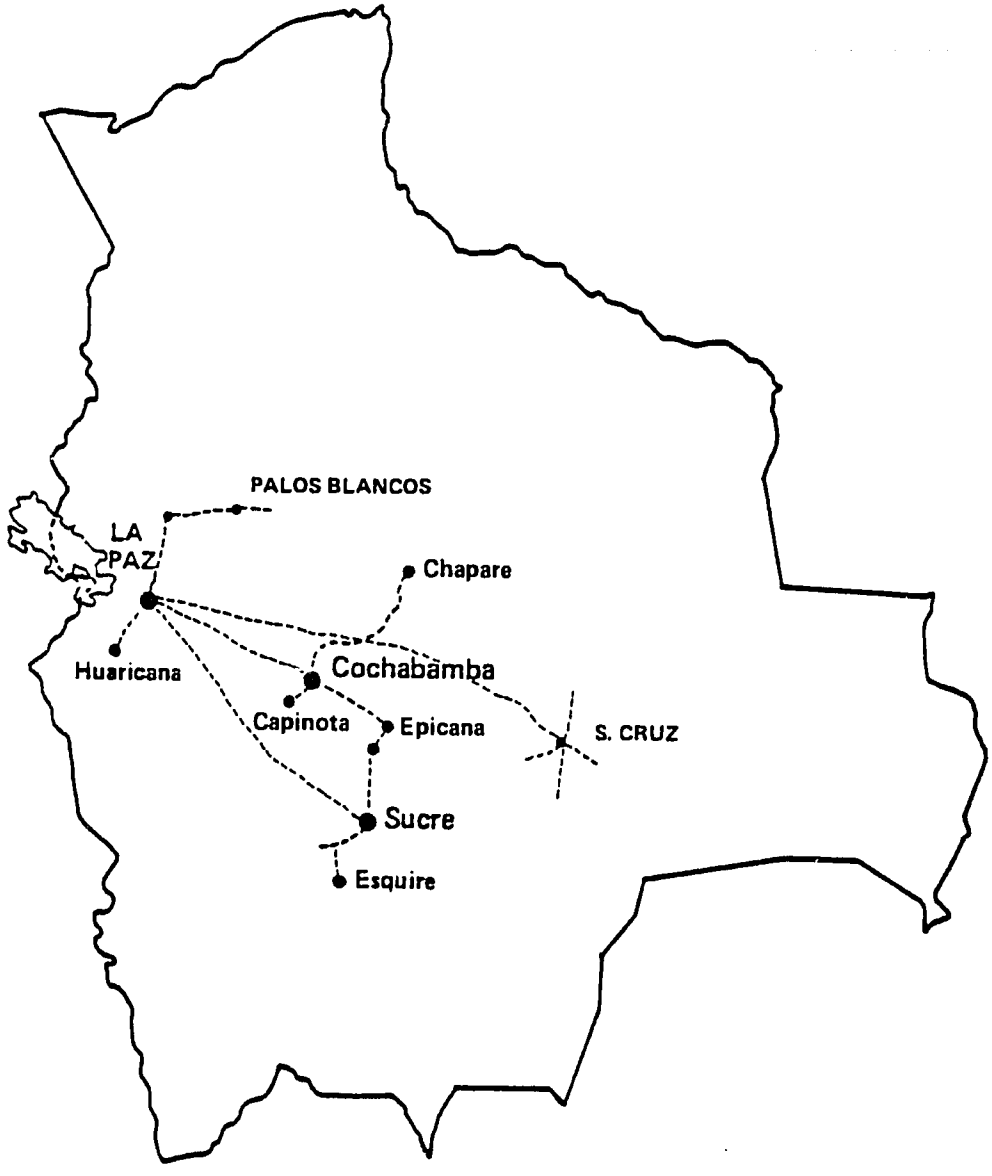
The frequency of the cultivated collected accession by departments are indicated in Figure 3. Localities where a great number of cultivated accessions were collected are:

Capiñota - Cochabamba - (7 accessions); Zurima, Oropeza - Chuquisaca - (5 accessions); Capellania, Coroico - La Paz; Lilata, Sur - Yungas - La Paz and Chaco, Oropesa - Chuquisaca (4 accessions).

The departments of Tarija, Bení and Pando have not been explored yet. Santa Cruz is recommended to be re-explored, specially in the south and east regions.

b) Colombia.- Three collecting expeditions were carried out in this country. The route and main localities explored are indicated in Figure 4. Sixteen departments and 338 localities were explored. A total of 533 accessions of cultivated and wild species have been collected. These accessions included:

Figure 2. Collecting sweet potatoes germplasm in Bolivia.



References

– No. collecting trips: 2
– Principal collaborator: R. La Fuente (IBTA)

------- Expeditions route
• Main collecting localities

Figure 3. Bolivia – No. of accessions of *I. batatas* collected by departments.

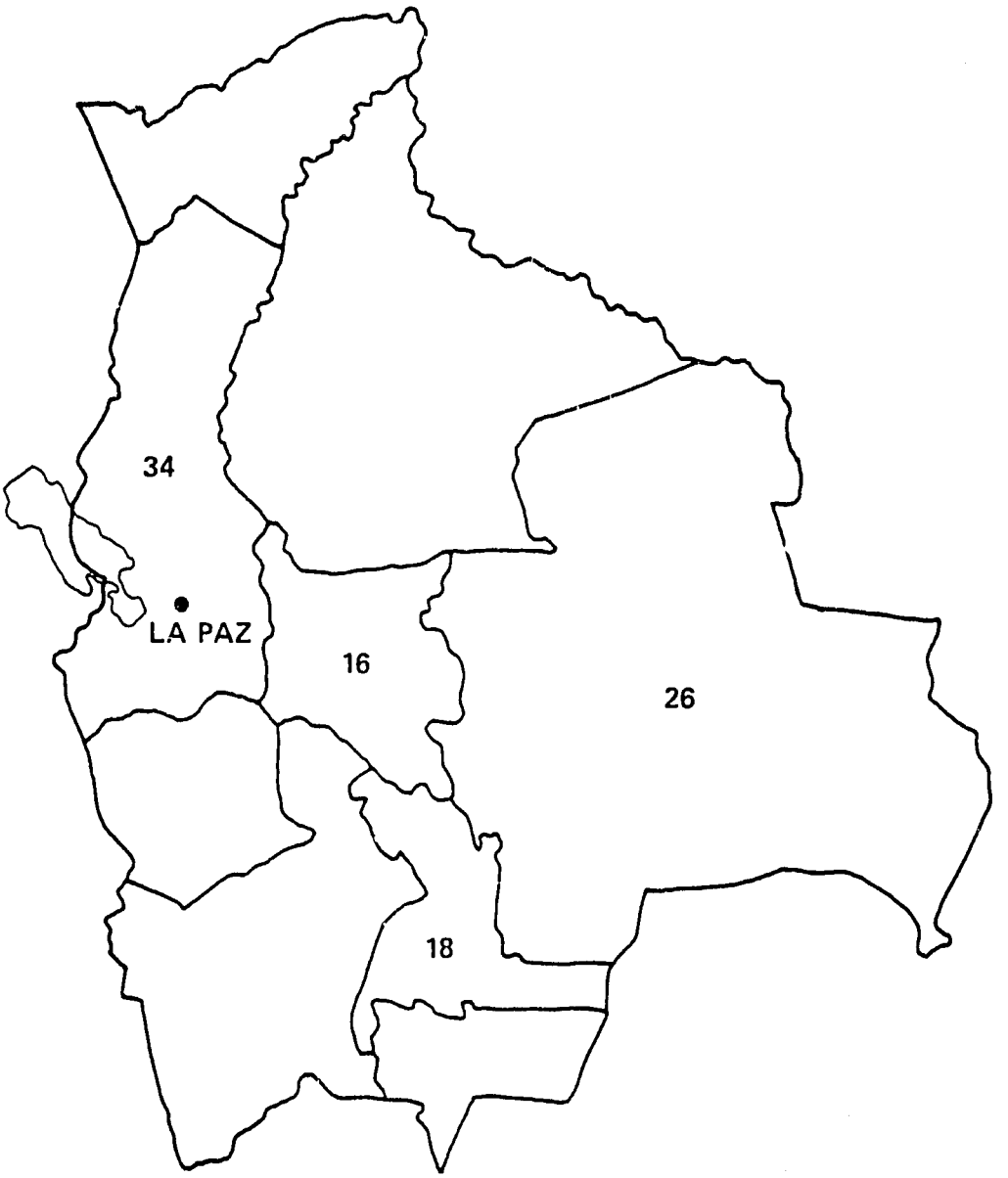


Figure 4. Collecting sweet potato germplasm in Colombia.

----- Expeditions route

• Main collecting localities

References

– No. collecting trips: 3
– Principal collaborator: L. Lopez (ICA)

243. I. batatas
3. I. trifida and I. triloba (section batatas)
13. Other Ipomoea
268. Wild undetermined accessions
4. Jacquemontia sp
1. Bignoniaceae sp
1. Merremia dissecta

The number of the cultivated accessions collected by department are showed in Figure 5.

Localities where a high number of cultivated accessions were collected are: Valencia - Cordoba; Purutal, San Agustín - Huica; Valparaíso - Taminango - Nariño; Chaguarurco, La Unión; Parraga, Rosas - Cauca and Yerasca, Codazzi - Cesar (4 accessions).

In this country, the departments of Caldas, Risaralda, Choco and Antioquía are recommended to be explored. The departments of Cauca and Valle de Cauca and the route of Cartagena, Barranquilla, Santa Marta, Valle Dupar, Bocana and El Carmen de Bolívar, should be explored for the presence of a high populations of wild species related to the Ipomoea batatas.

c) Dominican Republic.- One trip was carried out to this country. The main objective of this trip was to coordinate future collecting activities in Dominican Republic and surrounding areas. In this opportunity, a collection of cultivated material was conducted. Collection of wild species at this time was not considered due to improper time of flowering and fruiting of this material. The route and main localities explored are indicated in Figure 6. Seven departments and 14 localities were explored. A total of 43 accessions of Ipomoea batatas were collected. Localities in this explored area where a high number of accessions were obtained are:

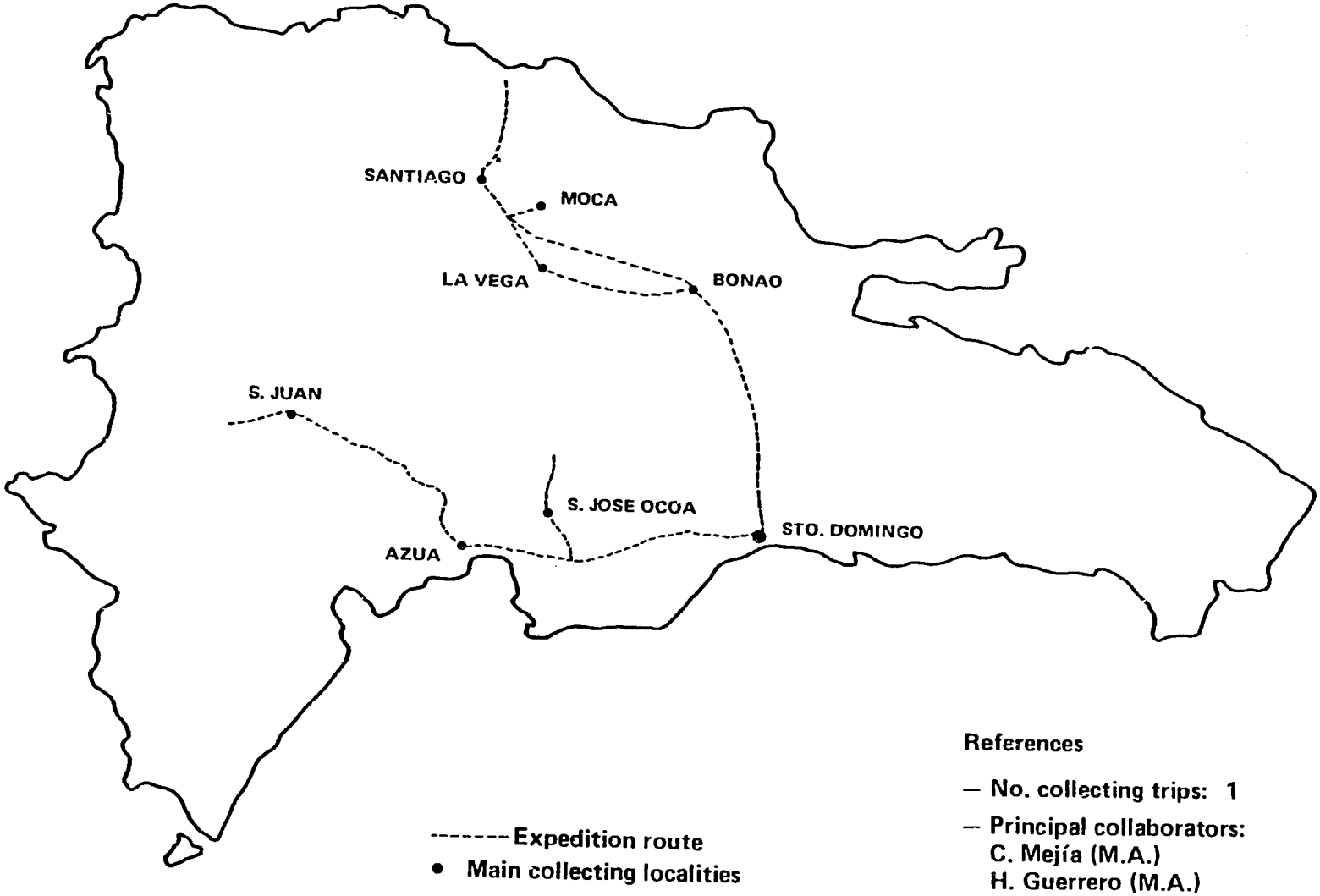
La Nuez, San Josè de Ocoa, Peravia (8 accessions); Licey al Medio, Licey (7 accessions) La Selva, Monseñor Nouel (9 accessions).

The number of cultivated accessions collected by department are presented in Figure 7.

d) Ecuador.- Route and main localities of the 4 explorations and collection trips are presented in Figure 8. The exploration area included 18 departments and 152 localities. A total of 384 accessions of cultivated and wild species were collected and these include:

Figure 5. Colombia – Number of accessions of *I. batàtas* collected by departments.

Figure 6. Collecting sweet potato germplasm in the Dominican Republic.



References

– No. collecting trips: 1

– Principal collaborators:
C. Mejía (M.A.)
H. Guerrero (M.A.)

------- Expedition route

• Main collecting localities

Figure 7. Dominican Republic — Number of accessions of *I. batatas* collected by departments.

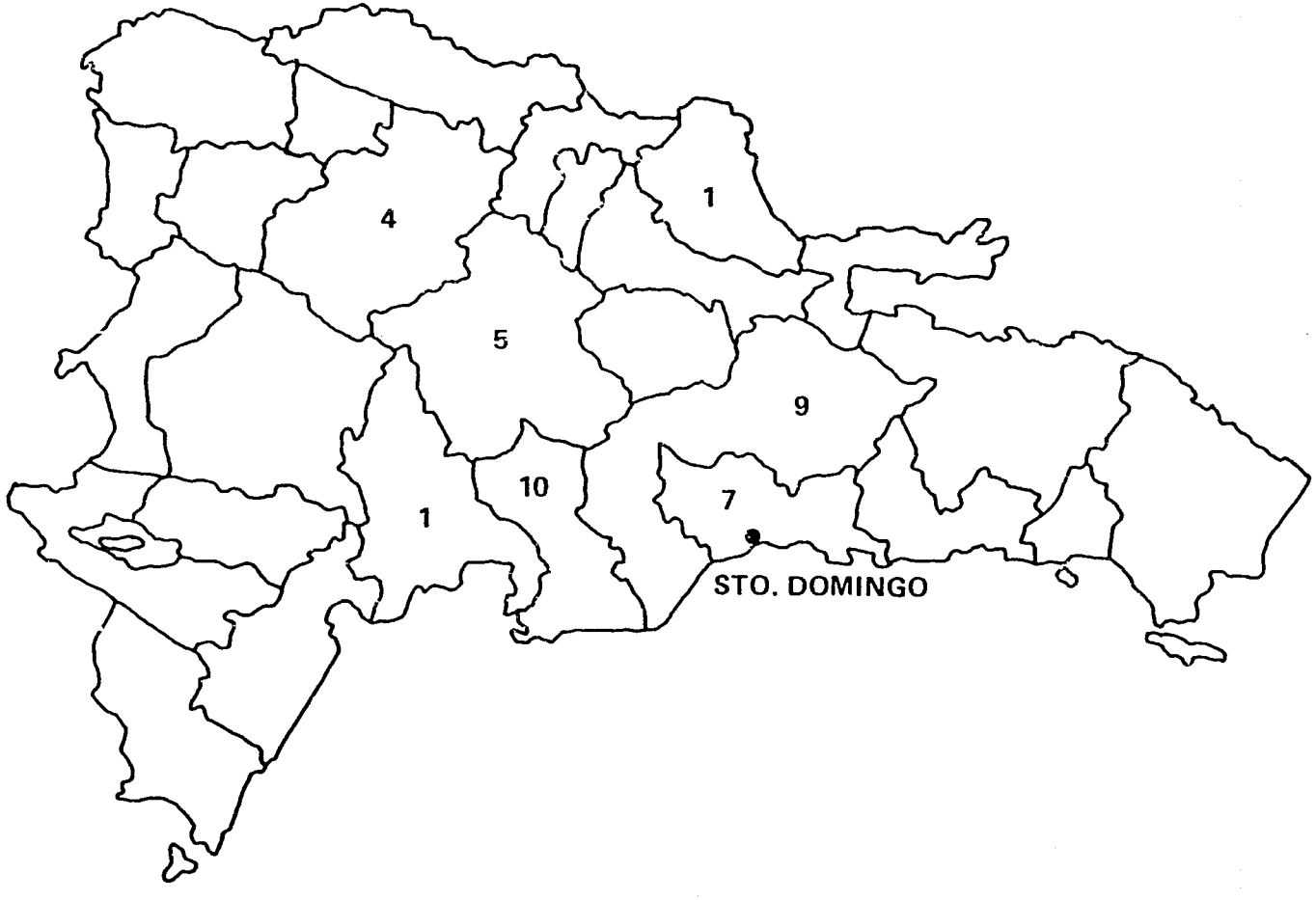
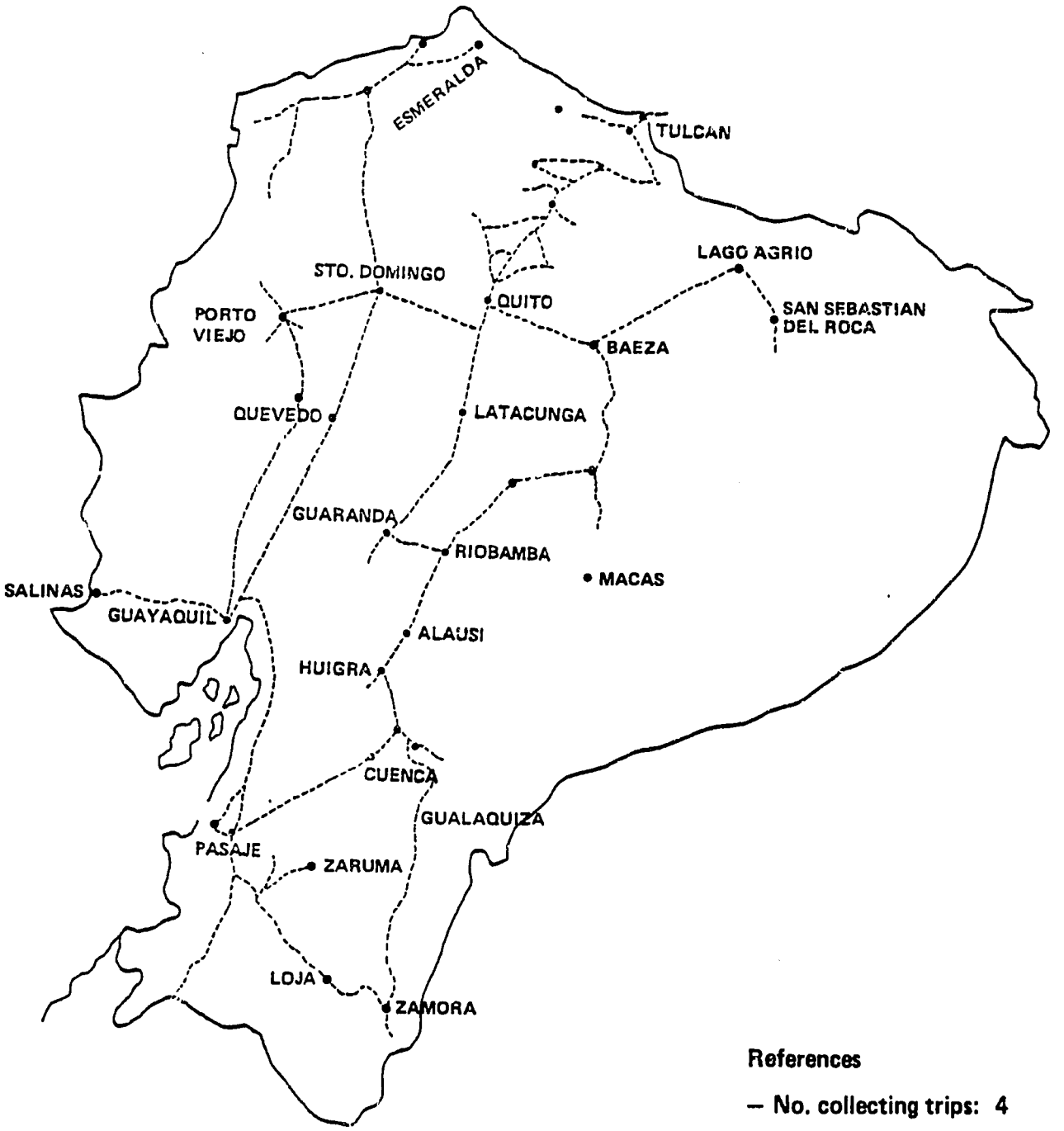


Figure 8. Collecting sweet potatoes germplasm in Ecuador.

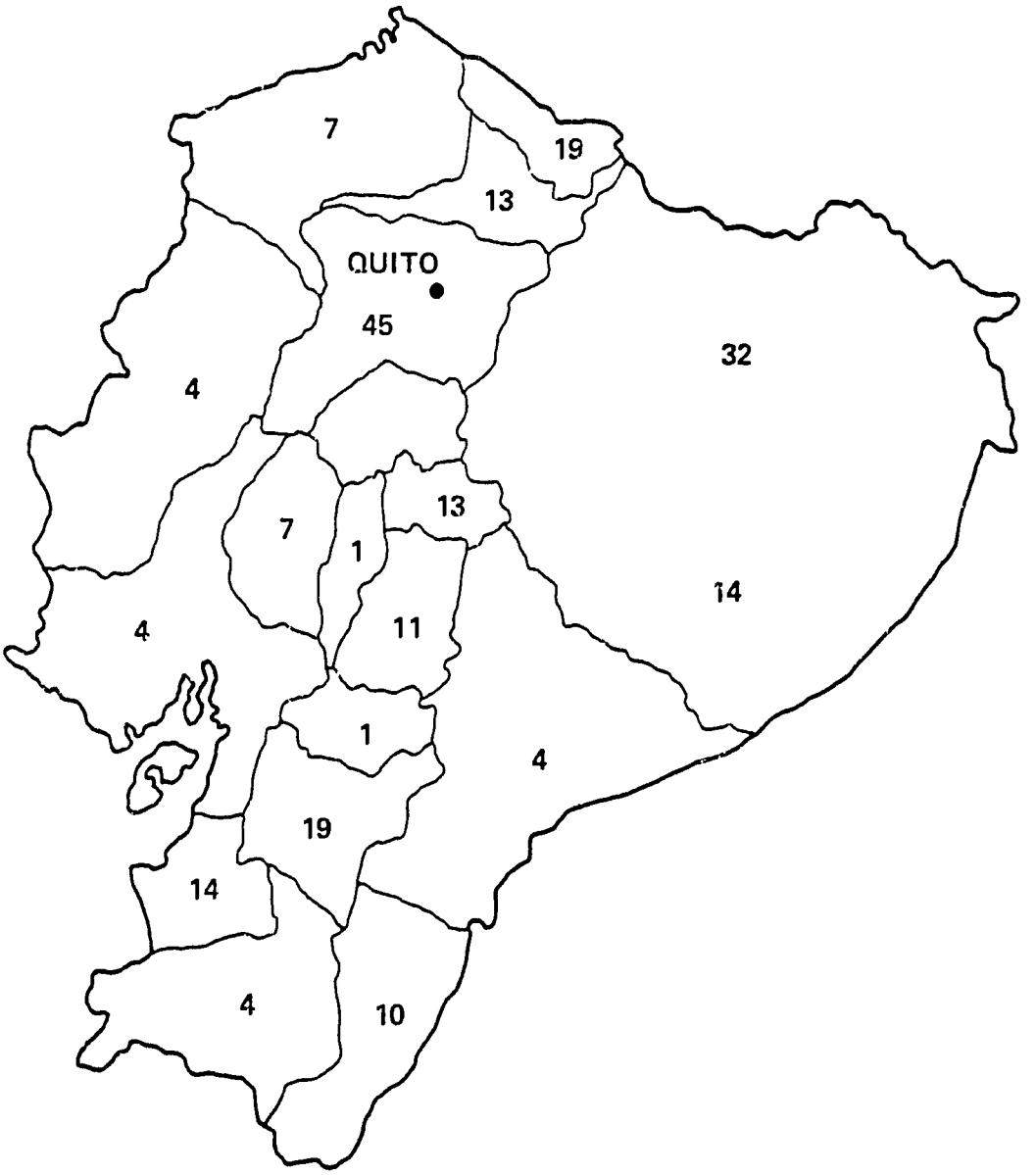


References

- No. collecting trips: 4
- Main collaborators:
  R. Castillo (INIAP)
  J. Fernandez (INIAP)

-------- Expeditions route
● Main collecting localities

Figure 9. Ecuador – Number of accessions of *I. batatas* collected by departments.



224. I. batatas
3. I. x leucantha (section batata)
2. I. ramossisima (section batata)
40. Of 17 other Ipomoea spp.
98. Wild samples undetermined
2. Merremia umbellata
3. Merremia quinquefolia
2. Merremia macrocalyx
2. Merremia aegyptia
2. Iseia luxurians
1. Operculina codonantha
1. Jacquemontia corymbulosa
1. Jacquemontia ciliata
1. Convolvulus nodíflorus
1. Convolvulus crematifolius
1. Turbina abutiloides

The frequency of the cultivated accessions collected by departments are indicate in Figure 9. Localities where a high samples of cultivated material were collected are: Giron - Azuay ; Atahualpa - Pichincha; and Diez de Agosto - Pastaza (5 accessions); Juan Montalvo - Carchi; Guallabamba - Pichincha (6 accessions); San Nicolás - Carchi (7 accessions); Cachuco - Pichincha (8 accessions) and La Sagus - Pichincha (10 accessions). The following routes and localities should be explored: Huigra - Guayaquil; Guayaquil - Salinas; Alegria - Bonita; Tulcan - Maldonado; Zumba - Jaen; Gualaceo - Maca and The Galapagos.

e) Perú.- The route and main localities included in the 24 collecting trips are indicated in Figure 10. The explored area comprised 18 departments and 320 main localities. About 963 accessions of cultivated and wild species were collected and they included:

733 I. batatas
5 I. ramossisima (section batatas)
102 Other Ipomoea spp
2 I. batatas hybrids
1 Tevetia peruviana
6 Merremia aegyptia
1 Merremia quinquefolia
2 Merremia umbellata
1 Jacquemontia sp
1 Merremia macrocalyx
1 Merremia tuberosa
1 Acantaceae
1 Operculina codonantha
106 Wild samples undetermined

Figure 10. Collecting sweet potato germplasm in Peru

The number of cultivated accessions collected by department are presented in Figure 11. Localities with a high variability in the cultivated germplasm are: Fundo Malito, Huarochiri - Lima; Huancapongo, Trujillo - La Libertad; Santa Rosa, Trujillo - La Libertad; Posope alto, Chiclayo - Lambayeque; Hualtaco, Tambo Grande - Piura; Atiquipa, Caravelí - Arequipa; Ranrahirca - Anchash; Estancia Santa Teresa, Caraz - Ancash; Indiana, Maynas - Loreto; Tingo - Cajamarca; Pampas, Contumazá - Cajamarca; Moche, Trujillo - La Libertad; Santa Eulalia, Huarochirí - Lima, Cumbil, Chota - Cajamarca; Yuramarca, Caraz - Ancash; Palpa - Lima; and Pisquillo, Huaral - Lima with 5 accessions each. In Cambarra, Trujillo - La Libertad; Aguas Verdes, Zarumilla - Tumbes; Chancay, Lima; Sausal, Trujillo - La Libertad; Huanchay, Yungay - Ancash; San Martín, Cajabamba - Cajamarca; Piura, Jaen - Cajamarca; La Laguna, Santa - Ancash; Huando, Huaral - Lima; and Orcon, Huaral - Lima with 6 accessions each. With seven accessions in La Capilla, Contumazá - Cajamarca; Bosa, Chancay - Lima; San Camilo - Arequipa; Cholocal, Trujillo - La Libertad and Santa Eulalia - Lima. With 8 and 9 accessions: Cascajal - Lambayeque; Pueblo Nuevo Colán, Paita - Piura; Palo Blanco, Ayabaca - Piura; Cerro Blanco - Tumbes; Huaral, Chancay - Lima; Ticaleta, Caravelí - Arequipa; La Grama - Cajamarca and Uchucota, Ranrahirca - Ancash. With 10 and 11 accessions: Matucana, Huarochirí - Lima; Tumilaca, Mariscal Nieto - Moquegua; Huaquillas - Cajamarca; Monteverde, Oxapampa - Pasco and Cuañinbita, Cajabamba - Cajamarca. With 13 and 14 accessions: Fdo. La Bomba, Sullana - Piura and Guañinba, Cajabamba - Cajamarca. With 16 accessions, Pueblo Nuevo, Colan - Piura and with 20 accessions: Limón, Celendín - Cajamarca.

The following areas should be explored: Bagua, Chachapoyas, Moyobamba, Tarapoto, Saposoa, Juanjuí, Jaen and Quillabamba.

f) Venezuela.- Eight departments and 137 localities were explored in the first collecting trip carried out in this country. The route and main localities of this exploration are indicated in Figure 12. One hundred and eighty accessions of cultivated and wild species were collected and they include:

52. I. batatas
10. I. trífida (section batatas)
1. I. trichocarpa (section batatas)
26. Of other Ipomoea spp
35. Wild samples undetermined.
1. Turbina abutiloides
1. Merremia macrocalyx
2. Odonellia hirtiflora
1. Merremia umbellata
1. Operculina hamiltonii
1. Operculina pteripes
1. Jacquemontia densiflora
1. Aniseia martinicensis
1. Merremia ternipolia
1. Merremia nervosa
1. Merremia quinquefolia
1. Jacquemontia sp

The frequency of collected cultivated accessions by departments are presented in Figure 13. Localities where high number of cultivated accessions were collected are: Samare - Lara (5 accessions) and El Batatal, Boconó - Trujillo (6 accessions). The following departments should be considered in the next collecting trip: Guarico, Miranda, Táchira, Anzoategui, Monagas, Bolívar, Falcón and Nueva Esparta.

Two hundred and thirty three additional cultivated accessions were obtained by donation from different national institutions (Table 3).

Table 3. Cultivated accessions obtained by donation during the collecting trips.

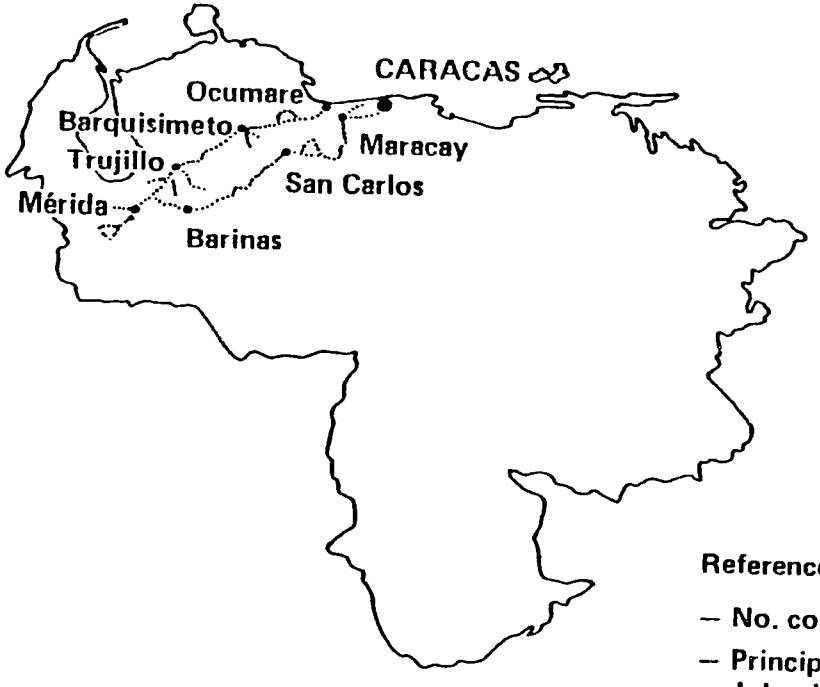
Donated By:		N° of Accessions
Perú:	Universidad Nacional Amazonia	46
Dominican Republic:		112
	CENDA	24
	CESDA	80
	Tissue Culture Laboratory	8
Colombia:	ICA	75
	TOTAL	233

The variability in this collected genetic resource is very important for the breeding purposes and some basic studies. This variability mainly concerned with its:

- Geographical Distribution and
- Phenotipic Diversity.

Figure 11. Peru – Number of accessions of *I. batatas* collected by departments.

Figure 12. Collecting sweet potato germplasm in Venezuela.



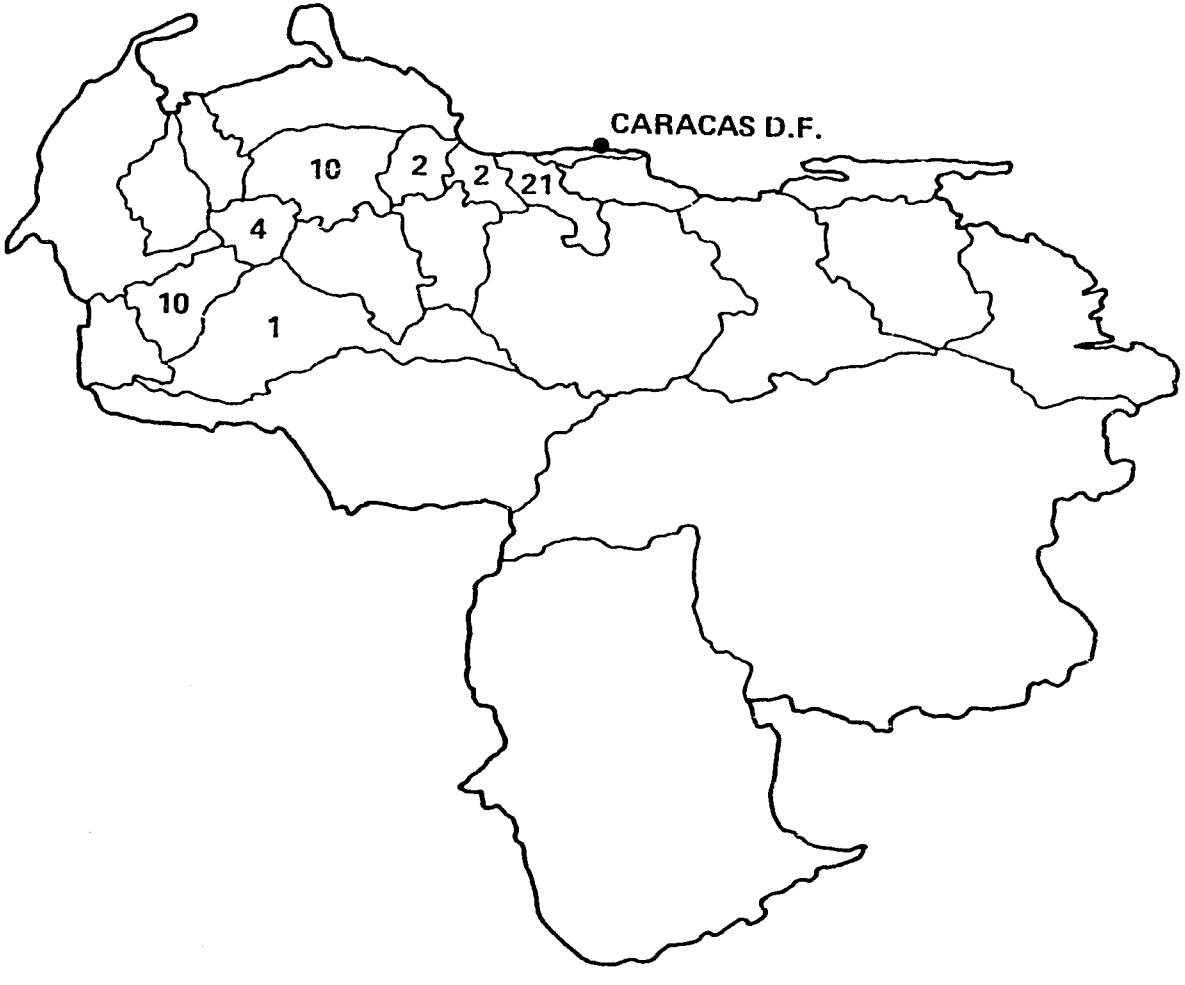
References

- No. collecting trips: 1
- Principal collaborators:
  J. Luciani (UCV)
  J. Mantilla (UCV)
  V. Quiñonez (FONAIAP)

---------- Expeditions route

● Main collecting localities

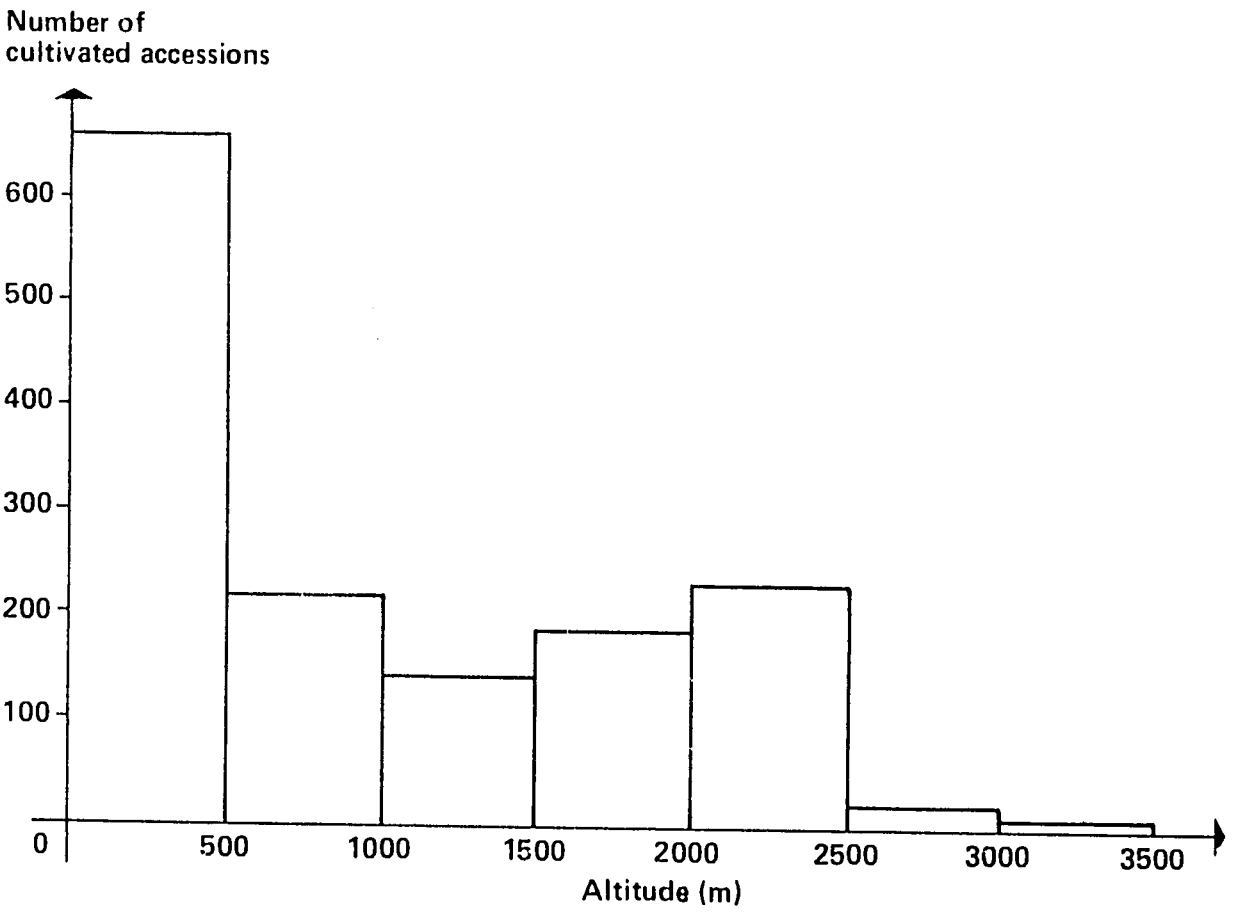
Figure 13. Venezuela – Number of accessions of *I. batatas* collected by departments.



Following Graphic (1) presents the frequency of the altitude of the localities where the cultivated accessions were collected in each country as a tentative indication of the geographical distribution of this genetic resource. About 62% of these accessions were found up to 1,000 m. of altitude and very few (16%) above the 2,000 m., the highest altitude of the localities where some cultivated accessions were collected are: Rumipampa, Ibarra, Ecuador (2,850m. altitude, 3 accessions, Dlp. 1407, 1408 and 1409) and Chavin de Huantar, Huari - Ancash - Perú (3,100m altitude, 3 accessions, Dlp. 476, 477 and 478).

During the field work, was possible to observe a great phenotipic variability in this collected Germplasm.

Graphic 1. Distribution of the cultivated, collected accession by its altitude.



POST COLLECTING ACTIVITIES

Some information about the introduction, quarentenary period and taxonomic identification will be also reported in this occasion.

INTRODUCTION

All regulations of the peruvian government was considered to introduce the foreign sweet potato germplasm. Herbarium samples, true seed and cuttings were the only collected samples introduced to Perú, no tubers at all were included in this introduction ; this material was treated with recommended pesticides, during sampling time and transportation.

QUARENTENARY PERIOD

The collected material at its arrival to CIP, was checked by a team of sanitary specialists. About 5.10% of the arrived cultivated accessions were eliminated for this quarentenary activity. In the case of the wild accession, approximately 10-15% was excluded for the same purpose. After this check, the cuttings were preserved in water in bottles of milk, for approximately 30 days. Buds of 8-10 cm. were obtained from these cuttings and transplanted to JF-7 under greenhouse conditions for preservation and future multiplication. A duplicated sample of cultivated collected accession was left in each country. This material is now preserved in the localities indicated in Figure 14, by the national institutions and CIP.

TAXONOMIC IDENTIFICATION

A primary taxonomic identification of the collected material was made in the field during the collecting time. At this time, the accessions were included into "Ipomoea batatas" or "Other Ipomoea" species. Later, the taxonomic treatment of the accessions included into the group of other Ipomoea species, were kindly identified by Dr. D.F. Austin, Florida Atlanta University in Boca Raton, U.S.A.. Fourty one Ipomoea species listed in Table 4 have been already identified in the 46 percent of the wild collected accessions. Six species of the section batata were included in this identification.

Table 4. Ipomoea Species Identified in Part of The Collected Material

1.	I. alba	Peru
2.	I. amnicola	Peru
3.	I. aquatica	Colombia, Ecuador, Peru
4.	I. aristochiaefolia	Bolivia, Ecuador, Venezuela
5.	I. asarifolia	Ecuador, Peru
6.	I. bonariensis	Peru
7.	I. cairica	Peru
8.	I. calantha	Venezuela
9.	I. carnea	Peru
10.	I. crysocalyx	Ecuador
11.	I. dubia	Ecuador
12.	I. dumetorum	Ecuador, Peru
13.	I. harlingii	Ecuador
14.	I. hederifolia	Bolivia, Ecuador, Venezuela
15.	I. incarnata	Colombia, Peru, Venezuela
16.	I. indica	Bolivia, Colombia,Peru, Venezuela
17.	I. Jujuyensis	Ecuador
18.	I. x leucantha*	Ecuador
19.	I. meyeri	Ecuador, Venezuela, Peru
20.	I. minutiflora	Venezuela
21.	I. nil	Colombia, Ecuador, Peru, Venezuela
22.	I. ophiodes	Ecuador, Peru
23.	I. parasitica	Venezuela, Ecuador
24.	I. phillomega	Ecuador
25.	I. pesca-prae	Peru
26.	I. piurensis	Ecuador, Peru, Venezuela
27.	I. purpurea	Bolivia, Colombia, Peru, Venezuela
28.	I. quamollit	Ecuador, Venezuela
29.	I. ramossisima*	Bolivia, Ecuador, Peru
30.	I. regnelii	Peru
31.	I. reticulata	Ecuador
32.	I. setosa	Ecuador, Peru
33.	I. signata	Venezuela
34.	I. squamosa	Colombia, Ecuador, Peru
35.	I. subrevoluta	Colombia
36.	I. tricolor	Peru
37.	I. triloba *	Colombia
38.	I. trifida *	Colombia, Venezuela
39.	I. trichocarpa x* lacunosa	Venezuela
40.	I. tiliacea*	Dominican R., Colombia
41.	I. wrightii	Ecuador

* Species included in section batatas.

In summary, in this short period of the development of this project, the following goals have already been achieved:

1.- The genetic variability of CIP's sweet potato germplasm has been expanded. Cultivated, wild and feral accessions of five latin-american countries have been included.

2.- About 2,219 accessions of cultivated and wild germplasm have been introduced to this germplasm.

3.- Localities with a possible great genetic variability in these Ipomoea species have been identified in Bolivia, Colombia, Dominican Republic, Ecuador, Peru and Venezuela.

4.- A well organized sweet potato gene bank has been initiated. The herborization, Taxonomic identification, characterization, preservation, computerized documentation and evaluation of this germplasm are underway.

5.- A great experience in collecting wild and cultivated sweet potato germplasm has been gained.

6.- Complementary localities of distribution for some wild Ipomoea species in each country have been identified.

7.- New Ipomoea species not yet reported in some countries have been found.

8.- The recognition of the importance of the preservation and utilization of this genetic resources at national programs has been promoted.

9.- A well organized herbarium for the Ipomoea genus are underway.

10.- Having promoted a conjunction work with other "collecting projects" such as IBPGR/IBTA (Bolivia) and IBPGR/ICA (Colombia).

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CURRENT STATUS ON THE MAINTENANCE OF SWEET POTATO GENETIC RESOURCES AT CIP

Zosimo Huaman

INTRODUCTION

Sweet potato production ranks second in world root and tuber crop statistics after potato. It is cultivated throughout the tropical world for its edible storage roots which are an important source of food in many countries. Sweet potatoes are usually eaten boiled or baked, they are also used as a source of starch, glucose, syrup and alcohol. The storage roots are also fed to livestock. The tender shoots and leaves are an important source of vegetable fiber and food or are used as a pot-herb in some tropical countries. The vines are widely used as a fodder for stock [19].

Sweet potatoes are grown at latitudes ranging from 40° N to 32° S. On the equator they are grown at altitudes from sea level to 3000 m. The crop is more tolerant than most other tropical roots to a wide range of edaphic and climatic conditions [19]. It requires only low inputs. Tolerance for limited water and little fertilizer permits production in semi-arid conditions. Sweet potatoes are grown as rotations of various crops and acceptable yields are frequently produced with residual fertilizer remaining from a previous crop [21].

The sweet potato is classified within the family Convolvulaceae which includes 40 or 50 genera and 1200 or more species. The genus Ipomoea contains about 500 species [1]. The sweet potato was described as Convolvulus batatas by Linnaeus in 1753. Some decades later it was re-described as Ipomoea batatas by Lamarck in 1791. Ipomoea batatas is classified within section Batatas and is a hexaploid with 2n=6x=90 chromosomes and a basic chromosome number of x=15.

As in most crop plants, the sweet potato genetic resources shows a wide spectrum of gene pools that can be grouped under the following categories:

1. **Wild species.** This category include 11 wild species and two hybridogenic species that are considered closely related to I. batatas. All of them are classified within Section Batatas and listed in Table 1 [3].

   There are, however, about 500 species that are classified in other Sections. Some of these species have been used as edible plants but have not reached extensive economic importance. Thus, I. aquatica, I. batatilla, I. biloba, I. fastigiata, I. grandiflora, I. hederacea, I. macrorrhiza, I. tuberosa, and I. turpethum [5]. Moreover, there are also some other species that, although, they produce storage roots, they are not related to sweet potatoes. Thus, I. digitata, I. eggersiana, I. leptophylla, I. lineariloba, I. longiflora, I. mammosa, I. pandurata, I. sinuata and I. tuberculata [17, 18].

   Other Ipomoea species are used as ornamental plants (I. purpurea, I. tricolor), virus symptoms indicator plants (I. setosa, I. nil), etc.

Table 1 - Wild Ipomoea species closely related to sweet potato Section Batatas (Austin,1983).

Species	Ploidy	Geographic Distribution
I. trichocarpa Elliot	2x	USA, MEX, ARG
I. lacunosa L.	2x	USA
I. x leucantha Jacquin	2x	Worldwide
I. triloba L.	2x	Caribbean (widespread)
I. tenuissima Choisy	2x?	Caribbean
I. ramosissima Choisy	2x?	Meso, South America
I. trifida G. Don	2x? (3x,4x,6x)	Meso America (CUB)
I. tiliacea Choisy	4x	Caribbean (BRA, ASIA)
I. cynanchifolia Meisner	2x?	BRA
I. x grandifolia O'Donell	2x?	BRA, PRY, URY, ARG
I. peruviana O'Donell	?	PER
I. gracilis R. Brown	2x,4x	AUS
I. littoralis Blume	4x	Austral-Asian Pacific (MEX)

2. **Weed** or feral species, which include those wild plants that are found growing in cultivated fields and adjacent areas in regions of traditional agriculture. In the case of Ipomoea species is more frequent to find escapes of I. batatas rather than truely weed species. A classic example of this is the hexaploid I. trifida (K123) collected by Nishiyama which is considered a feral sweet potato by Austin [3].

3. **Native** cultivars. This category includes all those cultivars which have been grown for long periods of time under traditional agriculture. Some of these cultivars may posses primitive features such as grooves in the storage roots, very dispersed storage root formation, strongly anthocyanin-pigmented flesh,etc.

4. **Advanced or improved** cultivars, which have been selected with modern methods of plant breeding. T[Bhey are generally well adapted to environmental conditions of major production areas.

5. **Breeding lines.** This germplasm resource generally include highly selected materials for a number of valuable traits. Very often some of these lines might fail to fulfill all the requierements to be released as an advanced cultivar in a given country but could became of major importance in another country.

Current knowledge of the distribution of sweet potato genetic resources indicates that maximum diversity of I. batatas occurs in Northwestern South America (Colombia, Ecuador and Northern Peru) and that this variation is greater than in Mexico and Central America. Secondary centers of diversity are located in 1) Mesoamerica with great diversity of weed and wild plants especially in Guatemala, and 2) in Southern Peru. Other secondary centers occur outside of the Americas [20, 22, 24, 8, 3].

In the same trend as in other major crop plants, the sweet potato genetic resources are facing a high risk of losing significant amounts of variation and this threat is expected to increase more in the future [8]. This process of genetic erosion started since the arrival of Spaniards to America when numerous sweet potato cultivars were lost because of the shift from predominantly starchy roots to the sweet types. This shift appeared to better suit the taste of Europeans who derived their starches from other sources.

Further genetic losses could have taken place by exchange and replacement of native cultivars with others developed by early European breeders [3, 22]. At present it is also recognized that the genetic base in highly developed countries is narrowing due to concentration on breeding specialized market types. In developing countries variation might be eroded through the trend towards cultivation of fewer commercial cultivars [8].

Since 1985 the International Potato Center (CIP), in collaboration with the International Board for Plant Genetic Resources (IBPGR), has initiated the development of a sweet potato gene bank in Latin America. This effort will complement the activities of other national or international organizations interested in preserving these valuable genetic resources. CIP is located close to the area of greatest genetic diversity which is also threatened with high genetic erosion. Furthermore, at present it appears that very little is known about cultivar variation within sweet potatoes in the Americas. Existing collections in Latin America are generally not well documented and their maintenance might not be adequate due to limitations in funding and facilities.

CONTENT OF CIP'S SWEET POTATO COLLECTION

Considerable progress has already been achieved in terms of numbers of accessions maintained in CIP's collection of sweet potato genetic resources. A total of 3,846 accessions have been obtained and the number of accessions within each type of germplasm is shown in Table 2. The collection comprises 77% of cultivated materials and 33% of accessions from several wild species. About 43% of the accessions have been received as donations to CIP by several institutions from six countries. The remaining 57% came from new collecting expeditions lead by Dr. F. de la Puente which were organized and sponsored jointly by CIP and IBPGR.

Table 2 - Number of accessions by type of germplasm

Type of Germplasm	Del Carpio	Arbizu U. Ayacucho	De la Puente CIP-IBPGR	Other Collec.	Total
Wild (Sec. Batatas)	--	1	110	27	138
Wild (Other Sec.)	--	10	495	3	508
Wild (Undetermined)	--	--	222	11	233
Native cultivars	288	554	1,392	181	2,415
Improved cultivars	49	--	--	27	76
Breeding lines	429*	--	--	47	476
T O T A L	766	565	2,219	296	3,846

* Selected from 797 received

Amongst the largest donations received by CIP were: 1) The Peruvian sweet potato collection maintained by Ir. Romulc del Carpio in Chincha (Departament of Ica) which has been widely known by many sweet potato researchers; and 2)The collection from the University of Ayacucho which was collected by Carlos Arbizu with IBPGR funding. These two collections have been duplicated in several other Peruvian institutions such as the Agricultural Experiment Station and the National Agrarian University at La Molina in Lima .These latter collections were, therefore, not included in CIP's collection to avoid further duplication. Many other accessions were also received from other six Peruvian institutions; from one institution each in Costa Rica, Dominican Republic and China, two institutions in the USA , and several scientists from Japan (Table 3).

Table 3 - Sources of Ipomoea accessions in the collection

Source	Country	Number of Accessions
De la Puente (CIP/IBPGR) collection	Peru*	2,219
R. del Carpio's Collection	Peru*	766
Univ. of Ayacucho (C. Arbizu)	Peru	565
Univ. of Iquitos	Peru	45
Univ. of Lambayeque	Peru	31
Univ. of Tacna	Peru	19
Agr. Exp. Sta. Cañete	Peru	47
Agr. Exp. Sta. Chincha	Peru	24
Agr. Exp. Sta. Yurimaguas	Peru	4
C.A.T.I.E.	Costa Rica*	34
Agricultural Development Center	Dominican Rep.	22
U.S. Vegetable Laboratory (Charleston, S. Carolina)	U.S.A.	24
U.S. Tropical Agric. Res. Sta. (Mayaguez, Puerto Rico)	U.S.A.	1
Y. Umemura	Japan	30
Several scientists	Japan	8
China	China	7
T O T A L		3,846

* Include accessions of several countries

The cultivated gene pool available at CIP consists of 2,491 accessions including 2,415 samples of native cultivars and 76 improved cultivars which originated in 21 countries (Table 4). About 68% of the cultivars were collected in Peru; 27% in Venezuela, Colombia, Ecuador, Bolivia and the Dominican Republic; and the remaining 5% were donations from other 15 countries.

Table 4 - Number of Sweet Potato Accessions per Country

Country	Del Carpio	Arbizu U. Ayacucho	De la Puente CIP-IBPGR	Other Collec.	Total
SOUTH AMERICA					
Venezuela	1	--	52	--	53
Colombia	--	--	243	--	243
Ecuador	1	--	224	--	225
Peru	288	554	733	121	1,696
Brazil	6	--	--	--	6
Bolivia	1	--	103	--	104
Chile	1	--	--	--	1
Argentina	1	--	--	--	1
CENTRAL AMERICA					
Guatemala	--	--	--	4	4
Honduras	--	--	--	3	3
Costa Rica	--	--	--	21	21
Panama	--	--	--	1	1
CARIBBEAN					
Dominican Republic	--	--	37	22	59
Puerto Rico	2	--	--	1	3
NORTH AMERICA					
Mexico	1	--	--	3	4
U.S.A.	30	--	--	25	55
OTHER					
China	--	--	--	7	7
Taiwan	1	--	--	--	1
Japan	1	--	--	--	1
Australia	1	--	--	--	1
South Africa	2	--	--	--	2
T O T A L	337	554	1,392	207	2,491

From the 1696 cultivated accessions collected in Peru, 1070 were collected along all the 10 departments located in the coastal region ; 431 accessions originated from the inter-Andean valleys of 9 departments in the highland region; and 195 accessions were collected in 4 departments of the lowland tropic region of Peru (Table 5).

Table 5 - Number of Sweet Potato Cultivars per Department in Peru

Department	Del Carpio	Arbizu U. Ayacucho	De la Puente CIP-IBPGR	Other Collec.	Total
COASTAL REGION					
Tumbes	8	14	25	--	47
Piura	3	12	108	--	123
Lambayeque	7	--	33	3	43
La Libertad	28	24	72	--	124
Ancash	11	74	74	1	160
Lima	161	33	126	28	348
Ica	36	4	--	24	64
Arequipa	13	36	49	--	98
Moquegua	--	10	13	--	23
Tacna	1	16	3	19	40
HIGHLAND REGION					
Cajamarca	--	125	149	--	274
Huanuco	--	25	7	--	32
Pasco	1	14	18	--	33
Junin	1	20	--	--	21
Huancavelica	--	7	--	--	7
Ayacucho	--	18	--	--	18
Apurimac	--	12	--	--	12
Cuzco	9	24	--	--	33
Puno	--	--	1	--	1
LOWLAND TROPIC REGION					
Amazonas	--	66	11	12	89
San Martin	--	5	29	24	58
Loreto	--	--	15	6	21
Ucayali	--	6	--	3	9
Madre de Dios	--	--	--	--	0
Unknown	9	9	--	--	18
T O T A L	288	554	733	120	1,696

The wild gene pool is represented by 879 accessions in the collection. Taxonomic identifications have been made in 646 of them by Dr. D. Austin from the Florida Atlantic University in Boca Raton, U.S.A. There are other 233 samples of wild species which have still not been identified.

From a total of 138 samples classified as species within Section Batatas, 2 are samples of I. cordatotriloba (=I. trichocarpa); 7 of I. leucantha; 18 of I. ramosissima; 3 of I. tiliacea; 93 of I. trifida; 9 of I. triloba; 5 are likely to be natural hybrids between unknown wild species and I. batatas; and 1 sample might be a hybrid between I. trichocarpa x lacunosa.

There are 508 accessions of wild species which have been classified within other Sections not related to I. batatas. A total of 304 of them comprise species of very wide distribution such as I. purpurea, I. nil, I. carnea spp. carnea and fistulosa, I. heredifolia, I. incarnata, I. squamosa, I. alba, I. indica, and I. piurensis. The other 200 accessions comprise 27 other species.

Data on the provenance of all these wild accessions are providing valuable information on the general distribution of Ipomoea species in the countries were extensive collections have been made [4]. This will certainly improve our knowledge about South American taxa which has so far been considered comparatively poorly known [2].

MAINTENANCE OF THE COLLECTION AT CIP

Although, all the sweet potato genetic resources can be maintained by sexual and asexual propagation, the form in which these resources are maintained depend on whether the material is cultivated or wild. At CIP all accessions of wild species are maintained in the form of seeds. However, in the case of cultivated germplasm , clonal maintenance will be needed until enough seeds are obtained and duplicate genotypes are identified.

It has been of major importance to decide the best method for clonal propagation of cultivated material that conserve as intact as possible the characteristics of each cultivar. The high frequency of somatic mutations in sweet potatoes producing changes in storage root skin color, flesh color, vine lenghts and pigmentation, etc. [9] could create problems in the maintenance of a large number of accessions. In other sweet potato collections, a common practice is to store roots for several months, plant them once a year, and then maintain the identity of each accession by hill selection. Furthermore, Martin in 1975 [14] suggested to maintain large collections of sweet potatoes in a state of inmaturity in which cuttings would be

grown in small containers and re-propagated periodically from small cuttings. This system would allow to maintain about 1000 cultivars in a space of 50 to 60 square meters.

At CIP we are presently maintaining the cultivated collection by clonal propagation twice a year using stem cuttings. However, continous growth of the collection in the field maintains high populations of insects and the chances for virus spread among accessions are extremely high. Therefore, we are developing a procedure to plant the collection in the field for only one season of about six months during the year. Sweet potato roots do not have a seasonal dormancy and require some careful management to secure a relatively long storage life. However, under the natural environmental conditions of La Molina, the roots stored at room temperature are in good conditions for several months.

Considering that any international distribution of cultivars maintained at CIP will have to be made in-vitro, CIP has initiated the tranfer to in-vitro culture of selected genotypes from the cultivated collection. So far about 310 morphologically different accessions of Peruvian cultivars and some foreign improved cultivars are already being maintained in-vitro. Furthermore, a CIP-IBPGR project to secure the in-vitro maintenance of national sweet potato collections in Latin America has recently been funded. This project considers training and the provision of supplies to install low cost in-vitro laboratories in each participating country. It is anticipated that the implementation of this project will facilitate the transfer to in-vitro culture of all cultivated germplasm collected in each country by CIP or other institutions.

For long term conservation, seeds of cultivated germplasm will be obtained in ways similar to those used to conserve potato genetic resources at CIP [6]. These include:

1) Open-pollinated seeds produced by plants grown in the field as soon as they have passed through quarantine. Furthermore, all accessions identified as duplicates of the same cultivar will be placed in a polycross to produce seeds prior to their elimination from clonal propagation.

2) Geographic seed pools produced in polycrosses of non-duplicate cultivars collected in the same geographic area. These seeds will conserve genes for adaptation to specific eco-geographical zones.

3) Trait-specific seed pools obtained in polycrosses of genetically different cultivars in the colection that posess the same desirable attribute.

The hard coated seeds produced by species in the genus Ipomoea are among those with the greater life spans [12]. These seeds are considered by IBPGR as "orthodox" and require mechanical or chemical scarification to enhance germination [7]. Experimental data showed that these seeds retain good viability for at least 20 years when stored at 50% relative humidity and 18°C. However, seed longevity should be higher when stored under temperatures below 0°C. For long term conservation, low density seeds should be removed by flotation in water containing a surfactant [10]. Seed weight also appears to affect storage life. Thus, large size seeds (15 to 30 mg) germinates more readily than those of smaller size [15].

Flowering appears to be one of the major problems to produce seeds in sweet potatoes. There are genetic differences and environmental influences that affect flowering incidence [23, 16]. Photoperiod appears to be an important factor to induce flowering and the optimum seems to be about 12 hours. Flowering and seed set is normally reduced when vine growth is rapid and vigorous. Therefore, low nitrogen fertility and low soil moisture are recommended agricultural practices [9].

One of the most recommended methods to obtain sweet potato seeds is by polycrosses. This method consists of planting about 30 cultivars in isolated plots to permit natural intercrossing by insects. Bee hives placed near these plots can assure adequate number of pollinators [11]. There are problems of low fertility due to the hexaploid nature of sweet potatoes as well as the existance of complex compatibility and sterility systems. The floral biology of the crop also makes it necessary to produce large number of fruits because each flower produces only four ovules.

If successful crossing takes place, the fruit requires about one month to attain maturity and seeds mature also in about a month when the capsules are completely dry and brown. Each capsule contains a maximum of 4 seeds but generally they contain 1 or 2 [9].

Most of the environmental conditions considered to be optimum for flowering and seed setting are met at La Molina located in the desert coast of Peru. Furthermore, representative samples of the collections are also grown in

other two experimental sites located in San Ramon, mid-elevation tropics, and at Yurimaguas in the low, humid tropics.

Peruvian cultivars that have been planted at La Molina during the summer showed great variations in their flowering ability under field conditions which did not include any special cultural practices to induce flowering. Results of evaluations of flowering ability made among Peruvian accessions grown at La Molina is shown in Table 6.

Table 6. Flowering habit of Peruvian accessions of *I. batatas* grown at La Molina in the Summer season.

Flowering Habit	Percentage of Accessions
None	9%
Scarse	21
Sparse	18
Moderate	49
Profuse	3
	100

Seed setting is also quite variable. Although, plants grown at La Molina set seeds during the summer, better flowering and seed set was observed at San Ramon during the dry season in a representative sample of the collection. The range of the number of seeds so far obtained from 10 plants per accession is shown in Table 7.

Table 7. Seed setting of Peruvian accessions of *I. batatas* grown at La Molina in the summer season.

Range of Number of Seeds obtained in 10 plants	Percentage of Accessions
0	16.6%
1 - 50	40.5
51 - 100	13.9
101 - 150	8.4
151 - 300	9.5
301 - 500	4.6
501 - 750	4.2
751 - 1275	2.3
	100.0%

The use of low nitrogen fertility, water stress, trelliswork, etc. will certainly increase the flowering ability and seed setting in a higher percentage of accessions in the collection. Some research on flowering induction in those cultivars which do not flower or produce scarse flowering has been conducted at CIP by Y. Eguchi. He reports (personal communication) that flowering is remarkably improved by means of short day treatment (9 hours/day) and grafting.

QUARANTINE

In order to minimize the risk of introducing new pathogens and/or pests to the area where the gene bank is located, the following procedures have been adopted for the transfer of genetic resources of sweet potato from the centers of diversity:

1) For accessions of wild species, as many seeds as possible are collected in each site.

2) For cultivated accessions the collection of storage roots are avoided as much as possible. If this type of material is received, they are desinfected with pesticides and stored in close containers kept under quarantine until they sprout. Stem cuttings from sprouted roots are then taken and the original samples destroyed.

3) Most of the cultivated accessions have been introduced as stem cuttings from plants that appear visually healthy and treated with insecticides at the moment of collection. The country which provides a phytosanitary certificate fumigates the material prior to sending the materials. On arrival to CIP they are inspected by CIP's pathologists and entomologists. The cuttings are then placed in bottles containing water in the quarantine house until they grow enough to obtain new stem cuttings which are then planted in pots.

4) All cultivated accessions from other countries are maintained only in the quarantine house. They are gradually being transferred to in-vitro culture until these accessions can be thouroughly evaluated for viruses.

5) In the near future all cultivated collections from outside Peru will be tranferred to in-vitro culture by national programs prior to sending to CIP. This will be possible through a CIP/IBPGR project to implement in-vitro laboratories in several countries of Latin America. Furthermore, the immediate transfer to in-vitro culture of single nodes and buds at the site of collection is currently being evaluated. This would reduce the risk of introducing major pests into the host country.

6) Seeds of wild and cultivated accessions are also fumigated prior to storage.

EVALUATION

One of the most important activities in a genebank is the evaluation of the accessions being maintained. The first step has been the proper taxonomic identification of all accessions of wild species. For this CIP has received the valuable collaboration of Dr. D. Austin a leading authority in the taxonomy of Ipomoea species.

The cultivated germplasm need to be characterized morphologically so that each accession could be easily identified to avoid mixtures due to mutations, wrong labelling, etc. Moreover, the presence of many accessions of the same genotype, i.e. duplicates, in the collection requires that each accession should be characterized for numerous morphologic features to make duplicate identification possible. CIP's experience in identifying duplicates in a very large collection of potatoes on the

basis of morphologic and biochemical comparisons could be successfully applied to sweet potatoes. Considerable differences have already been reported in banding patterns of peroxidase isoenzymes from roots of sweet potato cultivars using gel electrophoresis [13].

In the past two years a great effort has been placed in the development of a descriptor list that could describe most of the variation observed in this large collection. Eight plant and storage root characters considered to be key characters for a fast grouping of morphologically alike accessions have already been identified. Data recorded for this 8 characters in 854 Peruvian accessions has facililated the identification of 522 accessions which are likely to be duplicates of 138 different cultivars. Although, numerous groups comprise 2 to 3 duplicate accessions, some groups have from 10 to 19 duplicate samples collected over extensive geographic areas (Table 8). Protein and enzyme patterns produced from extracts of storage roots by electrophoretic analyses on these samples will verify the groups made on the basis of morphologic comparisons. Prof. Stegemann at the Institut fur Biochemie Biologischen Bundesanstalt, Braunschweig, West Germany, is analyzing several electrophoretic techniches to develop a standardized procedure to be used for the verification of duplicate accessions.

Table 8 - Number of duplicates identified among 854 Peruvian accessions.

Number of Aceessions per Group	Number of Groups	Total Number of Accessions
2	66	132
3	28	84
4	9	36
5	8	40
6	6	36
7	7	49
8	4	32
9	5	45
10	2	20
12	1	12
17	1	17
19	1	19
T O T A L	138	522

Priorities for the evaluation of the collection for the most important biotic and abiotic factors affecting the sweet potato crop will be established according to the needs of breeding programs. However, some preliminary evaluations have already been made for the following traits:

1) Reaction to root knot (Meloidogyne incognita). A total of 744 accessions including native cultivars, improved cultivars and breeding lines have been evaluated by artifitial inoculations. Good levels of resistance were found in 86 accessions, 39 were moderately resistance and 619 were susceptible.

2) Reaction to the root lesion nematode (Pratylenchus flakkensis). A sample of cultivars that showed some resistance to root knot nematode were grown in pots containing roots and soil infected with Pratylenchus. From 20 cultivars tested, 16 of them showed a very low rate of reproduction of the nematode in the roots thus indicating also possible resistance to this nematode.

3) Reaction to the sweet potato weevil (Euscepes postfasciatus). Very recently about 200 cultivars are being tested for their reaction to this weevil. Final results are not yet available.

4) Evaluation of the incidence of the sweet potato feathery mottle virus in the collection. From a total of 459 accessions from the Del Carpio's collection which have been clonally propagated for several decades, 77 showed positive infection with this virus using ELISA and host plant indicators.

5) Evaluation for tolerance to salinity, drought and boron toxicity. A total of 157 cultivars were grown in a saline-arid soil in the Atacama desert in Southern Peru. Good levels of tolerance were found in 9 cultivars while 14 other were moderately tolerant.

6) Tolerance to excess soil moisture and aluminum toxicity. A large sample of cultivars including native,improved and breeding lines comprising 463 accessions were grown during the wet season at Yurimaguas located in the Amazon basin. A total of 251 accessions did not produce storage roots when harvested at 150 days, 170 had low yields ranging between 0.5 to 10 tons/hectare, 36 yielded from 10 to 25 tons/hectare, and 6 accessions produced from 25 to 33 tons/hectare.

7) Dry matter content in storage roots. In a small sample consisting of 35 accessions, great variation for this trait was observed. The results obtained in 3 of them ranged from 18 to 25% of dry matter, 25 had between 26 and 35%, and 7 from 36 to 43%.

8) Other culinary attributes of boiled storage roots. About 900 accessions have been tested for characters such as consistency of boiled roots, sweetness, fiber content, etc. Great variation was found for all these characters.

DOCUMENTATION

Since the value of the materials conserved in a genebank is increased if the data related to each accession is readily available, CIP is developing a computerized data bank for the sweet potato collection. All available data on the collecting locality and other passport data, morphologic characterization and preliminary evaluation of each accession in the collection have been stored in a computerized data bank.

The descriptor list for sweet potatoes published by IBPGR in 1981 [8] has been used as much as possible to document the collection. However, the variation observed in the collection for many descriptors related to the characterization and preliminary evaluation made necessary to develop a more comprehensive list of descriptors.

CONCLUSION

In a relatively short period of time it has been possible to accumulate one of the largest collections of Ipomoea batatas in existance in the world. This is undoubtedly a very important step for the conservation of sweet potato genetic resources which has been possible thanks to an extensive international collaboration. Funding made available through the CIP/IBPGR project to develop a sweet potato genebank was instrumental for this progress. CIP has taken advantage of its strategic location in Peru close to the primary and secondary centers of high diversity of I. batatas and its allied wild relatives to organize numerous collecting expeditions. Furthermore, CIP's involvement with a large number of institutions in the Americas has also facilitated not only to receive donations

of several national or institutional collections but also to get the active participation of scientists from National Programs in Latin America in all collecting activities. Finally, CIP has also received a great support from many leading sweet potato scientists in the U.S.A. and other countries in the process of developing this genebank. All this international effort towards the conservation of sweet potato genetic resources will certainly contribute to save these valuable resources from extinction in their centers of diversity. The utilization of these resources in the genetic improvement of this important crop plant will contribute to solve the problems of food availability for the benefit of all mankind.

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THE U.S. SWEET POTATO GERMPLASM REPOSITORY

Robert L. Jarret

INTRODUCTION

The narrow genetic base of todays sweet potato cultivars emphasizes the need to introduce new sources of genetic diversity for use in sweet potato breeding programs. However, until recently the international movement of clonally propagated sweet potato germplasm has been restricted due to an inability to effectively identify and eliminate pathogens (principally viruses) from these materials prior to entry. This problem persists but has been partially overcome in the last few years as more efficient meristem culture techniques and more reliable virus assays have become available. As a result, the exchange of sweet potato germplasm is expected to increase. The U.S. Sweet Potato Germplasm Repository (SPGR), now being established, will assist in the maintenance, evaluation and distribution of the genetic diversity which characterizes *Ipomoea batatas* and related species.

LOCATION

The SPGR is located on the campus of the University of Georgia's Experiment Station in Experiment, Georgia. Experiment is located about 40 km south of Atlanta on Highways 19 and 41.

The repository is officially a part of the S-9 Plant Germplasm Project which handles germplasm of crops principally grown within the 13 southeastern states within the continental U.S. but includes Hawaii, Puerto Rico and the Virgin Islands. The mission of the S-9 project is to introduce plant germplasm and to provide this germplasm both nationally and internationally to scientists for their research. At the present time, approximately 57,000 plant introductions (PI's) are maintained by the Plant Introduction Department at Experiment. These PI's represent 298 genera (1,4[illegible] species) of largely seed-propagated cereal grains, forage grasses, groundnut, and various vegetables. The largest collections are those of Sorghum, *Arachis*, *Cajanus*, *Vigna*, *Capsicum*, *Cucumis* and *Citrullus*.

OBJECTIVES

The objectives of the repository will include the acquisition, maintenance, characterization, distribution and enhancement of

sweet potato germplasm. Not all of these objectives will recieve equal attention and, when possible, cooperative efforts will be established to pursue research in a particular area. Considerable expertise already exists within several national and international centers, and it is hoped that we will be able to draw upon this expertise as needed. For example, tissue culture techniques for germplasm maintanence are already well developed and are being utilized with sweet potato (2).

APPROACH

Acquisition. Plant introductions coming into the U.S. will pass through the USDA's plant quarentine facility in Beltsville, Maryland where the individual introductions will undergo meristem culture for virus and other pathogen elimination. Dr. Jim Moyer (North Carolina State University) is also collaborating in this effort. From Beltsville the 'clean' materials will be distributed to the requesting individual and a duplicate sample will be introduced into the clonal repository for permanent maintenance. Numerous clones are presently being maintained in Beltsville awaiting introduction into the repository pending the completion of the facilities.

A priority of the repository will be to introduce into tissue culture a wide array of native 'heirloom' cultivars, PI's already in the plant introduction system and clones from extinct breeding programs. These materials will be meristem-cultured for pathogen elimination and subsequently maintained. These represent a minimum of several hundred clones. In order to minimize duplication of accessions, the collection of Dr. Al Jones will be moved to the repository and will serve as a reference collection. In collaboration with other national and international programs, the repository intends to introduce a substantial amount of 'new' germplasm.

The repository will also introduce populations of *I. batatas* as seed which will be stored in the Plant Introduction Department's Seed Storage Laboratory. Seed of *Ipomoea* species, especially members of section Batatas, will also be introduced into the collection.

Maintenance. The bulk of the clonal materials will be maintained as tissue cultures. Clones of particular interest will also be duplicated in a field genebank. Various techniques are available for storage of plant germplasm as tissue cultures and these include: storage under normal growth, storage under growth limiting conditions, cryopreservation, undercooling and possibly others (2). For example, dessication-induced quiesce

of somatic embryos may enable their storage for considerable periods of time. Eventually, the repository will identify that technique most applicable to long-term conservation of sweet potato.

Several approaches to in vitro conservation of sweet potato germplasm are now being evaluated (2). Of these, storage under growth limiting conditions appears to be the most readily applicable given the present, rather limited, knowledge of factors effecting growth reduction. Various parameters including temperature, osmotic effects, chemical inhibition, low oxygen, low pressure (hypobaric) and possibly others await intensive investigation. The growth retarding effects of reduced temperature and high osmoticum in the culture media have already been established. Although growth reduction appears to be immediately applicable to the conservation of sweet potato germplasm, numerous questions remain to be answered. How long can individual cultures be safely maintained? How many replicates are necessary? Is absolute genetic stability essential? Are field grow-outs necessary and if so, how often? Is it necessary, or desirable, to maintain any type of field genebank? Given the enormous time and expense involved in the acquisition of germplasm, these questions deserve answers.

Seed of I. batatas stores well for long periods of time and will be regenerated in a polycross nursery established for that purpose.

Characterization. One of the principle objectives of the repository will be germplasm characterization. This will be accomplished at the morphological, biochemical and molecular levels.

Morphological characterization will be accomplished using a descriptor list. Specific characteristics of individual clones such as disease or insect resistance will be identified through cooperative efforts with specialists in those areas. In addition, germplasm will be characterized using several relatively new but powerful techniques including the use of protein and deoxyribonucleic acid (DNA) genetic markers. Clonal identification is always a problem with vegetatively propagated crops such as sweet potato which are subject to the frequent occurence of mutations. As clones are characterized using a variety of techniques, clonal identification will be facilitated. In addition, this information will enable more accurate estimates of allelic diversity within the collection to be made and also will provide information on interclonal and interspecific relationships.

Distribution. Germplasm from the repository will be freely available. At the present time it is the intention of the repository to fill requests for germplasm by providing tissue cultures. However, in specific instances where tissue cultures may be unacceptable, germplasm will be also be made available as storage roots and/or as mini-storage roots (3).

Enhancement. There are no plans at this time to initiate investigations in the general area of sweet potato germplasm enhancement. Interspecific hybridization, transformation and field evaluation of in vitro regenerated variants are research areas targeted for consideration in the future.

FACILITIES

The Sweet Potato Germplasm Repository will be housed in one half of the former S-9 Plant Introduction Building. The other half of the building will house a plant pathology/virology laboratory.

Facilities for the sweet potato repository (see attached floor plan) include an office/computer area, a main laboratory for research, a secondary laboratory for in vitro maintenance activities, a walk-in growth chamber for culture storage and a greenhouse. In addition, several growth chambers will be housed in the autoclave room. A fume hood, centrifuges and other equipment will be shared by the repository and the plant pathology laboratories.

Specifics on particular aspects of the facilities are included below.

General laboratory areas.

The main and secondary laboratories are adequately equipped to perform all aspects of in vitro culture establishment and maintenance. Facilities and equipment are available for research in the general areas of germplasm characterization, maintenance and enhancement. In addition, virus indexing facilities will be available within the repository in order to ensure the virus-free status of all introductions.

Greenhouse facilities.

A heated greenhouse is attached to the clonal repository laboratory. The structure provides 160 m^2 of floor space and 80 m^2 of bench space.

Growth chambers for culture storage.

A walk-in growth chamber (1.8 m x 2.7 m) will serve as the main storage facility for the in vitro collection. This chamber is

equipped with 3 tiers of lighted shelving. The light intensity on each shelf is variable and all lights are connected to a timer for photoperiod control. The unit is equipped with an alarm and a back-up generator.

The walk-in growth chamber contains a total lighted shelf area of about 10 m^2. Using 18 mm x 150 mm culture tubes this will allow for storage of about 10,000 cultures. This capacity may be increased to about 12,000 with additional shelving.

Three Percival growth chambers will provide storage for an additional 5,000 cultures as necessary.

Total storage capacity of the repository, at present, is approximately 15,000 cultures. If 5 replicates per introduction are maintained, this represents storage space for 3,000 clonal sweet potato introductions. These facilities can be expanded as needed.

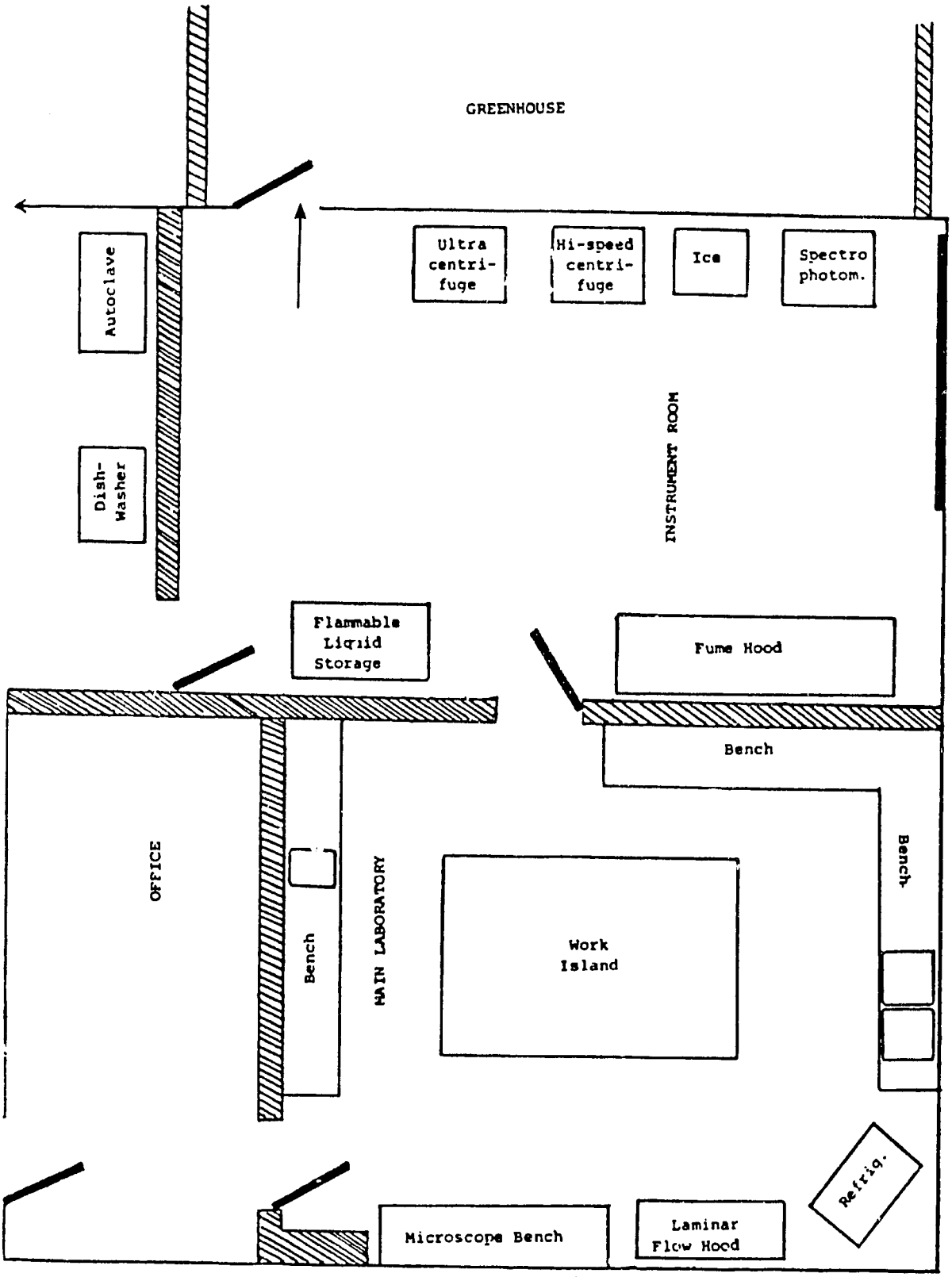
Computer facilities.

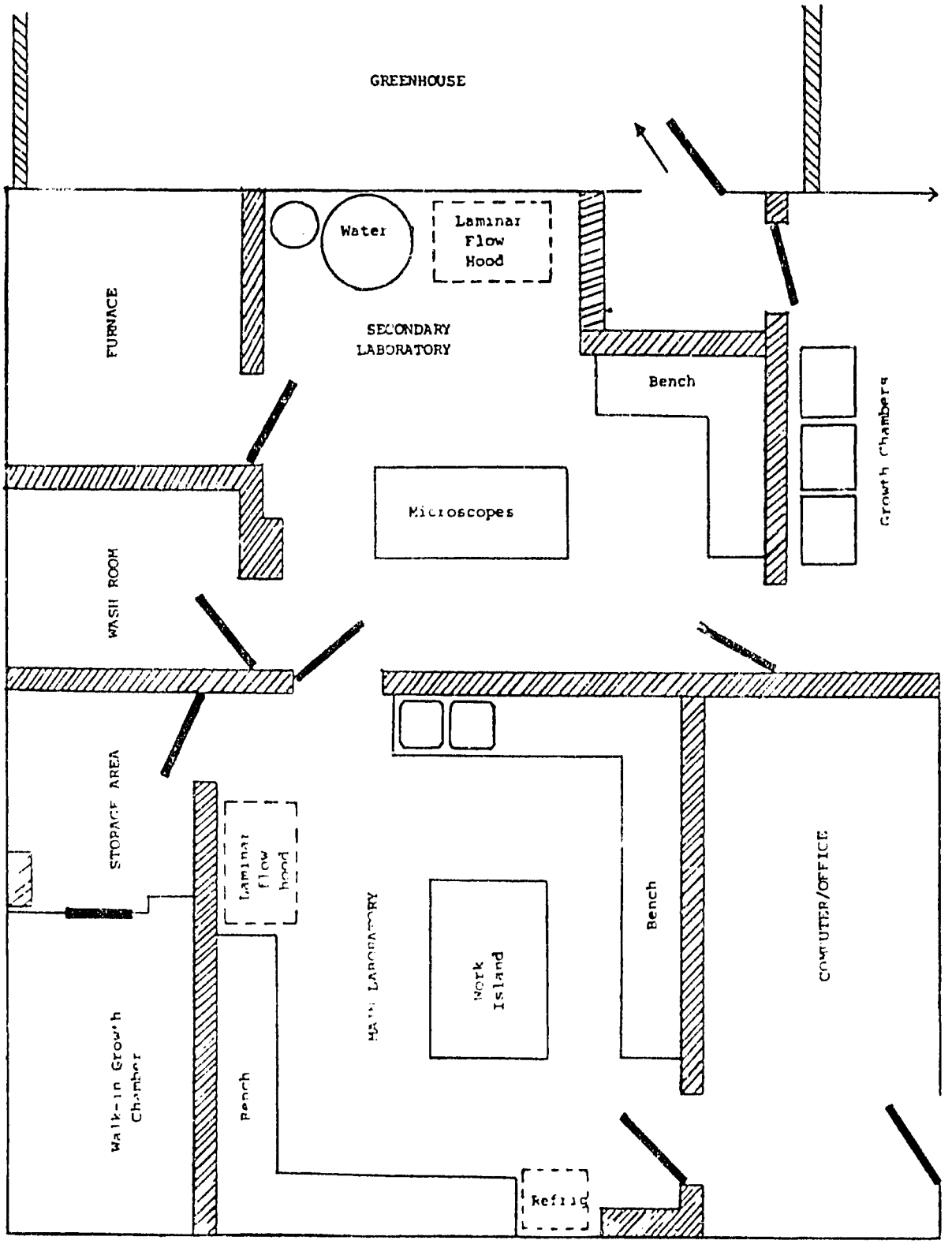
An IBM PC XT computer will be used to maintain the repository's records, for data storage and analysis and to project scheduled reculture/grow out dates. Several software packages will allow the computer to collect data directly from various instrumentation.

A separate software package 'Sire' is also available and will be utilized to store a reference list of all refereed and non-refereed journal articles related to sweet potato. The capacity of this system exceeds 30,000 entries. Literature searches will be available free of charge through the repository once this system is fully installed. A collection of reprints on germplasm releases and research articles is also being assembled and these materials will also be made available free of charge for research purposes through the repository.

Additional facilities (planned).

In addition to the facilities already described, the construction of two additional structures is scheduled for 1987. The first of these will be a prefabricated metal building which will house a curing chamber. The second structure is a 14 m x 60 m screen house which will be used for propagation, evaluation and maintenance of selected clones.


GREENHOUSE
Autoclave
Dish-Washer
Ultra centri-fuge
Hi-speed centri-fuge
Ice
Spectro photom.
INSTRUMENT ROOM
Flammable Liquid Storage
Fume Hood
Bench
OFFICE
Bench
MAIN LABORATORY
Work Island
Bench
Refrig.
Microscope Bench
Laminar Flow Hood


GREENHOUSE
Water
Laminar Flow Hood
FURNACE
SECONDARY LABORATORY
Bench
Microscopes
WASH ROOM
STORAGE AREA
Laminar flow hood
Work Island
Bench
COMPUTER/OFFICE
Walk-in Growth Chamber
Bench
Refrig

SUMMARY

The Sweet Potato Germplasm Repository is now in the final stages of completion. At this time, the objectives and operating procedures are still very flexible. Multiple research areas have been identified as potential candidates for future investigation. The research and maintanence activities of this repository will be integrated with those taking place at other centers designated to investigate and maintain sweet potato germplasm.

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STATUS OF SWEET POTATO COLLECTIONS MAINTAINED AT AVRDC

G.C.J. Fernandez, J.H. Lu and Y.K. Huang

Introduction

The Asian Vegetable Research and Development Center (AVRDC) has been dedicated to the promotion of sweet potato production and utilization, particularly in the Asian and Pacific regions through its intensive research and development programs since 1972. Since 105,524,000 tons of sweet potato were produced in 1985 in the Asian and Pacific regions, representing 92% of the world's sweet potato production (1), it is only of major economic importance in this zone. Through the end of 1986, AVRDC distributed 5,732 samples including clonal materials and botanical seeds to more than 50 countries for evaluation and utilization. Germplasm collection, conservation, characterization, documentation, utilization, and distribution of sweet potato materials have been emphasized at AVRDC's genetic resources and seed unit (GRSU). Recently, genetic resources activity has been expanded at GRSU with the completion of the new post-entry quarantine screenhouse, long-term storage facilities for seeds and fresh roots and facilities for in vitro collections. In 1984, the International Board for Plant Genetic Resources (IBPGR) designated AVRDC to become the repository for the Asian and Pacific sweet potato collection. This created a new dimension in the sweet potato genetic resources acitivity at AVRDC. This paper summarizes the status of sweet potato genetic resources activities at AVRDC, activities which are dedicated to increase world sweet potato production and utilization.

Germplasm Acquisition

Most of the sweet potato collection at AVRDC was introduced as donations and/or germplasm exchange from national programs and research institutions (Table 1). A total of 496 accessions was introduced in 1981 and 1982 from Papua New Guinea, an important center of genetic diversity. In addition, 13 groups of open-pollinated seeds of Papua New Guinea sweet potato accessions collected by the former IBPGR Intern, Dr. H. Takagi were transferred to AVRDC in 1986. From the Taiwan Agricultural Research Institute (TARI), Chiayi Station, 155 accessions were added to AVRDC collection on an exchange basis in 1983. Thus, sweet potato accessions from Papua New Guinea, Taiwan, and USA account for about 70% of the total collections.

Table 1. Institutions contributing to AVRDC's sweet potato germplasm collection.

Country	Institute	Accessions
Fiji Islands	Koronivia Research Station	5
Indonesia	Central Research Institute for Food Crops	9
Japan	Kyushu National Agric. Expt. Station	10
Nigeria	International Institute of Tropical Agriculture	17
Papua New Guinea	Kuk Agricultural Research Station	237
	Mendi Agricultural Research Station	152
	Aiyura Agricultural Research Station	84
	Laloki Agricultural Research Station	17
	Keravat Agricultural Research Station	9
Taiwan	Taiwan Agricultural Research Institute, Taichung	87
	Taiwan Agricultural Research Institute, Chiayi Station	177
	Tainan District Agric. Improvement Stn.	2
Thailand	Kasetsart University	6
USA	North Carolina State University	32
	US Vegetable Breeding Laboratory	99
	Sweet Potato Res. Center	23
Others	(collected by scientists)	253
Total		1,219

Table 2. *Ipomoea* species collections maintained at AVRDC.

Species	Accessions
Ipomoea batatas	1,207
Ipomoea setosa	10
Ipomoea nil	1
unidentified species	1
Total	1,219

At AVRDC, 12 wild and closely related species of sweet potato are also maintained (Table 2). Currently, efforts are ongoing to acquire more wild material to utilize in the breeding program, as well as for virus indexing and grafting studies.

Recently IBPGR has taken a very active role in coordinating, and sponsoring germplasm collection missions in the Southeast Asian and Pacific regions. Considerable unique material has been assembled by several national programs and by several collecting missions (Table 3). In order to prevent the deterioration of these collections, IBPGR and AVRDC agreed to assemble a duplicate collection at AVRDC. Thus, AVRDC's role has grown as repository for the Asian and Pacific sweet potato collections.

To safeguard against the introduction of any new pests and diseases into Taiwan, IBPGR donated a 226 m^2 aphid- and whitefly-proof post-entry quarantine screenhouse which has a capacity to handle 250-300 accessions per year. The sweet potato importation procedures at AVRDC are in close agreement with the Bureau of Commodity

Table 3. Current status of sweet potato germplasm collection in the Asian and Pacific regions.

Country	Accessions
Asia (7)	
Indonesia	249
Malaysia	335
Philippines	300
Thailand	354
Pacific (2)	
Cook Islands	11
Fiji Islands (France)	30
French Polynesia	15
New Caledonia (France)	54
Niue Islands	12
Papua New Guinea	1,505
Solomon Islands	359
Tonga	8
Tuvali	3
Vanuatu	8
Western Samoa	15
Total	3,258

Inspection and Quarantine, Taiwan, ROC. All introduced material, such as cuttings or roots, is treated with both insecticides and fungicides immediately upon arrival, and sprouting is induced inside the screenhouse. After sufficient quantities of meristem tissue culture have been derived from each accession, the original material is destroyed by autoclaving.

Recently, the first batch of 100 sweet potato samples from Chiang Mai University, Thailand were hand carried by AVRDC scientists, and are being propagated inside this quarantine screenhouse. Similarly, accessions from other Asian and Pacific countries will also be introduced in the near future. New introductions are first given a temporary number while under quarantine. After passing through the quarantine process, virus indexing, and checking for suspected duplication, each original accession will be assigned a permanent number.

Germplasm Conservation

Sweet potato germplasm conservation is a complex activity which includes both clonal maintenance and seed conservation. At AVRDC, the field genebank is utilized for maintenance of our active collection of 1,187 sweet potato accessions from 32 countries. It is re-established twice a year during March and September with cuttings obtained directly from the old field or sprouts regenerated from roots. Plot size of each accession is 1.5 m x 1.5 m with eight cuttings evenly spaced in the row. The whole field in planted only in alternate rows, leaving a row vacant to reduce the chance of vine intermingling among accessions. Field genebank operations require a large space, are labor intensive, and expose the materials to both biotic and abiotic stress. Because field planting of a large number of accessions is vulnerable to these hazards, duplication of the collection in *in vitro* culture is important as a back-up for the field genebank.

To date, 745 sweet potato accessions are being maintained *in vitro* culture, and the entire *in vitro* collection will be completed before the end of 1987. These *in vitro* cultures are maintained at 25±2°C in a 12-h photoperiod at 500-600 lux density. The culture medium contains MS salts, vitamins of B5 medium, 1 mg IAA, 1 mg kinetin, and 7 g agar in 1 liter of distilled water. The pH of the medium is adjusted to 5.7 to 5.8. Under these conditions, the *in vitro* cultures require sub-culturing every four months which is an expensive labor-consuming operation. Research is ongoing at GRSU to define the suitable growth limiting conditions that offer the possibility of reducing the requirements for frequent sub-culturing. A combination of treatments such as reduced temperature (15-20°C), addition of abscisic acid or mannitol and minimal nutrient medium are currently evaluated. Culture-induced mutations or somaclonal variations are undesirable side effects of *in vitro* conservation, and the extent of genetic instability in the culture will be monitored.

True sweet potato seeds, when stored at low temperature, maintain their viability for many years; therefore, it is the most practicable form of long-term storage of the sweet potato genepool. However, true seed production by open-pollinated, polycross, and geographic seed stocks, requires considerable background study and training on synchronous flower induction techniques, root stock establishment, grafting, seed handling, etc. The cost effectiveness has, therefore, to be assessed in relation to the long-term genetic conservation point of view. However, international transfer of genetic resources for long-term conservation in the form of true seeds overcome the limitation of quarantine regulations. At AVRDC, open-pollinated seeds of 13 Papua New Guinea sweet potato stocks are stored in medium-term stores at 2-3°C and at 45% relative humidity (RH).

Germplasm Characterization

The description of genetic material is a prerequisite to proper maintenance and potential utilization. Characterization and evaluation of sweet potato accessions are emphasized at AVRDC and the basic botanical traits that can be easily observed or measured and which have a reasonably high heritability in any environment are recorded. The IBPGR descriptor lists (3) are closely followed to characterize the entire collection for the above-ground vegetative parts and storage root characteristics. The current status of sweet potato characterization at AVRDC is presented in Table 4.

Table 4. Characterization of sweet potato accessions at AVRDC.

Characters	IBPGR Descriptor	Additional Descriptors	No. of Accs. Completed
Vine	4.1 - 4.6	-	1,179
Leaf	4.7 - 4.13	-	1,179
Flower	4.18 - 4.25	2 (petal width and pistil length)	821
Storage root color	4.14 - 4.17	-	990
Storage root measurement	5.4	2 (tuber cracking and tuber veiny)	990
Biochemical characters	6.1 - 6.5	1 (protein content)	734
Pest reaction	7.1.1	-	990

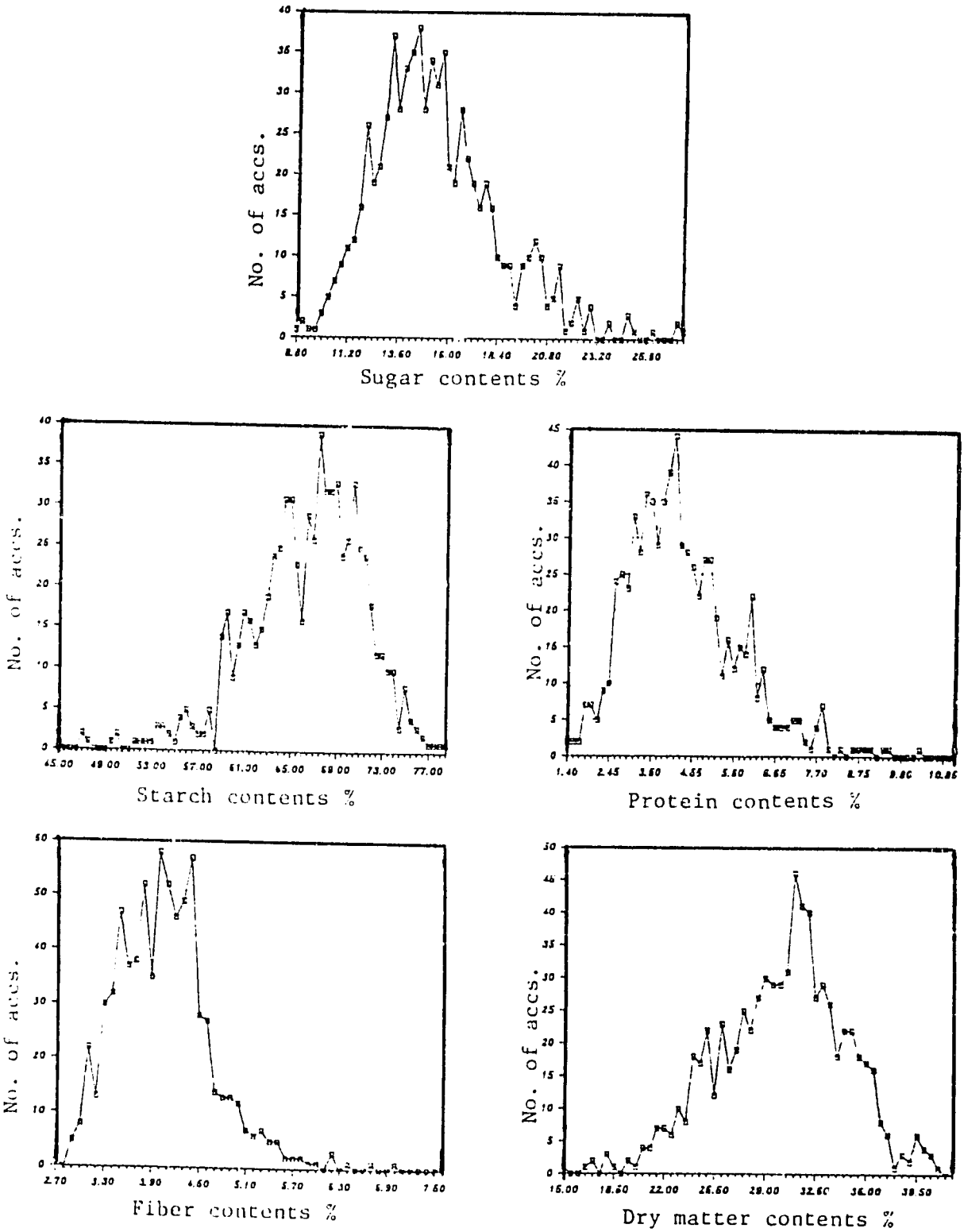

Fig. 1. Frequency distribution of nutritional characteristics of AVRDC sweet potato accessions.

Some of the IBPGR sweet potato descriptor states were modified by adding new catagories and/or by including additional characters to improve characterization efficiency (Table 4). The floral characteristics could be recorded for only 821 accessions which flowered under AVRDC conditions. The non-flowering accessions need to be induced to flower by grafting to a free flowering cultivar, I 172 (cv. American Yellow Skin) or Ipomoea nil to complete the floral characterization. Biochemical attributes are routinely evaluated and the frequency distribution of sweet potato accessions for sugar, starch, protein, dry matter and fiber contents are presented in Fig. 1. The use of biochemical methods such as near infra-red (NIR) analyzer for characterization of chemical constituents and/or polyacrylamide gel electrophoresis techniques (5) will be investigated in the future to differentiate suspected duplicates.

Documentation

An effective documentation system is essential in genetic resources operation, and forthe smooth flow of materials to the cooperating scientists. A computerized central data base consisting of passport and characterization data bases is underway on the HP 3000 minicomputer using the software package MINISIS. MINISIS is widely in use in IARCs which carry out information programs supported by the International Development Research Centre (IDRC). The sample format for passport and characterization data bases is presented in Fig. 2. Passport information and important traits will be compiled from the central data bases, and sweet potato germplasm catalogue will be released in the near future.

Germplasm Utilization

One of the major objectives of genetic resources maintenance is the utilization for genetic improvement. Experts from different disciplines in the crop improvement program evaluate sweet potato germplasm for pest and disease resistance, tolerance to abiotic stresses and nutritional aspects. Approximately 500 sweet potato samples are distributed internally to AVRDC scientists annually for utilization in crop improvement.

The sweet potato accessions maintained by AVRDC also are finding their way into breeding programs worldwide. Since the inception of AVRDC, 5,732 sweet potato samples have been distributed to more than 50 countries for evaluation and utilization. The countries in the Asian and Pacific regions received the major portion of sweet potato germplasm in the last six years (Table 5). Korea, Malaysia, the Philippines, Taiwan, and Thailand have all received more than 100 samples of sweet potato since 1981. Samples of AVRDC breeding lines and accessions were also introduced to mainland China through the

SWEET POTATO CHARACTERIZATION

ISN [5] ACC NO. [I00005]

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
[0]	[3]	[7]	[5]	[5]	[7]	[0]	[5]	[3]	[2]	[3]

A12	A13	A14	A15	A16	A17	A18
[3]	[2]	[2]	[2.5]	[3]	[PIP3-4]	[3.8]

A19	A20	A21	A22	A23	A24
[3.9]	[1]	[3]	[1]	[3]	[1.05]

A 1: TWINING
A 2: PLANT TYPE
A 3: VINE GROWTH RATE
A 4: VINE INTER NODE LENGTH
A 5: VINE PIGMENTATION
A 6: VINE TIP PUBESCENCE
A 7: MATURE LEAF LOBING
A 8: MATURE LEAF SIZE
A 9: MATURE LEAF COLOR
A10: IMMATURE LEAF COLOR
A11: ABAXIAL LEAF VEIN COLOR
A12: PETIOLE LENGTH
A13: PETIOLE PIGMENTATION
A14: PISTIL LENGTH
A15: PETAL WIDTH
A16: FLOWERING HABIT
A17: FLOWER COLOR
A18: FLOWER LENGTH
A19: FLOWER WIDTH
A20: EQUALITY OF SEPAL LENGTH
A21: NUMBER OF SEPAL VINES
A22: SEPAL SHAPE
A23: SEPAL APEX
A24: SEPAL LENGTH

SWEET POTATO PASSPORT DATA

SELECT RECORDS - ISN=1/10
ISN=5
P100 AVNUM : 5
P110 ACCNUM : I00005
P130 DONUMB :
P144 PINO :
P151 SPECIE : IB
P160 PEDCUL : TAINUNG NEW 10
P330 COUNTR : TN
P350 COSITE : HSIN SHIH
P400 SOURCE :
P420 STACOL : ORIGINAL

Fig. 2. Sample formats for sweet potato characterization and passport data bases.

Table 5. AVRDC sweet potato samples distribution from 1981-86.

Country	1981	1982	1983	1984	1985	1986	Total
ASIA AND PACIFIC							
Australia	-	3	4	-	-	21	28
Bangladesh	-	10	-	19	6	16	51
India	2	10	17	37	25	-	91
Indonesia	14	5	1	53	25	-	98
Korea	100	-	14	15	-	-	129
Malaysia	20	65	12	17	30	-	144
Papua New Guinea	21	4	-	14	-	22	61
Philippines	265	123	58	229	26	-	701
Saudi Arabia	-	-	-	9	17	-	26
Sri Lanka	-	-	4	27	4	-	35
Taiwan	10	59	986	-	3	-	1058
Thailand	10	18	8	60	319	-	415
Tonga	-	21	-	-	-	6	27
Subtotal	442	318	1104	480	455	65	2864
SOUTH AMERICA							
Brazil	3	8	-	5	4	-	20
Costa Rica	-	2	5	7	-	-	14
Peru	-	-	-	6	-	139	145
Subtotal	3	10	5	18	4	139	179
NORTH AMERICA							
USA	1	90	14	14	6	-	125
AFRICA							
Ethiopia	-	-	4	10	7	-	21
Kenya	-	-	8	19	2	-	29
Nigeria	-	-	-	31	4	-	35
Subtotal	0	0	12	60	13	0	85
OTHER COUNTRIES	173	48	45	260	70	1	597
Total	619	466	1180	832	548	205	3850

Thailand Outreach Program in the recent years. The north and south American and African countries also received more than one hundred sweet potato samples during the last six years. Eleven AVRDC sweet potato cultivars have been officially released by the authorities of the Philippines, Bangladesh, and Tahiti for use by their farmers.

The most common sweet potato planting materials, vine cutting or storage root are difficult to transport and may harbor virus diseases. Thus, international distribution of sweet potato materials is becoming more and more difficult.

To expedite the international distribution of pathogen tested sweet potato, AVRDC started to distribute meristem derived *in vitro* plantlets in 1982. However, *in vitro* plantlets also suffered from exposure to unfavorable environments during the transportation. In 1985, AVRDC distributed small storage roots, obtained from the single leaf cutting procured from the established pathogen tested plants (6). Presently, rigorous virus indexing is being carried out for efficient virus elimination (4), and AVRDC will be distributing virusindexed sweet potato materials by the end of 1987.

Future Plans

In the last decade, AVRDC has become an important international center for sweet potato genetic resource activities, particularly in the Asian and Pacific regions. The new post-entry quarantine screenhouse, *in vitro* and root storage facilities, and rigorous virus indexing operations will strengthen the sweet potato genetic resource activities. Sweet potato collections from the Asian and Pacific regions will be duplicated. Wild and closely related materials will be introduced and conserved in the form of seeds. Characterization of the entire germplasm will be completed and the suspected duplicates will be identified using poly-acrylamide gel electrophoresis technique. A germplasm catalouge will be developed from the central data bases. Efficient techniques to produce and distribute virus-indexed planting materials of accessions and AVRDC breeding lines developed by the crop improvement program will be utilized. Training program on sweet potato germplasm activities will be expanded and formal courses on specific topics will be organized. Cooperation with IBPGR and other IARCs, especially IITA and CIP, is expected to be further strengthened in order to achieve a free flow of materials between continents.

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REPORT ON THE SCOPE OF SWEET POTATO COLLECTION MAINTAINED IN JAPAN

Satoshi Sakamoto

Sweet potato is one of the important crops in the world due to high calorie production, nutritive value such as vitamins, minerals and dietary fiber and so on.

It was introduced about 370 years ago into Japan and carrying out important role for the farm economy of upland area, especially in the south western part of the country.

1. Scope of sweet potato genetic resources maintained in Japan

Genetic resources of sweet potato are conserving mainly at National Breeding Stations in Japan. Number and details of them are as follows:

Name of Station	No.of collection	Details of collection
Natl.Agric.Res.Center (Tsukuba,formerly at Yotsuka[illegible] ,Chiba and translocated on 1988)	938	Indigenous 34, Registered 38 and its mutant 13, Introduced 464 (Brazil 2,China(Taiwan) 2, Colombia 2,Fiji 5,Indonesia 15, Mexico 1,Papua New Guinea 7, Philippines 4, Solomon 3,USA 17 Venezuela 1,Unknown 18,Yen's collection 387), Breeders lines bred by NARC 190,bred by Kyushu Natl.Agric.Exp.Stn. 123,bred by Chugoku Natl.Agric..Exp.Stn.47, by other Stations 29
Kyushu Natl. Agric. Exp. Stn. (Kumamoto)	1,157	Indigenous 88, Registered 38, Breeders lines bred by Kyushu Natl.Agric.Exp.Stn. 595, by NARC 62, by Chugoku Natl.Agric. Exp.Stn. 22, by other Stations 18, Introduced 334(from Brazil, China(Main land and Taiwan), Colombia, Fiji, Indonesia,

		Mexico. Papua New Guinea, Philippines, USA, Venezuela, unknown and Yen's collections)
Kyushu Natl. Agric. Exp. Stn. (Ibusuki)	ca.1,100	Wild relatives ca.300(140 lines possible and ca.150 lines impossible to cross with sweet potato) collected from Tropical America Interspecific hybrid ca. 800

Important varieties are conserving at plural places to avoid the risk of extinguishment due to rotting or drying up during storage in the storeroom.

2. Method of conservation

It is necessary to plant the cutting of genetic resources to the field at the beginning of the cultivating season and store the tuberous root in the store facilities after the harvest at October or November in Japan except Okinawa area. In this case, there is risk of contamination during harvesting and handling. About the varieties which produce very poor tuberous root and wild relatives, vine or stock of the variety should be keep in a greenhouse at least 15°C. The hybrid seeds of Yen's collection with cultivars are stored at the Germplasm Seed Storage Center. National Institute of Agrobiological Resources (NIAR) so as to conserve the gene source of the parents.

The optimum temperature of storage is 13°C and it is necessary to keep between 10 - 15°C. If it is less than 10°C root might be rot and will be start sprouting more than 18°C. The optimum moisture of storage is 80 - 90 % RH. True seeds at NIAR are maintained in aluminum foil packets or vacuum-sealed cans at -30°C, 30% RH (base coll.) or -1°C, 30% RH (act. coll.). About 200 collections of Kyushu Natl. Agric. Exp. Stn. are maintaining in test tubes by meristem tissue culture for the purpose of to keep collection free from virus diseases.

3. Evaluation of genetic resources

To use genetic resources effectively, it is important to evaluate the characteristics of them. Characteristics are consist of morphological, ecological and practical characteristics. International Board for Genetic Resources (IBPGR) recommends to record 91 characteristics which include 26 morphological data, 13 data of root,14 data of

pest and 38 data of disease reaction. In Japan, 75 characteristics which include 50 morphological and 25 biological descriptors are using for registration of new variety and they are shown in annex. About 30 main characteristics of all collections are evaluating at each Breeding Station.

4. Construction and use of data base

All data collected from observation and measurement are input to computer to construct the data base. Using network system of computer, it is not difficult to search the desirable genetic resources from data base. Followings are example of searching for high dry matter content and high yield varieties by operation of Time Sharing System (TSS) through public telephone at Laboratory of information management system, Department of Genetic Resources, NIAR.

```
ENTER NEXT COMMAND
                          (wt. of storage root)
=HOW MANY ITEMS HAVE SOUIMO JUU1.FROM.5.0.TO.10.0 *

NO. OF ITEMS IN QUERY RESPONSE =    11
NO. OF ITEMS IN THE DATA BANK =     51
PERCENTAGE OF RESPONSE/TOTAL DATA BANK = 21.57

ENTER NEXT COMMAND
                          (Dry matter percentage)
=HOW MANY ITEMS HAVE KIRIBOSHI BUAI1.FROM.25.0.TO.50.0.AND.RESULT *

NO. OF ITEMS IN QUERY RESPONSE =     7
NO. OF ITEMS IN THE DATA BANK =     51
PERCENTAGE OF RESPONSE/TOTAL DATA BANK = 13.73

ENTER NEXT COMMAND
          (wt. of storage root, Dry matter percentage, Name of var.)
=PRINT : (SOUIMO JUU1,KIRIBOSHI BUAI1,HINSYU MEI ) FOR WITH RESULT *

NO. OF ITEMS IN QUERY RESPONSE =     7
NO. OF ITEMS IN THE DATA BANK =     51
PERCENTAGE OF RESPONSE/TOTAL DATA BANK = 13.73

 5.1 26.2 BIS 397-1
 5.1 29.5 WHITE STAR
 5.4 26.3 CAVITE
 5.4 26.9 MARKPAM-1
 5.4 27.5 BIS 20-1
 6.0 26.2 BIS 397-2
 7.2 26.6 BNAS 51

ENTER NEXT COMMAND

=END
```

From the result of evaluation, followings are cleared

(1) Though almost indigenous cultivars of Japan belong only 3 cross incompatibility groups of A, B and C, genetic resources of Peru, Brazil, Mexico and Colombia include many groups. This result suggests that the northern part of South America is the center of genetic diversity.[2,3]

(2) Some introduced varieties such as Pelican Processor, Tinian and Yen 316 show high combining ability with Japanese cultivars and excellent high yield lines are selected from the progeny.

(3) Some introduced genetic resources such as Yen 574, 613 show erect plant type and this plant type adapt to mechanical vine harvesting.[4]

(4) Some varieties in Yen collection such as Yen 258, 316, 382 and 404 are suitable as the parent of breeding for table use varieties because of beautiful red skin color.

5. Conclusion

To increase the breeding efficiency, it is necessary to use germplasm adapted to breeding objectives, for example, high starch content and high yield germplasm for breeding of varieties for starch production. For selection of these parental materials, evaluation of characteristics, construction of data base and searching of them play important role.

Collection of sweet potato germplasm is facing difficult problem of losing germplasm from the world as pointed out by IBPGR[1]. And conservation of present germplasm in each country should be more important in future.

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Annex Name of characteristics in Japan

Name of characteristics	Name of characteristics
Plant type	Flesh colour of steamed tuber
Vine growth rate	Flower colour
Twining	Flower length
Plant height	Flower width
Vine pigmentation	Flower shape
Node pigmentation	Length stigma and anther
Vine thickness	Stigma colour
Vine length	Equality of sepal length
Number of branch	Sepal shape
Vine internode length	Sepal apex
Vine tip pubescence	Cross incompatibility group
Colour of vine tip	Flowering habit
Leaf colour	Rate of sprouting
Leaf shape	Sprouting variability
Leaf size	Rate of sprout growth
Vein pigmentation	Amount of sprout
Nectary pigmentation	Sprouting ability
Petiole length	Seedling weight
Petiole thickness	Resprouting ability
Length of joint part of tubers	Adaptability for late planting
Strength of joint part of tubers	Adaptability for early harvesting
Place of tubers	Adaptability for heavy manuring
Difficulty of harvesting	Vine weight
Tuber shape	Weight of dried vine
Tuber shape variability	Number of storage root per hill
Tuber size	Weight of storage root
Tuber size variability	Storage root percentage
Skin colour of tuber	Storage ability
Flesh colour of tuber	Carotene content
Anthocyan colour in cross section of tuber	Dry matter percentage
Depth of eye	Dry matter percetage of vine
Furrow of tuber	Starch percentage
Vein-like surface of tuber	Eating quality
Smoothness of surface of tuber	Resistance to black rot
Appearance of tuber	Resistance to stem rot
Sprouting in the field	Resistance to root-knot nematode
Flesh texture of steamed tuber	Resistance to root-lesion nematode
Fibre of steamed tuber	

SWEET POTATO COLLECTIONS IN PAPUA NEW GUINEA

Hiroko Takagi

Introduction

Root crops have traditionally played an important role as staple foods in Papua New Guinea (PNG). Among them, sweet potato is the most widely planted (Table 1) especially in the highlands, and the country is known as one of the secondary origins of the crop, with remarkably wide genetic diversity available.

That sweet potato is generally said to have been introduced into PNG some time during the past 400 years from the West Indies via Africa, India and Indonesia (12). Yen (12) suggests that more cultivars could be collected in PNG than from any other area in the world. The relatively high frequency of spontaneous germination of true seeds in the highlands, cultural isolation of growers, and growers' taste preferences explain the large number of cultivars (3). According to Bourke (3), there are probably in the order of 5,000 cultivars grown in the country, although cultivars introduced since European contact are rapidly replacing traditional ones and which are now being lost.

On account of rapid development and the subsequent radical changes in the economic, social and ecological structures, PNG is also facing abrupt genetic erosion as many other regions of the world.

Table 1. Production area and annual production of major root crops in Papua New Guinea

Crops	Area (1,000 ha)	Production (1,000 t/year)
Sweet potato	74	1,020
Taro (*Colocasia*)	19	312
Taro (*Xanthosoma*)	4	146
Yams	7	237
Cassava	0.9	52

(Source: Walters, 1963).

Recognizing this situation, the PNG National Committee for Plant Genetic Resources was formed in 1980. Since then, plant genetic resources activities have been emphasized and promoted by the Department of Primary Industries (DPI) and the Agriculture Faculty of the University of PNG (UPNG) (8). Cooperation and support from international organizations such as the International Board for Plant Genetic Resources (IBPGR) have provided for sweet potato, one of the first priority crops of PNG.

Current Status and Characterization of PNG Sweet Potato Collection

Germplasm collections of sweet potato have been made in PNG over the last 20 years, especially in the highlands. The importance of intensive collecting and maintenance of sweet potato germplasm has been emphasized recently. New accessions have been added mainly by the Southern Highlands Rural Development Program (funded by World Bank) and the DPI lowlands sweet potato collecting (funded by IBPGR) (9).

A total of about 1,800 accessions are maintained at the following DPI experiment stations: for lowlands accessions at the Laloki Plant Quarantine and Horticultural Research Station (Laloki, Central Province), and at the Lowlands Agricultural Experiment Station (Keravat, East New Britain); for highlands accessions at the Highlands Agricultural Experiment Station (Aiyura, Eastern Highlands Province), and at the Kuk Agricultural Research Station (Kuk, Western Highlands Province) (Fig. 1). After the completion of the characterization and evaluation at each station (6, 9), the collection will be centralized, probably at Kuk.

Although substantial numbers of germplasm collections have been held at various stations in PNG, systematic description of sweet potato accessions has not been undertaken until recently and are going on at each location according to the IBPGR descriptor list for sweet potato (9). The collection at the Highlands Agricultural Experiment Station (HAES) is the only one for which descriptors are currently available (6).

Characterization of the Highlands Sweet Potato Collection

The sweet potato collection of the Highlands Agricultural Experiment Station (HAES) at Aiyura, the biggest collection in PNG, consists of 822 accessions. Only 22 accessions represent introduced germplasm. They are from New Zealand, Nigeria (IITA), the United Kingdom, and the USA. The indigenous accessions were mainly collected from the highlands area, e.g. Eastern Highlands Province, Simbu Province and Southern Highlands Province. The collection has been

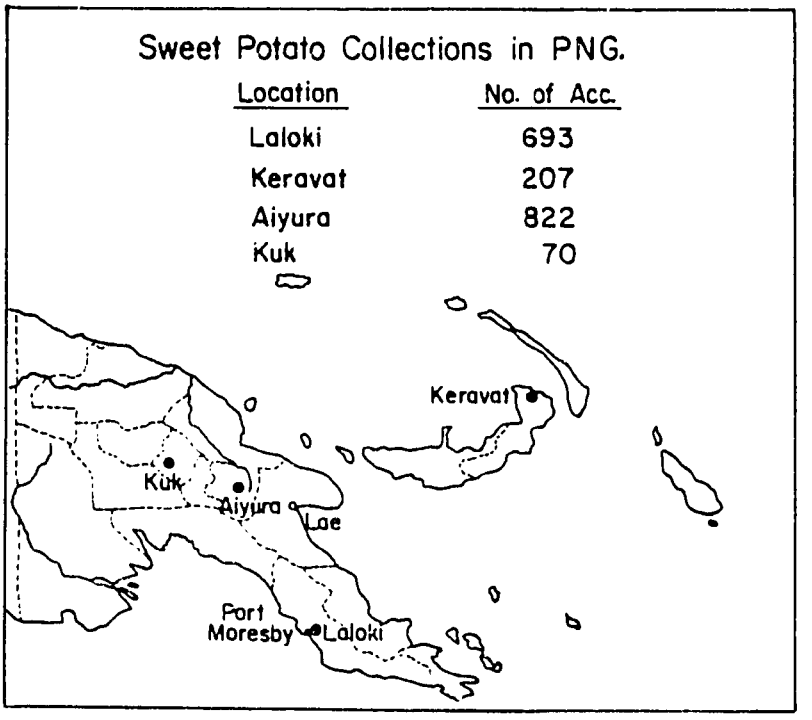

Fig. 1. Sweet potato germplasm collections in PNG.

replicated at Kuk and after the completion of the re-organization of research of DPI, it will no longer be maintained at Aiyura. From the collection, 468 accessions are duplicated at the Asian Vegetable Research and Development Centre (AVRDC), the IBPGR-designated sweet potato repository for Asia and the Pacific. These accessions have been almostly characterized by the Genetic Resources and Seed Unit, AVRDC, and will be available for international distribution after being virus indexed by virologists.

All of the accessions were characterized for 27 descriptors (Table 2) by the author who was IBPGR intern from March 1984 to March 1986. The characterization was primarily following the IBPGR descriptor list (7) with some modifications. The data collected have been computerized by the Plant Protection Project, U.N.D.P. in Suva, Fiji with IBPGR assistance. A print-out indexed on six descriptors, and a floppy disk containing full descriptors and passport data are available at DPI (6).

The results of the characterization for the six characters which are considered most useful keys to identify duplicates within a collection are summarized in Figs. 2 and 3. Almost all categories of each descriptor listed in "IBPGR Descriptor Lists" (7) and "Describing and Documenting Root Crops in the South Pacific" (6) were observed for 27 descriptors (Table 2) in the HAES collection except "V1" of leaf shape, "Purple spotting" of abaxial leaf vein color and "white" of flower color.

Table 2. Characters described for the HAES collection*

Growth type

1. Twining
2. Plant type

Vine

3. Internode length (cm)
4. Pigmentation
5. Tip pubescence

Leaf

6. Shape
7. Measurements of Leaf:
   Length, Breadth, Basal lobe (cm)
8. Color (immature leaf)
9. Color (mature leaf)
10. Abaxial leaf vine color

Petiole

11. Length (cm)
12. Pigmentation

Storage Root

13. Skin color
14. Main flesh color
15. Secondary flesh color
    & distribution

Flower

16. Flowering habit
17. Color
18. Length & width (cm)
19. Color of stigma
20. Color of style
21. Stigma & anther height

Sepal

22. Equality of length
23. Shape
24. Shape of apex
25. Pubescence
26. Color

Seed

27. Seed capsule set

*Full descriptors of the collection are available in "Describing and Documenting Root Crops in the South Pacific" (6).

While the living collection performs the role of maintenance of cultivars, the collection of true seeds is the alternative procedure towards long term conservation of genetic diversity. Regarding the latter method, naturally pollinated seeds were collected from the germplasm nursery. In order to stimulate flowering and seed setting, wooden stakes were set on each mound and vines were trained. Under this condition, 81% of the accessions flowered and over 120,000 true seeds have been collected from 581 accessions. The seeds have been sent to AVRDC and the National Institute of Agrobiological Resources (NIAR) in Japan for long-term conservation.

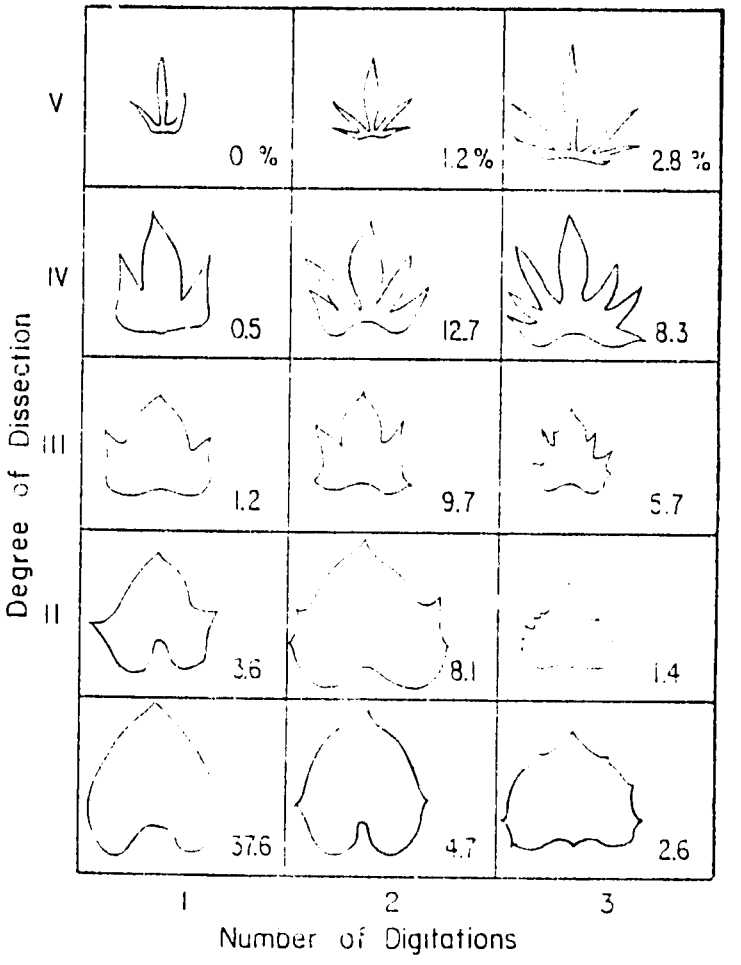

Fig. 2. Descriptors of the HAES sweet potato collection for leaf shape.

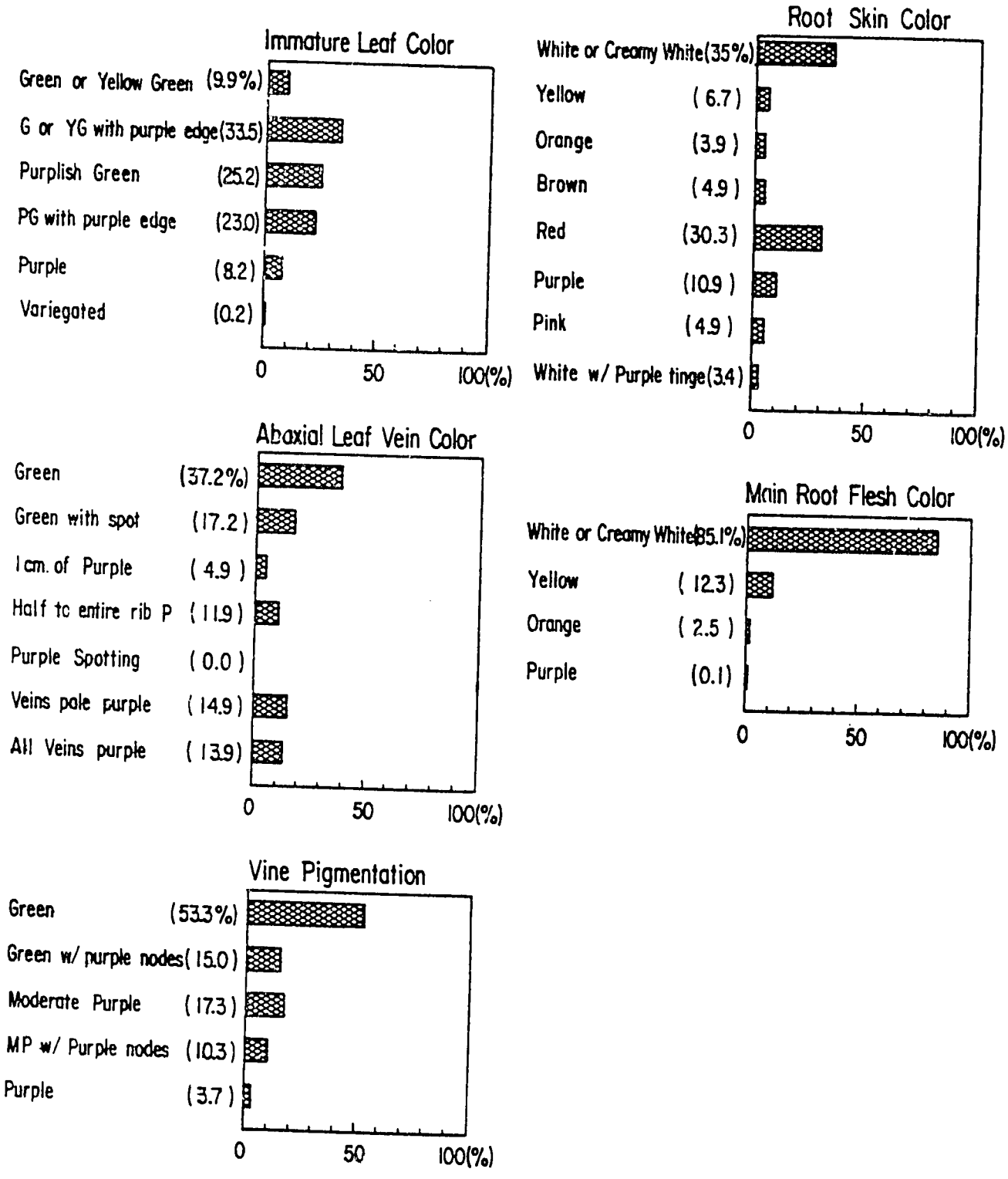

Fig. 3. Six descriptors of the HAES sweet potato collection.

Availability of PNG Sweetpotato Germplasm

Yen's (12) belief that more cultivars could be collected in PNG than from any other area in the world, is borne out by the enormous diversity of PNG sweet potato cultivars. The descriptors of the KAES sweet potato collection clearly reflect this fact. Although evaluation of the collections is to date only potential, the considerable environmental and cultural diversity of the country and the research work, both within and without, suggest the potential for utilization.

Environmental stresses

In PNG, the sweet potato is grown:

- from sea level to the altitudinal limit of agriculture, usually 2,700 m but reaches as high as 2,850 m in parts of Enga province;

- on a very wide range of soil types ranging from sandy loams to heavy clays and peat soils;

- in the highlands with mean annual rainfall from 1,500 mm to 5,000 mm and in lowlands under very dry conditions (3).

This wide range of ecological conditions where sweet potato is grown reflects the enormous adaptability of the crop and its wide genetic diversity within the country. Similar information has been reported on the following stresses:

Excess moisture. Under hot-wet conditions in Taiwan, 14 accessions were identified as moisture-tolerant, and eleven of which were introduced from PNG (1).

Drought. At DPI (Laloki), 54 varieties were evaluated during the dry season (400-500 mm irrigation) and five varieties were selected on the basis of consistently high yields (9).

Low temperature. The cultivars from the PNG highlands showed consistently good low temperature-tolerance as well as cultivars from the Andean region (12).

Pest and Disease Problems

Many pests and diseases have been recorded in the country, and the distribution is quite varied between areas (3). For example, sweet potato weevil (*Cylas formicarius*) can be a major problem, but is serious only in areas with a marked dry season or during very dry years. Sweet potato leaf minor (*Bedellia somulentella*), hawk moth (*Agrius convolvuli*), vine borer (*Omphisia anastomosalis*) have been

recorded as well as other occasional insect pests. Nematodes have been recorded with serious reductions in yield in the upper Mendy area of the Southern Highlands Province.

Sweet potato scab (Elsinoe batatas) is common in the country and the damage is greater in the highlands than in the lowlands. Leafspot (Cercospora timorensis) has also been reported frequently, but the economic significance is unknown. Sweet potato little leaf, caused by a mycoplasma-like organism, is a serious problem in the Central Province (3).

The current situation regarding the identification of resistance to pests and diseases is as follows:

Weevil. Evaluation for resistance to weevil was conducted at the DPI, Laloki and AVRDC, but no stable resistance source has been identified to date (1, 9).

Vine borer. Minibu 1, a cultivar from the Southern Highlands Province, was identified as vine borer-resistant by AVRDC entomologists (2).

Nematode. Results of the evaluation for root-knot nematode resistance in Japan showed that 75.4% of 69 PNG accessions were evaluated as highly resistant. The frequency of resistant clones was the highest in PNG and decreased with distance from the island (11).

Scab. The wide variation in resistance to scab has been recognized in PNG (3). According to preliminary observations by the author, the majority of the HAES collection showed high resistance to the disease under Aiyura natural conditions (Fig. 4).

Nutritional Value

Because of the importance of sweet potato in the PNG Highlanders' diet, protein content of sweet potato has been considered to have a major effect on the improvement of protein intake (3). Thus, much more attention has been paid to the evaluation of protein content than for other nutritional components. Compared to cultivars of other origin, the protein content of PNG cultivars have been quite low, although protein content is generally strongly influenced by the growing environments.

The range of 0.6-2.9% protein (fresh weight basis) was reported in the series of analysis in PNG (3). From the evaluation trial of PNG accessions conducted at AVRDC, a range of 1.14-3.66% (dry weight basis) was reported (1). Crude protein, amino acids, and trypsin inhibitor have been analyzed for cultivars from the Southern Highlands Province. The range of crude protein content is 0.5-2.09% (fresh weight basis) and the most limiting amino acids were cystine and methionine (4).

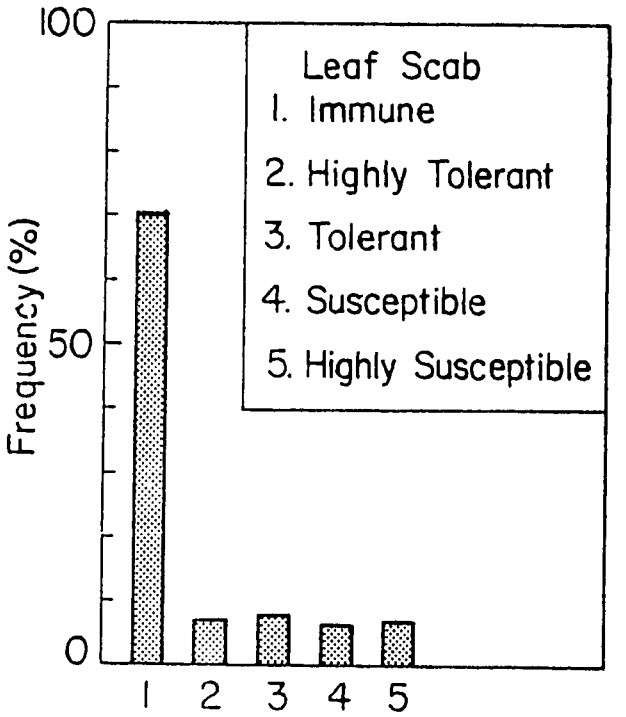

Fig. 4. Distribution of the tolerance to leaf scab in the HAES sweet potato collection.

Resulting from the general preference of Papua New Guineans, sweet and yellow fleshed cultivars with dry texture are popular through the country. The quite wide range of 12.5-29.4% sugar (dry weight basis) was reported in the evaluational trial conducted at AVRDC (1). For dry matter content of PNG accessions, ranges of 21.6-39.4% at DPI (Laloki) (9) and 30.4-39.4% at AVRDC (1) were reported.

β-carotene (provitamine A) is one of the important factors for supplemental use and is rich among deep orange-fleshed cultivars. In PNG, the flavour of orange fleshed sweet potato is not popular, thus the frequency of orange-fleshed cultivars is quite low. As shown in Fig. 3 (main root flesh color), only 2.5% (19 accessions) of the HAES collection have orange flesh and 6 out of these 19 accessions are introduced germplasm.

Yield

The farming system and cultural techniques used vary widely between production areas. The most common harvesting system in the Highlands is "progressive harvesting" whereas a single harvest is practised in Bougainville and in other lowland zones (3). Time to maturity is 5-6 months in the lowlands, 6-8 months in the highlands

and 7-12 months (or longer) at high altitudes (3). It is reported that subsistence yields range from 2-50 t/ha, with most values in the range of 5-25 t/ha. Experimental yields have ranged from crop failure to 71.2 t/ha (5).

Yield data of PNG cultivars in other countries is limited. AVRDC breeders reported that the yields of PNG accessions were generally very low under AVRDC conditions, ranging from 0.1 to 11.5 t/ha, although there was wide variation in the sugar, dry matter, and starch contents in the population (1). Almost all accessions tested in this trial originated from the PNG highlands where the growing conditions are relatively cool and wet in comparison with AVRDC's conditions. Even within PNG, it is generally said that most of the highland cultivars do not produce well in the lowlands. This might provide some explanation to the reported low yield at AVRDC. Since so many cultivars exists under different conditions, proper records of collecting site and environment is very important to carry out an efficient evaluation work. This should be noted in future collecting missions.

Conclusion

Although considerable progress has been made, plant genetic resources work in PNG is still in its early years in light of the wide genetic diversity and large number of cultivars existing there. Much more international cooperation is needed in the following fields to make the best use of this important resource:

- intensive and wide collecting expeditions in the unexplored areas;
- systematic characterization, evaluation, and centralization of information; and
- maintenance of duplicate collections within and without of PNG.

Acknowledgement

The author wishes to record her gratitude to the Department of Primary Industry, Papua New Guinea for their kind cooperation and to the International Board for plant Genetic Resources for the internship granted.

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PRESERVATION OF SWEET POTATO GERMPLASM AS POPULATION

Franklin W. Martin

INTRODUCTION

The need to collect, evaluate, propagate, multiply, and store sweet potato germplasm is evident to us all. Yet, the sweet potato poses a special challenge because it is propagated vegetatively. There may not be truly wild sweet potatoes that exist in populations of cross-breeding individuals, and thus there may not exist a natural gene pool. This means only that preservation of germplasm need be managed differently in the case of sweet potato than for crops that are planted from true seed. In the case of vegetatively propagated crops the clonal germplasm repository appears to be in vogue, and at first glance storing such crops in living collections would seem to be advantageous. However, some of such crops can also be stored as true seed. The comparative advantages of storage as living collections, plantlets in tissue culture, and as seeds will be reported here as well as some suggestions of how populations as represented by true seed can be managed and utilized.

FIELD COLLECTIONS

Let us consider briefly how a germplasm collection is to be used. If a particular entry is to be used as a farmers' variety, then it is essential that the collection be maintained in the vegetative form in the field or in tissue culture. In either case even a single plant can be rapidly multiplied in order to provide propagules for any particular need. However, rarely will a germplasm collection be used as the source of a variety. Smaller collections are maintained by farmers and experiment stations for this purpose. Yet, one can imagine that once in a while a variety may not be needed at a particular time for production purposes, but might be desired for future production, and thus might be temporarily maintained in a collection. In a large germplasm collection, however the purpose is not to maintain varieties for potential use by farmers.

A long term germplasm collection should not be confused with either a collection of varieties for supplying farmers with

their needs, which might consist of a few clones grown on a large scale, and a breeders working collection, which might consist of a dynamic changing collection grown on a smaller scale. A germplasm collection should maintain the genes of the species so that they are not lost because of human events, and so that they are available as needed.

A clone may be needed by a plant breeder as a source of a certain characteristic. Then, it is not the clone itself that is needed, but a certain gene or genes. In that respect it is well to remember that the sweet potato is a hexaploid from unknown species. Thus, there are six sets of chromosomes, and any gene may be represented by up to 6 different alleles. The segregation ratios in sweet potato are complex (2) and thus inheritance appears to be quantitative, even for characteristics that might be controlled by one gene of two alleles in a diploid. It is believed by plant breeders that outstanding sweet potato clones represent unique combination of genes rather than unique genes, and epistasis is probably very important.

The self-incompatibility and sterility of sweet potato have been studied in detail (5). Most sweet potatoes will not produce seed by self-pollination, and self-pollination leads to inbreeding depression. Each sweet potato is very heterozygous, a store-house of variability. When cross-pollinations are made the unique combination of favorable genes represented in a variety is broken in meiosis. Recombination occurs on fertilization, and each seed represents a new unique combination. Plant breeders search among thousands of seedlings for desirable varieties, according to their criteria of desirability.

Therefore, a unique combination such as an elite variety may not be a better source of certain genes than a chance seedling that also contains them. Without extensive testing it is impossible to say which clone might be a better parent, and in which ways.

. particular variety might be, however, a previously identified source of a gene or set of genes, thus making preliminary search for the character rapid. A plant breeder may wish to examine and combine several sources of a particular character, for they may be controlled by separate genes.

Varieties maintained in tissue culture may be a little slower to multiply, at first, as compared to varieties grown in the field. They have the additional advantages that they can be disease free, and, thus, they can be transported

internationally with less restrictions. The costs of tissue culture compared to field culture varies, and cannot be considered here.

THE NATURE OF A SWEET POTATO VARIETY

Consider for a moment the nature of the sweet potato variety. It is a clone which was produced from a single seed. Each plant, produced from a vegetative portion of another should be the same as others of the same variety. In practice, however, three kinds of differences are found in clones. The first is genetic. Mutations occur regularly and may theoretically effect any characteristic of the plant (4). Thus, there is a natural tendency for variability to increase, but whether such variability is preserved will depend on the degree of selection practiced within the clone, and the manner in which new plantings are established from old plantings.

A second form of variability is that related to virus infection. There are several viruses and a plant can have a variable dose of any one. If the dose is light, the clone might produce well, but heavy dosage impares growth and yield (1). To a certain extent the dosage or titer of a virus infection can be controlled by the environment. Optimum conditions for the growth of the plant may reduce the average titer of the virus. Thus, protection from the effects of virus include maintenance of the plant under optimum conditions.

A third form of clonal variability is associated with the physiological state of the plant. This is reflected in the readiness of the particular vegetative piece to grow rapidly. For example, cuttings taken of basal stems or of old plants need more time to establish themselves as healthy new plants than do vigorous terminal cuttings, and this results in reduced yield.

Taking these factors into consideration one sees that to maintain sweet potato germplasm as clones in field collections, one must replant the collection each three months, must maintain optimum growing conditions, and must rogue to type periodically or propagate from a single plant to assure that all cuttings are alike.

The maintenance of sweet potato germplasm as field collections is a labor intensive and thus expensive procedure.

POPULATIONS

Special genes can be preserved in populations as well as in individual clones, and such genes can be identified with the same screening techniques used to identify the genes in screening for sources of resistance. Polycrossing can be used to enhance the frequency of desirable genes in a population. Thus, improved populations might be better sources of genes than original collections.

Populations are easily established. Clones to be combined in a population are planted in an isolated area where treatments and environment stimulate flowering. Honeybees make the crosses. Seed pods are protected from insects with appropriate insecticide. Each generation of selection increases the frequency of desired genes. Populations can be combined as desired.

A population may contain either a wide range of other characteristics, or a narrow set of genes for characteristics that have been selected together. It can be tailored to the plant breeders' specifications.

Sweet potato seeds are hard and do not germinate regularly. When planted under normal conditions very few germinate promptly. Those few that do are abnormal or damaged. The majority slowly inbibe water as the seed coat deteriorates and then germinate irregulary, sometimes a year or more after planting. This natural dormancy of the sweet potato seed makes it one of the easiest kinds of seed to store. Even without special precautions the seeds retain viability for 20 years or more. Under conditions of protection, that is, low humidity and low temperatures, seeds could probably live for 100 years or more. Furthermore, seeds can be easily transported without special precautions, with confidence that they will not be damaged by normal variables of the environment.

When germination is desired there are two useful techniques. One is the use of a mechanical scarifier, generally consisting of a small rotating drum lined with sand paper. The speed and time of rotation as well as the number of seeds affect the degree of scarification. Some embryos are damaged by the process and either do not germinate or produce damaged plants. On the other hand, the treatment of the seeds with detergent to remove fungi followed by 30 minutes immersion in concentrated sulfuric acid promotes entrance of water and germination in 2-5 days. Sometimes many of the seed are especially hard. These can be treated a second time, and this gives spectacular results.

Thus, sweet potato seeds can be stored inexpensively and germinated conveniently. An entire field of sweet potatoes representing thousands of individual clones can be maintained as an envelope of seeds.

DEVELOPING POPULATIONS

If populations are to be used as a principal technique for maintaining germplasm, the methodology for developing them will have to be carefully standardized. The use of the polycross as a technique for improving populations has been encouraged by Jones, et al. (3), yet in the breeding situation the objectives of a polycross will be somewhat different than in the case of germplasm preservation. In populations one might expect changes in gene frequency due to selection. In preserving germplasm one might wish to avoid selection, and in enhancing germplasm one might wish to direct selection. The nature of flowering in the sweet potato is an obstacle to the development of populations.

It has long been known that the sweet potato flowers irregularly. While short days appear to stimulate flowering in most clones, there are clones that flower freely at any season and other clones that do not flower at all. The problem in establishing a population is to get all of the necessary genes into it, and that might suggest that each individual plant should flower, produce seeds, and thus contribute its genes to the population. Furthermore, the proportion that each plant contributes should be the same so that particular desirable genes do not become rare due to the failure of a clone to flower well.

The most important asset in rder to establish a population is an environment that stimu ates sweet potato to flower. It is possible to specify some of the characteristics of such an environment, but it is necessary to test flowering in the environment before populations are constituted. This is true whether the objective is preservation or enhancement. Practical experience has shown that the individual plants need room to grow, should be tied to stakes of up to 2 meters, should not have excess nitrogen or water, and preferably should be subject to short days. Growing conditions should be good so that sufficient foliage is produced to support flowering, but if growing conditions are too good, the plants will not flower. Practical experience has shown that timing is very important. The cuttings should be planted early enough to develop foliage before flowering is initiated, but not so early that senescence begins before flowering.

Even under the best conditions, some clones do not flower. Frequently they can be stimulated to flower by grafting them on a very floriferous clone or another species. The bush morning glory, Ipomoea fistulosa, is very useful for this purpose. It can be grown in a small space, furnishes many straight cuttings, roots readily without insect or disease problems, and is very effective in stimulating flowering of sweet potato. Nevertheless, it is not a good idea to include many non- flowering clones in the population for they tend to perpetuate the non-flowering condition. In an open-pollinated population, frequency of flowering tends to increase with each generation (6).

It may be desirable to limit the contribution of a particularly floriferous clone to the population. If known in advance, this can be done by including only one plant of the clone in the polycross, or by limiting its size or its flowering. While the seeds harvested can be limited, the contribution of the pollen to seed production of other plants will not be known. Perhaps the best way to insure that the genes for a particular character are present in a population is to include in the polycross several different clones that contain those genes.

KINDS OF POPULATIONS

Perhaps the nearest thing to a natural population of sweet potatoes would be those farmers' fields in Papua New Guinea where long growth periods and the presence of several clones in the same field increases cross pollination among varieties. Seeds fall to the ground, eventually germinate, and the mixture of known clones and unknown seedlings is replanted regularly and selected for superior types once in a while. However, true, freely interbreeding populations do not exist. In developing populations for preserving germplasm it must be remembered that these are not natural populations, but populations of convenience.

Although natural populations probably do not exist, a collection of varieties from a single location may have characteristics in common reflecting either the adaptation of varieties to the area or the common origin of the varieties. In that limited sense one might be able to distinguish regional entities. On developing populations it might be desirable to preserve these gene frequencies. Populations initially made up of individuals from a single area might be called regional populations.

More often a population will be developed that emphasizes a particular characteristic, such as specific culinary

properties or disease resistances. While it is desirable to have ready sources in populations for specific characteristics, there will always be a limit to the number of populations that can be conveniently maintained. On the other hand, one population that includes all of the variation of the species is not practical. To screen for a particular trait might require too many seeds. A program that includes a dozen populations might be very suitable for a germplasm maintenance program.

Populations will change in gene frequency. Each time they are regrown from seed there will be opportunity for selection, and we can assume that gene frequencies will change. The greatest change will occur with respect to the genes responsible for flowering, as well as the genes closely linked to them. These changes need not occur rapidly. If sufficient seeds are produced in polycrossing it will not be necessary to grow the population until the supply of seeds runs short. Growing the population permits light selection for desirable or against undesirable traits. If the selection pressure is not too great, populations can be improved with light selection without losing genes.

To maintain a population in a pristine, never changing status is impossible, and probably not even desirable.

Sweet potato breeders are used to working with large numbers of clones, and attach less importance to the individual than to its place in the population. This is not to say that individual clones are not important. On the contrary, clones are the fruit of the science and art of the plant breeder. It is probable that plant breeders discard regularly better clones than are found in many collections.

COMPARISON OF TECHNIQUES

The practical realities of preserving and using sweet potato germplasm are such that any program might be expected to have some material as clones in the field, some material as clones in tissue culture, and some material as seeds. The questions that must be faced in any program are the relative priorities given to the various techniques, and thus the appropriate use of each. The attached table summarizes several characteristics.

	Preservation as		
Point compared	Clones in field	Clones in culture	Population as seeds
Space requirements	High	Low	Very low
Start-up costs	Medium	Very high	Medium
Maintenance costs	High	Low	Very low
Risks from mechanical or electrical failures	Low	High	Very low
Resistance to disruption of program	Low	Low	High
Danger of loss from insects or disease	Medium	Low	Low
Evolutionary possibilities	Very low	Low	High
Preservation of unique combinations	High	High	Very low
Preservation of genes	High	High	Very high
Convenience of use	Medium	Medium	Medium

From these decisions can be made. Some of the potential decisions are as follows:

Preservation of elite varieties for international distribution: tissue culture.

Preservation of unique sources of genes where identification of the gene or genes is very difficult: tissue culture or field collections.

Preservation of breeder's lines: field collection.

Preservation of regional collections: populations as seeds.

Preservation of gene pools: populations as seeds.

Preservation of miscellaneous materials just in case needs arise: populations as seeds.

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CURRENT STRATEGIES FOR CONSERVATION OF SWEET POTATO GERMPLASM AT AVRDC

G.C.J. Fernandez and J.H. Lu

Introduction

Sweet potato is one of the important food crops in Asia in terms of the total food production, and more than 90% of the world's sweet potato is produced in Asia and Oceania (2). Increased awareness of genetic erosion of sweet potato germplasm has led in recent years to increased plant exploration, and an increase in the number and size of germplasm collection at AVRDC (3). If germplasm is maintained properly, the genetic constitution of the population at the time of its collection should be preserved (11).

Sweet potato cultivars are propagated vegetatively by means of either stem cutting or storage roots to preserve a valuable combination of quality factors including organoleptic characters, vigor, resistance to diseases and storage root yield. In sweet potato, out crossing is prevalent due to self-incompatibility and seed production is limited in some cases due to sterility (6). The clones are highly heterozygous, and the heterozygosity is further increased by the hexaploidy and by the accumulation of point mutation which are usually recessive and are not expressed under clonal propagation. Therefore, sweet potato germplasm conservation is complicated and different from the seed propagated crops.

At AVRDC, sweet potato genetic resources are maintained primarily as clonal materials to provide scientists and the cooperators with the superior breeding lines and accessions. The entire sweet potato collection is maintained in the field genebank, the traditional form of conservation and currently, accessions are also conserved in the *in vitro* cultures. This paper describes the current strategies for sweet potato germplasm conservation at AVRDC.

Field Genebank

The field genebank at AVRDC is usually reestablished twice a year during March and September using cuttings obtained directly from the old field or sprouts regenerated from tubers in a propagation nursery. Plot size of each accession is 1.5 x 1.5 m^2 with eight cuttings evenly spaced in a row. The whole field is planted only in alternate rows, leaving a row vacant to reduce the chances of vine intermingling among accessions. To facilitate locating an accession in the field genebank, the field plot numbers and the accession

numbers are kept identical. The AVRDC standard cultural practices (4) are adopted to establish the field genebank.

The sweet potato collection maintained in the field genebank requires a large field space, is labor intensive and exposes the plant materials to both biotic and abiotic hazards. Also, clonally propagated materials are bulky, difficult to transport and great care is required to keep these materials alive when they are transferred to the cooperative scientist. Quarantine and custom regulations also create additional problems in the international germplasm transfer. To circumvent these difficulties, *in vitro* methods developed initially for the propagation and virus elimination of sweet potato are currently being adapted for germplasm conservation.

In Vitro Active Collection

In *in vitro* cultures, the growth of plant cells, whole or part of plant organs, are manipulated under a defined nutrient medium, a controlled temperature and light. *In vitro* maintenance has demonstrated abundant potential for germplasm conservation because of recent developments in this field (1). There are certain prerequisites for the successful application of *in vitro* genebanks such as efficient methods to introduce tissues aseptically into cultures, to regenerate plants from culture and the development of storage conditions that offer a high level of survival, stability, and reproducibility in the culture (12).

At AVRDC, sweet potato *in vitro* cultures are used as a back-up for the field genebank, in the virus indexing operations, and for germplasm exchange. Stem tips derived aseptically from apical and lateral buds are cultured under *in vitro* conditions and are maintained at 25±2°C in a 12-h photoperiod at 500-600 lux photo density. The culture medium contains MS salts, vitamins of B 5 medium, 1 mg IAA, 1 mg Kinetin, and 7 g agar in 1 liter of distilled water. The pH of the medium is adjusted to 5.7 to 5.8.

Culture maintenance under these conditions involves, frequent sub-culturing with concomitant expenses and risk of microbial contamination, and loss through errors or equipment failures. Thus, the maintenance of cultures in continued growth at a normal rate is considered to be an unsatisfactory approach in germplasm conservation (12). The maintenance of cultures under growth limiting conditions offers the possibility of reducing the requirement for sub-culturing. By combining reduced temperature (10°C) and application of a growth retardant (n-dimethyl succinamic acid), a longer period of storage in potato shoot cultures was reported (9). The addition of abscisic acid and a mannitol to culture medium culturing under reduced temperature, 20-22°C, successfully reduced the *in vitro* growth in *Solanum* spp. (12).

Research is ongoing at AVRDC to confirm these findings and to define a slow growth medium and/or appropriate condition for in vitro conservation. High levels of phenotypic variability or abnormality and even the loss of totipotency might be observed in plantlets regenerated from in vitro cultures because of chromosomal abberations and point mutations (10). Furthermore, recessive genetic changes which occur during in vitro conservation of vegetatively propagated crops may not express phenotypically and may remain hidden because of high level of heterozygosity. Therefore, germplasm resources of clonally propagated species are likely to contain more genetic variation than in species in which seed is the form of conservation.

Although maintaining cultures under growth limiting conditions offers the possibility of reducing the requirements for frequent subculturing, genetic instability might be favored due to the imposition of environmental stress on in vitro plantlets (10). Thus, the use of minimal growth conditions over a long period for sweet potato germplasm conservation can be expected to favor genetic instability. This will be further investigated at AVRDC.

Storage Root Active Collection

Sweet potato accessions could also be conserved as storage roots for a short period when stored under 85-95% RH and 13-16°C after a postharvest curing period (8). However, preliminary studies at AVRDC indicated that a large amount of inter cultivar variability was observed for storage duration in the form of storage roots ranging from two months to one year under high humid environment.

Genetic stability of plantlets derived from storage roots reported to be greater than in vitro plantlets or plants propagated by cuttings (10). A combination of known root storage methods and chemical treatments may increase the storage duration for a full year without loss of viability (8). However, production of storage roots under field conditions requires additional resources and efficient control measures against sweet potato weevil. Thus, the economics of storage root production and conservation needs investigation.

At AVRDC, storage roots were also derived from single leaf cuttings of virus tested sweet potato plants in 10 cm plastic pots containing sterilized soil and sand mixtures (7). Using this method, virus tested storage roots were obtained within nine months of initial meristem-tip excision and culture (7). Further investigation is necessary to determine the feasibility of using storage roots derived from single leaf cutting as a means of genetic conservation in conjunction with other methods.

Cryopreservation

At present, no methods are available for long-term conservation of clonally propagated, hexaploid, and poor seed producing crops, such as sweet potato. However, cryopreservation of cells and tissues is being examined as a promising approach. The principle behind cryopreservation is to bring the cells into a non-dividing state by subjecting the cultures to ultra-low temperature in liquid nitrogen (-196°C) in the presence of cryo-protectants (1). This technique has been applied to a wide range of crops such as potato, cassava, strawberry, etc. (1). Meristem cultures are the ideal materials for cryopreservation (10). Cryopreservation should obviate the constraints of minimal growth methods because the known biological process causing instability is arrested at ultra low temperature (10). However, a certain amount of capital investment is required to establish cryopreservation facilities (12). Therefore, encouragement should be given to studies aimed at the development of general methodology and in particular methods that can be incorporated into ongoing genetic resources activities at AVRDC.

Seed Conservation

Genetic conservation by means of true seeds is the most economical and efficient means for long-term conservation in clonally propagated crops. The sweet potato seed sample of an accession is genetically heterogenous and does not conflict with the principals of germplasm conservation (5), although it can conflict with immediate utilization of superior breeding lines or accessions. However, due to self incompatibility and sterility, seed production of sweet potato is very much restricted (6), and needs special measures to induce seed production.

Seed conservation is more feasible for the long-term conservation of genes from wild sweet potato species. Seeds dried to 5% moisture content and stored in hermatically sealed packets under -15 to -20°C can be stored for many years. Maintenance of the wild population is of course more difficult than the cultivated species and often requires special cultivation procedures. Efforts should also be made to maximize production of seeds from the representative sample of the population so as to avoid the consequence of selection or shift in allelic frequency (11).

Summary

Sweet potato genetic resources are currently maintained at AVRDC in a field genebank and in vitro active collections as a back-up for the field collections. Research is ongoing at AVRDC to define an appropriate slow growth medium and/or favorable conditions for the

culture. Culture induced mutations or somaclonal variations are undesirable side effects of in vitro conservation and the nature and extent of genetic instability in the cultures will be studied. The facility of using storage roots derived from the field genebank and single leaf cuttings as a means of short-term genetic conservation in conjunction with other methods needs further investigation. Cryopreservation of living cells and tissue is considered as the promising approach for long-term genetic conservation. Studies aimed at the development of general methodology and in particular methods that can be incorporated into ongoing genetic resources activities should be encouraged. For the long-term conservation of genes from wild species and land races of certain geographical regions, open pollinated or polycross seeds will be utilized.

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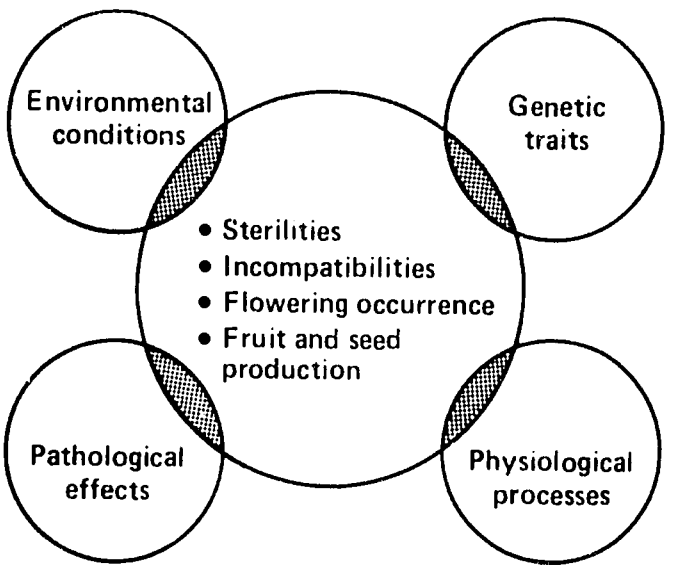
A REVIEW OF STRATEGIES FOR OVERCOMING STERILITY AND INCOMPATIBILITIES OF SWEET POTATOES

Helen Beaufort-Murphy

Introduction

The sterility and incompatibility problems of sweet potatoes (*Ipomoea batatas*) have been studied by numerous investigators, including: 1,2,6,11,12,15,16,20,22,24,26. During the last fifty years environmental, genetic, physiological, and pathological factors have been reported to be the continuing influences that have resulted in the existing problems of sterility, cross and self incompatibilities, as well as flowering occurrence, fruit and seed production, in sweet potatoes and other *Ipomoea* species (Fig. 1).

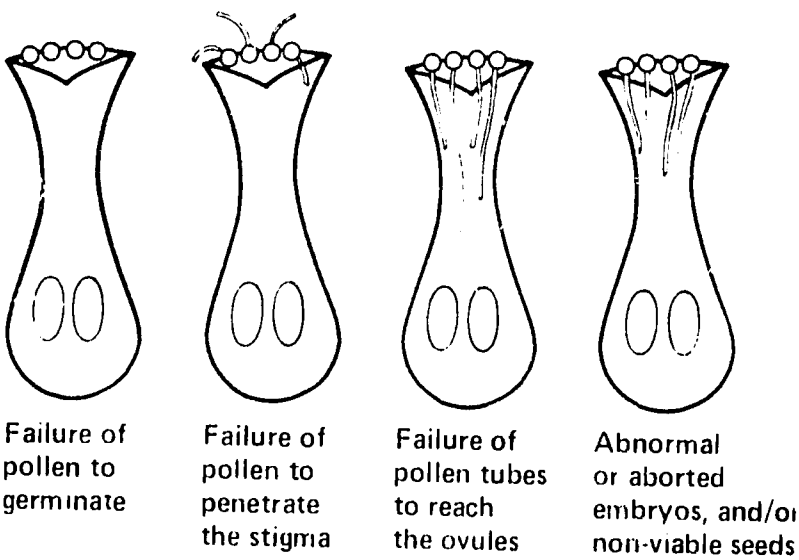
Fig. 1 Factors that influence the sterilities and incompatibilities of sweet potatoes



These problems include (4,6,7,8,9,12,13,14,16,22,24,25):

1. Lack of floral induction.
2. Weak or abnormal pollen development.
3. Failure of pollen to germinate on the stigma (fig. 2).
4. Failure of pollen to penetrate into the style (fig. 2).
5. Failure of pollen to fertilize the ovules (fig. 2)
6. Abnormal or non-functioning ovules.
7. Failure of fertilized ovule to develop into a mature, viable seed. This can be the result of either weak or abnormal embryos, or of the incompatibility of the embryo with the endosperm.

Fig. 2 Pollen and ovule related problems



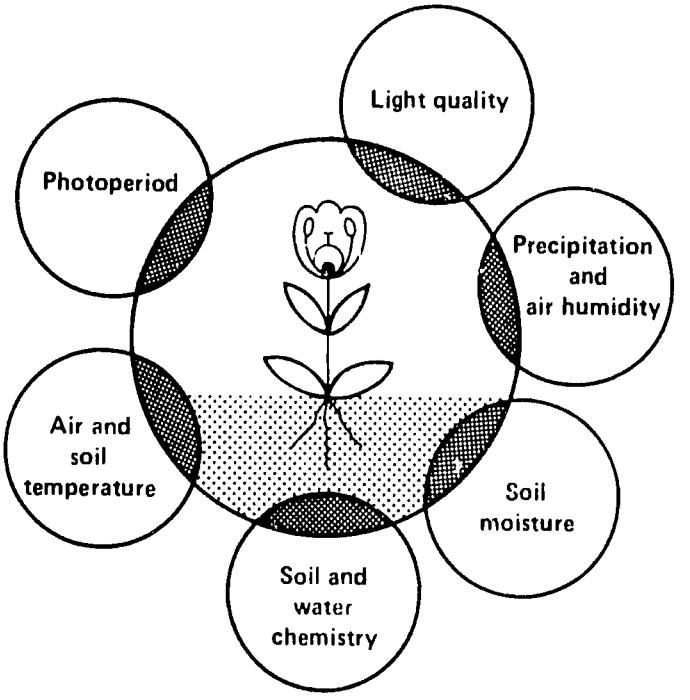
Discussion

Strategies for overcoming environmental and physiological influences

The environmental factors, and their interactions, that influence and control plant growth and development include: photoperiod, light quality, temperature, water availability and chemical composition, and soil properties including water holding capacity (Fig. 3) (3,5,17,18,23,25).

The genotype of a species, in conjunction with its adaptation to the climatic conditions of its phytogeography, determines the environmental requirements of the taxa for

Fig. 3 Environmental conditions that influence and control plant growth and development



plant growth and development, such as the need for a specific photoperiod for flowering. Consequently, the details of the environmental parameters of a species geographic origin, or distribution, can provide a valuable basis for the development of reliable plant growing regimens with which to optimize or control the developmental stages of the species. On the other hand, when the phytogeography of a taxa is not known the development of reliable plant growing regimens can entail extensive, long-term experimentation.

The exact geographical origin of sweet potato has not as yet been determined. Although, based on existing information, Central America, and/or northerm south America is considered to be the most probable location of its origin (21). Sweet potatoes are reported to be short-day plants for flowering (6). However, a detailed investigation of the influences of the various environmental factors, and their interactions, on the developmental stages of sweet potatoes, or other Ipomoea species, has not as yet been reported. Therefore it is not known to what extent the sterility and incompatibilities of sweet potatoes are influenced by environmental factors.

Plant growth and development studies with other plant species have demonstrated that plant growing regimens of specific ratios of photoperiod, light quality, temperature and available water, as well as the chemical composition of soil and water, can either initiate, inhibit or completely prevent the various stages of plant development (3,5). For instance, Xanthium pensylvanicum (cocklebur) a short-day plant, will not flower if the day length is longer than the critical point for its photoperiod requirement, even if the ratios of the other environmental factors are satisfactory for flowering (3,5,25).

A system of reliable and efficient plant growing regimens, based on the environmental requirements for the various developmental stages of sweet potatoes, could be an invaluable research asset. Such a system would provide a basic tool for investigating and resolving the existing problems of sterility and incompatibilities, as well as optimizing the flowering, fertilization and seed production of sweet potatoes and other Ipomoea species.

Strategies for overcoming genetic influences

It is not as yet known how much the sterility and incompatibility problems of sweet potato are related to environmental influences. Therefore it is not, possible to define just how much these problems are specifically related to genetic influence. However, strategies for investigating and overcoming genetic influences of plants include:

Breeding

A.1. Field grown plants with random insect-pollination (9.)

2. Selection of free-flowering fertile progeny for breeding programs (8,9,14).

B.1. Controlled, hand pollination of cultivars and/or species crosses (4,10,22).

In vivo techniques

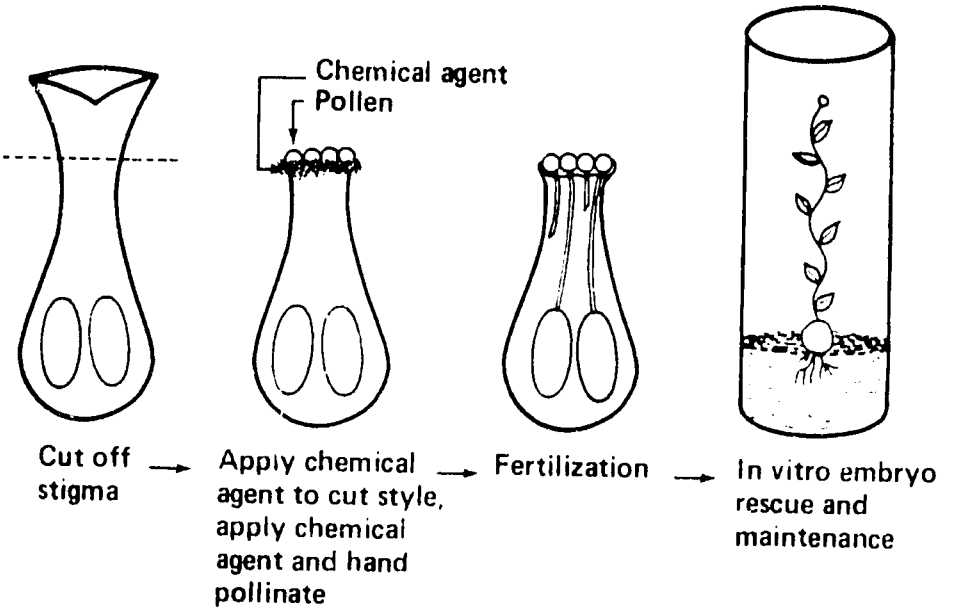
Flowering

Grafting or girdling of the plants, as well as hormone or other chemical treatment, for floral induction (4,6,19,20,22).

Fertilization enhancement

1. Removal of stigmas and/or the use of hormones or immunosupressants to increase pollination and fertilization occurrence (10) (Fig. 4)

Fig. 4 One method for overcoming pollen-stigma incompatibilities

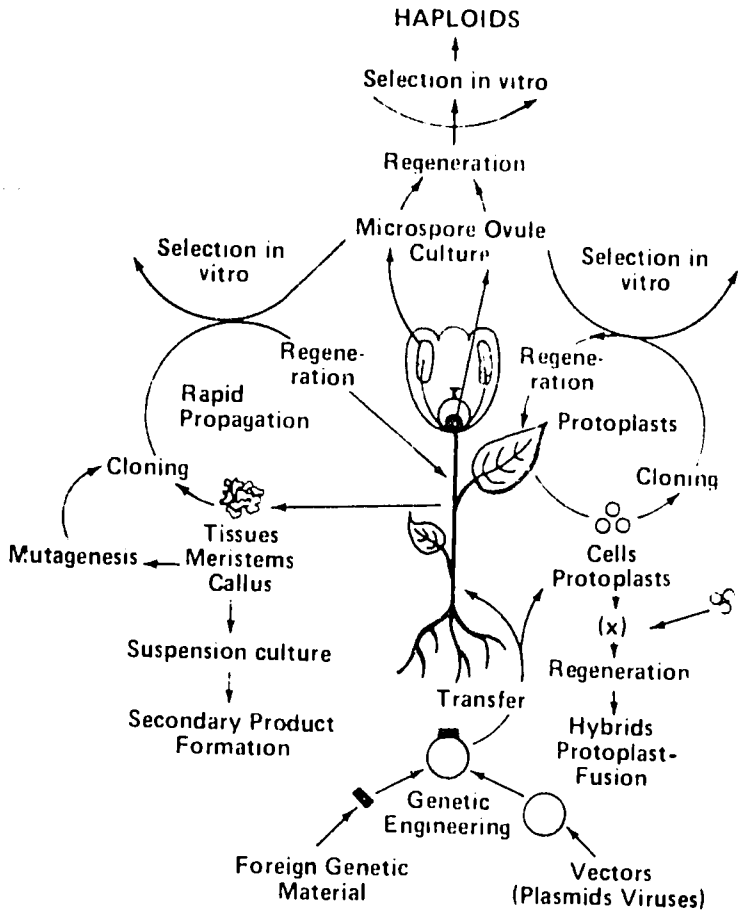


2. The use of fluorescent microscopy to investigate the mechanisms which inhibit normal fertilization and seed development (ie. pollen germination, and tube growth and development in the style).

<u>In vitro manipulation</u> (Fig. 5)

A.1. Embryo rescue of controlled crosses and selections of desirable progeny.
2. Tissue Culture regeneration and propagation of meristems, tissue and/or callus for rapid multiplication of desirable selections for future breeding programs.
3. Microspore and ovule culture for haploids.
4. Hybrids through cell protoplast fusion.
5. Genetic engineering.
6. Production of genetic bridges for future breeding programs.

Fig. 5 Summary of In-Vitro Manipulation Procedures Applicable to Sweet Potato



Strategies for overcoming pathological influences

In vitro

The production of pathogen tested plant materials.

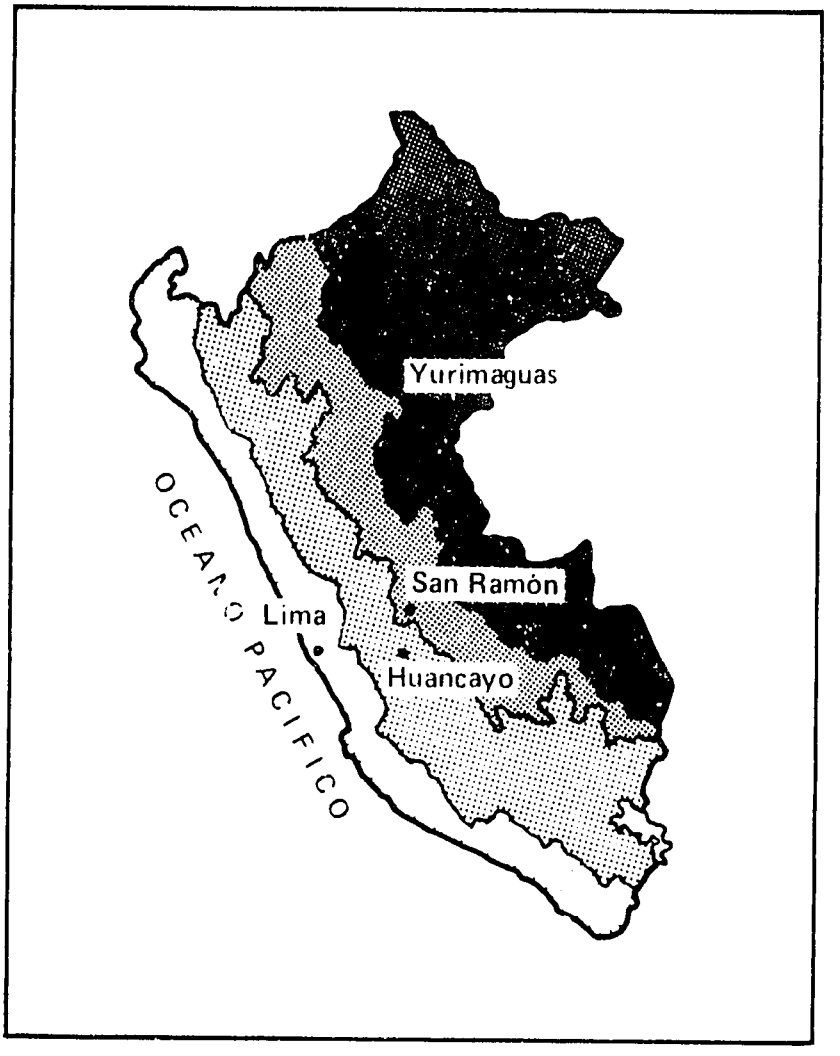
An ongoing investigation

As previously stated, a detailed report of the environmental requirements for the flowering response and seed production of sweet potato and other *Ipomoea* species has not yet been reported. Therefore, as a basis for developing an environmentally based system of plant growing regimens, an investigation is in progress by the author, at CIP, to define the factors that influence the developmental stages of selected sweet potatoes and other *Ipomoea* species. The objective of the study is to obtain as much environmental and developmental response information as possible.

Consequently, simultaneous experiments are being conducted at all four of CIP's research stations, thereby representing the four major agroecological zones of Peru, namely: Lima (arid), Yurimaguas (low-humid tropics), San Ramon (mid-elevation tropics), and Huancayo (highlands) (Fig. 6) The study will be conducted during tne growing seasons, for 3 years.

The primary objective of the study is to define the most effective environmental conditions for promoting maximum flowering and seed production of sweet potatoes and other Ipomoea species. In addition, CIP's four research stations, at which the study will be conducted, include a wide range

Fig. 6 Locations of CIP's Research Stations



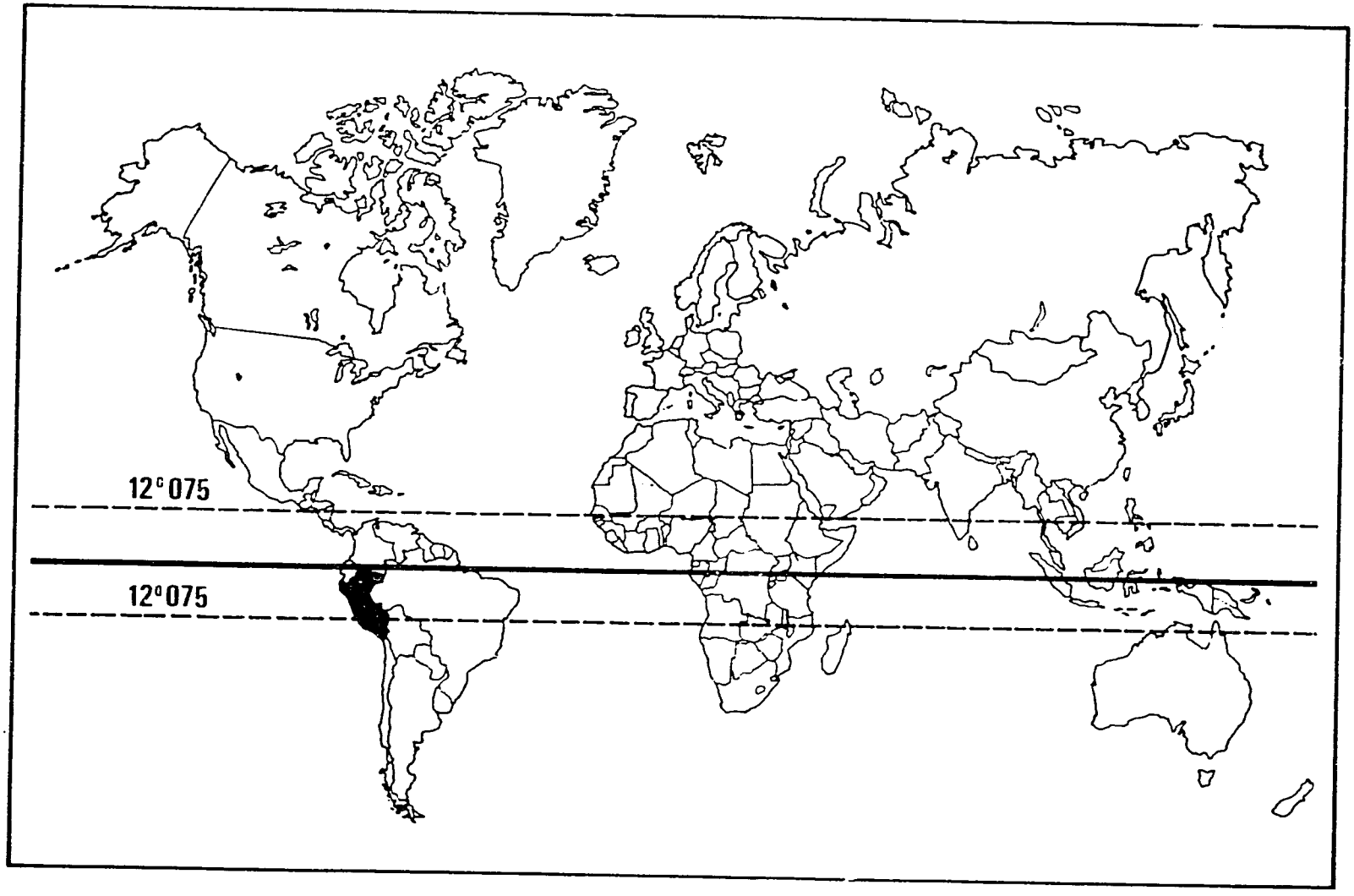


Fig. 7 Locations of CIP's Research Stations (3–12°S) and corresponding latitudes (12°S to 12°N) throughout the developing countries of the world

of agroecological zones and encompass the latitudes in which areas of major agronomic importance are located throughout the developing world (Fig. 7). Consequently, the resultant information will also be useful for other sweet potato (or potato) research, production, or intercropping programs, as well as for adaptation for on-farm usage, at either the locations investigated, or other locations with similar climates.

Summary

The various strategies discussed above have been used with investigations of sterility, incompatibilities or flowering occurrence, with either sweet potato or other Ipomoea species, or with taxa from other families. Some of the strategies are currently being used in ongoing investigations at CIP. But for the purpose of investigating the sterility and incompatibilities of sweet potatoes, all of the discussed strategies could be readily utilized within the sweet potato research program at CIP, or at the other national or international research centers with the necessary facilities. Therefore, the combined strategies of an environmentally based system of plant growing regimes, plant breeding, in-vitro and in-vivo techniques herein outlined should provide the means to overcome the existing problems of sterility, incompatibilities, flowering occurrence, and seed development.

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REVIEW OF IN VITRO PROPAGATION AND MAINTENANCE OF SWEET POTATO GERMPLASM

John H. Dodds

Propagation

Sweet potato is normally field propagated by the use of stem cuttings, however under in vitro conditions a wide range of methods are available for micropropagation.

Propagation by single node cuttings

Sweet potato germplasm can be introduced into in vitro culture in the form of a nodal cutting. When placed onto an appropriate culture medium the axillary bud is induced to grow and the result in the development of a new in vitro plantlet. It is important to note that this type of propagation involves the growth of an existing morphological structure, the axillary meristem. The hormone/nutrient conditions of the medium simply play a role in breaking the dormancy of the axillary bud and promoting its rapid growth. Several laboratories have developed media for single node propagation of sweet potato (1,2,3). Care must be exercised however that the culture conditions do not allow the formation of callus and subsequent de novo regeneration of plantlets, as will be shown in a later section this has been shown to affect the genetic stability of the genotype (4,5).

Most laboratories grow in vitro plantlets under long day (16 hrs light 3000 lux) conditions at 25-28°C. Under these conditions in vitro propagation rates are rapid and a single node cutting will have grown the full length of the culture tube and be ready for subculture after 6 weeks.

Several laboratories have shown that in vitro plantlets of sweet potato produced from single node cuttings can easily be transferred to non sterile conditions, for example transplant to jiffy pots, and in some cases plantlets have been transplanted directly to the field.

Propagation in liquid culture (stem segments)

From experience gained with other crops, especially potato, it is known that under certain conditions the speed and labour requirements for propagation by single node cuttings limit the potential production. As in potato, it

is possible to micropropagate sweet potato in flasks (250 cm^3) containing liquid culture medium. Whole stem segments 5 to 8 nodes long are prepared by removing the apical tip and roots. This stem segment is then inoculated into the flask so as to be bathed by the culture medium. The liquid medium contains gibberellic acid to break the dormancy of all the axillary buds along the length of the stem segment. Shoots develop from this and in 3-4 weeks the flask is full of vigorously growing sweet potato shoots, (6). The flasks containing shoots can be a source of plant material either for preparation of single node cuttings of stem segments depending on the needs or the program.

Propagation by plantlet regeneration

The sweet potato is developmentally a highly "plastic" plant. It has been possible to regenerate de novo in vitro plantlets from almost all plant parts when placed into culture. Several scientists have been able to successfully regenerate plantlets of sweet potato from cultured stems, petioles, roots and leaf discs, (7). In all cases the first step is the formation of callus at the cut surface, the size and type of callus varies between treatments and genotypes. When given an appropriate hormonal stimulus it is possible to induce the de novo formation of meristems within these calli which then eventually form a regenerating plantlet.

A number of disadvantages exist to using this method as a standard propagation method. Firstly the labour involved in dissecting off these individual plantlets would make the method cost ineffective within a production program. Secondly, callus derived plantlets are likely to have undergone minor or major genetic abberations during the callus stage, (8) thus, the regenerated plantlets would not be genetically the same as the original genotype. In a clonally propagated crop these types of genetic changes would probably be unacceptable to the producer or program.

Somatic embryogenesis

Plantlet regeneration de novo can take place through two possible routes, organogenesis, that is direct organ formation as described in the preceding section or by embryogenesis, the direct formation of embryos from somatic cells. The induction of somatic embryos has been reported in many plants (9). In a few cases somatic embryos are being encapsulated to form 'synthetic' or 'clonal' seeds.

Somatic embryogenesis has been reported in one genotype of sweet potato (10). However, to my knowledge no analysis has been made as to the genetic stability of these embryos. Since they are also derived from a callus/cell suspension

there is a high probability that the plantlets are not all genetically identical.

The importance of analysis of genetic stability in in vitro propagation (and conservation) programs

This section of this review is equally important both to propagation and conservation. In a clonally propagated crop it is important to know that each propagule is 'true to type', even small modifications could accumulate in the crop from one generation to the next and may affect uniformity and yield. In the case of conservation of clonal germplasm a detailed analysis of genetic stability in culture is vital. Clonal germplasm storage involves the maintenance of specific gene combinations (genotypes). If a plantlet should come out of storage with a different gene combination to that which it entered with, then the validity of the storage method must be questioned.

Our ability to detect genetic changes during propagation and storage are however only as good as the detection methods available.

Many germplasm collections evaluate the stored genotypes routinely on the basis of morphological characters of the plantlets when grown under controlled conditions. If the plants show different morphological characters, ie. leaf form, tuber or storage root colour change, then we know some genetic change has probably taken place. However, if the plants appear the same this does not mean that no change has occurred, it means we cannot detect it. For example a change in a virus resistance gene could not be detected on the basis of morphology.

A number of biochemical methods are currently used in both potato and sweet potato to study genetic stability, these being soluble protein patterns and isoenzyme analysis. Although these are highly effective methods for looking for variation in gene products they do not look for changes in the genes themselves. Novel methods such as restriction length polomorphism analysis is now being investigated as a more sensitive way of looking for genetic changes. It is important that major germplasm repositories and seed programs use the most sensitive methods available to determine the genetic fidelity of their storage and propagation systems. In the case of CIP, morphological, soluble protein and enzyme analysis is routinely performed on both potato and sweet potato collections. If and when a more sensitive restriction enzyme method for gene analysis becomes available its inclusion in CIP's routine methods should be considered.

In vitro conservation of sweet potato germplasm

A number of clonal in vitro sweet potato collections exist in many national programs and international organizations (11,12). There are many advantages to placing vegetatively propagated germplasm in an in vitro rather than field maintained form and these have been described previously (13).

A number of techniques exist for in vitro conservation, each with certain advantages or drawbacks.

Limiting growth media

Many years of research has gone into the development of propagation media for sweet potato where the objective has been to optimize rapid in vitro growth. In the case of conservation the objective is to limit growth to a minimum while maintaining viability of the cultures. By this means it is possible to maximize the time between transfers (sub cultures) of the in vitro plantlets. At CIP, for example, in the case of potato in LTS (long term in vitro storage) transfers are needed only once per year by most clones and in some cases only once every three years.

Experiments to limit sweet potato growth in vitro, in our own and in other laboratories have depended on the use of hormonal growth retardants, ie. ABA (Abscisic acid), growth inhibitors ie. B995, CCC (chloro choline chloride), or osmotic regulators such as high sucrose concentrations or the addition of osmotic sugars such as mannitol or sorbitol (14). The difficulty with these types of studies is that different genotypes will react differently under these conditions. When a large germplasm collection has to be maintained in vitro the objective of the studies must be the development of a conservation medium that is widely applicable to a broad range of genotypes. Several storage media have been reported for sweet potato, however again it should be emphazised that storage media should <u>not</u> allow induction of callus that may lead to genetic abberations.

Reduced temperature storage

The growth rate of in vitro plantlets can obviously be restricted by reducing the incubation temperature. The optimal growth temperature for sweet potato in vitro appears to be between 28-30°C. If the cultures are moved to a temperature of 8°C we have found that survival time is less than 1 month. The optimal reduced temperature for genotypes studied to date would appear to be 15°C, but this needs further confirmation. As in the case of other crops

maintained in vitro, ie. cassava, potato, yams, etc., it is possible to apply both reduced temperatures and osmotic/hormonal growth retardents at the same time. At the present time I believe the use of osmotic stress and reduced temperature (5°C) to be the most realistic and cost effective way to maintain a large sweet potato germplasm collection.

Cryopreservation

In the last decade there has been much interest in the use of cryopreserving (-196°C) plant materials in liquid nitrogen as a way of conserving germplasm (15,16).

This type of cryo-conservation is used routinely for storing animal cells and bacteria. The situation with plants is however more complex. It has been possible to freeze and thaw in viable condition plant cells from many plants, however these single cells then pass through a callus to regenerate whole plants causing genetic abberations. If intact plant structures such as meristems or embryos are frozen, their size (multicellular) leads to a problem of ice crystal formation within the tissue. Survival rates of frozen multicellular structures are low and little or no study has been made on the stability of the regenerated plant (with the exception of cassava). The concept of cryopreservation is one that would revolutionarize plant germplasm storage and as such deserves more investigation. However, in the short to medium term I do not see this as a viable option to sweet potato clonal in vitro repositories.

Phytosanitary status of sweet potato germplasm collections

The successful introduction of a sweet potato plant to in vitro culture would imply that the plantlet is probably free from bacterial, fungal and mycoplasma infections. The plantlets may still however be infected with viruses or viroid. The maintenance of the plantlets in vitro (rather than in the field) does, however, limit further viral degeneration of the collection that could result from cross contamination. It is therefore possible to enhance the phytosanitary status of a collection by in vitro introduction. It is also beneficial to virus/viroid eradication programs to already have the germplasm in in vitro. When germplasm is to undergo evaluation is in obviously optimal phytosanitary status is required.

Management of sweet potato in vitro germplasm collections

The size of any given germplasm collection will vary and the problem of managing a collection of several thousand

accessions are distinct from those with fifty accessions. However, with any in vitro germplasm colleciton care and consideration must be given to the following points: 1) How many replicates should be kept of each accession. 2) Should duplicate accessions be held by another institution. 3) What safeguards can be made against errors in data maintenance. 4) How often should the collection be checked. 5) Which accessions are the most valuable in case of emergency. In the case of CIP a computer data base is being established on the sweet potato collection. This should allow us (using the potato collection as a model) to maintain continual records of the in vitro collection and make the maximum amount of information and material available to developing country national programs. It should also facilitate inter-centre information flow on the status of any or all in vitro accessions.

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STRATEGIES IN SWEET POTATO BREEDING

Alfred Jones

The sweet potato is a vegetatively propagated hexaploid with 90 somatic chromosomes. Morphological traits are expressed in breeding populations as continuous variation rather than as discrete classes. Inheritance is best described as quantitative and mass selection procedures using rapid generation advance with high selection pressures have proven effective in its improvement (4).

Breeding strategies for any crop must take into account the germplasm available, inheritance patterns of the species involved and economic objectives and constraints. Rates of progress toward specific objectives will depend on gene frequencies in the originating populations, accumulated breeding experience with the crop and effectiveness of the methodologies used.

Sweet potato breeding objectives must be carefully ordered with consideration of short and long term goals, be comprehensive to allow improvement in all the many traits necessary for a cultivar to be successful, and be flexible to allow adjustments as gene frequencies change, new traits are considered or to take advantage of unique environmental variations. Realities of staffing, facilities and funding dictate continuing efforts to increase efficiency and improve methodologies.

This planning conference represents an exciting time with expanding prospects for sweet potato development and improvement. Germplasm collections have expanded rapidly in recent years with wide diversity in breeding sources now available (5). Our understanding of the complexities of sweet potato inheritance is improving and an enhanced appreciation of the sweet potato as a major food crop has increased funding for its collection and improvement.

The objective of any breeding strategy is to increase the frequency of desirable genes in order to increase the chances of extracting superior genotypes. Genetic studies of sweet potato indicate that continuous variation can be expected for most traits, heritabilities are generally high and traits are sufficiently independent to allow effective selection using sequential selection schemes (2). Recurrent mass selection has proven very effective in increasing both the frequency of desired types and higher levels of expression in desired types (1, 3). If the breeding population is sufficiently large this can be done without reducing the genetic variability of other traits.

An effective sweet potato breeding strategy will plan for improvement of many traits concurrently even when there is a major interest in some specific trait. Otherwise the level of expression of the desired trait will likely be reduced when crosses are made to germplasm with other necessary traits. This is because of the quantitative nature of the inheritance and the fact that all traits are essentially polygenic. It is easier to hold variation for many traits in a large population but progress on any one trait may be a little slower. Progress on a given trait at a specified level of expression can be faster in a small population but increasing the level of expression will be more difficult as will holding other desired traits. A comprehensive breeding strategy will achieve some balance within these extremes.

In our program we use large recurrent mass selection populations to provide a wide gene base and smaller polycrosses for more short term goals like cultivar development, short vining types or weevil resistance (Fig. 1). This general strategy is very flexible and can accommodate any number of mass selection populations and any number of smaller polycrosses. In the mass selection populations seed from selected clones are used to start the next generation, never the selected plant itself. This provides a rapid generation advancement and is coupled with high selection pressures (4, 7).

Presently we are using two year selection cycles starting with about 3000 seedlings from selected clones of the previous cycle. In the first year the population size is reduced to about 100 through use of seedling screening techniques and five plant field plots to eliminate those with obvious faults. This is followed by preliminary storage, baking and sprouting evaluations (including associated diseases). The selected 100 plants are set out the second year in crossing blocks replicated two to four times. They are also grown in replicated ten plant field plots and evaluated more precisely for all the many traits we are interested in. Seedling disease reactions are confirmed during the second summer in greenhouse trials. About 30 clones are selected as seed parents of the next cycle. Outstanding clones are saved for further testing and may be added to one of the polycross nurseries or possibly released as a breeding line or cultivar.

We limit the number of parental selections used in the smaller polycrosses to no more than 30. When a new selection is added one of the previous selections must be removed. This enforced discipline assures a constantly improving program so that five or ten years from now the nursery will contain new and improved germplasm. Of course any one clone can be retained so long as a better one to replace it is not found, but as a rule new selections will replace older ones. Selected clones that flower poorly may be entered more than once per replication or grafted to other stocks to encourage flowering. Four replications usually provide us with sufficient seed for our breeding program. The parental averages for the various traits of interest can indicate where improvement is needed in the parental makeup and can help in decisions

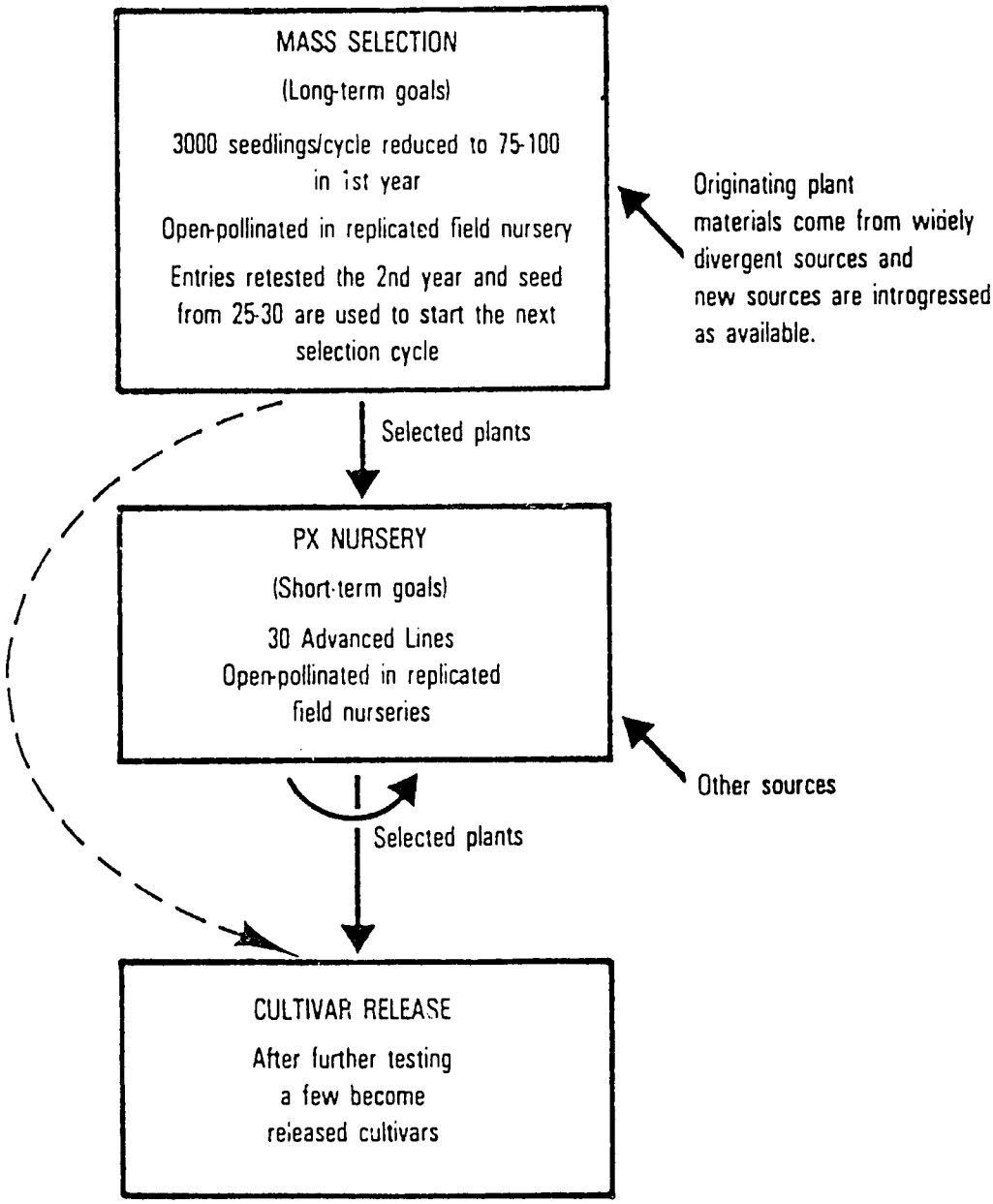

FIGURE 1. A comprehensive breeding program addressing both long- and short-term goals should contain mass-selected populations to provide new parental types and to assure the wide gene base necessary for continued selection advances in future years. The authors use two mass selection populations to provide new selections for the PX nursery, each with 2 years per cycle and grown on seed increase trellises in alternate years. Seedling selections from the PX nursery also provide materials for the next PX nursery. Selections from the mass selection population could become cultivars, but the probability is lower than for those from the PX.

of what new clones to add and which to drop. These averages can be compared over several years to monitor the progress being achieved.

When beginning a new mass selection population one may use one year per cycle for the first three cycles. Our experience indicates that essentially every plant will flower sometime during the season by the fourth cycle (6). We have also experienced some difficulty introgressing new germplsm into populations where selection pressures have been high because few of the progeny from the new germplasm meet the minimum requirements for all the traits evaluated. In some cases it may be better to start a new mass selection population. After a few cycles of selection it may be possible to integrate the two populations although I have not tried to do that.

The same goals may be attained using populations of different origins. However, rates at which those goals would be reached can be expected to be different because the rate of advance is affected by the frequencies of genes that control the trait. As experience with a given trait is gained the techniques of evaluation will likely improve and gene frequencies will also increase. Selection pressures will need adjustment to allow use of the higher levels of expression that occur. In a dynamic selection program emphasis may be shifted to a new trait as the gene frequency and precision of measurement in a previous trait improves. Selection indexes are not likely to be very useful because of the rapid changes in gene frequencies, changes in selection methodologies as experience is gained with a particular trait, environmental occurrences that provide unique opportunities for selection, and the frequent addition of new traits to the selection sequence.

In most cases good progress using sequential phenotypic mass selection can be made. However, some traits will be subject to wide environmental swings and will require wider geographic testing. Many different selection strategies are possible and seedling screening techniques should be considered when possible. At a later stage in the program some system of confirmation may be necessary to avoid possible escapes. Laboratory and greenhouse screening systems can be very useful but must be confirmed under field conditions. Good controls are necessary for any effective screening technique and usually should include both extreme types, like resistant and susceptible disease or insect selections. Often intermediate controls are also useful.

We are fortunate to be working with a crop that is so versatile and in which a single seedling can become a new cultivar. Since it is impossible to reproduce a given genotype sexually the pedigree systems of breeding used so well in other crops are of little value for sweet potato. Also, controlled crossing is very expensive compared to open-pollination. No unfavorable associations have been found between good flowering or seed set and any other useful trait. For these reasons I do not advocate hand crossing except for very special purposes.

When a plant that flowers has the particular trait or traits desired it should be favored over a non-flowering plant. Flowering is highly heritable like most other traits and use of non-flowering clones in the breeding program will make future breeding efforts that much more difficult.

The range of characters for which selection is required is so large that the effort requires a team approach. An effective breeding strategy requires trained scientists of diverse disciplines such as: genetics, pathology, entomology, physiology, nematology, virology, agronomy, sociology, and nutrition in addition to taxonomy and cytogenetics for phylogenetic studies. Some of these specialists will be needed full time, others on a consultative basis but in any case they need to work together in a cooperative spirit. A long term outlook is necessary and, for some of the team members, a long term commitment.

When I began my program a major need was a broader gene base and many years were required to put together that gene base and bring it up to an acceptable standard so that other breeders would be interested in its use. It has taken almost 25 years to reach that point. Here at CIP you are in a rather enviable position quite different from what I faced. You have a vast collection at your disposal (5) and must plan how to put it to best use and at the same time to preserve this valuable germplasm for future generations. I hope my experiences as related here will be of some help to you in this important task.

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USE OF WILD GERMPLASM FOR SWEET POTATO BREEDING

Masaru Iwanaga

Introduction

The definition of "wild germplasm" of sweet potatoes needs to be clarified first. It is defined here as Ipomoea species which do not belong to I. batatas but it does include feral types of I. batatas. Thus, K123 reported by Nishiyama (10,11) as a 6x form of I. trifida would be "wild germplasm" although it might be a feral type of I.batatas as argued by other scientists (2,3,9). The reason why feral types of I. batatas are also included in wild germplasm is that such germplasm is not usually included and maintained in regular cultivated germplasm collections, although it has value for sweet potato improvement as was demonstrated by the release of a successful variety (14).

It is often mentioned by sweet potato geneticists that sweet potato cultivated germplasm has a great genetic variability and that most of the traits important for breeding can be identified in the cultivated germplasm. If that is the case, we may wonder why we should try to utilize wild germplasm. Is there any justification? In general, there are two reasons why use of wild germplasm has attracted the attention of plant breeders. First of all, wild germplasm may be the only source of germplasm to provide specific trait(s) to cultivars. A good example of this type of use in potato breeding is the transfer of insect-trapping trichomes from Solanum berthaultii to cultivated germplasm of potato. The second type of use is to widen the genetic background of cultivated germplasm. The Mexican wild species, S. demissum, contributed much to widen the genetic background of potato cultivars.

In order to justify the use of wild germplasm for sweet potato breeding, we need to know its potential value and to understand the practical problems of utilization. If strong resistance to sweet potato weevil (Cylas spp) is found in some wild accessions, there is enough justification to explore the germplasm regardless of technical difficulties. On the other hand, there is not enough justification to use wild germplasm only as a source of resistant to root knot nematodes, since resistant commercial cultivars are available. An overview of previous work regarding the use of wild germplasm will undoubtedly indicate the best way to assess potential value of wild germplasm for sweet potato breeding.

A brief overview on the use of wild germplasm for sweet potato breeding.

Although only 4 lines of research have been pursued for the use of wild germplasm, an overview of the results obtained will lead to some insights into the potential value and practical problems of such use.

(1) Use of 6x I. trifida in Japan

Nishiyama (10,11) reported the finding of a 6x trifida (named K123) in Mexico which hybridized easily with sweet potato cultivars, and he proposed that such a 6x trifida was the ancestor of cultivars. Although the taxonomic identity of K123 has been questioned (3), it was utilized in variety breeding programs in an attempt to transfer its resistance to nematodes. Although some hybrids between sweet potatoes and K123 had high yield, they were backcrossed to cultivars to improve agronomic traits. From BC_2 progenies, Minamiyutaka was selected and released in 1975 (14). The main attributes of the variety are resistance to root knot nematodes and root legion nematodes, high yield and high starch content, and it has become the second most important starch variety in Japan, occupying about 5 thousand ha. in the southern part of Japan. It seems that Minamiyutaka has a deep root system, which is probably derived from K123 and which allows the variety to have a longer growing period until late autumn, resulting in high yield.

Although Japanese scientists claim to have released the first variety using wild species, it may not be exactly correct, if K123 is not trifida but a feral batatas as claimed by Jones (3).It is still true, however, and should be emphasized here that the Japanese pioneered the utilization of exotic and non-traditional sources of germplasm and produced a very successful variety which has contributed a lot to sweet potato cultivation in Japan. Minamiyutaka and other clones with a K123 background have also been used as good parents in variety breeding programs. Thus, K123 regardless of the taxomic argument, made an impact on variety breeding in Japan.

(2) Use of 6x trifida in China.

Some seeds which were classified as 6x trifida by Japanese scientists were provided to Chinese scientists. The 6x trifida plants were crossed with local varieties by breeders of the Zhangsu Academy of Agricultural Sciences. Some hybrids had very high yield (2.5 Kg/plant) and a high dry matter content (43.5%). The hybrids were backcrossed twice to cultivars to improve agronomic traits. According to Prof. Sheng Zha-Len, some BC_2 progenies are in an advanced evaluation stage and a couple of clones are expected to get released as varieties soon. The main

characteristics of this material are high yield and a high dry matter content.

It is interesting to note that the use of 6x trifida accessions resulted in the production of high yielding clones in both Japan and China. This is probably due to heterosis created by the introduction of foreign germplasm. Thus, the use of wild germplasm is valuable, not only for introduction of specific traits (i.e. root knot nematode resistance from K123 to Minamiyataka), but also for widening the genetic background which may result in high yield as was reported in other asexually propagated polyploid crops such as potatoes and cassava.

(3) Use of I. littoralis in China

The genetic variability of some important traits of interspecific hybrids between sweet potatoes and an accession of the 4x wild species I. littoralis was studied in China (8). Even though only 73 hybrid progenies were studied, one of them was found to have yield and dry matter content much higher than its cultivated female parent. The hybrid yielded 1.4 Kg/plant and 0.6 Kg/plant in 1983 and 1984, respectively, while the local variety had only 0.37 Kg/plant and 0.2 Kg/plant in the two years. Dry matter contents of the interspecific 5x hybrids were 33.2% and 36.41% in the two years, while the local variety (female parent) had 23.3% and 24.9%.

Resistance to the black rot disease, caused by Ceratocystis fimbriata was also evaluated in 29 clones of the hybrid progenies. The average level of resistance of the hybrids was much higher than that of 4 female parents (local varieties). Thirty one per cent of the hybrids were classified as highly resistant, i.e. more resistant than the local resistant variety, Nanjing 92. This clearly indicates that I. littoralis is a valuable source of resistance to this important fungal disease.

Surprisingly enough, one hybrid was identified as octoploid, instead of the expected pentaploid, which was presumably due to the functioning of 2n eggs (eggs with the somatic chromosome number). The octoploid hybrid had yield and dry matter content higher than its female parent (local variety). This indicated that 2n eggs existed in the sweet potato and might be useful for sweet potato breeding.

(4) Evaluation of the 5x interspecific hybrids between sweet potato and 4x trifida: a collaborative work of AVRDC, Japan, and CIP.

M. Iwanaga was granted a sabbatical research year in Japan and at AVRDC. The sabbatical research was conducted to evaluate the value of 4x trifida for sweet potato breeding in strong

collaboration with Japanese and AVRDC scientists. Four I. trifida (4x) accessions were crossed with 7 Japanese cultivars to produce 5x hybrids. The hybrid seeds were sown at AVRDC and a seedling nursery was established. Two field experiments were conducted by using cuttings taken from the nursery: one experiment was conducted to evaluate the hybrids for resistance to sweet potato weevil (Cylas formicarius) and the other to test general agronomic characters. Roots of some selected clones were chemically analyzed for their nutritional value. The main conclusions of the studies are summarized bellow:

(a) The majority of the 645 hybrids had poor storage root formation. More than 10% of the hybrids, however, had yields similar to the check cultivar.

(b) Hybrids with relatively good yield were checked for general root traits. No particular negative trait was found.

(c) 42 hybrids with yield of more than 1 Kg/plot were analyzed for nutritional value. Average dry matter content was extremely high (40%). Two hybrids had dry matter contents close to 45%; a value breaking the record by a wide margin. Protein contents (% fresh wt.) of some clones were also very high (3.1g/100g fresh weight). Thus, some of these hybrids present an excellent source of germplasm for improving sweet potato for dry matter and protein contents.

(d) Many hybrids with yield of more than 1 Kg per plot but without any weevil infestation were found while the check cultivar suffered from heavy infestation in the same field. These hybrids reserve further investigation as a potential source of resistance to weevil, and they will be evaluated thoroughly by an entomologist at AVRDC.

There are some interesting aspects commonly found in hybrids with input of wild germplasm, which should give us some general guidelines on the future use of wild germplasm.

(1) High yield: The hybrids combining different genetic sources showed heterosis and high yield in the all four studies. Very large variation in storage root yield was found in the F_1 hybrid progenies, and some of them yielded more than their female parents and/or local check cultivars. Although yield comparison should be considered as preliminary, due to the small plot size, few replications, different sanitary conditions of the check cultivars (or female parents) and hybrid progenies and etc., it is still intriguing to find such high yielding hybrids with a large input of wild germplasm which in turn has no yield (i.e. no storage root formation) at all.

The capability of storage root formation appears to be controlled by just a few genes. Even within full-sib families, large difference in storage root formation are found: some progenies had yield higher than the check cultivars and other progenies next to them did not produce any storage roots at all. Shiotani and Ogawa (14) reported relatively simple inheritance pattern for storage root formation in some 2x trifida accessions. If storage root formation is really controlled by only a few genes, as suggested, it has quite an important implication for evolutionary studies and sweet potato breeding programs using wild germplasm. Any theory on the evolution of cultivated sweet potatoes should include an answer on the origin of genes for storage root formation, because that is the most important character to make I. batatas useful for agriculture. From a breeding point of view, the use of wild germplasm for sweet potatoes becomes more feasible if just a few genes need to be manipulated in the hybrid progenies.

(2) High dry matter content: All four experiments identified clones with very high dry matter content in the F_1 hybrids. "Minamiyutaka" is a very successful variety for starch use in Japan. The dry matter content of an F_1 studied in China was as high as 43.5%. One of the F_1 hybrids involving littoralis had dry matter contents of 33.2% and 36.4% in 1983 and 1984, respectively, while its female parent (local variety) had only 23.3% and 24.9%. Some of 5x hybrids obtained from crosses between Japanese cultivars and 4x trifida accessions had dry matter contents as high as 45%, which was the highest value ever recorded at AVRDC where a strong breeding program emphasizes high dry matter content as one of the top priority breeding objectives.

In a histological comparison of storage roots of several sweet potato varieties, K123 and its hybrids demonstrated clear basic differences from each other (7). The dry matter content of storage roots was negatively correlated to the frequency of the large parenchymatous cell division in the xylem tissue. The interspecific hybrids showed high dry matter content and a low frequency of the cell division, and the reverse was true in the sweet potato varieties. Moreover, it was found that storage roots of interspecific hybrids with high dry matter content showed vigorous proliferation of vascular bundles and the related parenchymatous cells through active development of a secondary cambium. The use of wild germplasm for sweet potato breeding may result in significant changes in histological aspects of the storage root development which, in turn, leads to production of varieties with exceptionally high dry matter contents.

(3) Success in finding specific resistance in the hybrids: Transfer of specific resistance into cultivars is the most common use of wild germplasm in plant breeding. Release of Minamiyutaka

as a nematode resistant variety, represents a good example of the use of wild germplasm for sweet potato breeding. Finding of strong indications of resistance to the sweet potato weevil (Cylas formicarius) in the 5x hybrids evaluated at AVRDC was very exciting since the weevil is the most serious production constraint in many developing countries. Studies on the mechanism of the resistance need to be carried on to asses the value of such resistance in future breeding programs. The resistance may be due to antibiosis, which would be most preferable, or to the extremely high dry matter content of the hybrids, or to other reasons. The success obtaining hybrids with littoralis, which had resistance to black rot was also an important achievement, because it demonstrated the potential use of wild germplasm as an additional source of resistance to this important fungal disease.

In summary, this overview manifested a great potential value of wild germplasm for widening the genetic background of sweet potatoes and for introducing specific attributes (high dry matter content, resistance to weevil and black rot), although only a small portion of available wild germplasm was utilized. No major technical difficulty was encountered for the use of 6x trifida. The value of 4x germplasm (i.e. 4x littoralis and 4x trifida) for variety improvement, however, still remains to be demonstrated trough transferring the useful traits found in the 5x hybrids into commercial cultivars, although backcrosses of the 5x hybrids to sweet potatoes is not a major technical problem.

Important components for developing strategies for the use of wild germplasm

CIP intends to provide breeders/geneticists with useful genetic material to back up their variety improvement programs. There are several factors which should be taken into consideration to set up strategies for the utilization of wild germplasm in such a way that CIP can meet the needs of national programs.

(1) Well defined breeding objectives:

We should clarify the important traits that should be exploited in wild germplasm. Our knowledge of important production and utilization constraints in developing countries is essential. This Planning Conference is expected to help and orient CIP to define its breeding priorities. A questionnaire directed to national program scientists will provide very useful information on their needs.

(2) Capability of national programs to receive new kinds of germplasm and the important role of other International Centers:

Some national programs have full-scale breeding programs, and they can receive and utilize any germplasm that can be hybridized with local varieties without any problem. Take the Philippine as an example. If CIP identifies 6x trifida accessions with strong resistance to weevil, they would be able to use this material directly in their breeding program. The majority of national programs, however, do not have such capacity or resources, and they prefer more advanced material. Some countries are not able to handle any segregating populations and need to receive highly selected potential varieties. Others can handle segregating populations but still prefer advanced material in terms of agronomic characters for easier handling.

Other International Centers (i.e. IITA and AVRDC) should play on important role to bridge CIP and national programs by receiving CIP's rather basic row genetic material and then improving it for use by their prospective client countries. National programs with strong breeding activities such as those of the U.S.A., China, Japan, and the Philippines, may play a similar role.

(3) CIP's limitation in screening germplasm for some important traits and importance of research collaboration with other research groups:

It seems that CIP has the capability to evaluate germplasm for most abiotic stresses (i.e. heat and drought) but not for some of the major biotic stresses. For example, sweet potato weevil (Cylas spp.) and scab (Elsinoe batatas) are a most serious pest and disease in Asian and Pacific countries, and AVRDC is actively working on these problems. These organisms, however, do not exist in Peru and thus, no screening work can be carried out here. Therefore, CIP should clarify what can be effectively done at CIP and at the same time, CIP should develop strong collaborative research projects with other institutions where expertise and facilities are available to complement CIP's activities.

(4) How to evaluate efficiently the value of many wild accessions:

Most of the important sweet potato breeding objectives are related to the storage root (yield, earliness, eating quality, starch content, nutritional quality, storage capability, resistance to sweet potato weevil and etc.). Therefore, wild germplasm which does not produce any sizable storage root, can not be evaluated directly for those important characters. Although initial screening of many wild accessions and the subsequent use of selected

accessions for hybridization with sweet potato cultivars are an ideal method for evaluating the breeding value of the wild germplasm, this type of evaluation is lengthy, and indirect as it is only possible after obtaining the hybrids. In my opinion, this is the most serious bottleneck for efficient utilization of wild germplasm. CIP's breeding strategies should be organized in such a way that the value of as many accessions as possible can be evaluated without going through time-consuming hybridizations with sweet potato cultivars.

(5) Cytogenetic barriers for effective use of wild germplasm:

Which are the related species to be utilized for sweet potato breeding? According to Austin (2), there are 13 wild species in section Batatas to which I. batatas belongs. Other numerous Ipomoea species are so distantly related to I. batatas that they do not deserve any immediate attention for sweet potato breeding.

Among the species of section Batatas, I. trifida is the most important specie due to its crossability with sweet potatoes, availability of a great number of accessions, and its proven value for sweet potato breeding. Other species, which can be crossed with sweet potatoes should also be exploited. There is a clear genomic differentiation between some species in section Batatas (4,13) which makes hybridization with sweet potatoes and further utilization extremely difficult. Should we have to use such species, use of ovary/ovule culture to obtain hybrids, needs to exploited (Lu et al. unpublished). Furthermore, although some species like I. trifida have the same genome as sweet potatoes, ploidy level difference between sweet potatoes (6x) and its relatives (2x, 4x) require specific strategies for the efficient transmission of valuable genetic variability.

Strategies for utilization of B-genome species of section Batatas

Several ideas on the use of wild germplasm which has the B genome and some level of crossability with sweet potato, were already proposed (6,12). Based on the important factors discussed earlier, the following two routes for the use of wild germplasm seems to fit best with the research line at CIP.

(1) Development of synthetic hexaploid populations:

This approach intends to synthesize 6x populations by using 2x and 4x germplasm. First, many 4x accessions should be crossed with a large number of 2x accessions from different geographic areas and then, their 3x hybrids are

doubled somatically to obtain synthetic 6x plants which combine 2x and 4x germplasm with a different genetic background. The 6x plants are then intermated to produce highly heterozygous hexaploid populations with a wide genetic background. The synthetized 6x populations are not likely to produce any edible roots, but are ready to be crossed with sweet potato cultivars. The resulting hybrids, which probably produce storage roots, can be evaluated for characters related to storage roots, such as yield and dry matter content. Alternatively, if the 3x hybrids produce 2n gametes, they can be directly crossed with sweet potatoes. The most important advantage of this approach is that the synthetic 6x can be produced within a relatively short time (12-18 months), and it is technically feasible as demonstrated previously (5,13). Seeds of the synthetic 6x material can be exported to other International Centers and interested national programs with the capacity to use it. Meanwhile, CIP can use the populations for crosses with sweet potato cultivars to develop new hybrid populations with more input of cultivated genes and thus improve agronomic characters. Such improved populations are easier to use, and national programs with capacity to handle segregating progenies, may utilize these populations. In this way, CIP can meet the requests of national programs with different levels of capacity in terms of handling new germplasm.

Which type of selection should be applied during the process of developing such synthetic 6x populations? Shall we use only selected 2x and 4x accessions for 4x - 2x crosses, or shall we evaluate the 3x hybrids and only selected some for doubling? It appears that most of the important traits for breeding are not expressed in such a pure wild germplasm, and meaningful selection can not be carried out. Selection for resistances to abiotic stresses can be applied if proper screening methods on pure wild germplasm become available.

(2) Development of storage root initiators:

This is a rather long-term approach to solve the most serious drawback of the first approach, the delay of evaluation of the value of wild accession until they get crossed with sweet potato cultivars. Production of hybrids between sweet potato cultivars and 2x and 4x trifida accessions are technically possible (6) and evaluation of the hybrids which probably produce storage roots, may give us an idea on the value of the wild accessions. This direct method, however, does not permit the evaluation of many accessions because of the technical difficulty involved in such crosses. The approach proposed here

intents to solve the problem by developing 4x clones whose hybrids with 4x and 2x wild accessions produce storage roots so that the value of each accessions can be evaluated directly without going through the difficult process of hybridization with sweet potato cultivars.

Such storage root initiators can be developed by crosses between sweet potatoes and 2x trifida and subsequent improvement for yield by intermating the 4x hybrids. Such clones can serve as instruments to quickly check the breeding value of 2x and 4x wild accessions. Promising accessions, which are identified by the use of the 4x initiator, can be selectively used to develop a synthetic 6x population as described in the first approach.

Development of 4x sweet potato commercial cultivars may be achieved by further improving the 4x clones for important agronomic characters. Japanese breeders have tried to produce commercial 4x cultivars by 6x - 2x crosses and subsequent selection and intermating of hybrids to improve agronomic traits. According to their latest report (1), the hybrid population has been advanced up to the F_8 generation, and their yield are approaching that of regular cultivars. It seems, however, that the improvement of their 4x population has reached a plateau, presumably due to narrow genetic background they utilized. Expected advancages of 4x cultivars over regular 6x cultivars include earliness and high dry matter content, which are known to be related to ploidy levels in some crops. In addition, use of 2x and 4x germplasm will become much easier and 4x cultivars are expected to flower better than 6x cultivars, which also facilitate breeding activity.

How long does it take to develop such 4x clones? The Japanese group started the work in 1971, 15 years ago. Development of the clones which can induce storage root formation when crossed with 2x and 4x accessions can be done within three years, although development of commercial 4x cultivars will obviously need more time. A thesis work is being done at CIP to develop an efficient embryo rescue technique and apply it to produce many 4x hybrids between 5 sweet potato cultivars and 20 accessions of 2x trifida. The F_1 hybrids will be evaluated in the field in late 1987. Then, selected F_1 hybrids for good storage root formation will be crossed with a sample of 2x and 4x wild accessions to see if the hybrids can produce storage roots which are good enough to be evaluated for storage root traits such as shape, skin color and dry matter content. If some of the F_1 hybrids from 6x - 2x crosses really induce storage root formation in their hybrid progenies with wild accessions, our first objective is completed. Thus, within two years

we may identify 4x clones with the strong capability of storage root initiation. In case there will not be any clones with such capability in the F_1 hybrids, intermating of selected F_1 hybrids will be done and work to identify such clones in the F_2 population will be completed by the end of 1989. Development of 4x commercial cultivars will take more time since such clones need to yield at least good as regular 6x cultivars in addition to meeting with other requirements for commercial use.

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BREEDING SWEET POTATOES RESISTANT TO STRESS: TECHNIQUES AND RESULTS

Franklin W. Martin

INTRODUCTION

Growth of the plant can be thought of as the result of the interaction of the plant with its environment. The amount of growth, as well as the form of the plant, is controlled by both the genetic potential, and the array of elements which together can be classified as environment. Some of these elements are non-living, the abiotic environment, and some are living the biotic environment. Many of these elements, such as drought or a disease, can individually restrict growth drastically. One theory of growth is that of limiting factors, the concept that growth is always limited by one principal factor (or element). When the limitation is alleviated, then another factor becomes limiting.

Factors or elements that limit growth are also called stresses. A stress might be defined as a sub-optimal environmental factor, whether biotic or abiotic, that limits plant growth. Under normal conditions of growth stresses always occur. But, it may be impossible to distinguish which stress is the limiting factor in growth, and in many cases it is more convenient and probably more accurate to think of growth as the result of the integration of numerous factors. For example, in many parts of the tropics the soils are heavy, poorly drained, acidic, and of low natural fertility. These soils impose several stresses on plant growth, stresses which may also occur separately in other situations. When an environment imposes one or a series of stresses on plants, the environment might be marginal for plant growth for some species or for many species. Nevertheless, some species are adapted to grow well in environments that are limiting for others. One might say that they are capable of dealing with the stresses of such an environment. The way a particular species is adapted to stress varies and indeed this is what makes plants so varied and plant physiology so interesting. Many mechanisms to deal with stress are still little understood.

It is obvious that the amount of land available on this finite planet is limited and can be increased only by very small amounts. Increases in crop production can take place

by genetically modifying plants to produce more in current cropland, or by extending crops to new lands (1). In the first case, increasing yields on current croplands includes in most, if not in every case, increasing adaptation to stresses. Since most lands easily used for crops are already in use, the remaining lands are those that are not very suitable for crops, often characterized by rather severe abiotic stress. These stresses, because they are strong and limiting, can often be named. They include drought, flooding, salinity, cold, inadequate light, and mineral deficiency. In addition, biotic stresses are very common and may be intensified by environment. These include those imposed by disease, insects, and weeds.

Breeding for increases in yield involves breeding for stress resistance. In some cases the stresses may not be identified or distinguished, or may be hidden beneath the umbrella word, adaptation. Perhaps what distinguishes breeding for stress resistance from breeding for yield in general, is a conscious recognition of individual stresses or stress complexes and an effort to overcome them. The stress itself and mechanisms to deal with it may themselves be objects of study.

STRESSES IN SWEET POTATO AND BASIC METHODS

In spite of the greatness of the sweet potato as a food crop, relatively little study has been made of its stress resistances. Nevertheless, we can speak from our common base of knowledge about the stress tolerances of sweet potato. Sweet potato is tropical. It is not tolerant of frost nor cold temperatures. Sweet potato thrives in the sun. It does not tolerate excess cloudiness nor shading due to other objects. Sweet potato cannot tolerate dry conditions at the moment of planting. It can tolerate some drought near the end of its life cycle, but it can hardly be thought of as a drought tolerant crop. Sweet potato can tolerate excessive water and grows very well in some wet situations in the tropics. Nevertheless, excessive rainfall at the time of harvest in the temperate zone leads to post harvest rotting and physiological problems. Of its salinity tolerance we know nothing, but beleive it is not tolerant. We know that some sweet potatoes grow very well in acid soils, and thus concede some acid tolerance but the question is, "How much?" From this brief analysis it is obvious there is ample room for research with stress tolerances in sweet potato. The tropics has numbers of typical environments where stress tolerances are needed, the heavy acidic soils of the plains, the sands of the deserts, the cool highlands, the shade beneath coconut plantations.

There are two basic approaches to breeding sweet potatoes for tolerance to stresses. One of these is to grow the sweet potatoes in the environment where the stress occurs. All trials and evaluations are made only under condition of the stress, although some tests, maintenance of stocks, and polycrossing may be managed elsewhere. The advantages of this technique are that the products of breeding are very closely adapted to the real situation. The disadvantages are that stresses are not well defined, may be missed, and vary from one season to another. It is difficult to extrapolate, that is, to be sure that what is useful in one environment is useful in another.

The second approach is to select for stress resistance in a controlled environment. This does not signify that special growth chambers are necessary but that most of the factors influencing growth are not subject to random changes and thus do not become limiting factors. In a controlled environment it should be possible to add a stress according to what is desired. It may be possible to define the stress in rather exact fashion so that it can be duplicated at convenience. The advantage of this technique is the control it gives. The disadvantages are that the stress in question may not be equivalent to that which occurs in the field, and that selection might be for unforeseen characteristics such as adaptation to the greenhouse.

Examples of breeding sweet potatoes in Puerto Rico using both approaches will now be presented and progress and problems will be emphasized.

BREEDING SWEET POTATOES IN A HEAVY SOIL

The soil at the Tropical Agriculture Research Station, Mayaguez, Puerto Rico, is typical of that of many areas of the tropics. It is a Ultisol of pH 4.8, with nitrogen, phosporous, and potassium of 8, 3, and 194 ppm. This soil is heavy and sticky with poor internal drainage. Annual rainfall is more than 2000 mm per year, falling chiefly over 9 months, with heaviest rainfall from August to November. This soil is not good for most crops and is especially poor for sweet potatoes. Not only are yields reduced but shapes are distorted by the resisting soil. Two sweet potato varieties are recommended for growth in Puerto Rico. The white fleshed variety, 'Miguela', produces 23.2 marketable tonnes/hectare in the much better soils of Isabela and Fortuna, P. R. but only 0.4 tonnes/hectare in Mayaguez, a reduction of 98 percent. The introduced orange-fleshed variety, 'Gem' has become a standard. It produces 31.6 marketable tonnes/hectare in Isabela and Fortuna, and 13.6

tonnes/hectare in Mayaguez, a reduction of 57 percent. The quality of both in terms of form and appearance is much reduced in Mayaguez. Sweet potatoes are seldom grown commercially in the area, and, indeed, the area would not be considered suitable for sweet potatoes. We consider that the Mayaguez area stresses the sweet potatoes, especially by the heavy soil and poor aeration, the frequent flooding in the rainy season, the low natural fertility and marginal pH.

We have been breeding sweet potatoes for the soil of Mayaguez using the following techniques: Seeds are germinated in January and February, and plants are established in the field in March and April. Before 1986 they were not replicated in the field. They are harvested at 4.5 months of age in August and September. At the time of harvest a preliminary selection is made in the field on the basis of appearance, estimated yield, and internal characteristics. The tentation selections are taken from the field to the lab where they are evaluated for culinary characteristics. Those that are acceptable are given a number, stimulated to sprout, and are established in observation trials, two in Mayaguez and two in the better soils of Isabela. During the 4 observation trials the number of selections is reduced, and the advanced selections are evaluated for yield in 8-12 small yield trials, 4 of which are in Mayaguez. Meanwhile, the best materials are included in polycrosses each year that are based on culinary classification. Thus, seed is produced for another round of selection. In summary, any clone used in a polycross has shown superior yields and forms in Mayaguez.

Now, I would like to show you the results of 3 generations of selection in Mayaguez in terms of clones produced and their yields (Table 1).

The clones in the table represent the highest yielding among the advanced selections. They demonstrate that yields in the Mayaguez soil increased dramatically during 3 rounds of selection. The selections 'Tapató' and 'Dune' produced such large storage roots that we ourselves were surprised. The selection Dune produced these roots in a field with very poor drainage and the roots were harvested out of the mud. We believe these two high yielding selections might be useful in the industrialization of the sweet potato. They are not, however, useful as normal household types. They illustrate, that the sweet potato can be adapted to production in heavy soils, and I believe thay also show that the polycross is a very effective way of combining the necessary genes for the

Table 1. Selections of sweet potatoes produced by breeding in heavy soils of Mayaguez, and total yields in Mayaguez and Isabela

Cycle	Selection	Type of Sweet Potato	Kg/Plant Mayaguez	Kg/Plant Isabela
0	Miguela[1/]	White, sweet	.28	1.08
0	Gem[1/]	Orange, sweet	.77	1.82
1	Papota	White, low sweet	.92	3.14
1	Sunny	Orange, low sweet	1.04	2.46
2	Toquecita	White, sweet	1.40	3.02[2/]
2	Viola	White, low sweet	1.29	3.85[2]
3	Tapató	White, low sweet	2.49	3.64
3	Dune	White, non-sweet, starchy	2.06	4.36

[1/]Standard varieties recommended for Puerto Rico

[2/]Fortuna. Data not available for Isabela

characteristics in question. Please note that yields also increased in Isabela.

A word of caution is desirable here. We could not have predicted in advance this type of progress. I attribute these results to the existence in the sweet potato of the necessary genes, the wide base of germplasm used, an environment that was very selective, and our good fortune. Progress for other environments may not have been the same.

Now, another defect seen in sweet potatoes in Mayaguez has been their form. In this respect we have made less progress, which leads me to conclude, tentatively, that such soils might be better suited to production of industrial than table sweet potatoes.

TESTING FOR STRESS TOLERANCES IN THE GREENHOUSE

Because the greenhouse affords control usually more easily than does the field, is tempting to try to measure stresses under greenhouse conditions. If this can be done it might be possible to plan experiments with more confidence, execute them in less space, and thus breed more rapidly. Of course, tolerances selected in the greenhouse will have to stand the tests for tolerances in the field as well, but this might be more difficult to measure.

During the past six years populations of stress tolerant sweet potatoes have been developed in Puerto Rico using the following methodology:

For stress tests sweet potatoes are planted in 4" plastic pots (for flooding stress, 3" clay pots). Standard, sterilized greenhouse soil is used, and pots of soil are wet at least one day before planting. A stress test consists of 3 or more individual plant replications. Cuttings of 10 cm are taken from healthy plants 2-3 months old in the field and are planted in the pots. The pots are watered normally for 2 weeks and then the stress is applied.

For flooding stress, the clay pots are placed at time of planting in a water bed, 2 1/2 cm deep. For shading stress, the plants are placed in a shade house permitting 20% of the light to enter. For drought the plants are permitted to wilt severely, and are then watered heavily. For competition, three corn seeds are planted per pot when cuttings are planted, and all but one corn seedling is eliminated later. For acidity, the plants are watered only with pH 2 water (44 ml HCl in 17 gallons of water). For salinity, plants are watered once each week with 1% NaCl solution (50 g in 5000 ml), and otherwise watered normally. For low fertility tolerance the plants are established in sand.

Stress tests have been harvested at 4 months but we think we can have the same results in 3 months. The storage roots are washed, drained, counted, and weighted. Differences among clones are obvious. The problem is how to interpret them.

Three types of measurements seem feasible. A measurement of tolerance to stress might be yield under stress divided by yield under no stress. The comparison of varieties for stress resistance would, however, be possible only among varieties that yield about the same under conditions of no stress. Since some varieties yield very little even when

not stressed, stress cannot reduce very much of what is already an inferior yield. Still another technique is to calculate the average yield reduction of a group of plants and consider those to be yield tolerant that have their yields reduced more than the average. The problem with this technique is that in practice the poor yielders are always those that would appear to be stress tolerant. A third technique, what we are using, is that those that yield the best under stressful situations are considered stress tolerant.

Using these procedures we have selected numerous clones for tolerance of flooding (2), shade, competition, and drought, and we have increased the frequency of tolerances in populations. We have tested for the presence of the stress tolerance in the field as follows:

Flooding. This is measured in Mayaguez fields that are subject to standing water during the rainy season. The cuttings in this case are not planted in ridges.

Shading. This is tested in a special area under trees of *Gliricidia sepium*, madre de cacao. The field must be plowed deeply to cut roots, the trees pruined to permit about 50% of the light to pass, and weeds in the rows of trees destroyed with Roundup before the test begins.

Competition. This can be tested at any season in a weak and a strong test. In the strong test, no efforts are made to control weeds, and the plants are harvested at 3 months. In the weak test, Amiben herbicide is used once, there is no further weed control, and the plants are harvested at 4 months.

Drought. This is best tested in a soil that does not hold water well. The plants are irrigated well for two weeks and are then watered as little as possible.

The stress tests in the greenhouse have resulted in selection of clones resistant to stress in the field. Thirty two selections made for shade tolerance in the greenhouse all outyielded 18 standard varieties under heavy shade, although none yielded satisfactorily. (3) We have found this to be a very difficult trait to develop. Two standard varieties yielded nothing in a flooding test in the field, but of 12 selections for flood tolerance, one produced 11 tonnes/hectare. Many selections tolerant to maize have produced reasonables yield under weed cover, leading us to believe that it is possible to develop this characteristic by breeding. We have no field data on

Table 2. Correlations[1] among 8 tests of storage root production of 40 selections of sweet potato in greenhouse pots.

	Acidified Water	Planting in sand	Competition with maize	Flooding	Drought	Heat Shock	Shade
Normal soil	0.72 xxx[2]	0.72 xxx	0.64 xxx	0.55 xxx	0.60 xxx	0.55 xxx	-0.06
	.74 xxx	.52 xxx	.67 xxx	.51 xxx	.52 xxx	.55 xxx	.40
	.83 xxx	.80 xxx	.78 xxx	.60 xxx	.56 xxx	.55 xxx	.20
Acidified Water		.74 xxx	.72 xxx	.72 xxx	.60 xxx	.78 xxx	.20
		.41 xx	.68 xxx	.55 xxx	.64 xxx	.69 xxx	.41
		.72 xxx	.80 xxx	.64 xxx	.71 xxx	.75 xxx	.43
Planting in Sand			.75 xxx	.70 xxx	.65 xxx	.65 xxx	.20
			.64 xxx	.41 xx	.22	.44 xx	.36
			.85 xxx	.52 xxx	.42 xx	.52 xxx	.12
Competition with maize				.66 xxx	.57 xxx	.60 xxx	.10
				.40 x	.47 xx	.52 xxx	.27
				.49 xxx	.54 xxx	.59 xxx	.31
Flooding					.63 xxx	.79 xxx	.10
					.55 xxx	.63 xxx	- .40
					.65 xxx	.74 xxx	.32
Drought						.58 xxx	.42 xx
						.54 xxx	.41 xx
						.71 xxx	.69 xxx
Heat Shock							.29
							.52 xxx
							.54 xxx

1/ Significance indicated by asterisk: *=0.05, **=.01, xxx=.001

2/ Coefficients (r) from top to bottom are for number of roots, wt/roots, and total weight of roots.

drought resistance but selections made for drought tolerance in the greenhouse consistently show themselves superior in other kinds of drought tests in the greenhouse. At this time it appears that polycrossing can be very successful in breeding stress resistant sweet potatoes, and that greenhouse tests are suitable for preliminary screening.

Nevertheless, in measurement of stress tolerances we have come across an unexpected result, clones that show tolerance of one stress are very likely to show tolerance of another. This can be seen in a correlation matrix (Table 2). This suggests that of 7 stresses applied in separate tests all but one are related to each other and to yielding ability in the greenghouse. Only tolerance to shade appears unrelated to other stresses.

Thus, we think that in the greenhouse we have developed tolerance of two broad types, one is tolerance to the particular stress involved, and the second is tolerance to the greenhouse situation. We are in the process of testing this possibility.

I would like to suggest that plant breeders always selected for stress tolerances in the sweet potato. However, identifying the stress, and screening for tolerance to it, appears to be a very effection way of making more rapid progress.

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IMPROVEMENT OF NUTRITIONAL AND EDIBLE QUALITIES OF SWEET POTATO FOR HUMAN CONSUMPTION

Wanda W. Collins

Introduction

In 1984 sweet potato ranked seventh in production among world food crops surpassed only by wheat, rice, maize, potato, barley, and cassava (6). In the developing world - China included - they rank fifth behind wheat, rice, maize and cassava. However, if China is excluded they rank much lower behind other root and tuber crops such as cassava, potato, and yam. In that world sweet potato is not the major root and tuber crop even though it is highly nutritious and produces more mass per unit area in a shorter time than most other similar crops. Why then, it is not an even more important crop supplying both energy and nutrients to the vast populations of the developing world.

Excluding China, which alone produces 85% of the world supply of sweet potatoes, the remainder of Asia has the next highest production with 9%. According to a survey by Lin et al. (8), the most important factor limiting utilization of sweet potato in Asia and the Pacific was lack of proper varieties. Furthermore, the most important variety characteristics needing improvement were eating quality and nutritional content. Obviously, the sweet potato, as it currently is presented in those areas, does not provide a suitable alternative to the consumer in quality or nutrition to other root crops as a major food item. Consequently, prices would be low and farmers would turn to other alternatives as cash crops. However, breeding efforts can improve the components of edible quality and nutritional value in sweet potatoes and the extent of variability in edible qualities will allow the development of whatever type is needed for consumer satisfaction.

Components of Edible Quality and Nutrition

The basic components of edible quality and nutrition in sweet potato are 1) carbohydrates: starch, sugars, fiber; 2) vitamins: A and C; 3) minerals: K and Fe; and 4) protein. Flavor, texture and aroma, although less well-defined, must also be considered part of edible quality. Anti-nutritional factors reported are trypsin inhibitors and furanoterpenoids.

Carbohydrates. Components of sweet potato carbohydrates are starch, sugars and a loosely defined group collectively called "fiber". The latter group consists of cellulose, hemicellulose and pectins. Starch is the major and most important component in the raw root

regardless of cultivar or use. The starch is composed of about 70% amylopectin and 30% amylose. The major sugar is sucrose in the raw root and maltose in the cooked root. Dietary fiber is of interest mainly because of its aid to digestibility and suggested association with lower levels of certain types of cancer.

Moderate to high carbohydrate content at harvest is desirable not only for edible quality and nutrition but for keeping quality.

Vitamins. Sweet potato in moderate amounts can provide over 100% of the recommended daily allowance (RDA) of vitamin A and 49% of the necessary vitamin C (9). Other vitamins are present but supply very small amounts of RDA's (9).

Minerals. Minerals are present in varying amounts depending on cultivar. The two minerals provided in sufficient quantity to meet a portion of the RDA's are iron (10%) and potassium (15%)(9).

Protein. Protein content in sweet potato roots provides very little of the daily protein needs (9). Protein quality, however, is very good with the exception of lysine and total sulfur amino acids when compared to FAO protein (4). Data also show that it is a high nutritional quality protein (1).

Flavor. Flavor is a largely undefined quality attribute which is vital in its presence for a luxury food product and vital for its near-absence in a staple food product. It results from a combination of factors but sweetness is one of the major components and this is in large part due to high beta-amylase activity in cooking. Beta-amylase converts short-chain dextrins to maltose during cooking.

Texture. Texture is also a function of several components, one of the most important of which is alpha-amylase activity (9). This enzyme degrades starch to dextrins during baking paving the way for final conversion to maltose by beta-amylase. As the starch is degraded by alpha-amylase the water-binding capacity decreases and the perception of "moistness" to the consumer increases. Low levels of alpha-amylase activity result in a perception of "dry mouth feel". Texture is also a function of the consistency of the dry matter.

Aroma. Aroma is due to organic volatiles released on cooking. However, identification of the major impact volatiles responsible for aroma in sweet potatoes has not been completed.

Anti-nutritional components. Trypsin inhibitors, which reduce the body's ability to utilize protein via trypsin, are present in sweet potatoes but are much lower than the levels found in soybeans, for example. Research results indicate that heating roots to 90°C for several minutes deactivates most of the trypsin inhibitors (3). Furanoterpenoids are also found in sweet potatoes as a result of microbial

infection, mechanical injury or chemical treatment. The toxic materials are limited to damaged tissue and removing damaged tissue removes the danger of consuming them.

Breeding for Edible Quality and Nutrition

Traditional breeding efforts should focus on those traits for which improvement is both necessary and realistic. However, consumer demand always dictates the final product. Sweet potatoes are primarily consumed as three different products in the developed and developing world and both the edible qualities and nutritional components of those products differ. Sweet potatoes are consumed as, 1) a staple food; 2) a supplemental staple food (to rice, potatoes or maize); or 3) a luxury product.

Sweet Potato as a Staple or a Supplemental Staple. A staple food, one that is eaten every day, should be bland, relatively colorless, high in starch, low in sugar and have a low aroma impact with a firm or "dry" texture. In terms of selection criteria this would mean high carbohydrates, low (or no) carotene, low beta-amylase and low alpha-amylase. The chemical components of aroma are, as yet, unidentified and this character must be subjectively evaluated. All other characters listed are within the range of variability in sweet potatoes.

The criteria for selecting a cultivar to be used as a supplemental staple are much the same as for a staple. However, the selection need not be as strict. A supplemental staple - one that is used in conjunction with a staple such as rice or maize but still provides a significant portion of the daily energy requirements - may have a mild flavor and aroma, may have more starch/sugar conversion on cooking, and may have more beta-carotene content.

Sweet Potato as a Luxury Food. A luxury food should have a high impact flavor, aroma and appearance. It should, therefore, have high levels of carotene but could have moderate to high levels of beta-amylase and alpha-amylase depending on consumer preference. It should also have moderate levels of initial starch.

In terms of nutritional content, the final product determines the amount of vitamin A precursor (carotene) which will be accepted by the consumer. Staple types will have very little carotene. Supplemental staples could have slightly higher levels and luxury types will have the highest levels. Other nutritional components should be present in maximum amounts possible. However, breeding efforts to further increase those components is probably not justified at this time. These components would include vitamins (other than C and A-precursor), minerals and protein. Fiber, which can be objectionable, should be selected against only at the level that it can be detected by sight or taste.

Breeding Strategy and Germplasm Evaluation

Selection for edible quality and nutritional value should be an integral part of a total breeding effort. Parents selected for agronomic traits (yield, disease resistance, etc.) should be screened at the earliest stages of parent selection for edible and nutritional traits. Parents should then be chosen according to what the final product will be if possible. Staple and supplemental staples may be selected out of the same breeding population; however, progress for developing luxury types would be faster if high carotene parents are used. If a luxury product is the main focus, then staple and supplemental staples may be selected out of the luxury breeding population, but progress will be slower in that event.

Screening levels should be established for primary characters. Suggested levels of the most important characters of raw and cooked roots are shown in Table 1 for different products. Intercellular space is included because, combined with a knowledge of dry matter, it gives some idea of how long edible quality can be maintained in terms of storage. In addition to screening for these characters, evaluation of fiber content, protein and ascorbic acid are desirable as well as the highest possible level of non-objectionable fiber. As new sources of germplasm are evaluated for protein, its status as a selection character could change. At present, known protein levels in sweet potato are too low to justify a breeding effort that could result even in a 25% increase. With new advances in the use of gene insertion, it is quite likely that much more rapid increases in sweet potato protein content could be achieved in that way (5).

All breeding programs or germplasm collection centers may not have the capacity to screen for such things as biochemical parameters. However, programs that do have such capability should screen raw roots for beta-amylase activity (an indicator of flavor impact) and alpha-amylase activity (an indicator of texture). Selection for flavor using a biochemical selection index has been proposed as a tool for sweet potato breeders (6) but specific indices have not yet been developed.

Dry matter, protein content, intercellular space and baking quality of roots are subject to genotype x environment interactions as are most traits in sweet potatoes. They also vary with environment. For these reasons it is necessary to test over a range of environments to get the most accurate estimate of these parameters. Variance studies using clonal means indicate that two years, four locations and four replications would provide reliable data (2)

Summary

Three types of sweet potatoes are consumed in the world: 1) staple types; 2) supplemental staple types; and 3) luxury types. Variability exists in known sweet potato germplasm for the edible and nutri-

tional characters necessary to develop these types. Breeding and selection for edible and nutritional qualities of each of these should be an integral part of the overall breeding effort for new cultivars. Guidelines for screening levels of various traits are suggested.

Table 1. Suggested screening levels for edible qualities and nutritional content of sweet potatoes

	Final Product Type		
	Staple	Supplemental Staple	Luxury
Raw Root			
Dry Matter	≥ 35%	30-35%	24-28%
Sugar	< 1-2%	5%	N/A
Carotene	< 5 mg	5-10 mg/100 g	≥12 mg/100 g
Intercellular Space	<10 mg/100 g	< 10 mg/100 g	<10 mg/100 g
Cooked Root			
Flavor Impact	Low	Low	Mod-High
Aroma Impact	Low	Low	Mod-High
Texture	Dry	Dry	Mod. Dry-Moist
Fiber	Acceptable	Acceptable	Acceptable
Appearance	Acceptable	Acceptable	Acceptable

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REVIEW OF SWEET POTATO BREEDING IN JAPAN

Satoshi Sakamoto

After the introduction of sweet potato into Japan about 370 years ago, the cultivated area had spread to a major portion of the country in a span of two centuries. A cultivated area of about 150.000 ha in 1880 increased to 440.000 ha in 1949. Although the acreage began decreasing since 1950, over 300.000 ha were still cultivated for mainly raw material of starch up to 1965. The drastic decrease of acreage occurred due to competition with the starch produced by imported raw materials. thus acreage has been decreasing about 10 % per year and became about 65,000 ha at present.

The average yield of tuberous root per ha was about 12 tons before the 2nd World War and it has been increased to 22 tons at present by the extension of improved varieties and improvement of the cultivation method.

The main use of sweet potato before the 2nd World War was as food for farmers and during the War about 20 % of product was used as raw material of alcohol production. After the consumption for food decreased due to the dissolution of food shortage, it was mainly used as raw materials of starch production from around 1950 and it became about 50 % of product in 1963. At present,it is consuming for table use, raw material of starch production, animal feed and alcohol production 40. 30, 13, 8 % of product, respectively. The trend of consumption is shown in Fig. 1.

1. Organization of sweet potato breeding

The systematic sweet potato breeding started 1926 and hybridization conducted at Okinawa on the time. At present, sweet potato breeding is conducting mainly at 3 National Breeding Laboratories in which hybrid seeds are producing at Ibusuki (Kyushu Natl. Agric. Exp. Stn.) and seeds are sending to Kumamoto (Kyushu Natl. Agric. Exp. Stn.) and Tsukuba (Natl. Agric. Res. Center. NARC. formerly located at Yotsukaido. Chiba and translocated in 1986) for selection. Priority is given for the breeding of the varieties adapted to western part of the country on Kyushu Natl. Agric. Exp. Stn. and to eastern part on NARC.

Promising lines selected at Breeding Laboratories are dispatching to the related Prefectural Agricultural Experiment Stations for regional adaptability trials. The Ministry of Agriculture, Forestry and Fisheries

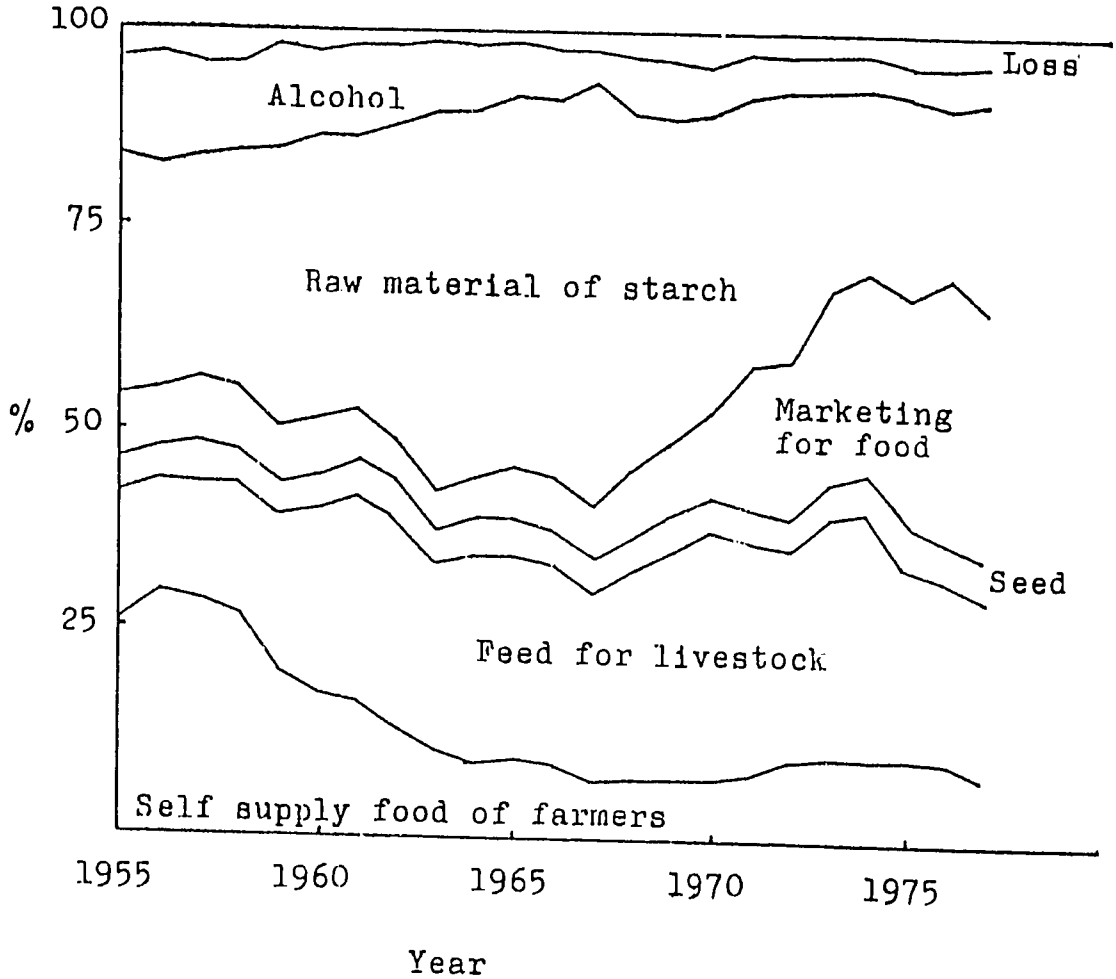

Fig. 1. Trend of consumption of sweet potato in Japan

decides the registration number and name for new cultivar after investigation and releases for extension in recommended area. Up to date, 38 cultivars were registered by MAFF.

Besides of them, sweet potato breeding is carrying at some Prefectural Agricultural Experiment Stations and some private companies in small scale.

2. Breeding objectives

Breeding objectives of sweet potato are different due to the use of the varieties. Varieties for table use are required delicious taste, nice looking, good skin and flesh color and storability. Varieties for starch production should be high yield and starch content. Varieties for

feed which use tube and vine are required good growth, high yield and dry matter content. For alcohol production, varieties for starch production are being in use. In addition of them, high resistance against pests and diseases are required generally.

Major pests and diseases of sweet potato in Japan are nematodes (Southern root-knot nematode Meloidogyne incognita and Coffee root-lesion nematode Pratylenchus coffeae), black rot Ceratocystis fimbriata, stem rot Fusarium oxysporum f.sp. batatas, soil rot Streptomyces ipomoea and viruses (Feathery mottle and Russet crack-like symptom). There aren't sweet potato weevil and scab in main island of the country and it doesn't need to select for them.

3. Parental materials of breeding

At the early days of breeding in Japan, indigenous varieties were used as parents of crossing and excellent cultivars such as Norin 1, Norin 2 and Okinawa 100 were released as a result.

However, the breeding efficacy has decreased due to the possession of common genes between parental varieties. Thus, introduced varieties and wild relatives were used as gene sources to introduce new superior genes and extend the variation of offspring plant. They played important roles in the breeding of new cultivars.

About 300 accessions of wild relatives had been introduced into Japan from tropical America. They are classified 2 groups based on cross ability with sweet potato and about half of them belong group 1 which could be cross with sweet potato. Ipomoea trifida is the only species recognized belong group 1 and there are diploid, tetraploid and hexaploid in it. They have been used parent of crossing to introduce new germplasm into sweet potato. Whenever wild relatives are used, sweet potato should be use as the recurrent parent in backcrossing to eliminate undesirable characters of wild species and accumulate the yield ability of sweet potato cultivars.

4. Breeding method

Up to date, all improved cultivars were bred from single cross in Japan. As first step, about 100 crosses of small scale for combining ability trial and about 40 crosses of large scale for selection are made by artificial hybridization every year at Ibusuki. Cross of large scale were selected from combining ability trial of previous year at Breeding Laboratories. Individual selection, line selection, preliminary and advanced yield trials were conducting from large scale crossed population at Breeding Laboratories every year.

The investigation to utilize the random mating population in sweet potato breeding which is proposed by A. Jones was conducted[1]. It is concluded that the method which is the random mating combined with mass selection is very effective to select the promising individuals[8].

At National Agriculture Research Center, utilization of K_2O/N ratio as selection character in tuber yield was proposed by T. Shiga in 1985. The K_2O/N ratio in tuber showed a positive correlation with fresh and dry tuber yield and a negative correlation with N content of tubers. These characters in 1st year clones were closely related to those of the 2nd year clones. It is concluded that the K_2O/N ratio and N content in tuber could be a useful selection index for tuber yield[8].

5. Result of breeding

Koganesengan is a excellent cultivar registered in 1966 in which superior genes of foreign varieties of Pelican Processor and T No. 3 are accumulated. In comparison with other cultivars being used for starch production, it is 2 - 3 % higher in starch content, 20 - 30 % higher in yield and is early maturing and adapted for early harvesting. The cultivating area of this cultivar covered 30 % of the total sweet potato cultivating area of the country in 1971. It has, however, some defects in resistance against nematodes and black rot and in storability[3].

Minamiyutaka is a cultivar bred up to improve the above defects of Koganesengan and registered in 1975. For the breeding of this variety, a wild relatives Ipomoea trifida was used as parental materials to improve the resistance for nematodes and black rot and storability. In this case, sweet potato was used twice as recurrent parent of backcrossing to improve the economic traits of wild relatives[4].

For lowering the cost of products by labor saving, direct planting of tuberous root without nursing is a promising cultural technique. Naeshirazu is the cultivar released for the purpose of direct planting in 1974. It is an unique variety with characteristics that only daughter tubers grow up without growth of the mother tubers[7].

Moreover, true seed planting is a promising cultivating method of more labor saving. In this case, the growth of early stage after germination is very slow and it is important to stimulate the growth. Following results were obtained from the studies: 1) Two cycle of recurrent selection for seed setting and yield increased the tuber weight in true seed planting at the rate of 14.3 % per cycle of selection. 2) Acceleration of early growth of seedling by using paper pot increased the yield in true seed planting by 30-40 %. 3) The highest yield in true seed planting obtained at the planting density of about two times of

vine planting. 4) Selection efficiency for flowering habit was high and it is easy to accumulate the genes of flowering[9].

To increase the yielding ability, it is one of method to improve and accumulate the photosynthetic capacity, light intercepting characters and tranlocating efficiency of photosynthesis products. There is positive correlation between tuber producing ability of single leaf and tuberous yield of the line in the field. Selection for tuber producing ability of single leaf have been used for selection of high yielding. As the result, promising lines have been selected[2].

6. Strategy for future breeding

Utilization of sweet potato product for starch production, table use, feed and alcohol production have been retarded due to price competitions and decreasing of consumption. And it is necessary to develop new uses for maintain the present cultivating area. Thus, use for food processing have been considered as one of them.

Already, carotene cultivar Benihayato have registered and released in 1985 and have been used for snack food[5].

Biotechnology will be effective to solve the barrier of sweet potato breeding in future. Fusion of protoplast should be useful for cross the varieties between same cross-incompatibility group and embryo culture will be solve the sterility between different species which possess different genomes and cross impossible.

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SWEET POTATO BREEDING AT AVRDC TO OVERCOME PRODUCTION CONSTRAINTS AND USE IN ASIA

H. Takagi and R.T. Opeña

Introduction

Sweet potato ranks seventh in total production among the world's food crops (8), and has played a very important role as food source in Asia and Oceania. In the early 70's, the world's sweet potato harvested area peaked to a high of 15 million hectares, with a total tonnage of over 130 million metric tons (7). At about that time, the Asian Vegetable Research and Development Center (AVRDC) was established with sweet potato as one of its principal crops primarily because of its high nutritional value, high energy production, relatively low input requirements (10), and importance in the AVRDC's mandate region. Moreover, sweet potato has traditionally played an important role in Asian agriculture.

The changing social and economic situations in recent years has brought a significant decrease in the world's sweet potato production area to eight million hectares with 114 million tons output in 1983 (8). Nonetheless, Asia still accounted for 93% of the total production, amounting to 106 million metric tons. There is great potential use for sweet potato as food, feed, and vegetable in Asia and in many other tropical regions. These facts provide the rationale for AVRDC's continuing research attention on the sweet potato.

Constraints of Sweet Potato Production in Asia and the Pacific

Although sweet potato is traditionally a tropical crop, most of the improved varieties have been developed in the temperate regions and are not basically adapted to Asia's adverse hot, wet environments. Moreover, only the traditional Asian white- or yellow-fleshed cultivars have been used mainly as high energy food source.

The initial goals of the AVRDC sweet potato improvement program were to develop well-adapted, high yielding, nutritious cultivars which could be grown under low input conditions, and to establish management practices suited to the tropical farming systems and environments (10, 17). Initial progress was achieved in breeding orange-fleshed (high ß-carotene content), early-maturing clones which could be grown under post-rice cropping systems.

Such improved selections with better nutritional characteristics and higher yield potential were later found, however, to be unacceptable to the consumers, particularly in the Pacific Islands, who were not accustomed to the "wet", highly soluble "mouth feel" taste of the new varieties (2). Moreover, production and utilization patterns of sweet potato in Asia and the Pacific appeared to be changing as economic growth and social welfare improved. AVRDC scientists conducted, therefore, a general survey of sweet potato production and utilization in Asia and the Pacific in 1983 to redefine the goals of the sweet potato program so that its output could better serve the requirements of AVRDC's target regions (9).

In the above survey, biological and environmental factors were listed as the most serious production constraints. Of the respondents, 70% reported problems of diseases and pests whereas 40% cited problems of adverse environments. Lack of improved cultivars and postharvest problems such as storage, processing, and marketing, were listed as the next most important constraints.

Biological Constraints

In Asia and the Pacific, insect pests and diseases were the most important constraints. Table 1 summarizes the distribution of the major sweet potato diseases and insects.

Table 1. Distribution of major sweet potato diseases and insect pests.

Country/Territory	Witches' Broom	Fusarium Wilt	Scab	Nematodes	Viruses	Stem Borer	Weevil
Bangladesh	+	-	+	(-)	+	(-)	---
Cook Island	(-)	-	+	(-)	(-)	-	-
Fiji	-	+++	+++	+	+	+++	+++
Guam	-	-	-	(-)	-	(-)	++-
India	+	(-)	+	(-)	(-)	(-)	+--
Indonesia	+	(+)	+++	(-)	(-)	+++	+--
Japan	-	+++	(-)	+	+	-	-
Korea	-	+	(-)	(-)	+	-	(-)
Malaysia	-	+	+	(-)	+	+++	+++
New Zealand	(-)	+		+	(-)	-	-
Niue	-	-	-	-	(-)	+++	+-+
Palau	(-)	+++	+++	(-)	(-)	+++	+++
Papua New Guinea	+	-	+++	(+++)	(+)	(+)	(+++)
Philippines	+	(+)	+++	+	+	+	+++
Ponape	-	-	+++	-	-	(-)	-
Puerto Rico	-	-	(-)	+	+	+	-++
Sri Lanka	-	-	-	(-)	-	+	+--
Tahiti	-	-	-	-	-	-	+
Taiwan	+	+	+	(-)	+	(++-)	+++
Thailand	(-)	(-)	(+)	(+)	(-)	(+++)	+--
Tonga	+	+	+++	+	+	+	-
USA	(-)	(+++)	(-)	+	+	(+)	-++
Vanuatu	+++	+					-

Note: - no; (-) no or uncertain
+ yes, not serious; (+) yes or uncertain
+++ very serious; (+++) yes or very serious

Source: Lin et al, 1983.

Sweet potato weevil (Cylas formicarius) was considered as the most destructive and most widespread pest except in Japan, Korea, and New Zealand. Vineborer (Omphisa anastomosalis) was rated next in importance and is especially destructive in Fiji, Indonesia, Malaysia, Niue, and Palau.

Although sweet potato is relatively tolerant to many diseases, sweet potato scab (Elsinoe batatas) is serious in almost all countries of tropical Asia and the Pacific regions, especially under hot, humid conditions. Fusarium wilt (Fusarium oxysporum) and witches' broom ranked next in importance.

Environmental Constraints

Of the adverse environmental factors, drought and excessive rainfall/flooding were the most severe problems in the surveyed regions (Fig 1). As sweet potato is considered a low input crop, only about 10% of the farmers reported that they regularly irrigated their fields, and 76% of the sweet potatoes in Asia and the Pacific are grown without irrigation. Frequent flooding or high moisture conditions also occur in more than 26% of the sweet potato areas. Growth retardation and other types of damage due to frost or low temperature were reported mainly in Japan, Korea, and the highlands of Papua New Guinea and Indonesia.

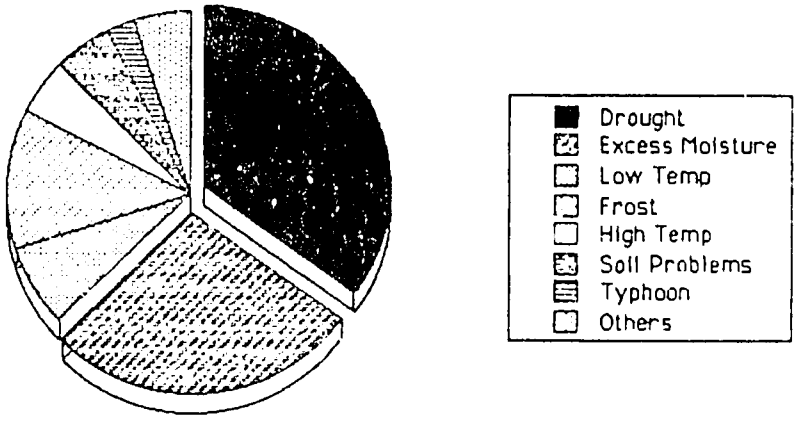


Fig 1. Environmental constraints to sweet potato production in Asia and the Pacific.

Lack of Improved Cultivars

Lack of improved cultivars was listed among the next major constraints. Inspite of the recognition of the importance of variety improvement, there are very few such programs in the tropical regions. According to the survey, about 300,000 sweet potato seeds are screened each year in the tropical regions of Asia and the Pacific. However, Taiwan and the Philippines account for 98% of this total. Rigorous quarantine regulations for the crop further restrict the introduction and utilization of foreign materials.

Considering the dearth of variety improvement programs in the region, development of a system to provide disease-free materials has to have high priority along with the shift in breeding objectives of international centers to meet the requirements. The respondents of the survey showed that improvement was especially needed in the following characteristics: eating quality, nutritional composition, insect resistance, yield, maturity, appearance and uniformity, and disease resistance. Fig. 2 depicts some of the desirable characteristics of sweet potato in Asia and the Pacific regions.

Redefined Targets and Progress of AVRDC's Sweet Potato Improvement Program

The 1983 production survey indicated the need for a thorough review of the research priorities in AVRDC's sweet potato improvement program. The redefined targets currently include the following major areas: intensified search and breeding for disease and pest resistance; evaluation of available genetic resources for major stress tolerance; enhancement of dry matter content among advanced selections; improvement of sweet potato as vegetable greens; and development of tissue culture and virus-indexing techniques for safe international germplasm transfer.

AVRDC's crop improvement scientists adopt the multi-disciplinary team concept to solve the problems limiting the productivity and quality of vegetables in the tropics. Plant breeders, plant physiologists, plant pathologists, entomologists, and other relevant disciplines work jointly in achieving the desired goals (11). The sweet potato improvement program utilizes this team approach.

Minimization of Biological Constraints

Sweet potato weevil. Sweet potato weevil is the most destructive pest in tropical and subtropical regions. Since the establishment of AVRDC, our entomologists has screened the entire germplasm collection numbering over 1000 accessions. Despite these efforts, none showed a stable resistance to weevil. Similarly, in the other institutes like IITA (International Institute for Tropical Agriculture), no single cultivar with consistent weevil resistance has been bred (12). Since no useful genetic resource for weevil resistance was evident from our previous work, the development of effective and economical control measures was accorded high priority for sometime now in the AVRDC program. Pre-plant dipping of cuttings in 0.05 to 0.10% carbofuran solution or three weekly applications of two kg ai/ha carbofuran were found effective though the latter method proved uneconomical because of the large amount of chemical used (2).

Preliminary evaluation of interspecific hybrids between 6x cultivated sweet potato and its 4x relatives (*Ipomoea trifida*) showed none or low weevil damage (6, 13). However, confirmation of resistance and further backcrosses to recover the desirable traits of the cultivated species are necessary.

Vineborer. Sweet potato vineborer is a common pest in Asia and the Pacific, and is especially serious in the semi-arid areas. In 1981, AVRDC entomologists identified two accessions, namely, I55 (PI 324889) and I92 (PI 308208), with moderate levels of resistance. Because of the difficulties of inducing I92 to flower, I55 is the only current source of resistance available for breeding so far. Selection among its segregating populations are now ongoing (6).

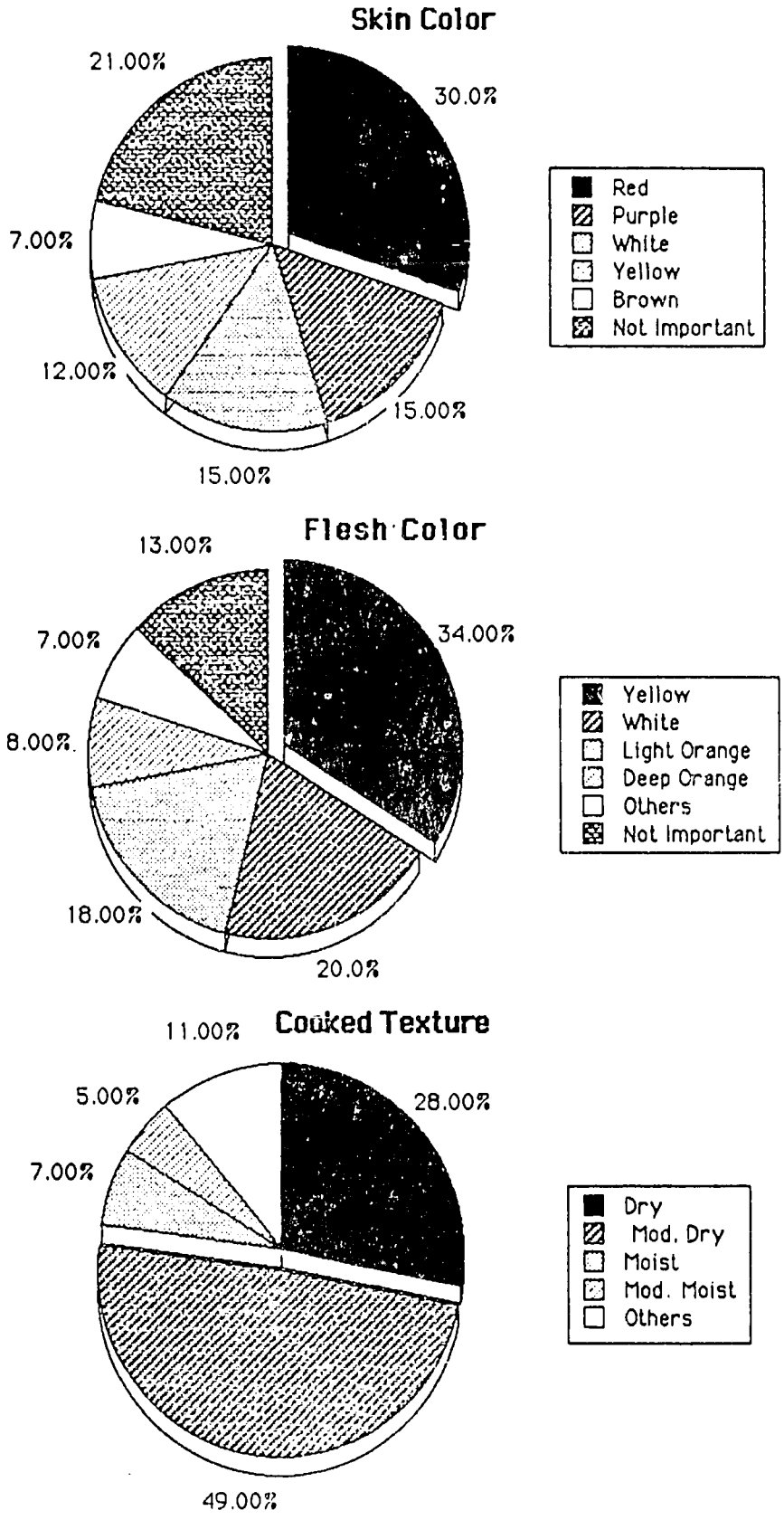
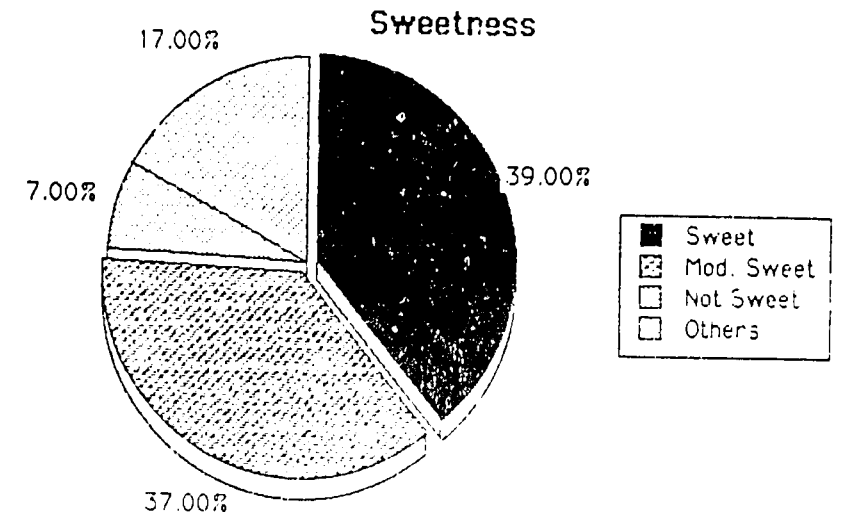
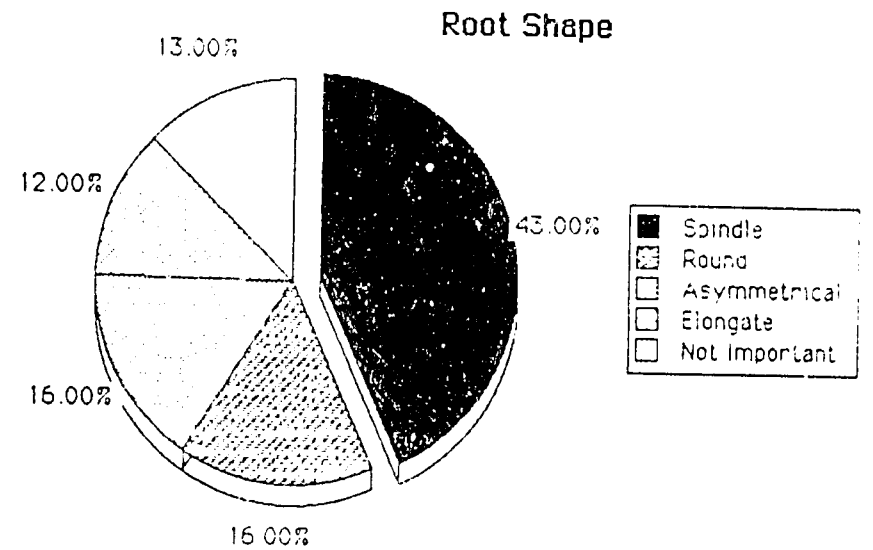


Fig 2. Preferred characteristics of sweet potato in Asia and the Pacific regions


Sweetness
17.00%
7.00%
39.00%
37.00%
Sweet
Mod. Sweet
Not Sweet
Others


Root Shape
13.00%
12.00%
43.00%
16.00%
16.00%
Spindle
Round
Asymmetrical
Elongate
Not Important

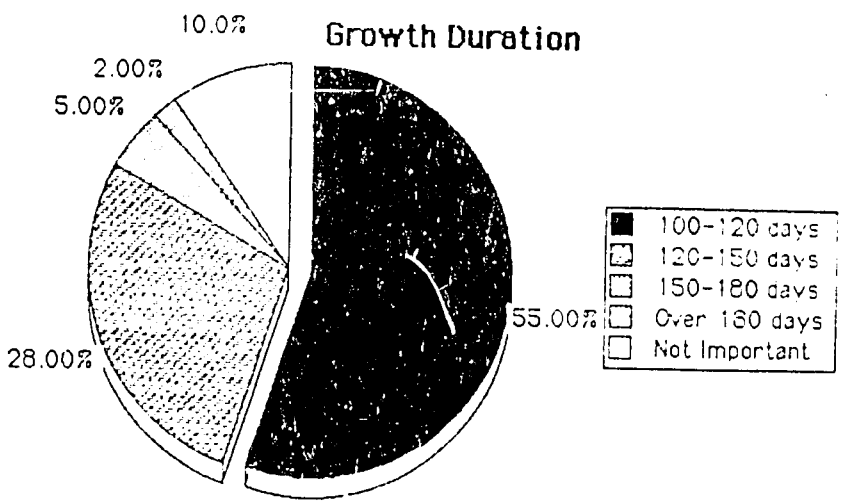

Growth Duration
10.0%
2.00%
5.00%
28.00%
55.00%
100-120 days
120-150 days
150-180 days
Over 180 days
Not Important

Fig 2 (cont'd)

Scab. The importance of the scab disease and the requirement for resistant lines in the tropical countries necessitated the initiation of a scab resistance project at AVRDC in 1985. The resistance of some cultivars has already been confirmed in several screening tests (5). Cultivars V2-30, GI6, and GI13 have been used as sources of resistance in the AVRDC program. AVRDC pathologists have already developed a suitable method for *in vitro* propagation of the causal organism (*Elsinoe batatas*), the mass screening technique via artificial inoculation, and the disease scoring method. Further improvement of the seedling screening technique and screening of segregating populations are underway (6).

Minimization of Environmental Constraints

The importance of cultivars that are tolerant to flooding, excess moisture and drought was evident from the 1983 survey. The AVRDC germplasm collection was screened for tolerance to these stresses to identify useful genetic resources (2).

Flooding. In the screening of 372 accessions under flooded condition, only three accessions, namely, I100 (PI 318848), I103 (PI 318855), and I423 (Tainan 17), yielded more than 10 tons per ha and were considered to possess relative tolerance to flood stress (2).

Excess moisture. Under hot, wet conditions of Taiwan, 230 accessions were screened for ability to tolerate excess moisture. Fourteen entries outyielded the local wet season cultivar, Tainung 63. The best four lines, namely, I597 (NG7570; PNG), I444 (Kin-men; Taiwan), I549 (Piksin; PNG), and I435 (Nakamurasaki; Japan) are especially promising, with marketable root yields of nearly 20 tons per ha, comparable to the performance of AVRDC's elite wet season clones. Interestingly, 11 of the 14 accessions were introductions from the highlands of Papua New Guinea where annual rainfall is close to 2,500 mm (2).

Drought. Although AVRDC does not have a truly dry environment, evaluation for drought tolerance is normally achieved by screening materials during the dry season with no irrigation. Twenty-nine accessions were screened in this manner, of which, none was superior to the local cultivar, I444 (Kin-men). This cultivar also showed moisture tolerance and was identified, therefore, as having good environmental adaptability (2).

Improvement of Nutritional Quality

ß-carotene and protein. Initially, AVRDC scientists emphasized the development of dessert type cultivars, with high ß-carotene and protein contents, and adapted to the tropical environment. Clones were subsequently developed with over 9 mg of ß-carotene per 100 g fresh weight and more than 7% protein on a dry weight basis (1).

Dry matter content. High dry matter content is required in the yellow- or white-fleshed clones for staple or feed and industrial use. Sweet potato cultivars with high dry matter content have better marketing appeal for feed and starch extraction. Progress has been attained to raise the dry matter content and yield of new AVRDC selections. The average dry matter content of the entries in the preliminary yield trials during the hot, wet season was raised from 26% in 1981 to 35% in 1986 (Fig. 3).

Moist texture and low dry matter content are unacceptable to the sweet potato consumers in Asia and the Pacific. Ironically, the orange-fleshed clones tend to have moist

texture compared to clones with other flesh colors. The efforts to raise the dry matter of orange-fleshed clones have been continued and orange flesh was combined in selections CN 1108-13 and CN 1028-15 with the preferred dry texture. Dry matter content of these clones is about 26% during the wet season (2). This program is ongoing.

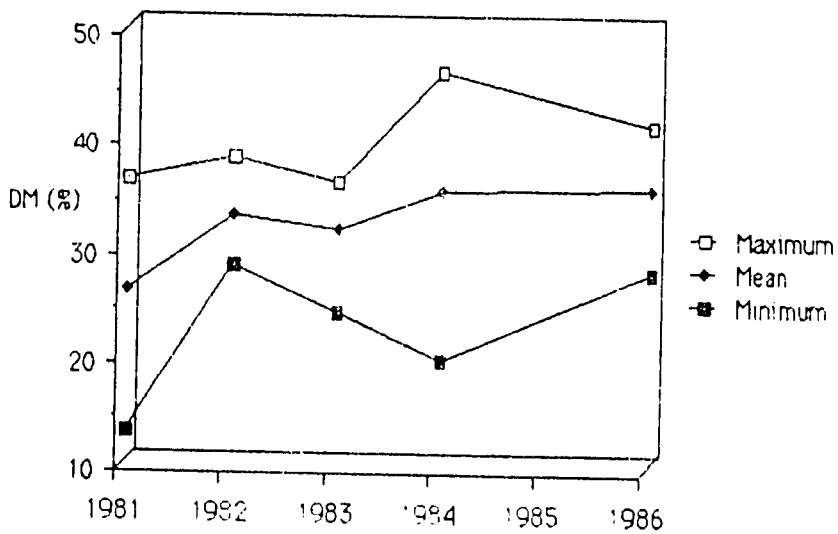


Fig. 3. Dry matter content during the hot, wet season among AVRDC selections in the preliminary yield testing stage.

Protein digestibility. Cultivars and accessions which exhibit lower trypsin inhibitor activity and better starch property for digestibility have been identified. Preliminary results indicate that it is possible to develop cultivars which do not require cooking before feeding them to hogs (3).

Improvement of Sweet Potato as Vegetable Greens

Sweet potato greens (leaves, stems, and petioles) have high nutritional value, especially Vitamins A and B2, and can tolerate the adverse tropical environments and their associated constraints such as diseases and pests, better than other leafy vegetables. Inspite of these advantages, lack of high yielding, tender cultivars makes sweet potato greens unpopular. Research in this area has also generally been neglected.

After the preliminary studies on yield, nutritional and eating quality of the tips of breeding lines and selected accessions, AVRDC scientists recognized the need for further work to enhance the utilization of sweet potato greens (14, 15, 16). An expanded improvement program for vegetable greens was, therefore, initiated to select cultivars with better tenderness as well as bush or semi-bush plant habit which generally show better tip yield than the conventional prostrate types.

Several lines were identified to exhibit bush habit with good eating quality and with edible tip yields of 10 to 13 tons per ha (2, 3). CN1367-2, a yellow-leafed clone, shows superior tenderness. This special purpose clone has been distributed for international adaptability trials.

Breeding and Screening Methods

Induction of flowering. The free-flowering cultivar, I172 (American Yellow Skin), was identified as the best root stock to induce other clones to flower. Its availability enables the easy establishment of crossing programs, especially natural pollination schemes such as the open-paired and polycross methods. In the last few years, these pollination techniques have been used at AVRDC more frequently than the resource-consuming hand pollinations to produce large numbers of hybrid progenies.

Screening techniques. AVRDC chemists are able to analyze the chemical composition for dry matter, starch, fiber, sugar, and protein from about 200 samples a day using the Technicon Infra-Analyzer (4). This rapid analysis enables breeders to screen a large number of genotypes for chemical attributes.

Basic studies on the consistency of traits among seedling and subsequent vegetative generations have been conducted to identify appropriate selection techniques (18). As a result of such studies, rigorous selection is now practised on stable traits such as dry matter content and color of root skin and flesh in the early stages of breeding. On the other hand, only moderate selection pressure is applied to traits with high genotype-environment interactions, e.g., root yield and protein content, until the replicated evaluation stages for the breeding materials have been reached (Fig. 4).

High correlation between specific gravity and dry matter content allows the use of brine solution for rapid, in-field screening to eliminate clones with low dry matter in the early stage of the selection process (5, 6).

International Cooperation

International distribution for wide-scale testing of improved sweet potato breeding materials has always been constrained by strict quarantine regulations. AVRDC plant physiologists and virologists have developed a system of generating pathogen-tested initial stock materials from tissue-cultured meristems (4).

A virus-indexing scheme has been instituted by AVRDC scientists as a self-imposed requirement to insure that only " clean" stocks are provided to AVRDC's international cooperators. The international distribution of AVRDC's advanced sweet potato clones has been suspended since mid-1985 until all important stocks have been through the scheme. Virus-indexed materials will be available for international distribution this year (6).

Intensive distribution of the most advanced clones from the AVRDC sweet potato program commenced three years ago. Since then, 11 clones have been officially released (Table 2).

Fig 4. Standard breeding procedures for sweet potato at AVRDC.

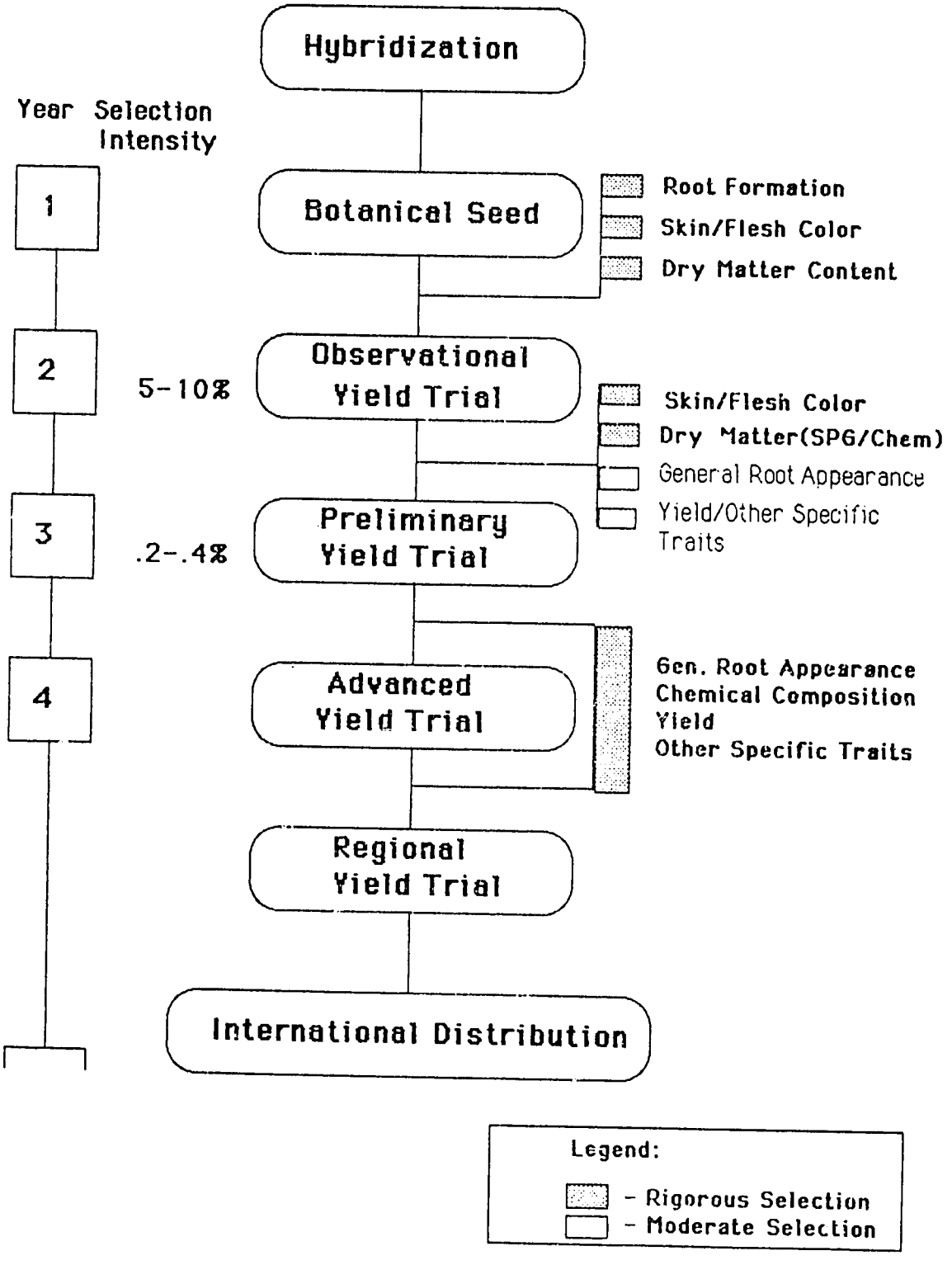


Table 2. Official releases of AVRDC sweet potato germplasm in the last three years.

AVRDC ID No	Local Name	Year	Country
BNAS White		1985	Bangladesh
AIS 0122-2	KamalaSundari	1985	Bangladesh
Tinirining		1985	Bangladesh
CI 693-9	BPI SP 2	1985	Philippines
I 367	Lo 323	1983	Philippines
CN 942-47	CN 942-47	1984	Tahiti
CN 1028-15	CN 1028-15	1984	Tahiti
CN 1038-16	CN 1038-16	1984	Tahiti
CI 590-33	CI 590-33	1984	Tahiti
CI 591-14	CI 591-14	1984	Tahiti
CI 591-14/ Au Marie Vareau	No 7	1984	Tahiti

Future Prospects

Despite the present modest status of sweet potato production, the crop should receive more attention than it currently gets especially because of its high potential as energy and nutritious food source. The AVRDC sweet potato improvement program will continue to focus on the following areas:

1. Further evaluation of the germplasm will be carried out to identify sources of resistance or tolerance to weevil, scab and environmental stresses, sources of better eating quality and nutritional composition and other important characters. Exploration of wild species may also be carried out depending upon the circumstances.

2. The establishment of breeding populations and their subsequent improvement will be aimed at developing disease and pest resistance, stress tolerance, high yield, high dry matter, high nutritional value and good storability. Superior varieties can be selected therefrom for use by national programs. Alternatively, seeds with already high frequency of desirable genotypes can be availed for further selection by national programs.

3. Due to the crop's high level of heterozygosity, high ploidy level, and asexual propagation, the success of any sweet potato breeding program rests largely upon the ability to handle large populations of hybrid progenies under proper selection pressure. In this respect, the development of reliable and rapid screening techniques for desirable characters will be continued.

4. Accomplishment of the virus-indexing scheme and development of safe, relatively fast method to multiply virus-free genetic materials for international distribution and testing will be essential and shall be continued and improved.

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THE GOALS OF SWEET POTATO BREEDING IN CHINA

S.Y. Lu, G.L. Shen and B.F. Song

Introduction

Sweet potato (Ipomoea batatas (L.) Lam) is one of the major crops in China. It is generally accepted that sweet potato was introduced to China about 420 years ago by oversea Chinese. Because of its high productivity, wide adaptability, outstanding natural stress resistance and regenerability, as well as richness in nutrition, sweet potato is now grown widely throughout most of the country, ranging from Heilongjiang Province in the north (45°N) to Hainan Island in the south (18°N) and from the coastal plains in the east to the Northern-Shanxi tableland and the Sichuan Basin in the west. It may be said that sweet potato is cultivated in every province of China except the Qinghai-Tibet plateau and the inner-Mogolia Autonomous Regions. It is now the fourth most productive field in China, ranking only after rice, wheat and maize and has the world's largest amount of sweet potato cultivated area and total output.

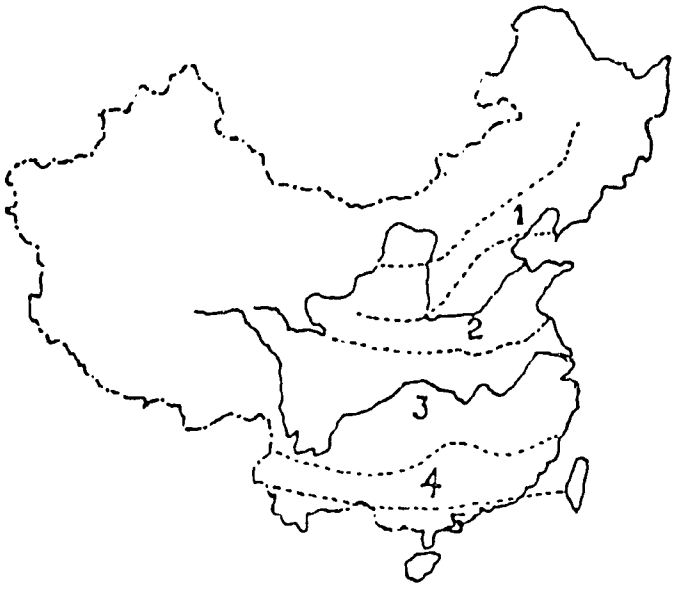
Before 1949, sweet potato was mainly used in China as a staple food in rural area. Then the consumption as food decreased when other major crops production increased rapidly. In 1970s'-1980s', it was mainly used as feed and materials for starch industry. For example, in 1985, 40% of the total production of sweet potato in Shangdong was used for feed, 30% for raw starch processing, 20% for food processing and 10% for seed storage and losses. At present, when the agricultural structure has changed from a self-supply type to a commercial type, the tendency of multi-utilization of sweet potato has also increased obviously.

Production situation

Distribution of sweet potato in China

According to geographic position and natural conditions, the total area of sweet potato in China might be devided into five regions (Fig. 1)

Fig. 1. Distribution of sweet potato in China



1. Northern spring sweet potato region
2. Yellow river and Huai river valley spring and summer region
3. Yangtse river valley summer region
4. Southern summer-autumn region
5. Southern autumn-winter region

1. The northern spring region. The weather in this region is characterized by scanty rainfull and dry atmosphere in both spring and autumn, plenty of rainfull in summer, and a rapid dropping of temperature in early autumn. The natural conditions are suitable only for spring-planted sweet potato. This is the smallest region among the five, about 5% of the Chinese total sweet potato acreage.

2. The Yellow river and Huai river valley spring and summer region. This region has clear-cut four seasons. Temperature goes up abruptly in spring and stays high in summer with plenty of rainfull. During autumn season, it is cool and temperature varies greatly between day and

night, favourable for the growth of the tuberous roots. This is the largest region of sweet potato production in China and improved varieties have been released mostly in this region, occupying about 40% of Chinese total sweet potato acreage.

3. The Yangtse river valley summer region. This region is located within the subtropicol zone, humidity being rather high and it contains probably 30% of the total sweet potato acreage in China.

4. The southern summer-autumn region. During winter period, the climate in this region is influenced by frequent cold spells, resulting in low temperature and frost. About 15% of Chinese sweet potato were grown in this area.

5. The southern autumn-winter region. This is a tropical monsoon region, including some islands in south sea and a portion of coastal area, with no frost all the year round. About 10% of the Chinese sweet potato acreage are in this region. They are mainly the autumn and winter planting type, but sweet potato can grow here all the year round.

Acreage and yield level

The period of 1950s'-1960s' was the fast developing stage for the sweet potato acreage in China. There were about 3,344,000 hectares of sweet potato in 1946. Then it increased to rapidly about 5,811,000 hectares in 1950, with an increase of about 75%. By 1963, there are about 9,640,000 hectares, as the peak acreage of sweet potato in China. This figure remain somewhat the same about 10 years. Since the late of 1970s', it begin to decrease gradually, but so far over 6,500,000 hectares of sweet potato were still grown every year throughout China. The annual acreage of sweet potato in China from 1940s' to 1980s' is presented in Table 1. But the distribution in different regions is uneven (Table 2.) due to the different natural conditions and economic situation.

The average yield of sweet potato per unit area in China was about 7.4 ton/ha in 1950-1955, it increased to 17 tons/ha in 1982-1984, with an increase about 130%.

Table 1. Annual area of sweet potato under production in China (1940s'-1980s')

Year	Annual total area (1000 ha)
1946	3,344
1950	5,811
1963	9,640
1978	9,260
1982	6,908
1983	6,840

Table 2. Annual area of sweet potato under production in different provinces or districts (1980)

Annual area(1,000 ha)	Provinces or districts
1,000-1,133	Sichuan, Honan, Shangdong
340-666	Hobei, Guangdong, Anhui
93-333	Jiangsu, Zhejiang, Guangxi, Hubei, Fujian, Hunan, Jiangxi
3- 66	Shanxi, Yunnan, Guizhou
Below 3	Liaoning, Shanxi, Gansu, Jilin, Xinjiang Ningxia, Shanghai, Tianjin, Beijing

Variety improvement

Accomplishments

Growing high-yielding varieties probably is the most important approach to raise the yield level of sweet potato in China. Eventhough systematic breeding of sweet potato started as early as 1920s', the principal cultivars used in commercial production have been local varieties for a long time. In 1930s' and 1940s', a few foreign varieties, such as Okinawa 100 and Nancy Hall, were introduced to China and replaced a portion of local varieties, resulting in yield increase. Since 1949, a lot of new varieties have been released to replace the land varieties and introduced ones. For instance, during 1960s'-1970s', over 30 new varieties were released for commercial use each having an acreage of more than 6,600hectares. Among them, 8 varieties, including Yanshu 1, Ningshu 1, Yubeibai etc, had an acreage of more than 100,000 hectares. An extremely successful example is Xushu 18. It is a superlative variety developed by Xuzhou Sweet Potato Research Centre, released in 1976 and reached to the maximum annual area of 1,440,000 hectares in 1983. It was awarded a prize of national inventions. A brief introduction of Xushu 18 is given in Table 3. Owing to better comprehensive characteristics, higher stress and disease resistance, these varieties could yield 15% more than the previous leading commercial varieties.

Altogether over 100 new varieties or lines have been developed in the past three decades contributing a lot to sweet potato production in China.

Breeding objective

Generally speaking, the dry matter content of the Chinese varieties is rather low. In a study of 60 currently used commercial varieties, it was found that only 10% of them had dry matter content high than 33%; 60% are medium (26%-32% dmo), and 30% are low (below 26%). Dry matter content is closely related to starch content, and few of the above-mentioned varieties have a starch

Table 3. Main properties of a superior variety XuShu 18

Traits	Yielding* ability	Resis.	Susce.	Tolerances
skin: purplish red flesh: pale yellow higher self-fertility	tuber y. +39% dry y. +55% raw starch content +4%	root rot (HR)	black rot nematode	drought excessive moisture, soil sterility premature senility

*Average value in 157 loci; Okinawa 100 was used as control

content higher than 23%. They cannot meet the requirement of the processing industries, are inferior in palatability, and more liable to decay during storage.

As more and more sweet potatoes were used for processing industries instead of human food, the importance of starch content becomes more obvious. On the one hand, starch is less vulnerable in storage and more convenient in transportation than tuber; on the other, it is an intermediate product between the tuber and a series of derivative products, including, wine, glucose, alcohol, citric acid etc. Therefore, to increase the starch content and consequently the dry matter content of sweet potato is one of the urgent tasks and major breeding objectives of the sweet potato breeders in China.

However, a few new varieties with high starch content were developed recently, including Yanshu 3, Zheshu 1, Huaishu 3 and Shennan (Table 4). The average starch yield per unit area of those four varieties was over 6 tons/ha, an increase of 10-20% than the check cultivar Xushu 18.

The some current breeding objectives for sweet potato in China are as follows:

Smooth and regular shapes tuberous root, white flesh, high starch content (starch rate of the spring crop should be 3% higher than that of released varieties, that of the summer should be 2% higher.), starch yield per unit area should be 10% more than the released variety, resistant one or two to root rot, black rot, nematode and bacterial disease, with better comprehensive characters and good adaptability. Studies on combining ability for starch

Table 4. Percentage of dry weight and starch content in four new varieties (1984-1985)

Variety	spring planting type				summer planting type			
	dry weight aver.	(%)	starch aver.	content (%)	dry weight aver.	(%)	starch aver.	cont. (%)
Huaishu 3	34.7	106.6	22.6	105.8	31.7	105.9	21.6	104.4
Zheshu 1	29.8	101.7	18.1	101.3	27.6	101.8	19.2	102.0
Yanshu 3	30.4	102.3	18.8	102.0	27.3	101.5	18.4	101.2
Shengnan	28.8	100.7	18.3	101.5	27.7	101.9	18.7	101.5
Xushu 18(ck)	28.1	100.0	16.8	100.0	25.8	100.0	17.2	100.0

content were carried on in Beijing Agricultural University and Jiangsu Academy of Agricultural Sciences, some promising combinations were identified, it is hoped that new varieties with high yield, high starch content and disease resistance could be obtained from these combinations.

Another important attribute in sweet potato breeding. Since more sweet potatoes were used as feed to hogs, dairy cattle, and poultry, protein content should be consider as another important breeding objective. Obvious differences in protein content could be observed between different genotypes, and it was found that the leaves and vines of the sweet potato plant contain much more crude protein than the tuberous root, therefore sweet potato breeding for high protein content has a bright prospect, although the work has just been started with the exception of Taiwan Province where the scientists had made some progresses. The breeding objective here includes better regeneration and higher protein content in the vine, more than 15% in dried vines, and other characteristic same as above.

Third kind of breeding objectives. Since sweet potato is also rich in Vitamins content, including carotene, B complex, Vitamin C and some minerals, such as calcium, iron, sodium, potassium. Breeding for higher carotene content has been carried on in China, and a number of varieties, including "166", "51-93", "138", "Beijing 284" and "Beijing 553" etc., were released as early as in 1950s'. This type of sweet potatoes were mostly in-

tended for human comsumption. The most outstanding among these are"DaNanFu" and" LongYan 8-6" developed in Fujian Province. They are rich in both vitamine A and sugar. "LienOheng Dried Red Sweet Potato" is a derivative of "DaNanFu", it sells pretty well on both domestic and foreign markets. The breeding objectives of this type of sweet potatoes are: regular and beauty shape of tuberous root, flesh from yellow to orange red, starch content over 20%, yield level as good as local commercial variety, dry matter content over 27%, caretene content will be over 10mg/100g, soluble sugar content not less than 3% in tuberous root, lower fibre content, disease resistance and other characteristics also the same as above.

Method of sweet potato breeding

1. Intervarietal hybridization is the most common approach in sweet potato breeding and most of the varieties released in recent years belonged to varietal hybridization varieties. The main obstacle in making crosses is the problem of flowering in higher latitudes. To overcome this obstacle, wild species such as I. aquatica, Calonyction aculeatum, Quamolit coccinea, Pharhitis spp., have been used as stocks in grafting with sweet potato scions to promote efflorescence. Grafting were usually combined with short day treatment in some places. The choice of parental materials is very important in making intervarietal crosses. For example, the resistance of Xushu 18 to root rot is perhaps derived from its early progenitor Nancy Hall, inspite of another highly susceptible parent Okinawa 100. And the adaptibility comes from Okinawa 100 and perhaps a third parental material Jiaoudazi.

2. Wide crosses. Direct utilization of wild Ipomoea species in sweet potato breeding in China started in 1977 when some wild relatives were introduced from United States. So far the distant crosses have been made only between the B group of Ipomoea batatas section. Some BC_1 or BC_2 progenies of interspecific crosses between I.trifida (6x) and sweet potato indicated higher starch content and disease resistance than their cultivated parents. The key problem here is the choice of the most suitable cultivar as the recurrent parent (Table 5). Another approach is to use the derivatives of wide crosses, such as minamiyutaka as source of wild germplasm. It has been demonstrated a promising way for indirectly introducing wild germplasm into sweet potato cultivars.

Table 5. Yielding ability in BC 1 of interspecific hybrid between I.trifida(6x) and sweet potato (1986 Nanjing)

Strains	Backcrossing generation	Parents	Tuber yielding ability (± %)*
B 361	BC 1	Xushu18 x H91**	+15.5
B 54-20	BC 1	H.X.D. x H91	-36.0

*Control: Xushu 18

**Interspecific hybrid F 1 beteen 52-45(cultivar) and I.trifida(6x)

3. Induced Mutation has been used widely in sweet potato breeding in China. For example, Xushu 18, (high resistance to root rot, but susceptible to black rot.) was irradiated with gamma ray from ^{60}Co source and several clonal lines possessing resistance to black rot were obtained in M_1V_2 by Beijing Agricultural University in 1984 (Table 6). In another study, 6543 hybrid seeds from 23 combinations were irradiated with fast neutrons at suitable dosages of 3.8×10^{11} and 1.1×10^{12} n/cm^2 and several promising lines with disease resistance and high yield or high starch content were obtained in 1978-1984 by Yantai Agricultural Institute (Shangdong province)(Table 7). On the other hand, selection from natural clonal variations is a common traditional method widely used by farmers or breeders. For instance, 77-6, a variety with high yield than Xushu 18, was developed from a natural bud mutation of Xushu 18 and covered an acreage of over 130 kilohectares in 1980s'(Xuzhou).

4. Utilization of heterosis by crossing inbred line has been successful in many crosspolinated species. In case of sweet potato, little has been done in this approach due to the self-incompatibility. However, a few varieties possess the self-fertility that makes inbred strains possible. For instance, land varieties Gaozi 1 and Gaozi 73-14 have been tested to have self-fertility as high as 85%. A series of inbred lines have been obtained in some breeding institutions, Hunan and Shangxi provinces, but no significant advance has been made as yet.

5. Application of quantitative inheritance in sweet potato breeding programs based upon a randomly intercrossing population was first initiated by Afred Jones

Table 6. Resistance to black rot in individual plants of M_1V_2 obtained by gamma ray treatment (1984 Beijing)

Plant number	Dis. inci.	Plant number	Dis. inci.	Plant number	Dis. inci.	Plant number	Dis. inci.	Plant number	Dis. inci.
CK-4-1	+*	18-123-1	+	18-229-1	-	18-82-1	-	12-11-1	-
CK-4-2	+	18-123-2	+	18-229-2	-	18-82-2	+	12-11-2	-
CK-4-3	-	18-123-3	+	18-229-3	-	18-82-3	+	12-11-3	-
CK-4-4	+	18-123-4	+	18-229-4	-	18-82-4	-	12-11-4	-
CK-4-5	+	18-123-5	+	18-229-5	-	18-82-5	-	12-11-5	-
CK-4-6	+	18-123-6	+	18-229-6	-	18-82-6	-	12-11-6	-
CK-4-7	+	18-123-7	+	18-229-7	-	18-82-7	-	12-11-7	-
CK-4-8	+	18-123-8	+	18-229-8	-	18-82-8	-	12-11-8	-
CK-4-9	-			18-229-9	-				
				18-229-10	-				

* " + " showed infection " - " showed uninfection

Table 7. Resistance to black rot in adventitious bud obtained by fast neutron treatment with the hypocotyl of hybrid seeds(1984 Yantai, Shangdong province)

Combination	Treatment	Resistance or susceptible frequency(%)			
		HR	MR	HS	MS
American Red x 59-541	Neutrons*	0	28.5	28.5	42.9
American Red x 59-541	Control	0	14.3	50.0	35.7
Funshouhung x Honghong	Neutrons	5.5	27.7	41.6	25.0
Funshouhung x Honghong	Control	0	12.4	68.8	18.7

*1.1×10^{12} Neutrons/cm^2

in 1965. This principle has been widely used in sweet potato breeding in the United States and Japan. In China, some breeding station are also attempting to use this principle for variety develpment.

So far, the conventional breeding method has been, and shall be the principle appoach in sweet potato breeding. For the time being, it is necessary to enhance the breeding efficiency rather than to enlarge the breeding scale and the emphasis should be shifted from a single objective-yield to a multiobjective complex. i.e. for processing industries, feed and food. However, perhaps it is the biotechnique that will bring a bright future to sweet potato breeding. For instance, haploid breeding could be a desirable approach to bring along higher heterosis in sweet potato. The plant tissue and cell culture in vitro could provided an opportunity for increasing the genetic variation for somatic clonal variation selection. The in vitro fertilization technique, the protoplasts fussion and genetic transformation may introduce alien genes into commercial cultivar. And finally prospect of using gene engineering in sweet potato breeding shall not be unpossible.

Germplasm resources

The collection and preservation of sweet potato germplasm resources in China was started in 1952. Up to 1981, a total of 1096 entries have been collected and preserved in both the central and the provincial institution, including 589 land varieties, 377 improved varieties, 134 introduced foreign varieties. It has been emphasized in recent years to collect germplasm with multi-resistances and high starch content from foreign or wild resources. Research on sweet potato consist of following aspects, a) Identification of disease and pest resistance (black rot, nematode, root rot, bacterial or virus disease and sweet potato weevil) and tolerances to enviromental stress (drought, poor soil fertility and excessive moisture etc.); b) Quality analysis (starch, fibre, crude protein, soluble sugar, Vitamin A, Vitamin C and other components); c) Incompatibility group test; d) Evaluation, preservation and utilization.

Breeding institutions

Most of the sweet potato breeding programs were carried out in agricultural research institutes and universities in more than 20 different provinces or cities. Major research and breeding were done in Xuzhou, Nanjing, Shangdong, Beijing and Sichuan, germplasm resources were collected and maintained in Xuzhou and Gangdong respectively. And a cooperative network composed of 15 research units was initiated recently.

Conclusion

Sweet potato, as one of the major crops in China, have play an important role in the development of the Chinese agriculture. Although it was introduced 4 centureis ago from abroad, China has now become the number one country in sweet potato growing, both in total acreage and in total production. Breeding developed rapidly in the last 3 decades, bringing along higher yield and better quality. So far, the conventional method has been the main approach of sweet potato breeding, in China, but it is perhaps the modern biotechnique that shall bring about a bright future.

At last but not the least, for the future development of sweet potato breeding and production in China, it is very important to strengthen international cooperations, especially with Asian and Pacific countries in the exchange of information, experiences, and germplasm.

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SWEET POTATO BREEDING IN A DEVELOPING COUNTRY - THE PHILIPPINES

Florencio A. Saladaga

An archipelago off the southeast coast of Continental Asia, the Philippines consists of 7,107 islands with a total land area of around 300,000 square kilometers. Ninety-two per cent of its about 50,000,000 people are Christian, 5% professing Islam and the rest with various beliefs and/or non-beliefs. Filipinos have common racial stock with Continetal Malays and Indonesians but the Philippines has a sizable Spanish and American blood dating back to the 16th century starting when Magellan landed on its shores in 1521 up to 1898 when Spain turned over the islands to the Americans.

President Emilio Aguinaldo Proclaimed Philippine independence in 1898 but was a short-lived republic having been defeated and colonized by the U.S.A. from 1898 until July 4, 1946 when the Philippines gained independence again.

Rice is the number one staple food, followed by corn, sweet potato, cassava and others, i.e. yams, cooking bananas, xanthosoma etc.

Although sweet potato is used either as staple, as vegetable or as snack item, the data of the Philippine Department of Agriculture show that sweet potato is the leading vegetable in the Philippines "consumed with an average rate of use of 11.0 kilogram per capita per year (Aviguetro, et.al. 1976) that is more than double that of any other important vege-

table (Santos, 1977). Sweet potato hectarage for the last 50 years ranged from 190,000 to 200,000 hectares producing about 855,000 to 900,000 metric tons of fresh roots - the national average yields during the period from 4.5 to 5.0 tons per hectare. Most of these produce is consumed in the country and very little if any is exported. Recent developments in the Philippines augered well for the increasing role of sweet potato in the national economy.

The present paper traces the beginning of sweet potato production/utilization in the Philippines thru the changing times to the present pointing out the role being played by the crop improvement work of an interdisciplinary, interdepartmental team at the Philippine Root Crops Research and Training Center (PRCRTC), the research arm for root crops research of the Visayas State College of Agriculture (ViSCA), Baybay, Leyte 7127-A, Philippines.

SWEET POTATO INTRODUCTION AND EARLY CROP IMPROVEMENT WORK IN THE PHILIPPINES

Most of the sketchy evidences point to within the Spanish colonial period in the Philippines which lasted from the early 16th century up to close to the end of the 19th century as the time when sweet potato was introduced into the Philippines from Central/South America which is the most likely center of origin of the sweet potato.

An earlier time of introduction or even possible site of the origin of the sweet potato in the Philippines, however, can not yet be completely ruled out. Present evidences have not yet provided even the minimum required to make strong conclusion on the origin of the sweet potato.

At least, three groups of evidences are necessary before a definitive conclusion can be made about the origin of any crop species, i.e. (1) the crop species has been grown in the area for a very long period of time preferably as early as the origin of agriculture as borne by written historical records and/or by archaeological/fossil evidence; (2) there must be found in the area many plant variabilities within and/or related to the crop species in question ranging from closely related genera, species, botanical varieties and strains or geographical races; (3) a progenitor or parent wild species must be found in the area or, at least, a hypothetical parent could be shown to have existed therein but which had already become extinct. Some data have been gathered in sweet potato of the second group of evidences but very nil or none at all for the first and second group of evidences. Although there are more plant variabilities within the genus Ipomoea and related genera in Central and South America, Merill (1912) has described a number of genus and species within the Morning Glory (camote) family that were found in the Philippines.

Whatever improvement of the sweet potato crop species since it started in the Philippine up to the early 1900's could have been brought about only through unconscious selection by Filipino farmers. As noted earlier (Saladaga, 1983) the sweet potato plant flowers and bears fruits and seeds freely in the tropics, i.e. the Philippines. Most varieties usually flower during the short days from September to December but a few varieties also flowers and set seed during short days from April to June. Any seed produced by a sweet potato plant which may fall on the ground may grow into a plant which will have different sets of characteristics from

its parent and from its siblings because of the genetic recombination that had taken place during sexual reproduction coupled with the highly heterozygous nature of the sweet potato species. Farmers, therefore, may choose to propagate a new plant type that he finds in his field which he can maintain and/or multiply for the next crop. This can explain the presence in the Philippines of many cultivars differings in root, stem and leaf characteristics as early as when agriculture as a formal educational subject was offered in the early 1900's in the Philippines.

One of the earliest planned sweet potato breeding in the Philippines was done by Mendiola starting in 1918 when he made collections of several native varieties and started the production of true seeds from which he later grew several breeding lines (Mendiola, 1921). Although progress of the work was limited, the project was maintained as one of the activities of the Department of Agronomy, University of the Philippines, College of Agriculture, College, Laguna, Philippines together with other research work (Juliano, 1935). Uichanco (1961) has described the early leading varieties of sweet potato in the Philippines.

In the early 1950's, Dr. Dominador Clemente became superintendent of the then Baybay National Agricultural School (BNAS) now the Visayas State College of Agriculture, Baybay, Leyte, Philippines. Assisted by the late Mr. Luis Catamen, Dr. Clemente made selections among the sweet potato varieties in the school and named a specific selection BNAS-51 which up to this day is planted by a sizable number of Filipino farmers and has been used as a check variety in a number of sweet potato researches in the Philippines.

CROP IMPROVEMENT WORK FROM EARLY 70's TO PRESENT

Impetus for more research work on the improvement of the sweet potato was provided by the National Science Development Board (now the National Science and Technology Authority, NSTA) when it funded the research proposal on rootcrops breeding by Dr. Azucena Carpena, of the Department of Agronomy, U.P. College of Agriculture, College, Laguna, Philippines. Further impetus came with the establishment of the Philippine Council for Agriculture and Resources Research and Development (PCARRD) in 1972 which took the lead in identifying the status and future research thrusts of different commodities and later monitoring and evaluating further development.

In 1975, PCARRD provided funds for the project of the present author entitled, "Collection and evaluation of native and introduced root crops varieties in the Philippines" which then served as the nucleus of the national research program in sweet potato in particular, and root crops in general. Recognizing the need for establishing a national research center for root crops in the region where root crops is predominantly grown, the Philippine Root Crops Research and Training Center was created by a Presidential Decree in 1977 to serve as ViSCA's implementing arm for root crops research. Financial support for the center was obtained from national and international sources, i.e. directly from the Budget Ministry of the Philippine Government, from PCARRD, and from the International Development Research Center (IDRC) which provided the biggest funding of any of the external sources.

By 1976, a sizable collection of native and introduced varieties of sweet potato, cassava, yam and others had been pooled (Saladaga, 1976) and preliminary and advanced yield trials conducted. It was also in 1976 that, IDRC funded the "Program for the establishment of a national root crops research center" for the conduct of root crops research, construction of some infrastructure facilities and for the centers' staff development. In 1978, PRCRTC received the prestigious Tanglaw Award from PCARRD "For having made extensive collection of root crop varieties and spearheading a comprehensive research program on root crops."

In late 1980, the proposal entitled, "A program for varietal improvement of sweet potato in the Philippines" was prepared by a team consisting of plant breeders, agronomist, entomologist, biochemist, post-harvest physiologist and food scientist headed by the present author was submitted and subsequently funded by ViSCA, PCARRD and IDRC. A second phase of the program was prepared in 1983, this time it included economist and agribusiness scientists for the project on the economics of sweet potato production and marketing.

Related research projects and studies undertaken by other faculty in PRCRTC/ViSCA have provided synergistic effect on the sweet potato improvement program making faster approach to its goals and objectives. The organization of the Root Crops Technical Group of the Philippine Seed Board spearheaded by Dra. Carpena in 1982 paved the way for a collaborative work of various agricultural colleges and universities together with several research stations of the Bureau of Plant Industry, Ministry of Agriculture and Food.

The Philippine SeedBoard is mandated by an Act of the congress of the Philippine to evaluate, recommend, name and release crop varieties and coordinate the registration and seed certification and distribution of approved varieties. It carries out its functions of releasing crop varieties through a three - layered organization; (1) the Technical Committees which formerly was only on rice and corn but which in early 1980's has expanded with one each for Root Crops, vegetables, fiber crops, plantation crops, and others; (2) the Recommendation Committee which reviews the nominations of the Technical Committees, and, (3) the Approving Committee.

Before the organization of the Root Crop Technical Group of the Philippine SeedBoard, sweet potato varieties were released by agencies based on data collected by respective agencies and its supervised cooperators. For example, PRCRTC released the cultivar PRCRTC No. 10 (new name of what actually was BNAS-51). UP Los Baños also released UPL-sp-1 (new name of a farmer's variety, kinabakab).

The year 1983 marked the beginning of the recommending, naming and release of sweet potato varieties by the Philippine SeedBoard of entries from research agencies based on data collected by the SeedBoard's own Technical Group. The sweet potato varieties released in 1983 included three varieties from ViSCA, namely; VSP-1, VSP-2 and VSP-3, one variety from UPLB, i.e. UPL-sp-3 and one from BPI, MAF, i.e. BPI-sp-1.

The entry of UPLB which was named by the Philippine SeedBoard as UPL-sp-3 was a selection of the farmer's variety called Tinipay while the entry of BPI-MAF which was named by the Philippine SeedBoard as

BPI-sp-1 was formerly designated as Lo-323, a breeding line produced by the breeding program at Louisiana State University, Baton, Rouge, Louisiana, U.S.A. which formed a part of the collection of AVRDC and tested by BPI-MAF as part of the work in an AVRDC outreach Program in collaboration with BPI-MAF.

The three new varieties from ViSCA (Saladaga, 1983), were results of a polycross breeding technique under the "Program for varietal improvement of sweet potato in the Philippines". They were selections from a series of evaluation and screening conducted on about 80,000 plant types grown from true seeds produced in various polycross nurseries. In the middle part of the evaluation and screening process, a few hundred selections were given breeding numbers. Three of these selections were called ViSCA 2-1, ViSCA 2-27 and ViSCA 2-3 which after regional trials were found to have many superior characteristics and therefore named and released by the Philippine SeedBoard as VSP-1, VSP-2, and VSP-3, repectively.

A description of the polycross breeding technique as used in sweet potato at ViSCA together with the method of evaluating and screening the plant variabilities has been described earlier (Saladaga, 1981, 1982 and 1983). Compared with conventional hand pollination, a hand pollinator can pollinate only about 200 flowers a day and with fruit set of only 20% of hand pollinated flowers plus the fact that each fruit produce an average of only 1.25 seed, only a few seeds can be produced per year per person (Saladaga 1981, 1983 and 1984). Since the frequency distribution of sweet potato progenies is skewed toward the low yielding classes (Saladaga, 1981a, Villordon and Saladaga, 1983, Bernardo and Saladaga, 1984), the

probability of identifying high yield genotypes in combination with other desirable traits is low.

Using the polycross breeding technique, thousands of true seeds can be produced per year. With efficient and rapid screening and selection ppocedures, the chances of identifying new recombinant genotypes possessing several desirable traits have high probabilities.

Part of the genetic studies of the program in ViSCA had looked into the compatibilities of the different cultivars that were used as parents in the polycrosses. It was shown that sweet potato cultivars in ViSCA have different cross incompatibilities and almost all cultivars exhibit self-incompatibilities. Those that can be selfed at all, has a very small percentage (less than 3%) of fruits setting of the pollinated flowers. These findings together with other considerations led to the predominance of the polycross technique as the method used in increasing sweet potato plant variabilities even though in the project proposal three methods were indicated to be used, namely; (1) biparental crosses, (2) polycrosses, and (3) mutation breeding. Biparental crosses were used mostly in genetic studies.

The work of the sweet potato crop improvement team at PRCRTC/ViSCA has continued to catalyze the improvement of the sweet potato industry. The ultimate objective of crop improvement work is for the varieties to become useful in the lives of the Filipino farmers.

To hasten the adoption by the farmers of the new varieties, articles and news bulletins have been published. A leaflet entitled, "New sweet potato varieties: VSP-1, VSP-2 and VSP-3" were produced by the Department

of Plant Breeding and Botany, The Philippine Root Crops Research and Training Center, and the Visayas State College of Agriculture (Saladaga, undated). The ViSCA Newsletter and the ViSCA ViSTA both carried articles during their May-August issues on the new ViSCA-produced sweet potato varieties. Radio station, DYAC of ViSCA aired in its programs the good news about VSP-1, VSP-2 and VSP-3. Extension and training personnels of ViSCA disseminated information and materials of the new varieties in various farmers' fairs, science weeks, fiesta celebrations, and other community activities. Articles on VSP-1, VSP-2 and VSP-3 were also published in the Agriculture section of the National dailies i.e. Bulletin Today Aug. 1, 1983, Daily Express news, Times Journal. Regional Newspapers, i.e. "The Balalong", the largest Bicol newspaper published a series of articles on sweet potato with emphasis on VSP-1, VSP-2 and VSP-3. Other regional newspapers like "The Reporter", a Leyte-Samar publication and "The Samar Times" each published articles on the ViSCA-produced varieties. Articles were also published in national and international magazines, i.e. "The Greenfields", "Countryside Banking News", "The IDRC Reporter". The present author was interviewed in many occasions by Radio and Television stations.

By the end of the year 1983, over 3,000 farmers have already availed of planting materials of either one or all of these ViSCA produced varieties. These 3,000 ranged from the small farmers to the big-time farmer proprietors and large corporations. Big farms that have availed considerable amounts of planting materials include Sagay Sugar Central, Inc. and Victorias Milling both of Negros Occidental; Lorenzana

Foods/Farms of Kavotas, Rizal, former Gov. Triviño of Camarines Sur, Gov. Alberto of Catanduanes, Mayors of many municipalities, and KKK supported projects.

The new varieties were entered in the National Inventions Week of 1984 sponsored by the Philippine Inventions Development Institute of the National Science and Technology Authority. Fortunately, the Presidential Board of Judges adjudged the new Sweet potato varieties 1983, as First Place in the Creative Research Category. Word spread of the potentials of what was formerly referred to as the lowly camote.

Soon, the business community begun to look at the prospects of what the former Agriculture and Food Minister Arturo Tanco referred to as the Sunshine commodity leading former Economic Planning Minister Valedepeñas to remark in 1985 that the sweet potato is now a hot topic in the Makati Board rooms. Makati is the hub of business activity in the Philippines.

This development brought to the Philippines the Director of GRANARIA of Rotterdam followed by his representative, Dr. Harry Van Ruiten to look at the prospects of the sweet potato local and export potential. Sweet potato farmers' associations are now organized in many of the country with a national association for the production and marketing of sweet potato.

In 1984, the breeding line ViSCA 7-27 was named and released by the Philippine SeedBoard as VSP-4 and in 1985, another breeding line ViSCA 10-95 was named and released as VSP-5. These two varieties have

given the farmers better options in choosing the best sweet potato cultivar to plant in his farm.

The project on Economics studies on sweet potato is generating data useful in deciding the most profitable input level for certain situations; looked at the traditional marketing systems and tried some innovative marketing strategies; and, conducted some feasibility studies of the various alternative uses of sweet potato.

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PRINCIPAL BACTERIAL AND FUNGAL DISEASES OF SWEET POTATO AND THEIR CONTROL

C.A. Clark

Many of the bacterial and fungal diseases of sweet potatoes have been known for almost 100 years (17) and several monographs and reviews have been written in the USA over that period of time (6,7,23,35,53,56,57,81,84).

The relative importance of bacterial and fungal diseases of sweet potato is highly dependent on two factors: i) the type of sweet potato production system, and ii) the intended utilization of the crop. Generally, sweet potatoes are produced in one of two systems. In warm tropical climates they are usually grown year round and therefore may be propagated using vine cuttings taken from fields already in production. In subtropical and temperate regions, they are propagated from transplants produced from storage roots which must be preserved during the cool season and sprouted prior to transplanting. Many important bacterial and fungal diseases are root diseases, and thus increase to much greater extent when storage roots are involved in the propagation cycle.

Sweet potatoes are utilized in diverse ways in different regions of the world and their use influences regional perceptions of the relative importance of prevalent diseases. Where sweet potatoes are grown primarily for foliage or vine tips, foliar diseases may be regarded as more important than root diseases. Where sweet potatoes are grown for storage roots, the perceived importance of foliar and root diseases is reversed.

Fungal and bacterial diseases affecting storage roots are important because they affect yield, esthetic quality, storage life, and nutritional value of storage roots. Fungal pathogens in particular can induce sweet potato storage roots to produce an array of furanoterpenoid phytoalexin-like compounds which may be toxic to animals (9,48,70). Because of esthetic requirements and potential detrimental health effects, the amount of root disease that can be tolerated on sweet potato is much lower than it is for nonroot crops which generally require multiple infections by root pathogens before the crop is economically affected.

BACTERIAL DISEASES

There are four major diseases caused by prokaryotes each of which occurs only in a restricted geographic region.

Bacterial Soft Rot

Bacterial soft rot of sweet potato was first reported in the southeastern United States in 1977 (47). It is caused by Erwinia chrysanthemi and affects both vines and storage roots (47,74). A soft, moist decay resembling Rhizopus soft rot turns affected storage root tissue light brown. In storage, the lesions have a dark brown to black margin and appear to be restricted, but in plant production beds, some roots are totally decayed leaving only residual fibers and periderm. Sprouts may become infected from partially decayed mother roots in beds or vines may become infected during or after transplanting. The pith of the vine is quickly decayed and the hollowed out vines become extensively necrotic, wilt and sometimes die.

Bacterial Wilt

Although sweet potatoes are grown in many regions of the world where the causal organism of bacterial wilt, Pseudomonas solanacearum, occurs on other crops, the disease has been reported on sweet potato only in The People's Republic of China (35). Apparently Chinese strains of the bacterium are unique in their pathogenicity to sweet potato (26). The bacterium induces vascular discoloration and wilting of vines in the field and can invade storage roots and cause them to breakdown.

Soil Rot or Pox

Soil rot, caused by the host-specific, soil-borne actinomycete, Streptomyces ipomoea, has been reported only in the USA (72). It causes severe losses under conducive field conditions but does not affect roots in storage. Symptoms are similar to those reported from China for Fusarium root rot, including extensive necrosis of feeder roots and scab-like lesions on the storage roots. The pathogen invades the storage roots through feeder roots and does not penetrate the periderm directly. When storage roots are infected early in development, subsequent enlargement at the site of infection is prevented. This leads to the development of indentations or constrictions in the fully grown root. The disease develops only in soils with pH of about 5.2 or higher although the pathogen may persist in more acid soils without causing disease (52,71). Disease development is also much greater in dry than in moist soil (73).

Witches' Broom

Witches' broom, also known as little leaf or Ishuku-byo, is caused by a mycoplasma-like organism (13,29,78). It was first reported in 1947 and now occurs in southeast Asia and Oceania.

Proliferation of axillary shoots and stunting of vine growth and leaf enlargement are the most pronounced symptoms. Etiology of the disease can be confirmed by observation of the characteristic pleomorphic bodies in the phloem (13,33,86). Geographic distribution of the disease has been correlated with the range of the leafhopper vectors, Orosius lotophagorum ryukyuensis and Nesophrosyne ryukyuensis (89). The disease has a very long latent period which makes detection difficult.

FUNGAL DISEASES

Most of the diseases of sweet potatoes caused by fungi have been recognized for many years (17). A number of these are foliar diseases. Some are quite common and others have been observed only in certain geographic areas, but with the exception of vine and leaf scab, they have not been observed to cause sufficient damage to the plant to warrant control efforts. Included in this group are: rust, caused by Coleosporium ipomoeae; white rust, caused by Albugo ipomoeae-panduranae; and leaf spots caused by; Alternaria spp., Cercospora spp., Phyllosticta batatas, and Septoria bataticola.

Several fungal diseases, particularly black rot, foot rot, and scurf are very efficiently transmitted through the storage root propagation cycle but do not persist many years in soil. These pathogens have narrow host ranges, however, Convolvulaceous weeds become infected following artificial inoculation (11). Whether such weeds play an important role in pathogen survival between sweet potato crops has not been determined. Many fungi can occasionally cause storage rots, especially under adverse conditions (24), but those discussed below are the most common.

Black Rot

Black rot, caused by Ceratocystis fimbriata, was once one of the most economically significant diseases of sweet potato in the USA (83). It no longer causes significant losses in the USA but remains a serious problem in other regions of the world. Strains of the same fungus cause disease on other hosts such as taro, almond, cacao, and others, but the strains seem to be very host specific. A black, dry rot is produced on the storage roots which is often restricted to the cortex. Black sunken cankers are produced on sprouts below the soil line. Perithecia of the causal fungus are sometimes produced on the surface of infected tissue and the tissue has a characteristic fruity odor.

In the USA, it has been determined that C. fimbriata does not persist in soil for more than 1-2 years in the absence of a susceptible host. The pathogen is very efficiently transmitted from infected mother roots to the underground portions of sprouts and from infected sprouts to the succeeding crop of storage roots

(15). Chewing insects and rodents may also transmit the pathogen (16) and spores may also be carried in wash water.

Charcoal Rot

Although charcoal rot may appear on some storage roots prior to harvest, it is primarily a postharvest disease (83). It is caused by Macrophomina phaseolina, a warm weather pathogen with a very broad host range. It produces a firm decay of the storage roots which first turns the tissue reddish-brown and then black as sclerotia of the pathogen are produced within the tissue. Often the sclerotia are produced only in the cortex of the storage root even though the whole root is affected.

Circular Spot and Sclerotial Blight

Sclerotium rolfsii, a pathogen of many crops grown in warm climates, causes two distinct diseases of sweet potato that occur at different stages in the development of the crop. Circular spot develops on storage roots in the field just prior to harvest. The lesions are seldom more than 1-2 mm deep but may be from a few mm to a few cm in diameter with a well-defined margin (41). The lesions cease development when the roots are harvested, and within a few days after harvest it is very difficult to isolate the pathogen from them. When harvested roots are placed in a high-humidity environment immediately after harvest, mycelia of S. rolfsii often grow out. Eventually, the root produces an abscision zone around the lesion. There is still doubt about the role of circular spot lesions on mother roots as potential sources of inoculum for sclerotial blight which develops in plant production beds.

Sclerotial blight first appears as wilting of the sprouts at about the time they are ready for transplanting (19,27). Necrotic lesions girdle the sprouts at the soil line and they then quickly desiccate and die. Expanding, circular foci of infection can destroy large areas of the bed. Coarse white mycelia of the fungus, and later sclerotia, appear on the soil surface around the plants and if the mother roots are unearthed, the mycelia can be seen on the surface of the roots and at late stages of infection the mother root may be extensively rotted with minimal discoloration of the tissue. Cultivars vary in reaction to sclerotial blight and those with a degree of resistance may develop restricted lesions on sprouts below the soil line rather than the more aggressive blight. Volatile chemicals emanating from mother roots with any of several storage rots stimulate germination of sclerotia of S. rolfsii and may increase disease incidence.

Foot Rot

Foot rot, caused by Plenodomus destruens, occasionally causes serious losses in isolated fields but is not a limiting factor to sweet potato production. The most commonly observed symptom is the

occurrence of necrotic lesions which often girdle the vines in the field at or just below the soil line (18). The pathogen may grow down the vine into the storage roots and cause a slowly progressing decay which does not usually destroy the entire root even in storage. The pathogen readily spreads from infected mother roots to sprouts. Pycnidia of the fungus are commonly produced near the surface of infected vines and just beneath the periderm of storage roots.

Fusarium Rots

Surface rot is a long-known disease which affects sweet potatoes only in storage (22,54). It is caused by cortical-rotting strains of *Fusarium oxysporum*, a soil-borne, wound pathogen distinct from the Fusarium wilt pathogen. Symptoms usually develop following harvest and consist of a brown, dry rot restricted to the cortex of the storage roots. Symptoms may occur in the field if growth cracks develop in the storage roots. Disease severity is affected by conditions in the field leading up to harvest, and dry weather, which favors skinning' of the roots during harvest, may lead to an increase in disease incidence (61).

Fusarium solani has been reported in the USA to cause a complex syndrome which manifests itself in different ways depending on the cultivars and environmental conditions involved. It can cause a surface rot which is difficult to distinguish from that reported for *F. oxysporum* (8). On some cultivars, it more commonly enters the storage root from one of the ends causing an end rot (8). Recently, some strains of *F. solani* have been shown to cause a more aggressive root rot that frequently penetrates the vascular ring, causing a dry rot which can slowly consume much of the root (65). It is characterized by the presence of lens-shaped cavities which often have mycelial growth on their inner surfaces. In addition, some of these strains are also capable of moving from infected mother roots into the sprouts and growing in advance of macroscopic symptoms (55,58). In sprouts and vines, these strains cause a stem canker that includes necrosis and splitting of the stem. Infection can apparently occur either through the storage root propagation cycle or as a result of invasion of harvest associated wounds from soil-borne inoculum.

Fusarium solani has also been described as the cause of a root rot in China which differs from that described in the USA in that it involves extensive feeder root necrosis (28,39).

Fusarium Wilt

Fusarium wilt, also commonly known as stem rot, is caused by *Fusarium oxysporum* f. sp. *batatas* (21). Symptoms on sweet potato may appear on sprouts in the plant beds or more commonly shortly after the transplants begin growing in the field. Symptoms include yellowing of the lower leaves, pronounced vascular discoloration, wilting and sometimes stem necrosis and death of the plant.

Surviving plants may produce daughter roots with discolored vascular tissues that serve as a source of inoculum for the next crop, or the roots may become infected during harvest (60).

The pathogen is relatively specific with regard to the hosts in which the wilt syndrome is induced, which include: sweet potato, related Ipomoea spp., and certain genotypes of tobacco (2,11). However, the pathogen can also colonize other plants without inducing wilt. It also persists in the soil for many years in the absence of a sweet potato crop. The disease was once especially serious in many sweet potato growing areas in the USA and Japan. However, wilt has been relatively unimportant in many parts of South and Central America. In some cases, biologically suppressive soils may limit the distribution and severity of the disease (77).

The disease is no longer considered to be a limiting factor in some areas where it once threatened the economic survival of the sweet potato industry due primarily to the use of resistant cultivars and also to the use of crop rotation and sanitation procedures (62).

Java Black Rot

The name for this disease is a misnomer as the disease is widely distributed, especially in the warmer areas of the world (12,32,83,87). It generally only affects the storage roots following harvest and is caused by Diplodia gossypina (syn. = Diplodia tubericola, Botryodiplodia theobromae et al.). Symptoms often progress from the end(s) of the storage root and involve the entire root. The decay is firm, at first reddish-brown then turning black. The root desiccates and becomes very hard. When infection occurs through wounds on the side of the storage root, lesions are often restricted and develop a black center surrounded by a wide brown zone (69). At advanced stages of infection, the disease is readily recognized by the black stromatic domes which erupt through the periderm of the root. The stroma contain pycnidia with many 1 or 2-celled conidia.

The fungus is soilborne and infects storage roots through wounds incurred during harvest. Stressed roots are particularly susceptible (1). Susceptibility of the storage roots increases significantly during storage as does the availability of inoculum. Thus the greatest losses to this disease often occur following handling of stored sweet potatoes (40).

Rhizopus Soft Rot

Several different species of Rhizopus can be associated with soft rot but in temperate and subtropical areas the predominant pathogen is R. stolonifer (syn. = R. nigricans) and in tropical areas R. oryzae predominates (25,37,88). Storage roots are very rapidly destroyed by a soft, watery decay that consumes the entire

root. Whiskers', consisting of mycelia, sporangiophores and sporangia of the causal fungus commonly appear as the infection progresses. Storage roots affected by Rhizopus soft rot also give off a distinctive alcohol-like odor.

Although Rhizopus spp. are the most common storage rot pathogens, they are fastidious about the type of wound required for infection. Infection occurs only when wounds kill surrounding tissue, or when exogenous nutrients or pectolytic enzymes are added to the inoculum (79). Only the harvested storage roots are affected, but the losses have been tremendous in some circumstances. Roots are predisposed to the disease by prior chilling or exposure to direct sunlight.

Scurf

Scurf is a superficial disease of storage roots and below-ground portions of the stem that is caused by Monilochaetes infuscans (20,34,85). Affected roots have dark brown lesions, resembling a stain, which are restricted to the periderm. Lesions continue to enlarge and may coalesce and spread from mother roots onto sprouts produced on them and from there to daughter roots. When infected roots are incubated in a moist chamber, the fungus produces simple, dematiaceous conidiophores from a bulbous basal cell and a curved chain of hyaline, single-celled conidia. Although the flesh of the storage root is not directly affected, severely diseased roots are much more subject to water loss and shrinkage during storage (14).

Vine and Leaf Scab

Also known as bud atrophy, this disease caused by Elsinoe batatas (anamorph = Sphaceloma batatas), may sufficiently affect yield of sweet potato to justify control efforts. Round to elliptical lesions first appear on leaf veins, petioles or stems as yellowish-brown spots which become gray-brown and finally corky (7,30). Symptoms are more pronounced on young shoots and leaves and on particularly susceptible genotypes the disease may cause stunting of the shoot system and distortion of the leaves.

The disease is restricted in its geographic distribution to southeast Asia and many of the Pacific islands (7,57). It is most common and severe in areas and seasons that are rainy.

Violet Root Rot

Helicobasidium mompa causes a serious root disease of sweet potato and many other crops in some parts of southeast Asia (82). Feeder roots are extensively decayed and the storage roots are often totally decayed prior to harvest. Storage roots begin decaying from the distal end and develop an odor similar to that associated with Rhizopus soft rot. The decayed roots are held together by a thick mantle of coarse mycelia over their surface.

The mycelia are at first white, becoming pink, brown and finally violet with a velvet-like texture as a hymenial layer with basidia and basidiospores is formed. Brown sclerotia may form on the stem near the soil line and a mat of purple-brown mycelia may grow over the surrounding soil (35).

The fungus persists in soil for several years as sclerotia, mycelial strands or in debris. The disease is most severe in wet soils, especially when saturation occurs late in the growing season.

CONTROL

Preventing infection is the key to control of bacterial and fungal sweet potato diseases since few effective therapeutic techniques are available to treat infected tissue. This is achieved by preventing contact between the pathogen and the crop and is accomplished on an international scale by regulatory controls designed to prevent introduction of pathogens into regions where they have not been previously detected (66). Several important bacterial and fungal sweet potato diseases appear to be geographically restricted. However, there has been a lack of organized effort involving plant pathologists to determine the true distribution of sweet potato diseases. Reports of diseases such as bacterial soft rot and circular spot/sclerotial blight imply a far more restricted distribution than the known ranges of the pathogens which cause them. In other cases, it is difficult to determine whether the diseases reported in different regions are the same. An example is Fusarium root rot as reported from the USA and China (8,28,39,65). Differences in disease occurrence in different regions may be due to use of different sweet potato genotypes which may differ in relative susceptibility or symptom expression for many diseases. Some of these questions might be resolved by increased interaction among plant pathologists in different areas of the world.

Generally, bacterial and fungal sweet potato pathogens have not been considered as important as viruses in regulation of international exchange of germplasm. This is because these pathogens are not known to be carried in true seed and in most cases can be detected as contaminants in tissue culture. They are also more readily eliminated by meristem-tip culture than most viruses and thus procedures routinely used for virus elimination are also effective for bacteria and fungi. However, it should be recognized that several very destructive bacteria and fungi such as E. batatas, H. mompa, P. solanacearum, S. ipomoea, and the witches' broom MLO, are currently restricted in their geographic distribution. It will continue to be necessary to exchange germplasm only in the form of true seed or meristem-derived tissue cultures to confine these pathogens as well as the viruses.

Bacterial and fungal diseases are in general most successfully controlled by an integrated program of sanitation, rotation, curing and fungicide application. In addition, some practices are designed for specific diseases. For example, particular advantage can be taken of the fact that certain important root pathogens (C. fimbriata, P. destruens, and M. infuscans) have limited persistence in soil and a restricted host range. They cause greatest losses when associated with the storage root cycle of propagation, and breaking this cycle is an important aspect of their control.

An important sanitation measure is the use of mother roots as free of disease as possible. Mother roots should be chosen from a crop with few disease problems to begin with, and they should be sorted before they are bedded to cull roots with any symptoms. In addition, by harvesting mother roots only under weather conditions that minimize subsequent storage rot development and by immediately curing roots after harvest, it is possible to limit entry of pathogens into the cycle during storage.

Crop rotations which include several years of nonhost crops between sweet potato crops are very effective in reducing soil-borne inoculum of pathogens such as C. fimbriata, P. destruens, and M. infuscans to levels below the threshold necessary for infection. Inoculum potentials of Fusarium spp., S. ipomoea, and D. gossypina are also reduced even though these pathogens persist for many years.

The intact periderm of the sweet potato storage root is a very effective barrier to the known sweet potato pathogens with the exception of M. infuscans. However, storage roots must be broken from the vine at harvest, and they are also easily injured during the harvest process. Thus all storage roots are wounded and infection sites are available for the many wound pathogens which can infect them. Curing sweet potatoes immediately after harvest by placing them in conditions of 85-90% RH and 28-30 C for 5-10 days effectively promotes the formation of wound periderm and thus protect wounds from invasion by a number of different pathogens (36,56). Subsequent storage at 15-16 C also helps reduce storage rot problems.

Fungicide use on sweet potatoes is limited, but it is important for control of certain diseases. Treatment of storage roots with dichloronitroaniline after washing and grading is a very effective and commonly used measure in some areas to control Rhizopus soft rot (43). Treatment of mother roots just prior to bedding with fungicides such as thiabendazole or benomyl combined with dichloronitroaniline is an important aspect of control of black rot, foot rot, Fusarium rots, Java black rot, Rhizopus soft rot, sclerotial blight, and scurf (4,45,46). Transplants have also been dipped in fungicides to control Fusarium wilt when susceptible

cultivars are grown (63). Fumigation with formulations containing chloropicrin has also been used to reduce the inoculum potential of S. ipomoea.

Heat therapy has been used on transplants and/or mother roots to reduce several soil-borne diseases (44,64). However, it also reduces survival of the sweet potatoes even under precisely controlled conditions. Thermotherapy is an effective control for witches' broom (6).

RESISTANCE - PRESENT USE AND FUTURE POTENTIAL

Fusarium wilt, which once threatened the continued existence of the sweet potato industry in the southeastern USA, is now controlled almost exclusively by the use of resistant cultivars (53,68,80). Resistant cultivars are also available which can be used to control soil rot under commercial growing conditions (51,59). Some degree of variation in the reaction of commercial cultivars and advanced breeding lines has also been recognized for nearly all the other major bacterial and fungal diseases of sweet potato including: Fusarium root rot (8,10,65,76), surface rot (75), bacterial soft rot (47,74;Clark, unpublished data), circular spot, sclerotial blight, vine and leaf scab, Java black rot (31), bacterial wilt (35), scurf (50,67), violet root rot (35), witches' broom, black rot (5,42,67), and Rhizopus soft rot (31). However, resistance to these diseases has not been commercially exploited either because the level of resistance is not sufficient or the resistance has not been combined with suitable horticultural quality (49). There has been some suggestion that Fusarium root rot and bacterial soft rot problems may have arisen in the southeastern USA in part due to the release of new cultivars that were more susceptible to these diseases than their predecessors (8,10,47,65,74).

It appears that virtually all the major bacterial and fungal diseases of sweet potato could be the subject of projects to improve the levels of resistance in commercial cultivars by traditional breeding approaches. Many such projects would be primarily of local interest, depending on the diseases which cause the greatest problems in a given region. Examples might include: soil rot in the USA, vine and leaf scab and witches' broom in southeast Asia and Oceania or bacterial wilt and violet root rot in China. The success of such projects would depend on access to resistant germplasm through germplasm collections as well as subsequent enhancement of locally-adapted cultivars.

Identifying sources of resistance to different diseases may be important even for those diseases such as Fusarium wilt, which are now satisfactorily controlled with resistance. The commercial cultivars of sweet potato currently used in the USA have resistance

to Fusarium wilt originally derived from the same source, Tinian (80). That new races of F. oxysporum f. sp. batatas have not yet been observed is fortuitous, but the possibility that new races may appear should not be overlooked.

General 'storagability' has been a criterion of selection in most of the US sweet potato breeding programs for many years. The most widely adopted cultivars, such as 'Jewel' and 'Centennial', seldom totally fail to keep in storage. However, the individual components affecting storagability of different lines are not always identified. The most widely used cultivars, even when cured, develop certain specific storage rots, such as Fusarium root rot and Java black rot, that can limit their storage in some regions. Storage characteristics have not been considered important in the tropical growing areas, in part because sweet potatoes are harvested year round, but also in part because many of the local cultivars do not store well under the prevailing conditions. The availability of cultivars that could be stored for at least a limited time could provide greater flexibility and economic opportunities for sweet potato growers and reduce losses that occur even in the brief time between harvest and consumption as practiced in the tropics.

Resistance has been observed to many individual storage rots, but to be commercially useful a cultivar should have broad spectrum resistance to the whole complex of storage rots. Furthermore, storage rot resistance that improved storagability in situations where curing cannot be practiced would have even greater value. It thus appears that the greatest potential benefit could be obtained from a program aimed at developing lines with broad-spectrum storage rot resistance effective under adverse conditions. While this would necessarily include screening of germplasm for reaction to individual storage rots, it should go beyond that and involve more basic studies of factors that might influence the incidence of the entire storage rot complex. Included might be studies of: the role of latex constituents and oxidized latex in protection of wounded ends of storage roots; factors influencing the rate of wound periderm formation; the involvement of ethylene in wound healing and disease resistance in storage roots; the role of furanoterpenoid phytoalexin-like compounds in storage rot resistance; the influence of duration of storage on susceptibility; the relationship of sugar, organic acid, and dry matter content to storage rot susceptibility; the role of lignified barriers in storage rot resistance; and the influence of storage insects, such as weevils, on storage rot incidence. Each of these factors might be studied with regard both to variation among sweet potato genotypes and with the possibility of developing more generally applicable screening methods for evaluation of resistance to the storage rot complex.

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COMPLEX VIRUS DISEASES OF SWEET POTATO

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Abstract

Both components of the virus complex that causes the sweet potato virus disease (SPVD) in Nigeria can individually be transmitted by their respective vectors from diseased sweet potato to healthy sweet potato and to the test plant, *Ipomoea setosa.* But in isolation, neither the aphid nor the whitefly-transmitted component, both latent in sweet potato, can be thus transmitted. The aphid-transmitted component does not reach concentrations in sweet potato that are detectable by ELISA or ISEM, unless the plants are simultaneously infected with the whitefly-transmitted component, which has been isolated from this complex; however, its properties remain largely unknown. The aphid-transmitted component is serologically closely related to, or identical with, *sweet potato feathery mottle virus* (FMV).

The apparently, extremely low concentration in sweet potato of the potyvirus (FMV) component of SPVD, as well as the hitherto unknown properties of the whitefly-transmitted disease component, has special implications for developing reliable indexing procedures for each of the viruses.
We have developed a simple testing procedure, based on the interdependance of both viruses, at IITA. It seems to provide a reliable indexing method for detecting both components of SPVD.

SPVD, or very similar complex diseases have been identified from various other countries in Africa, and Taiwan.

Introduction

Sweet potato is one of world's miracle crops. Its cultivation in its regions of primary distribution is known to date from ancient times. Until the present time, in most of its growing areas, sweet potato has shown only remarkably low, or no virus disease; however, various diseases of proved or virus-like etiology are known to occur in this crop. Some crippling diseases, like the sweet potato virus disease (SPVD) in Nigeria(Africa) (13), leaf curl in Taiwan (3), and witches' broom, described from this crop in Southeast Asia and the Pacific Islands (16) have geographically restricted distribution only, and have shown no epidemic potential in any of the world's major growing areas, so far. Whereas most of the viruses isolated from diseased sweet potato are known to have a regional distribution, notably *feathery mottle virus* (FMV): USA (10); SPV-A, and SPV-N: Taiwan (7), *sweet potato mild mottle virus* (SPMMV): East Africa (5), SPVD: Nigeria (13), it is still largely unknown whether some, or even most, of the viruses occur more widely. Possibly even worldwide. Lack of such information makes decision-making regarding international (intercontinental) exchange of genetic resources extremely difficult, particularly considering the quarantine implications of such transfer (17).

The most relevant information available on viruses and virus diseases of sweet potato is briefly reviewed. Some results recently obtained from our comparative studies of various disease conditions from various places in the world also are presented and we compare the new information with the latest results from further studies of SPVD in Africa.

Finally, implications to present and future international transfer of sweet potato germplasm is discussed, considering the quarantine implications in view of the apparent lack of information on the virus spectrum in this crop in its main regions of distribution.

Sweet potato virus complexes and complex virus diseases

Whiteflies, as well as aphids have been implicated in variously described diseases in the U.S. (10,4,11), East Africa (Kenya) (14,15), and Israel (9). There is little doubt that different viruses, notably those transmitted by aphids and others transmitted by whiteflies, are involved in diseases various authors describe. Very little, however, can be concluded from studies regarding their exact role in the etiology of such diseases and even less about their actual relationships, as no work has attempted to isolate and recombine virus isolates obtained by various vectors. Whether the 'virus-free' sweet potato test plants used by various researchers were indeed virus-free is questionable, as most plants were not obtained from true seed. Most data seem to indicate that whitefly-vectored conditions, like SPMMV in East Africa , 'yellow dwarf' as a component of the 'feathery mottle complex' (4) in the U.S., and sweet potato vein clearing in Israel (9), result from a complex infection of such agents with undetected aphid-transmitted, poty(?)viruses, which were overlooked in sweet potato test plants.

Except for *sweet potato mild mottle virus* (SPMMV), reported from East Africa (5), and thought to represent a virus with potyvirus-like particles, little is known about the particle structure of any reported whitefly-borne viruses of sweet potato, including the one causing '*leaf curl*' in Taiwan; although rod-shaped particles were thought to be involved (3). Thin, fragile-looking, filamentous particles have recently been associated with the whitefly-transmitted component of SPVD (12).

The sweet potato virus complex (SPVD) in Nigeria

Schaefers and Terry (13) were the first to report on the complex nature of the sweet potato virus disease (SPVD) in Nigeria. They found that a filamentous virus (potyvirus?) is transmissible from diseased sweet potato to *Ipomoea setosa* by aphids, notably *Myzus persicae* and *Aphis gossypii*. They reported vein-clearing sympoms developed in *I. setosa*, so they named the virus,*sweet potato vein clearing virus* (SPVC). They also reported that a whitefly-vectored agent can be transmitted from diseased sweet potato to this test plant. In this case, *I. setosa* showed stunted growth, accompanied by a general and nontypical chlorosis. They named this component, *sweet potato chlorotic stunt virus* (SPCS). They also found that symptomless plants among severely affected plants of a susceptible clone (TIb 10), on inoculation by means of whiteflies, developed characteristic SPVD symptoms

and that the aphid-transmitted, poty-like virus could be recovered from such plants by means of *M. persicae* but not from the same materials before these were inoculated by whiteflies.

Leaf curl and other virus diseases of sweet potato in Taiwan

Although several distinct viruses have been isolated from sweet potato in Taiwan, none had been shown fully responsible for sweet potato disease symptoms (8). Only '*leaf curl*', or '*virus-B*', a known whitely-vectored disease agent, in isolation caused well-defined disease symptoms.

Sweet potato '*leaf curl*' was first reported from Taiwan, in 1979 (3). Symptoms associated with it, reportedly, are marked swellings of veins on lower sides of leaves, and leaves are rolled upward conspicuously. These symptoms have been described as prominent on young plants and in the hot summer months, (May — September) when temperatures exceed 30° C. No transmission was obtained by sap inoculation; but '*leaf curl*' was transmitted by the whitefly, *Bemisia tabaci*. It appears to be an efficient vector, at least when *I. nil* is used both as the source of the virus and as test plant (3). Chung and associates obtained transmission with only two viruliferous whiteflies per test plant. Transmission was also obtained in healthy sweet potato seedlings, as well as in *Ipomoea setosa*, which developed prominent symptoms. *Leaf curl*, as decribed in Taiwan is not known to occur anywhere else except possibly in Japan (6). Its relationship to other whitefly-borne diseases, reported in various other countries, is unknown.

Further studies of SPVD in Nigeria

In our studies, we attempted to confirm the apparent complex nature of SPVD, and further, elucidate the unusual interdependence mechanism of its constituents. We also attempted to isolate both components by suitable test plants, to be able to purify enough of each so we could produce specific antisera for seriological detection of both the viruses. We also used virus isolates obtained from other regions of Africa, Taiwan, and elsewhere to compare whitefly- and aphid-vectored isolates with the two components of SPVD, looking specifically at their 'compatibility' in the complex infection in sweet potato.

Vector transmission

In other studies we allowed colonies of whiteflies established on diseased sweet potato 4 days access to healthy *I .setosa* seedlings. No obvious symptoms were observed in the inoculated test plants; however, all plants thus inoculated showed positive infection. Infection was determined by grafting the *I. setosa* plants to sweet potato cuttings taken from a plant that had been graft-infected with the aphid-transmitted component of the disease. It had been similarly obtained by aphid transmission to *I. setosa* from the same diseased sweet potato, virus-source plant. In contrast, similar transmission attempts from sweet potato virus source plants containing only the whitefly-transmitted component

caused no infection in *I. setosa* , which seems to indicate that, like the aphid-transmitted component, the whitefly-vectored component can only be transmitted from plants which contain both components of the disease.

Sap transmission

Using sap of diseased sweet potato to inoculate several *Nicotiana* -species produced suspected symptoms of virus infection in *N. benthamiana* only (12). The symptoms that developed were extremely mild, and became apparent only toward the end of the growing cycle, about 6 weeks after inoculation. Inoculation of a second set of *N. benthamiana* plants from the first set of plants suspected of now being infected led to early, more obvious symptoms. Symptoms consist only of an unusual type of undulating leaf curl, no other clear symptoms. Electron microscope studies revealed numerous potyvirus-like particles in the plants with the undulating leaf curl.

When we inoculated 50 sweet potato seedlings (25 each from Tlb 8 and Tlb 10, both highly susceptible clones) with sap of infected *N. benthamiana,* none of the 50 plants expressed any symptom. All 50 seedlings had earlier been clonally propagated and divided into 2 test plants each. On grafting to SPVD-infected sweet potato, all 50 seedlings proved susceptible to the disease, each developing symptoms of various severity. On inoculating *I. setosa* with the virus isolated by *N. benthamiana*, vein-yellowing symptoms characteristic of the aphid-transmitted, poty-like virus developed.

Sap inoculation of another set of 25 sweet potato seedlings grown in the open, unprotected from insect vectors, with the *N. benthamiana*- isolate led to symptoms typical of SPVD in 3 seedlings. Healthy plants of these 3 seedlings, cloned before sap inoculation, were further propagated, and sets of clonally propagated test plants established from them. Seven of 15 plants from one of the 3 seedling clones (no. 11), inoculated with the *N. benthamiana* - isolate, developed SPVD symptoms within 6 weeks.

Approach grafting of 10 cuttings of 'seedling clone 11' to *I. setosa* produced no obvious symptom expression. Apparently the whitefly-transmitted component is latent in this test plant, which is in contrast with earlier reports (13). When *I. setosa* test plants, earlier either aphid-inoculated from diseased sweet potato, or mechanically inoculated from diseased *N. benthamiana*, were grafted to 'clone 11' cuttings, all showed the severe disease syndrome from infection with both disease components as earlier described for SPVD in *I. setosa* (13), which proves that seedling no. 11 was naturally infected with the whitefly-transmitted component. Grafting healthy *I. setosa* seedlings to diseased sweet potato mostly resulted in the extremely severe disease symptoms, characterized by extreme stunting, deformation of the leaf laminae, often nearly filiform leaves.

All attempts to detect the potyvirus isolated by *N. benthamiana* in the artificially inoculated sweet potato test plants by ELISA proved futile (Thottappilly, unpublished data). Similarly, not a single particle was detected by immunosorbent electron microscopy (ISEM) on EM-grids treated with the homologous antiserum, whereas countless particles

were observed when materials that had also been inoculated with the whitefly-transmitted component were thus tested (Rossel, unpublished data). ISEM is not even necessary, as numerous particles can be found in conventional, crush preparations of such materials.

Indexing for SPVD

The potyvirus isolated from SPVD-infected sweet potato, like the other component, on its own, infected but causes no symptoms in sweet potato. Moreover, it cannot be detected by sensitive serological methods (ELISA, ISEM), despite reports for FMV, although detection reportedly was achieved only in symptomatic(?) leaves (1). Testing of the same, symptomless sweet potato materials, that contain only this potyvirus component, by grafting to *I. setosa* resulted in vein-yellowing symptoms in this test plant, characteristic for the potyvirus component. Grafting to *I. setosa* of symptomless sweet potato plants infected with the whitefly-transmitted component, however, showed no symptoms as reported earlier for this component (13).

The complex nature of the disease and the latent, though serologically undetectable status of the aphid-transmitted component, and that indexing for the whitefly-transmitted component by grafting to *I. setosa* produced no reliable, diagnostic symptoms in our studies, led us to develop an indexing method that depends strongly on the two components of SPVD (12).

The simple method merely involves using test plants of a pre-infected sweet potato seedling clone, derived from a sweet potato seedling selected for high susceptibility and characteristic symptoms with SPVD (referred to as TIb 8, s.c.9). This method, in contrast with graft-testing on *I. setosa*, is quite convenient, as test plants can simply be cut from preinfected plants, maintained in the greenhouse (TIb 8, s.c.9—A and TIb 8, s.c.9—W.F., infected with the aphid-transmitted and with the whitefly-transmitted virus, respectively).

A secondary consideration in developing this testing system was that the two known, fixed isolates of the individual disease components, could show variations in either that might exist in the field (strains?), possibly by different symptom expressions in the indexing test clone plants used.

No variation had ever been observed in *I. setosa*, previously reported to develop symptoms of similar or identical nature from inoculation with various other viruses of sweet potato that were isolated elsewhere, as SPV-N in Taiwan (2), or SPMMV (5), from East Africa. The latter reportedly represents a whitefly-transmitted virus, but its particles were typical of a potyvirus. On the other hand, our test clones proved very useful in obtaining impressions of natural variations within the two disease components of SPVD in Nigeria. Grafting five cuttings each from symptomless plants of two elite clones in IITA's sweet potato breeding program (TIS 2532 and TIb 11) to each five test clone cuttings containing the 'aphid-component' and five containing the 'whitefly-component', resulted in four cuttings of clone TIb 11, and five cuttings of TIS 2532, showing the 'aphid component'; whereas none contained the 'whitefly component'. In all cases, symptoms developing in the

plants of the test clone differed from the systemic, necrotic spotting and progressive defoliation symptoms used to select this seedling clone.

Interestingly, symptoms developing, with both TIb 11 and with TIS 2532, were of a type commonly seen in the IITA field and elsewhere in Nigeria (Rossel, unpublished data)--symptoms are best described as 'fan leaf'. They consist of conspicuous narrowing of leaves, mostly leading to straightening the main veins as from the leaf base, to create the fan-like shape.

Using our test clones to graft the materials to, cuttings taken from symptomless plants collected in all ecological zones of Nigeria, and symptomless plant material from Rwanda, Gabon, and Zaire, were all shown to contain potyvirus-component(s) (FMV and, in some cases, still another, so-far-unidentified potyvirus). Characteristic symptoms developed only in the test clone preinfected with the whitefly-transmitted component.

Interestingly, symptomless materials obtained from the U.S., and the Philippines (Leyte), although shown to contain FMV-like viruses (by grafting to *I. setosa*), developed no symptoms in IITA's test clone.

Symptomless materials collected in Indonesia (Bali) apparently contain no virus; grafting to these developed no symptoms in IITA's test clones. Neither were symptoms obtained in *I. setosa* in repeated attempts (Rossel, unpublished data).

That the potyvirus-component of SPVD in Africa, representing FMV, or a virus very closely related to it, is serologically detectable by ELISA or ISEM only in the presence of a whitefly-vectored virus, and that the same or a very similar mechanism applies to virus diseases of sweet potato in other parts of Africa casts considerable doubt on the detectability of such viruses in sweet potato in general. Additionally, since no whitefly-vectored agent has been isolated, purified, or its nature elucidated, indexing for viruses occurring in sweet potato will continue to depend on graft-indexing methods.

As no serological, or any other laboratory detection method for the two constituent viruses involved in SPVD is yet available, graft-indexing to preinfected test clones seems a reliable alternative for detecting of both viruses involved in this disease.

Viruses from sweet potato in Taiwan and their possible relationship to SPVD

'Leaf curl' or 'Virus B'

To obtain an impression of the incidence and relevance of 'leaf curl' disease symptoms in sweet potato in general, a survey was conducted of part of AVRDC's germplasm collection, which is maintained in fields at AVRDC's headquarters, at Shanhua, near Tainan, in southern Taiwan. The obviously and consistently affected germplasm accessions among 500 accessions surveyed were estimated at around 10% (10 severe, 20 moderate, and 23 mild). Except for ringspots on older leaves in some accessions, none of the clones showing 'leaf-curl' displayed any other obvious virus disease symptom, thus proving that 'leaf curl'

represents a whitefly-transmitted virus, which, unlike the whitefly-transmitted component of SPVD, generally does not lead to the kind of disease symptoms in sweet potato described for SPVD.

SPV-N

SPV-N represents a poty(?)virus so far reported from Taiwan only (7). It is not related, serologically, to FMV nor to SPV-II, a newly isolated virus from sweet potato in Taiwan (Rossel, unpublished data).

To determine whether this virus is detectable in sweet potato, we inoculated one plant each of 14 seedling clones twice with SPV-N, which was maintained in *N.benthamiana,* in which it causes conspicuous mosaic symptoms, and tested the plants for SPV-N in ELISA approximately 2 months later. No virus was detected in them. Apparently, this virus of sweet potato is not detectable in its original host either. In contrast, it was readily detected in *I. setosa,* in which symptoms similar to those of FMV and SPV-II developed.

'Ringspot' caused by FMV?

Interestingly, potyviruses of the FMV group are not always totally latent. Conspicuous, purplish ringspot symptoms, commonly observed in certain sweet potato cultivars in Taiwan, could be readily attributed serologically to infection with FMV or a potyvirus closely related to it (SPV-A?). Isolates of FMV (SPV-A?) were obtained by aphid transmission to *I. setosa* and sweet potato seedlings from similarly diseased clones. Ringspots, typical of those observed in susceptible clones, were obtained in certain seedlings established from seeds from a clone showing the purplish ringspots on its older foliage. Three of seven sweet potato seedlings inoculated developed the characteristic symptoms. However, in
ELISA, using SPV-A (FMV) antiserum, with which the
aphid-transmitted isolate had earlier been shown to be closely related serologically, the virus was neither detected in the three symptomatic plants nor in the other four, nonsymptomatic plants.
So it is not possible to detect this potyvirus of the FMV group in sweet potato, even when certain genotypes clearly show
symptoms (ringspots).

When combined with the whitefly-transmitted component of SPVD (by grafting to test clone TIb 8, s.c.9—W.F.), symptoms typical of SPVD developed in this test clone as well as in the ringspot-affected materials tested in this manner. Potyvirus particles, heavily decorated with FMV-antiserum were readily detected with the electron microcope in crude juice preparations of such plants.

During later surveys in the region, the 'ringspot disease' was seen only in the Peoples Republic of China (Guangzhou-area), and Japan (Kyushu), not in Indonesia (East Java, Bali), or The Philippines (Leyte) (Rossel, unpublished data).

SPV-II, a newly-isolated potyvirus

Our work also revealed that still another potyvirus, not related or only remotely related, serologically, to SPV-A (FMV), occurs in this crop in Taiwan, and possibly in other major sweet potato growing areas of Southeast Asia. This new virus, referred to as SPV-II, was isolated from various diseased sweet potato plants collected in central Taiwan (Taichung area). Most diseased plants from which this virus was obtained showed only comparatively mild symptoms consisting of mottle, vein yellowing, and/or ringspots. The virus was isolated by *N. benthamiana*, from which it was also purified. In it symptoms were comparatively mild, consisting of vein yellowing, then chlorotic mottle. An antiserum with a titer of approx. 512 was obtained. The virus developed no symptoms in 14 sweet potato seedling clones established in the greenhouse and earlier inoculated with the virus. The virus was also inoculated to healthy plants of the test clone of seedling origin used to index SPVD (TIb 8, s.c.9—H). It proved undetectable by ISEM in plants infected with this virus.

These findings show that SPV-N, SPV-A (FMV), and the newly isolated virus, tentatively called, SPV-II, may not be detectable by serological means, as is the case for the 'aphid-component' of SPVD in Africa.

When SPV-II was combined with the whitefy-transmitted component of SPVD, by grafting to test clone, TIB 8, s.c.9—W.F., no symptoms were observed, neither was the virus detected in the graft-inoculated plants. SPV-II may therefore not be 'compatible' with the whitefly-transmitted component of SPVD (see table 2).

Detectability of potyviruses in general

We performed another experiment to assess the infection rate with 'poty-virus' of symptomless plants of new, improved clones widely grown in Taiwan, and to determine whether such infection can be reliably detected.

Five plants each from cuttings from five healthy-looking plants of each of two widely-grown, local, improved clones, 'Tainung 64' and 'Tainung 66' were established in an insect-proof greenhouse. The plants thus obtained were later monitored for symptoms. After a 6 weeks' observation in the greenhouse, none of the plants had developed any symptom. They all tested negative in ELISA for presence of SPV-A (FMV) and SPV-N.

We later approach-grafted all symptomless, virus-tested plants to *I. setosa* seedling plants. Between 10 days to 6 weeks later, all *I. setosa* test plants developed conspicuous vein-yellowing symptoms, typical of aphid-transmitted potyviruses of sweet potato, proving the presence of one or more such viruses in each of the symptomless plants, which were negative in ELISA. Testing, in ELISA, of the infected *I. setosa* plants, in which a high concentration of potyvirus was observed in the E.M., showed that none contained SPV-N. Although not all, several *I. setosa* plants showed a weak, positive reaction with SPV-A (FMV), so potyvirus(es), both related and unrelated to FMV, most likely, are universally present in sweet potato, in Taiwan. However, these viruses are not detectable by sensitive

serological methods, except possibly, when accompanied by whitefly-vectored agents like those found for SPVD in Africa.

Symptomless materials of two sweet potato clones from the U.S. ('Jewel' and 'Travis'), received at IPO Wagenigen for intermediate quarantine and further transfer to IITA, when tested serologically and electron microscopically, as well as on the test clone, Tlb 8, s.c.9—W.F., did not reveal presence of any (poty)virus; however, when these materials were grafted to *I. setosa,* the presence of FMV was readily revealed (see table 1).

Whereas the aphid-transmitted component of SPVD represents FMV, or a virus to which it is serologically closely related, whether a similar complex disease mechanism pertains to FMV in the U.S., or in the whole of Central and South America, remains to be answered.

SPVD or a disease of very similar properties was identified from Taiwan (Rossel, unpublished), notably from the locally grown clone, 'Simon-1', which reportedly is of Brazilian origin (Hong, personal communication). In addition to a typical 'ringspot'('virus B') isolate, a whitefly-transmitted isolate was obtained from severely diseased plants of the same clone, which was collected in central Taiwan (Taichung-area). When combined with the aphid-transmitted component of SPVD (test clone Tlb 8, s.c.9—A), prominent symptoms developed in this test clone. ISEM revealed many potyvirus particles in the test plants which heavily decorated with homologous, SPVD-'Aphid component' (FMV)-antiserum (see table 1). It thus seems likely that SPVD originates in South (Central) America.

Sanitation for international transfer of germplasm

Sanitary procedures adhered to at IITA in connection with international transfer of improved breeder's germplasm include meristem culture followed by testing for viruses according to grafting procedures described earlier. Only *in-vitro* cultures are shipped, thus adhering to generally accepted quarantine principles. Since we found that *I. setosa* may develop obvious symptoms with a wide range of potyviruses in sweet potato, grafting to *I. setosa* is prominent in our testing procedures. *I. setosa* was shown to be important also as evidence indicates that, with regard to FMV, specifity exists vis à vis different isolates of the whitefly-transmitted component of SPVD. In certain cases, no symptoms developed in our test clones with materials that were shown to contain FMV or a closely related virus. This phenomenon urgently needs further investigation.

Similar virus diseases occuring in other countries in Africa, as well as in Taiwan, supports the likelyhood that SPVD, or similar complexes of viruses, occur worldwide. Potyviruses isolated from sweet potato in Taiwan, in isolation, were undetectable by ELISA. A similar approach in virus testing has therefore been recommended for germplasm shipments from AVRDC.

An idea only partly warranted is that indexing by infectivity tests requires too much time, manpower, and greenhouse space, and is less rapid, efficient, and convenient than serological testing procedures, like ELISA or ISEM. It is irrelevant to consider the time

factor in virus indexing for vegetatively propagated crops like sweet potato because a guaranteed absence of viruses is prerequisite to international exchange of germplasm in vegetative form. It is better to spend a few months on time-consuming, biological testing procedures than to accidentally introduce new diseases with the transfer of germplasm. The new diseases may last for ever. It takes extra time to re-establish a plant suitable for graft-testing from *in-vitro* cultured plantlets of meristem culture origin, but not so long as to establish the *in-vitro* plantlet from the excised meristem itself. Reliable testing is needed and is highly important. If one cannot guarantee the absence of potentially harmful viruses, crop improvement efforts, particularly those attempted and organized internationally, will not reach goals desired, but add to existing problems.

Finally, one must also take into consideration that in addition to the known viruses, a number of non-, or only insufficiently characterized viruses occur in sweet potato in various parts of the world. They stand a good chance of being detected by infectivity tests on selected test plants, i.e., by grafting to *I. setosa* , or certain selected and specially prepared seedling clones of sweet potato, as IITA practices for SPVD.

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Table 1: Detectability of potyviruses in sweet potato

Clone	In E.M.	Origin	s.c.9—W.F.	on 'B'	on S-1—W.F*	In I. setosa		Ser. rel. to FMV
						Sympt.	E.M.	
Tlb 8 s.c.9-A*	-	Nigeria	+	-	-			close
Rusenya	-	Rwanda	+	n.t.**	n.t.	+	+	close + remote
Wadada	-	,,	+	n.t.	n.t.	+	+	close
local cultivar	-	Zaire	+	n.t.	n.t.	+	+	close
NTM 80/30	-	Gabon	+	-	n.t.	+	+	close
local 'red'	-	Bali	-	-	n.t.	-	-	none
local 'white'	-	,,	-	-	n.t.	-	-	none
VSP-2	-	Philippines	-	-	n.t.	+	+	close
Germpl. 835	-	Taiwan	-	-	n.t.	+	+	remote
" 925	-	,,	-	-	n.t.	+	+	remote
" 940	-	,,	-	-	n.t.	+	+	remote
" 1030	-	,,	-	+(?)	n.t.	+	+	remote
Simon-1	-	Taiwan(Brazil?)	+	-	+	+	+	close + remote
Kokei- no.14	-	Japan	+	-	+	+	+	close + remote
Travis	-	USA	-	n.t.	n.t.	+	+	close
Jewel	-	USA	-	n.t.	n.t.	+	+	close

* S-1—W.F.: Whitefly-transmitted isolate from 'Simon-1' ** n.t.— not tested

Table 2: Potyviruses isolated from sweet potato in Nigeria and Taiwan

Isolate	Origin	In E.M.	Ser. relationship with FMV	On Tlb 8, s.c.9—W.F. *
SPVD-'aphid'	Nigeria	neg.	close (identical ?)	pos.
SPV-A	Taiwan	n.t.	close (identical ?)	n.t.
SPV-N	Taiwan	neg.	unrelated	neg.
SPV-II	Taiwan	neg.	non-, or remotey related	neg
SPV-'ringspot'	Taiwan	neg.	close (identical ?)	pos.

* IITA's SPVD—Aphid test clone

PRINCIPAL VIRUS DISEASES OF SWEET POTATOES, THEIR CONTROL AND ERADICATION

James W. Moyer

INTRODUCTION

Sweet potatoes (Ipomoea batatas (Lam.) L.) harboring graft transmissible agents which cause diseases can be found in nearly every commercial sweet potato planting not produced from disease-indexed planting material. The reason for this phenomenon is the necessity to propagate sweet potatoes with vegetative organs to preserve varietal purity. Vegetative propagation provides an excellent vehicle to perpetuate these agents from one planting to the next. It is generally assumed that viruses or viroids are the cause of these diseases. Indeed, at least five distinct viruses and a mycoplasma-like organism have been associated with these diseases (Table 1). However, the etiology of many of these sweet potato diseases remains to be determined (Table 1).

Early on in the development of information on sweet potato viruses each new disease thought to be caused by a virus was frequently given a new name. The name was usually indicative of the symptoms expressed in the genotype in which the disease was described. It has seldom been possible to compare biological or biochemical characteristics of the causal agent(s). This practice has lead to the problem of synonymy similar to that which occurred in the early studies of virus diseases of other crops (4, 21). Our knowledge of the viruses which cause these diseases has been slow in coming because the sweet potato-virus pathosystems have not been adequately developed. The viruses are difficult to mechanically transmit to and from sweet potato, virus-indexed sweet potato is not always available for completion of Koch's Postulates, high quality antiserum for virus comparison and indexing purposes is not readily available because of the difficulty in purifying these viruses and there has been no internationally agreed upon criteria for sweet potato virus identification.

The viruses that infect sweet potato interfere both directly and indirectly with the farmers ability to realize the full potential of sweet potatoes. Viruses have been implicated in acute and chronic sweet potato diseases. The acute diseases such as the sweet potato virus disease complex found in Africa (25) and russet crack (3, 4) and internal cork (22) found in the United States have a dramatic impact on production of edible roots. Chronic diseases such as those caused by various strains of sweet potato feathery

mottle virus (SPFMV) (20) have a less severe effect on individual plants but still may significantly reduce yield when considered on a regional basis. This reduction in grower efficiency may go unnoticed when all the plants in the area are infected with the same virus(es).

Grower efficiency is indirectly reduced by the justified impediment viruses cause to the international exchange of germplasm and, thus, slow the introduction of desirable traits into national breeding programs to resist stresses and generally improve yield potential. This should not be interpreted to imply that quarantine regulations should be relaxed. In general, quarantine standards are based on the available biological information. Our lack of understanding of sweet potato viruses has greatly contributed to the conservative establishment of standards to reduce the probability of introducing new pathogens. Improved understanding of this group of pathogens will significantly increase the confidence with which these standards are upheld as well as providing more efficient technologies that can be used to document the status of plant health.

The status of sweet potato viruses is, however, not a hopeless one. The resurgence of interest in sweet potatoes has already begun to promote additional research into sweet potato viruses. Only a few viruses have been identified and there are many disease syndromes with an unclear etiology (Table 1). Future research should be directed at obtaining a complete understanding of the biological and biochemical properties of these viruses. Only then can we devise the most efficient and expeditious strategies to control, and hopefully eradicate, these viruses from our germplasm stocks. These same procedures may well be extended with minimal modification to evaluate germplasm and breeding material for resistance to these viruses.

The solution to the problem of viruses in sweet potato germplasm will include research in several areas. Little can be accomplished until we more fully understand the etiology of these diseases. Only then can effective and reliable virus-indexing or detection procedures be developed. Then a source of "healthy" genotypes can be made available for distribution to facilitate biological comparison of viruses and to serve as indicator hosts, especially where biochemical assays may not be feasible.

Virus Identification

There are many sweet potato diseases suspected of having a viral etiology that have been reported from all over the world (Table 1).

Table 1. A list of viruses and selected virus-like diseases reported from sweet potatoes.

Virus and Disease Names	Vector	Geographic Distribution [u]	Selected References
Viruses			
SPFMV[v]	Aphid	World-wide	4, 19, 20
SPVMV[w]	Aphid	Argentina	23, 24
SPLV[x]	?	Taiwan	5, 6, 15
SPMMV[y]	Whitefly	East Africa	12, 26
CMV[z]	Aphid	Africa	Thouvenel, J.C., Ivory Coast
Diseases			
Sweet Potato Virus Disease	Aphid & Whitefly	Africa, ?	9, 25
Sweet Potato Leaf Curl	Whitefly	Taiwan, Japan	6, 27
Sweet Potato Mosaic	?	Taiwan	6
Unnamed	?	World-wide	Unpublished

[u] Based on published reports and personal communications.

[v] Sweet potato feathery mottle virus; [w] Sweet potato vein mosaic;

[x] Sweet potato latent virus; [y] Sweet potato mild mottle virus;

[z] Cucumber mosaic virus.

The named viruses identified from sweet potatoes, are sweet potato feathery mottle virus (SPFMV) (3, 4, 13, 19, 20), sweet potato mild mottle virus (SPMMV) (12), sweet potato vein mosaic virus (SPVMV) (23, 24), sweet potato latent virus (SPLV) (6, 15) and cucumber mosaic virus (CMV) (J. C. Thouvenel, Ivory Coast). SPVMV is a long flexuous rod but has not been purified and its relationship to other viruses is unknown (24). SPFMV, SPLV, and SPMMV are all long flexuous rods (750 - 900 nm), but are not serologically related (A. A. Brunt, R. J. Chiu, personal communication and J. Moyer, unpublished data). In general, though, there remains much confusion over the identity of sweet potato viruses (4, 21).

SPFMV is the predominant virus infecting sweet potatoes in the United States (4, 13, 20). Research in progress has also shown that strains of SPFMV occur in virtually every country where sweet potatoes are grown (17). This virus is a member of the potyvirus group, but has an unusually large capsid protein and long virion with a correspondingly large RNA genome (19). The virus virion and RNA are 10 - 15% larger than in most potyviruses. However, other biological properties and the presence of pinwheel-type cytoplasmic inclusions are consistent with characteristics of the potyvirus group (4, 14, 20). The other viruses isolated from sweet potato have only been partially characterized and high quality antiserum for comparative purposes and for indexing are not yet available for all of those viruses.

Two new virus-like agents, which are distinct from SPFMV, are also currently under investigation in my laboratory. One virus was isolated from sweet potato plants exhibiting distinct chlorotic mottling. The intensity of the symptoms, the chlorotic pattern and failure of the symptoms to go into remission were all characteristics of a disease syndrome distinctly different from that caused by SPFMV. In addition, sap from infected plants did not react serologically with SPFMV antiserum. Research on the second virus-like agent has recently been initiated to identify the cause of a disease with symptoms similar to those described for Georgia Mosaic or Yellow Dwarf (8, 10).

There are many other sweet potato diseases which have one or more characteristics that suggest a viral or viroid etiology (Table 1). The vectors are known for some of the agents associated with these diseases such as the sweet potato virus disease and sweet potato leaf curl (6, 25). Unfortunately, there are many other disease syndromes whose causal agents have been graft transmitted, but little additional information is available. Indexing sweet potatoes for these disease agents is cumbersome at best and then the evaluation of large number of genotypes is not practical.

Indexing

Indexing is a term that is used by plant pathologists to denote the monitoring of plants for the presence of pathogens in order to maintain and provide "healthy" plants for propagation and dissemination. The development of indexing procedures can be divided into four tasks. First, the target pathogens must be identified such as is described above. Second, potential techniques or procedures should be evaluated to determine the most effective strategy for that host-pathogen interaction. Third, the selected procedure should be tested thoroughly to ensure that it has a sufficiently broad spectrum of recognition to detect all forms of the target pathogen, yet retain enough specificity to minimize false positives. Fourth and most important, particularly for perennial crops or vegetatively propagated hosts, the life cycles of the pathogen and the host should be examined to determine when indexing can be conducted most reliably.

Assays

The approach in my program has been to use SPFMV as a model for the development of virus indexing procedures in sweet potato. Hopefully, much of this information will be applicable for the new viruses described in the previous section. Indexing for SPFMV and other graft transmissible agents has traditionally been conducted by grafting scions from sweet potato into *I. setosa* or other sensitive *Ipomoea spp.* (11). This procedure requires considerable time to conduct and for symptoms to be expressed. Symptom expression is dependent upon environmental influences (e.g. 1, 22) and we have recently found that there is also variability in symptom intensity and duration due to the strain of SPFMV (17).

In efforts to improve indexing procedures for SPFMV (2, 7), we have emphasized an evaluation of methods which detect the presence of viral proteins through serological assays. Currently, we are focusing on the problems of extremely low virus titer and the presence of substances in sweet potatoes (e.g. phenolics, phenol oxidases, quinones, latex and carbohydrates) which interfere with these assays. At the present time conditions which favor optimum sensitivity and reduced nonspecific interactions have been identified (18); and we have produced an antiserum which has been shown to be specific for all known strains of SPFMV (3, 18, 20). We anticipate that many of the sweet potato related problems have been elucidated and that modifications will be required for new viruses.

Pathogenesis

The temporal cycle of SPFMV in sweet potato is of both practical and theoretical interest. It is of practical importance to know when and/or under what environmental conditions virus titer (accumulation) is favored in order to develop the most effective procedures for indexing. (See above). SPFMV is acknowledged to be highly "variable" and unevenly distributed in its occurrence during the life of the sweet potato plant (2, 7, 10). Ourselves (7) and others (2) have repeatedly demonstrated that the use of arbitrary sampling procedures used to assay other crops are inadequate to insure detection of SPFMV in sweet potato. It is my opinion that reliable indexing procedures for sweet potato viruses must be based on a thorough understanding of the biology of these viruses in sweet potato.

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AVRDC VIRUS ELIMINATION AND INDEXING PROCEDURES FOR INTERNATIONAL EXCHANGE OF SWEET POTATO GERMPLASM

Silvia K. Green

Introduction

More than 94% of the world's sweet potato (*Ipomoea batatas* (L.) Lam.) is produced in Asia and Oceania (6). In Asia, the crop is ranked fourth in terms of total food production. However, there are few sweet potato improvement programs in these regions, a fact which forces most countries to depend on imported sources of improved germplasm.

Since its establishment in 1971, the AVRDC has a mandate to improve and disseminate knowledge for greater use of the sweet potato in the tropics as a staple, a vegetable, as animal feed and for industrial use. AVRDC has, therefore, played an important role in all of the different activities related to conserving sweet potato genetic resources and assisting national breeding programs around the world by providing valuable germplasm and breeding lines, improved for many desirable traits. The genetic resources maintained by AVRDC have an enormous potential to solve present and future constraints to increasing sweet potato production.

In view of the important role AVRDC has had in the collection and preservation of valuable germplasm, the IBPGR has designated AVRDC as the official repository for sweet potato germplasm for Asia and the Pacific. To date a total of 1,300 accessions have been collected from all parts of the world. These genetic resources are being effectively used in the AVRDC breeding program and are also widely distributed to national programs of many developing and developed countries.

To facilitate international movement of vegetative sweet potato germplasm, it is essential to ensure the disease-free status of these materials, in particular with respect to viruses and mycoplasma-like organisms (MLO). It is, therefore paramount to identify the viruses occurring in the sweet potato production areas, so that the plants produced by methods such as thermotherapy, meristem tip culture and chemotherapy, can be accurately indexed for the viruses concerned.

Viruses of sweet potato

Many virus diseases of sweet potato have been described, primarily on the basis of symptoms and vectors, but very few have been precisely characterized, nor have their causal agents been purified. For many sweet potato viruses, criteria such as biological and biochemical properties and serological relationships which are needed for the classification of viruses have not been determined. Furthermore, many different names have been used in describing sweet potato virus diseases and in some cases two or more names in fact refer to the same disease. Different virus diseases have also been described by the same name.

The sweet potato viruses and virus diseases have been reviewed extensively (7, 4, 1, 8). Among the few well characterized viruses are the feathery mottle virus complex, prevalent in North America, and probably everywhere else where sweet potato is grown; the sweet potato vein mosaic of Argentina; and the sweet potato mild mottle of East Africa.

In Taiwan, three sap-transmissible viruses have been detected on sweet potato and extensively characterized: feathery mottle virus (FMV), sweet potato latent virus (SPLV) and sweet potato yellow dwarf virus (SPYDV). Two other viruses, sweet potato leafcurl virus and sweet potato mosaic virus, are also known to occur, but these have not yet been fully identified and characterized (Table 1).

Virus elimination

Methods used for the eradication of sweet potato viruses are meristem culture, stemtip culture, thermotherapy and chemotherapy, or a combination of any of these. At AVRDC, meristem tip culture is presently used. Storage roots and stem tip cuttings, selected for meristem tip culture are treated with fungicide and insecticide before being transferred to sterile sand in a growth room at 28°C with continuous light. Stem tips, 2 cm in length, are removed, surface- sterilized and meristems of 0.2-0.4 mm are excised. The explants are placed onto a solid culture medium (Table 2) and stored at 16°C under fluorescent lights, giving 15 hours of illumination at an intensity of 3-4 Klux. The time it takes to produce small plantlets under these conditions varies from 2-4 months, this being very genotype dependent.

To ensure absence of virus in the meristem-derived plantlets, they are indexed by both enzyme-linked immunoassay (ELISA) and by grafting to susceptible indicator

Table 1. Viruses of sweet potato in Taiwan[1].

	Viruses of Sweet Potato in Taiwan				
	FMV	SPLV	SPYDV	SPLCV	SP. Mosaic
Transmission					
Sap	(+)	+	+	-	?
Aphid	+	-	-	-	?
Whitefly	-	-	+	+	?
Host range					
Convolvulaceae	+	+	+	+	+
Chenopodiaceae	+	+	+	-	?
Solanaceae	-	+	+	-	?
Amaranthaceae	-	-	+	-	?
Compositae	-	-	+	-	?
Physical Properties					
DEP	10^{-3}-10^{-4}	10^{-2}-10^{-3}	10^{-6}-10^{-7}	?	?
LIV (Days)	1	1	7	?	?
TIP (^{0}C)	55-60	60-65	85-90	?	?
Particle					
Shape	fl. rod	fl. rod	fl. rod	short rod	?
Size (nm)	850/900	700/750	750	18	?
Coat Prot. Mol. Wt.(KD)	37.6	36	33	?	?

[1]Chiu et al. 1982, Chung et al. 1986.

Table 2. Medium formulation for sweet potato meristem culture.

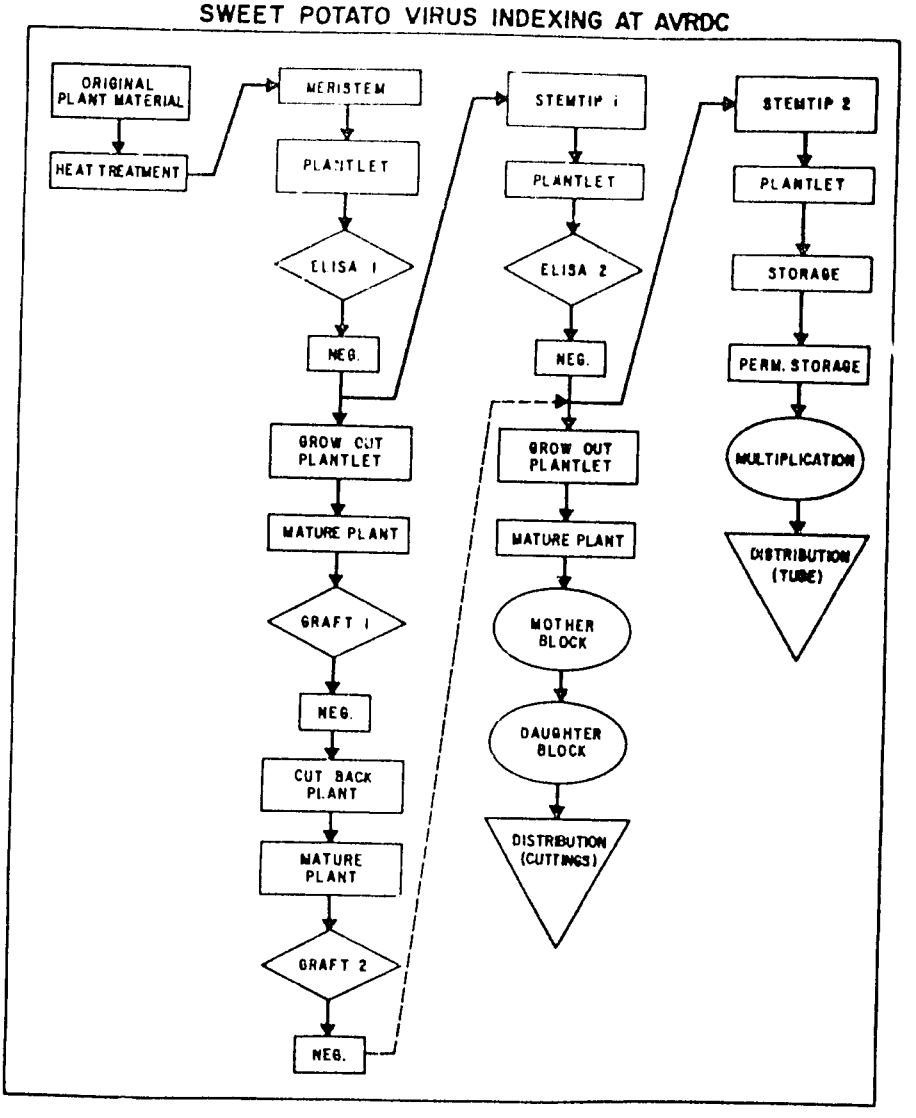
Component	Mg/l
Saltbase	MS[1]
Myo-Inositol	100
Nicotinic Acid	0.5
Pyridoxine HCl	0.5
Glycine	2.0
Thiamine HCl	0.1
IAA	1.0
Kinetin	1.0
Sucrose	30.000
Agar	7.000

[1]Murashige and Skoog, 1962.

plants (Fig. 1). A first ELISA test for the presence of feathery mottle virus (FMV-common strain), sweet potato latent virus (SPLV) and sweet potato yellow dwarf virus (SPYDV) is done on regenerated plantlets at the 5-leaf stage while still in the culture medium for early elimination of virus-infected plantlets.

Our experience with AVRDC breeding lines has shown that after meristem tip culture, about 20% of the plants are still infected with virus, sometimes with two or three of the viruses simultaneously. The percentage of meristem-derived plants containing SPLV and/or SPYD was generally

Fig. 1. The sweet potato virus indexing scheme at AVRDC.



considerably higher than those containing FMV, indicating that the latter is probably more readily eliminated by meristem tip culture than the other two viruses (3).

By using these ELISA pretested materials it is possible to reduce the number of plantlets used for the consecutive time- and space-intensive virus indexing steps through grafting.

The shoot tip section (0.5 cm in length) of plants found to be negative in the first ELISA test is transferred to new medium. The remaining part of the plantlet is grown out and subjected to two cycles of graft indexing in an insect-free isolation room. It is approach-grafted to Ipomoea setosa and the grafted scions are observed weekly for six weeks for symptom development. Plants which do not produce any visible symptom on the grafted I. setosa scions are cut back and subjected to a second graft indexing after approximately two months, or when the new side shoots have matured.

The shoot tip portions of plants negatively indexed by both ELISA and grafting are tested again by ELISA at the 5-leaf stage for the presence of FMV, SPLV and SPYDV. If negative, they are used for the establishment of mother block plants and for permanent storage in tissue culture.

Distribution

To safeguard against the introduction of new pests and diseases, many countries have imposed strict quarantine regulations with respect to the importation of vegetative sweet potato materials. Some countries have completely prohibited the entry of such materials, in which case, the tissue-cultured and virus-indexed germplasm has been the only means to receive foreign germplasm for their evaluation and improvement programs. Meristem culture has been successful in national and international institutes for the past 10-15 years. This success has facilitated the production of virus-free cultivars and breeding lines for use in many parts of the world. Even though this method does not prevent their getting reinfected by local pathogens, it nevertheless greatly reduces the probability that new pathogens or new strains or pathotypes of already existing pathogens will become established.

The genetic resources maintained at AVRDC are freely available for distribution in two forms: as true seeds and as tissue-cultured plantlets, produced under quarantine conditions from virus-indexed stock. All materials are

supplied with a phytosanitary certificate and are usually shipped by air or handcarried to their destinations.

Current perspective

Tissue-cultured materials transported in this form, however, suffer from exposure to extreme temperatures and/or rough handling. And moreover, even if the materials arrive intact, regeneration of the fragile plantlets is often complicated by lack of facilities or personnel trained in handling tissue-cultured materials. Sweet potato storage roots produced directly from virus-free plantlets in vitro should be better suited for international distribution than meristem-tip derived plantlets in culture tubes, since they are easier to ship, handle and store. White potato tubers, which, in the botanical sense are simply thickened modified stems, can easily be produced in vitro through the manipulation of the auxin:cytokinin ratio. In the case of sweet potato, the "tubers" are true underground storage roots and can not be readily produced in culture medium. However, AVRDC physiologists have been concentrating their efforts to induce storage root formation in vitro on meristem-derived sweet potato plantlets. Although this goal has not yet been fully accomplished, initial results are promising in that, slightly thickened roots have been produced by increasing potassium and decreasing the auxin and cytokinin ratio in the culture medium (2).

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MAJOR INSECT AND NEMATODE PESTS OF SWEET POTATOES AND RECOMMENDATIONS FOR TRANSFER OF PEST FREE GERMPLASM

P. Jatala and K.V. Raman

Sweet potato, a native of tropical America, is widely cultivated in the tropical and warm temperate climates. Although in these habitats a large number of nematode and insect pets are known to be associated with this crop, a few are of major importance to its cultivation. Similarly, some of these pests are associated with the planting material and can be transferred to other areas if the necessary precautions are not taken for their elimination prior to distribution of the germplasm.

Following is a brief outline of the major nematode and insect pests of sweet potatoes found in Peru and those occurring elsewhere and recommendation for their elimination prior to the transfer of germplasm.

Nematodes

The most important nematode species attacking sweet potato is *Meloidogyne incognita* which occurs in the areas where sweet potato is well adapted for cultivation. It seems to do well in light, sandy soil which happens to predominate and constitute the major production of the world's sweet potato growing area. *Meloidogyne hapla* also attack this crop, but its distribution is limited to the cooler, temperate region of the world. Although *M. javanica* also attacks the roots of sweet potatoes, it cannot complete its life cycle on this crop. However, if the planting material are infected, this nematode can be disseminated readily.

Another nematode of major importance is *Rotylenchulus reniformis* which is rather widely distributed in the warm tropical regions of the world. Since it is a semi-endoparasite, and larvae penetrate the roots, can be transferred by movement of the infected germplasm.

Pratylenchus species also attack sweet potatoes and are widely distributed in the temperate and warm tropical regions of the world. Like *Meloidogyne* species, these nematodes have a rather wiede host range and because of their feeding habit inside the root tissue, they can be readily disseminated by movement of infected material.

Insects

Several insect pests of sweet potatoes are known to occur in Peru and other regions of the world where sweet potatoes are intensively cultivated. Following are some of the most important insect pests of sweet potatoes.

1) Foliar Pests

Members of this group of insects feed on foliage, causing irregular shaped holes. Severe damage leads to considerable yield loss. They are primarily lepidopterous pests and include:- Brachima sp. near jugata which in Peruvian literature is reported as Tricotapha sp., Ochyrotica fasciata, Sylepta helcitalis and Cosmopterin sp. which is often reported as Bedellia minor.

2) Stem Feeders

The most important insect pests of major consequence which is both stem and storage root feeder is Euscepes postfasciatus. This insect is commonly known as West Indian sweet potato weevil and occurs in the West Indies and Carribean, Central and South America. Larvae of this insect can be readily disseminated by movement of infested plant material.

3) Storage Root Pests

Two of the most important pests reported to attack storage roots in Peru, Central and South America are E. postfasciatus and Diabrotica spp. The latter causes irregular shallow holes while E. postfasciatus causes mining inside storage roots.

Perhaps the most feared and the most important pests of sweet potatoes are the sweet potato weevils, Cylas formicarius and C. puncticollis which occur in many countries. Cylas formicarius is pantropic, occurring from West Africa through East and South Africa, Madagascar, Mauritiuis, Seychelle, India, Bangladesn, Sri Lanka, S. E. Asia, china, Philippines, Indonesia, Papua New Guinea, East Australia, Solomon Isles, Hawaii, Samoa, Fiji, Coroline, Gilbert and Mariana Isles, South USA, West Indies, Mexico, Guyana and Venezuela. Cylas puncticollis only occurs in Africa, primarily Burundi, Cameroon, Chad, Congo, Guinea, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Tanzania and Uganda. Both of these pests can be disseminated by movement of infested plant material.

Recommendations for Transfer of Pest Free Germplasm

Following is a list of recommendations which should be taken into account when transferring sweet potato germplasm in order to avoid introduction of the destructive nematode and insect pests mentioned above to different locations.

1. The introduced as well as the export material should have been grown in nematode and insect free environment. Soil analysis for nematode detection and utilization of pheromones as monitoring tools for C. formicarius should receive high priority.

2. All the introduced and the export planting material (stem cuttings & storage roots) should be inspected by qualified personnel and the contaminated material should be destroyed.

3. Chemotherapy. Planting material may be treated chemically to eliminate the destructive pests. Similarly, as a perventive measure, the export planting material may be treated with a suitable insecticide. Fumigation may also aid in controlling some pests, but requires additional studies.

4. Thermotherapy. Application of heat by either placement of the planting material at high air temperature or soaking them in hot water may elimiate shallow seeded pests. Similarly, combination of certain systemic pesticides and hot water treatment may be useful in eliminating the pests present in the planting material.

5. Grow all the introduced material in a quarantine greenhouse for observation prior to their release.

6. In-vitro transfer of germplasm will eliminate possibility of transferring all the pests mentioned above and should receive major attention.

Application of some or all the above mentioned recommendatins would safeguard against the introduction and dissemination of major nematode and insect pests of sweet potatoes. These recommendatins may also be applicable in avoiding the introduction of pathogens of important consequences.

IN VITRO METHODS FOR PATHOGEN ELIMINATION AND INTERNATIONAL DISTRIBUTION OF SWEET POTATO GERMPLASM

J.H. Dodds and S.Y.C. Ng

Introduction

The introduction of plant material to in vitro culture conditions requires a prior surface sterilization step to remove superficial contaminants such as bacteria and fungal spores. If the internal tissues of the plant material are not infected the explant can then be easily introduced to a sterile culture environment with little difficulty. However, plant pathogens that will not grow on the nutrient medium such as viruses and viroids cannot be simply removed by surface sterilization. The use of in vitro culture methods for eradication of viruses is not a particularly new technique, the first successful use of meristem culture for virus eradication was reported by Morel and Martin in 1952 (1).

In the case of a vegetatively propagated crop such as sweet potato there are two principal reasons for eliminating pathogens. Firstly, if material is to be distributed internationally then quarantine regulations normally require that the material is of a pathogen-tested nature. Secondly, it has been shown in many crops that pathogens can significatly reduce yield and marketable quality of the crop. A successful pathogen elimination program required a close cooperation between tissue culture specialists who are responsible for meristem culture and regeneration of plantlets, and virologists and bacteriologists who are responsible for testing the regenerated plantlets. A fundamental criteria for this type of study must be a detailed knowledge of the pathogens since a pathogen elimination program can only be as good as the sensitivity of the testing methods.

Elimination of Bacteria/Fungi/Mycoplasmas

These types of pathogens are either on the surface of the plant material or can be internal, tissue infections transported within the

vascular bundles. A number of pretreatments can be used that normally involved watering or soaking the plant material in antibiotic solutions for several hours. The following have been used.

- Gentamycin
- Rifampicin
- Nystatrin + Carbenicillin
- Gentamycin + Amphotericin B
- Vancomycin-HCl + Mycostatin
- Steptomycin - Carbenicillin

Care must be exercised in the use of antibiotics since reports in the literature have shown that some antibiotics show phytotoxicity at the appropriate concentration.

One technique now being applied routinely at CIP for potatoes is the use of filter paper wicks infiltrated with antibiotics, these wicks are inserted into the culture medium and the meristem or single node is inoculated onto the surface of the filter paper wick.

Pregrowth of the plantlets obviously plays a major role in the phytosanitary status and it is always preferable to use plants grown in screenhouses or growth rooms to field grown material. The plant materials should be used while at active growing stage. Routine spraying of plants with fungicides and bactericides for several weeks prior to in vitro introduction can be of great assistance.

Meristem Culture and Virus Eradication in Sweet Potato

As stated in the introduction, it was shown many years ago that isolating meristems could be a successful way of eradicating virus infections.

Success in virus elimination by meristem culture depends on virus type, host plant species, and size of the meristems used for culture. In general, virus-free plants produced is inversely proportional to the size of the meristem used. The mechanism involved in virus elimination by meristem culture is not clear.

Several hypothesis have been evolved. It is postulated that the meristem and even the young leaf primordia which have not been in contact with the main vascular system, therefore, the virus particles which may be present in the vascular system can not easily reach the meristem. It is also possible that the meristematic cells can produce virus-inhibitory substances. The presence of hormones in the culture media may also have contributions to the virus elimination.

It has been reported that sweet potato virus diseases such as mosaic virus, feathery mottle virus (2, 3), internal cork virus (2, 4), sweet potato virus (SPVD) (5) and some unidentified viruses (6, 7) were eliminated from sweet potato plants by meristem culture alone or in combination with thermotherapy.

Thermotherapy

It has since been shown that heat treatment (thermotherapy) can greatly increase the success rate of virus elimination. The logic behind thermotherapy is to raise the temperature to a level at which the plant meristem is still able to grow but replication of the virus is inhibited. In the case of potato, CIP uses a thermotherapy regime of $37/25^0$ 16 hr/8 hr in continuous light, whereas IITA uses a thermotherapy at 37^0 constant temperature at 16 hr light for cassava. CIP is also testing the use of thermotherapy on sweet potato clones at a range of temperatures up to 40 grades C.

In recent years interest has developed in the possibility of carrying out thermotherapy on materials that are already in vitro (8). The advantages of in vitro thermotherapy would appear to be the volume of plantlets that can be cleaned and a significant reduction in unit cost for the clear up process.

Chemotherapy

For many years there has been interest in the use of antiviral chemicals for virus elimination (9, 10). The most commonly used antiviral chemicals are virazole and adenosine arabinoside, these compounds do however exhibit pronounced phytotoxic effects at their effective antiviral

concentrations. The use of these chemicals has been highly effective for reduction of the concentration of virus in many cases although true eradication was not achieved. This reduction in virus titre can be an important pretreatment to produce stronger plants for entry to thermotherapy.

Scheme for Disease Elimination in Sweet Potato

Meristem culture technique is routinely used at IITA to eliminate virus diseases from sweet potato (11), it was found that about 85% of the regenerated plants were free from SPVD by applying this technique alone.

The sweet potato tubers harvested from the field are cleaned, planted in pots and grown in the greenhouse. When sprouted, both apical and later buds are excised for culturing. After disinfection process, meristem with one to two leaf primordia are excised and cultured in vitro. Six to eight weeks after incubation, plantlets are obtained and can be transplanted to jiffy peat pellets and then to sterile soil in pots in isolation room for virus testing.

At IITA, several virus testing methods are used. (1) After one to grafted to I. setosa, an indicator plant for a number of sweet potato virus diseases. This type of grafting are repeated three times for each plant. (2) A complementary grafting test is also carried out on the cuttings of the plant since the virus disease that we have in Nigeria consisted of two viruses and that if two viruses are presented at the same time, severe disease symptoms are observed whereas if appears singly, it is latent. (3) Serology tests such as, enzyme linked immunosorbent assay (ELISA) and serologically specific electron microscopy (SSEM) are carried out on the leaf extract of the sweet potato plants.

Problems of Genetic Stability During pathogen Elimination Procedure

Genetic stability of vegetatively propagated plants is of primary importance or the characters of the clone will be lost. In the case of potato many examples exist of changes in plant phenotype as a result of meristem culture, these are normally chimeras that result in change of tuber skin color. It is important that testing procedures to screen such changes be carried out.

At IITA, sweet potato materials entering pathogen elimination are well characterized in terms of plant type, storage root colour (skin and flesh), growth habit and other morphological characters. The meristems regenerated plants are also evaluated for these characters while being planted in isolation room for virus indexing. Besides, a number of randomly selected varieties which are maintained in pathogen tested collections are periodically being transplanted for such evaluation. The experience in CIP using electrophoresis of soluble proteins and isoenzyme analysis with potato will also be used at IITA for the evaluation of the in vitro sweet potato collections.

In the case of potato it is well known that the formation of callus and subsequent plant regeneration will cause minor or major genetic abberations (12, 13). Sweet potato is a crop that is known to exhibit somatic mutation so care must be taken during meristem regeneration and plantlet propagation to keep callus formation to minimum, ideally complete avoidance of callus formation should be maintained in a clonal propagation program.

Routine Testing

Once plantlets have been regenerated and fully tested against known pathogens the material can then enter an in vitro pathogen tested collection. If handling procedures are appropriate it should not be possible for these plantlets to become reinfected. However, if the materials in the pathogen tested collection are to be routinely distributed internationally it is a good fail-safe procedure to routinely screen the collection once every year for known viruses. It should be remembered that in vitro does not necessarily indicate that the materials are pathogen tested, it is important therefore that pathogen tested material is clearly identified with the routine testing carried out and the types of methods used for the testing.

International Distribution of Sweet Potato Germplasm

The international movement of sweet potato germplasm is subject to quarantine regulations, there regulations vary from country to country but in most cases there exists a list of quarantine hazards for any given crop.

In vitro cultures are the most effective way of removing quarantine problems for insect pests, bacteria, fungi and mycoplasmas. The *in vitro* plantlets can also be tested by indicator plants and serologically against viruses and the plants are not likely to be attacked by aphids.

Applying meristem culture technique and virus testing, IITA is able to eliminate diseases from its improved sweet potato varieties. The *in vitro* cultures have been distributed to more than fifty countries throughout the world. The distribution is mainly by hand carry. However in same cases, the cultures are despatched via air freight by our collaborator, The Research Institute for Plant Protection (IPO), Netherlands, to the requesting national programs. Superior varieties that are adapted to different ecologies are selected by IITA collaborators in many countries and are distributed to the farmers (14).

The major drawback of exporting *in vitro* plantlets is that the cultures need to reach their destination in a period of less than 14 days. A successful alternative may be the production of *in vitro* swollen roots that would store well in the dark. However, more research is needed on *in vitro* storage root induction before this would become a possiblity.

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DESCRIPTORS FOR THE CHARACTERIZATION AND EVALUATION OF SWEET POTATO GENETIC RESOURCES

Zosimo Huaman

In August 1980 the International Board for Plant Genetic Resources (IBPGR) convened an ad hoc working group to discuss the Genetic Resources of Sweet Potato. This was held in Charleston, South Carolina, USA. One of the outcomes of that workshop was the development of a list of descriptors to be used for the characterization of sweet potato accessions [1]. This list included descriptors grouped under three major sections: Passport Data, Characterization and Preliminary Evaluation, and Further Evaluation.

The IBPGR list of descriptors has already been tested in the characterization of some fairly large sweet potato collections in Fiji and Papua New Guinea [4, 3, 7]. However, the reports of those evaluations indicated that the IBPGR list required some modifications in the descriptor states (categories) of several morphologic characters as well as some additional descriptors to describe more accurately the variation present in those collections.

Some preliminary work to characterize a collection of about 1500 accessions of sweet potato cultivars from Peru now maintained at the International Potato Center (CIP) has been undertaken in 1986. For this purpose we have used an expanded IBPGR list of descriptors which included all the additions and modifications mentioned above. Our experience was that even this expanded list was not adequate enough to describe all the morphologic variation shown in CIP's collection.

The development of a more comprehensive list of descriptors for the characterization and evaluation of sweet potato genetic resources is considered of major importance at CIP. It is the key factor to facilitate a rapid identification of duplicate cultivars in the collection whose number of accessions is increasing at a very fast rate through numerous collecting expeditions. Therefore, we have gradually been developing an expanded list of descriptors which has been tested in CIP's sweet potato collection.

The list of descriptors that follows includes:

1) Most of the IBPGR descriptors for the characterization and preliminar evaluation [1].

2) The modifications and additions to the IBPGR list developed by Larsen,1984 [4]; Jackson and Breen, 1985 [3]; and Takagi, 1986 [7].

3) A number of characters that were used in publications containing descriptions of sweet potato cultivars such as those published by Groth, 1911 [2]; Thompson, 1922 [8]; and Yen, 1963 [9].

4) The description of plant variation in a large sweet potato collection from countries of the Americas, Polynesia, Melanesia, and S. E. Asia published by Yen, 1974 [10].

5) Several other storage root characters described by sweet potato breeders such as those published by Martin and Rhodes, 1983 [5]; Ruberte and Martin, 1983 [6].

Priorities to record data have been assigned according to the relative importance of each descriptor to differentiate cultivars. New accessions added to the collection are characterized first for those descriptors considered to be the most useful for identification purposes (i.e. key characters). These data are then used to locate the accession close to other accessions in the collection having similar data for those characteristics. The evaluation for other descriptors with lower priority is then continued on groups of plants showing similar characteristics to determine more similarities or differences among accessions maintained in the collection.

These priorities are as follows:

FIRST PRIORITY

Twining
Plant type
Vine pigmentation
Mature leaf shape
Foliage color
Abaxial leaf vein pigmentation
Storage root color
Storage root flesh color

SECOND PRIORITY

Other Plant and Storage root characters.

THIRD PRIORITY

Floral characters.

FOURTH PRIORITY

All characters of Preliminary evaluation.

Once enough data have been recorded for identification purposes and potential duplicates have been grouped, data on descriptors listed under further evaluation should be obtained.

DESCRIPTOR LIST FOR SWEET POTATO

PASSPORT DATA

1. ACCESSION DATA

See IBPGR list.

2. COLLECTION DATA

See IBPGR list.

CHARACTERIZATION AND PRELIMINARY EVALUATION

3. GENERAL

See IBPGR list.

4. MORPHOLOGIC CHARACTERIZATION

PLANT CHARACTERS

With the exception of vine growth rate, all plant characters should be recorded at about 90 days from planting or 10 days before harvest in early maturing cultivars.

Descriptor states related to length or size should be scored as the average value of measurements made on five to ten plants of each accession in the collection growing under the same environment and at the same plant density.

Vine and leaf characters should be recorded as the average expression of the character observed in a section of the main stem located between the 8th and the 10th fully expanded leaf from the apical shoots unless otherwise specified.

4.1 TWINING

Description of the ability of vines to climb adjacent stakes placed in those accessions showing twining characteristics.

0 Non-twining
9 Twining

4.2 PLANT TYPE

Description of the growth habit at about 90 days from planting.

3 Compact
5 Semi-compact
7 Spreading
9 Extremely spreading

4.3 VINE GROWTH RATE

Description of the relative speed of growth of the main vines based on the average length reached at about 60 days from planting.

3 Slow (less than 50 cm)
5 Intermediate (50-100 cm)
7 Fast (more than 100 cm)

4.4 VINE INTERNODE LENGTH/DIAMETER

Described by a 2 digit code where the first digit (tens) indicates the average internode length and the second digit (units) indicates the average internode diameter.

INTERNODE LENGTH	INTERNODE DIAMETER
1 Very short (less than 3 cm)	1 Very thin (less than 4 mm)
3 Short (3-5 cm)	3 Thin (4-6 mm)
5 Intermediate (6-9 cm)	5 Intermediate (7-9 mm)
7 Long (10-12 cm)	7 Thick (10-12 mm)
9 Very long (more than 12 cm)	9 Very thick (more than 12 mm)

4.5 VINE PIGMENTATION

Extent of distribution of anthocyanin pigmentation in the vines.

1 Green
2 Green with pigmented nodes
3 Slightly pigmented
4 Slightly pigmented with pigmented nodes
5 Moderately pigmented
6 Moderately pigmented with pigmented nodes
7 Totally pigmented - red
9 totally pigmented - purple

4.6 VINE TIP PUBESCENCE

Degree of hairiness of immature leaves recorded from the apex of the vines.

0 None
1 Very sparse
3 Sparse
5 Moderate
7 Heavy
9 Very heavy

4.7 MATURE LEAF SHAPE

Described by a 3 digit code where the first digit (hundreds) indicates the type of the most common expression of leaf lobing; the second digit (tens), the average total number of lobes; and the third digit (units) indicate the shape of the central lobe of leaves (see Fig. 1,2,3).

TYPE OF LEAF LOBING	NUMBER OF LOBES	SHAPE OF CENTRAL LOBE
0 None	0	0 Absent
1 Very slight (teeth)	1	1 Broad teeth
3 Slight	3	3 Semi-circular
5 Moderate	5	4 Semi-elliptic
7 Deep	7	5 Elliptic
9 Very deep	9	6 Lanceolate
		7 Oblanceolate
		9 Linear

4.8 MATURE LEAF SIZE

3 Small (less than 8 cm)
5 Medium (8-15 cm)
7 Large (more than 15 cm)

Fig. 1. Examples of mature leaf shape

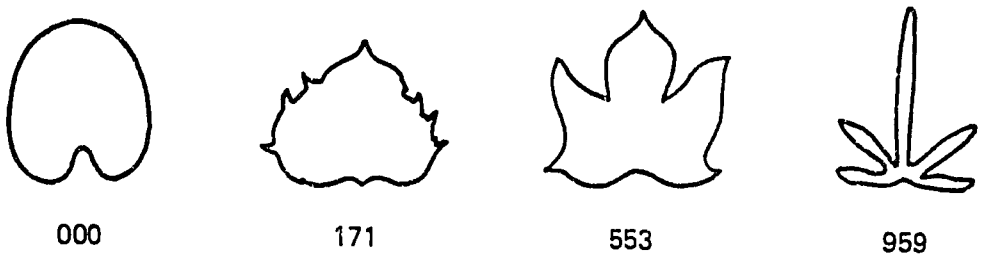


Fig. 2. Type of leaf lobing

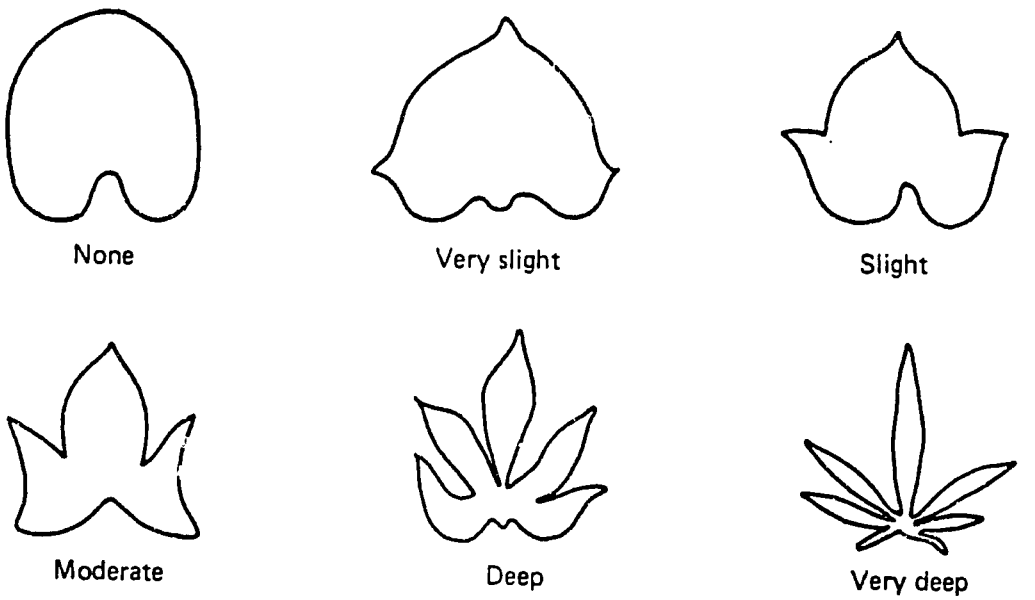
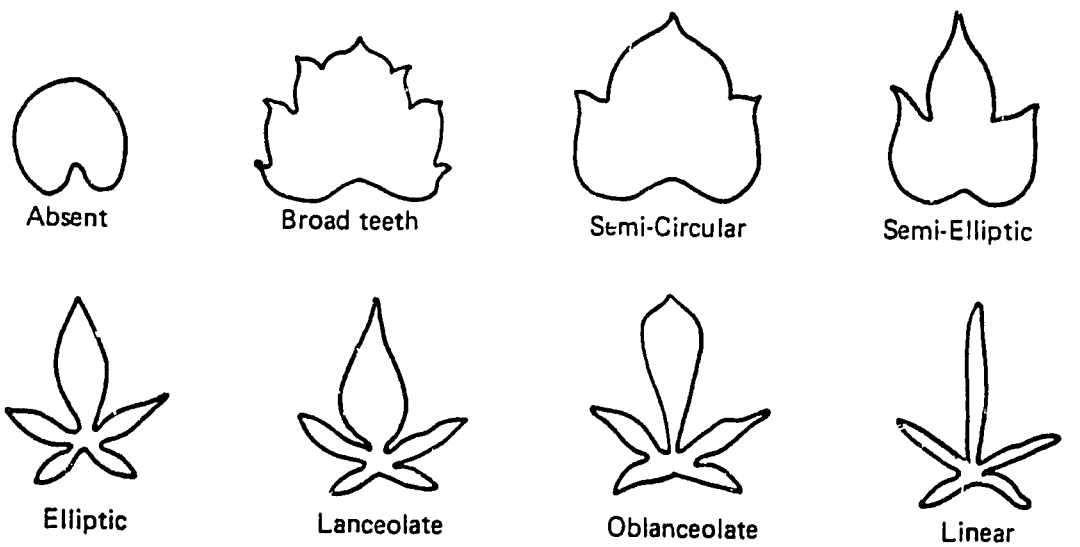


Fig. 3. Shape of central lobe



4.9 FOLIAGE COLOR

Description of the overall foliage color considering the color of fully expanded mature and immature leaves shown by several plants. The variegation in leaf color due to virus symptoms should not be recorded. This character is described by a two digit code where the first digit describes the mature leaf color and the second digit, the immature leaf color.

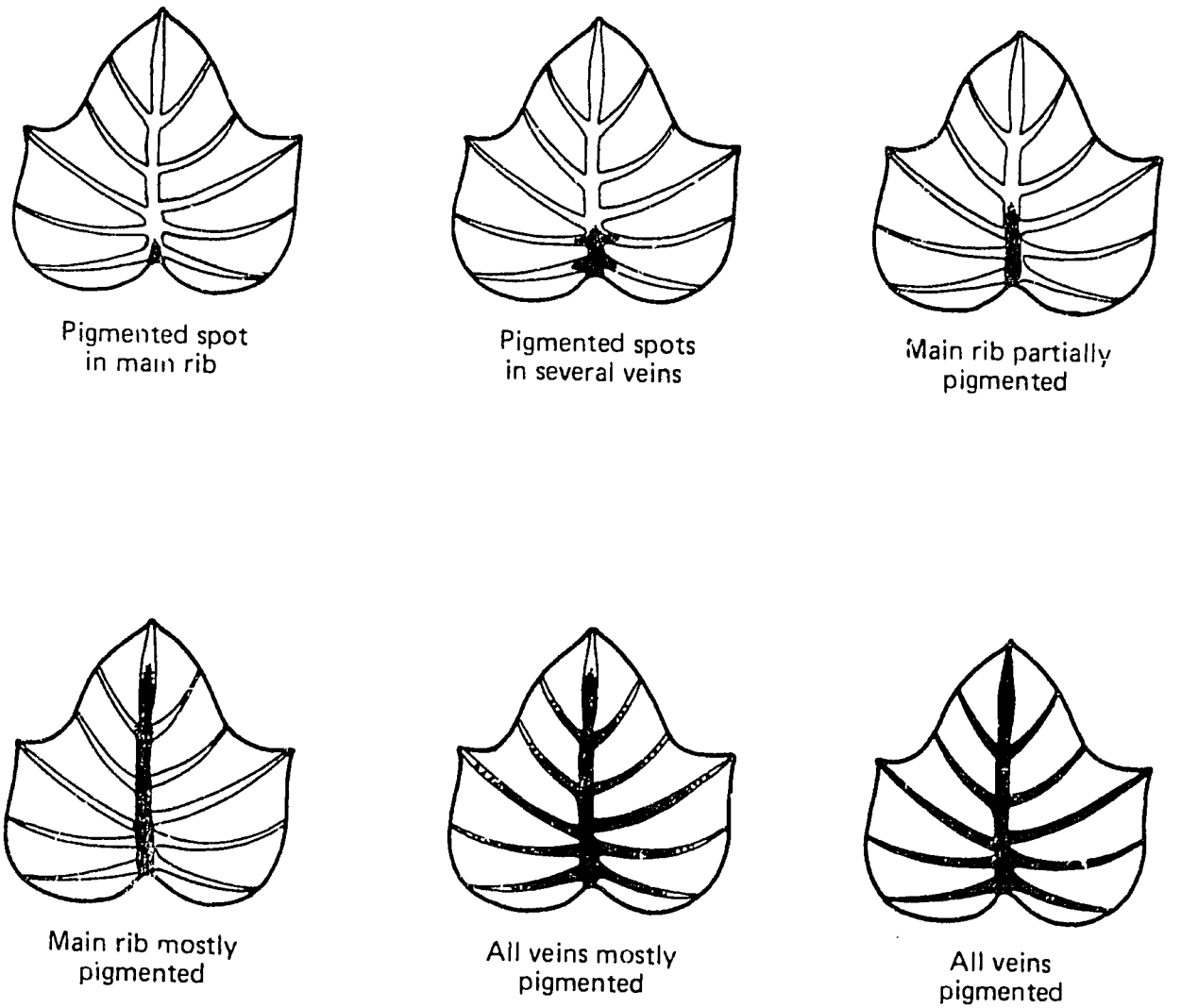
MATURE LEAF COLOR	INMATURE LEAF COLOR
1 Yellow	1 Yellow
2 Yellow-green	2 Yellow-green
3 Green	3 Green
4 Green with pigmented edge	4 Green with pigmented edge
5 Greyish-green (due to heavy pubescence)	5 Greyish-green (due to heavy pubescence)
6 Slightly pigmented	6 Slightly pigmented
7 Moderately pigmented	7 Moderately pigmented
8 Mostly pigmented	8 Mostly pigmented
9 Totally pigmented	9 Totally pigmented

4.10 ABAXIAL LEAF VEIN PIGMENTATION

Description of the distribution of anthocyanin pigmentation shown in the veins of the lower surface of leaves. The most frequent expression should be recorded (see Fig.4).

1 Yellow
2 Green
3 Pigmented spot in the base of main rib
4 Pigmented spots in several veins
5 Main rib partially pigmented
6 Main rib mostly or totally pigmented
7 All veins partially pigmented
8 All veins totally pigmented
9 Lower surface and veins totally pigmented

Fig. 4. Abaxial leaf vein pigmentation



4.11 PETIOLE LENGTH

The average petiole length of leaves located between the 8th and the 10th node from the apical shoots.

1 Very short (less than 10 cm)
3 Short (10-15 cm)
5 Intermediate (16-20 cm)
7 Long (21-25 cm)
9 Very long (more than 25 cm)

4.12 PETIOLE PIGMENTATION

Distribution of anthocyanin pigmentation in the petioles of leaves. The most predominant color is always indicated first.

1 Green
2 Green and pigmented close to the stem
3 Green and pigmented close to the leaf
4 Green and pigmented close to the stem and leaf
5 Partially pigmented throughout petiole
6 Pigmented and green close to the stem
7 Pigmented and green close to the leaf
8 Pigmented and green close to the stem and leaf
9 Totally or mostly pigmented

STORAGE ROOT CHARACTERS

All storage root descriptors should be recorded considering the most representative expression of the character shown in medium to large sized storage roots of several plants.

4.13 STORAGE ROOT SHAPE

Described as the storage root outline shown in a longitudinal section (see Fig. 5).

1 **Round** - an almost circular outline with a length to breadth (L/B) ratio of about 1 to 1.
2 **Round elliptic** -a slightly circular outline with acute ends. The L/B ratio not more than 2 to 1.

Fig. 5. Storage root shape

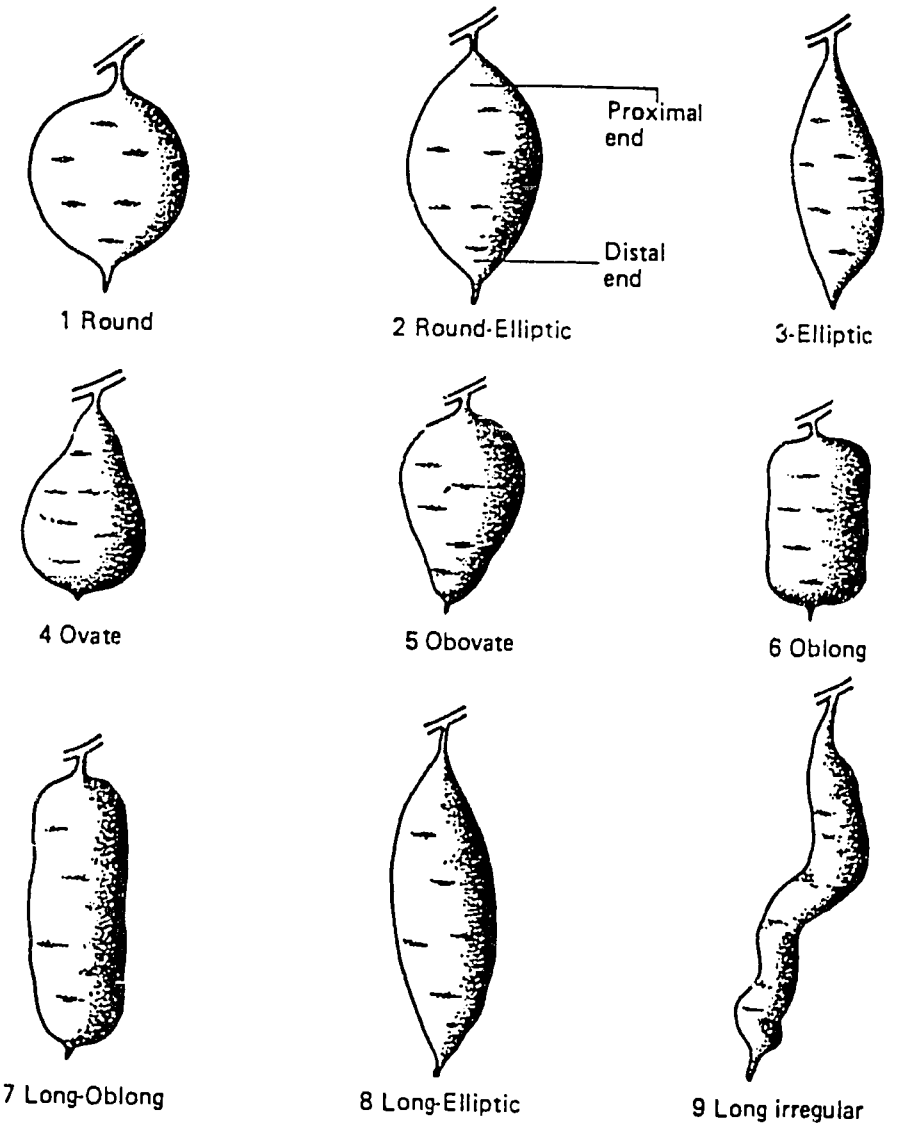
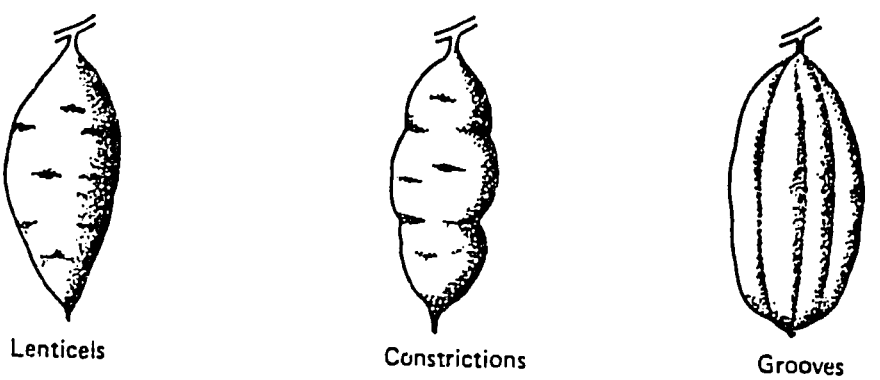


Fig. 6. Storage root surface defects



3 **Elliptic** - an outline with about the same breadth at equal distance from both ends which are slightly acute. The L/B ratio should not be more than 3 to 1.
4 **Ovate** - an outline resembling the longitudinal section of an egg. The broadest part is in the distal end (i.e. opposite to the root stock).
5 **Obovate** - an outline which is inversely ovate. The broadest part is in the proximal end (i.e. close to the root stalk).
6 **Oblong** - an almost rectangular outline with sides nearly parallel and corners rounded. The L/B ratio about 2 to 1.
7 **Long** oblong - an oblong outline with a L/B ratio of at least 3 to 1.
8 **Long elliptic** - an elliptic outline with a L/B ratio of at least 3 to 1.
9 **Long irregular or curved**

4.14 STORAGE ROOT SURFACE DEFECTS

See Fig. 6.

0 Absent
1 Few lenticels
2 Many lenticels
3 Shallow constrictions
4 Deep constrictions
5 Shallow longitudinal grooves
6 Deep longitudinal grooves
7 Deep constrictions and deep grooves

4.15 STORAGE ROOT CORTEX THICKNESS

1 Very thin (< 1 mm)
3 Thin (2 mm)
5 Intermediate (2-3 mm)
7 Thick (3-4 mm)
9 Very thick (> 4 mm)

4.16 STORAGE ROOT SKIN COLOR

Freshly harvested storage roots should be washed and dried prior to evaluation. The color recorded should correspond to the most representative color of the cultivar. It is described by a 3 digit code where the first digit (hundreds) indicates the predominant skin color; the second digit (tens), the intensity of the color; and the third digit (units) indicates the presence of a secondary color distributed either as spots or small areas.

PREDOMINANT COLOR	INTENSITY	SECONDARY COLOR
1 White	1 Pale	0 Absent
2 Cream	2 Intermediate	1 White
3 Yellow	3 Dark	2 Cream
4 Orange		3 Yellow
5 Brown		4 Orange
6 Pink		5 Brown
7 Red		6 Pink
8 Purple-red		7 Red
9 Dark purple		8 Purple-red
		9 Dark purple

4.17 STORAGE ROOT FLESH COLOR

Described in cross sections made about the middle of freshly harvested storage roots.

1 White
2 Cream
3 Dark cream
4 Pale yellow
5 Dark yellow
6 Yellow with orange or viceversa
7 Pale orange
8 Dark orange
9 Strongly pigmented with anthocyanins

4.18 DISTRIBUTION OF ANTHOCYANIN PIGMENTATION IN FLESH

See Fig. 7.

0 Absent
1 Narrow ring in cortex
2 Broad ring in cortex
3 Scattered spots
4 In the vascular cambium
5 In the cortex and vascular cambium
6 In the cortex and central parenchyma
7 In the vascular cambium and central parenchyma
8 In the cortex, vascular cambium and central parenchyma
9 Totally or mostly pigmented

4.19 STORAGE ROOT SPROUTING

Medium sized storage rots stored in paper bags should be evaluated for their natural sprouting ability. This is described by a 2 digit code where the first digit (tens) indicates the speed of sprouting and the second digit (units) indicates the sprouting uniformity.

SPROUTING RESPONSE	SPROUTING UNIFORMITY
0 Absent	3 Uniform
1 Very fast	5 Slightly variable
3 Fast	7 Moderately variable
5 Intermediate	9 Highly variable
7 Late	
9 Very late	

FLORAL CHARACTERS

Although characters related to the flower are very important and not influenced by environmental conditions, there are strong differences among cultivars in their flowering ability. Flowering can be stimulated by water stress or trelliswork. However, in difficult cases grafting or chemical treatment might be needed (see Fig. 8).

Fig. 7. Distribution of anthocyanin pigmentation in storage root flesh

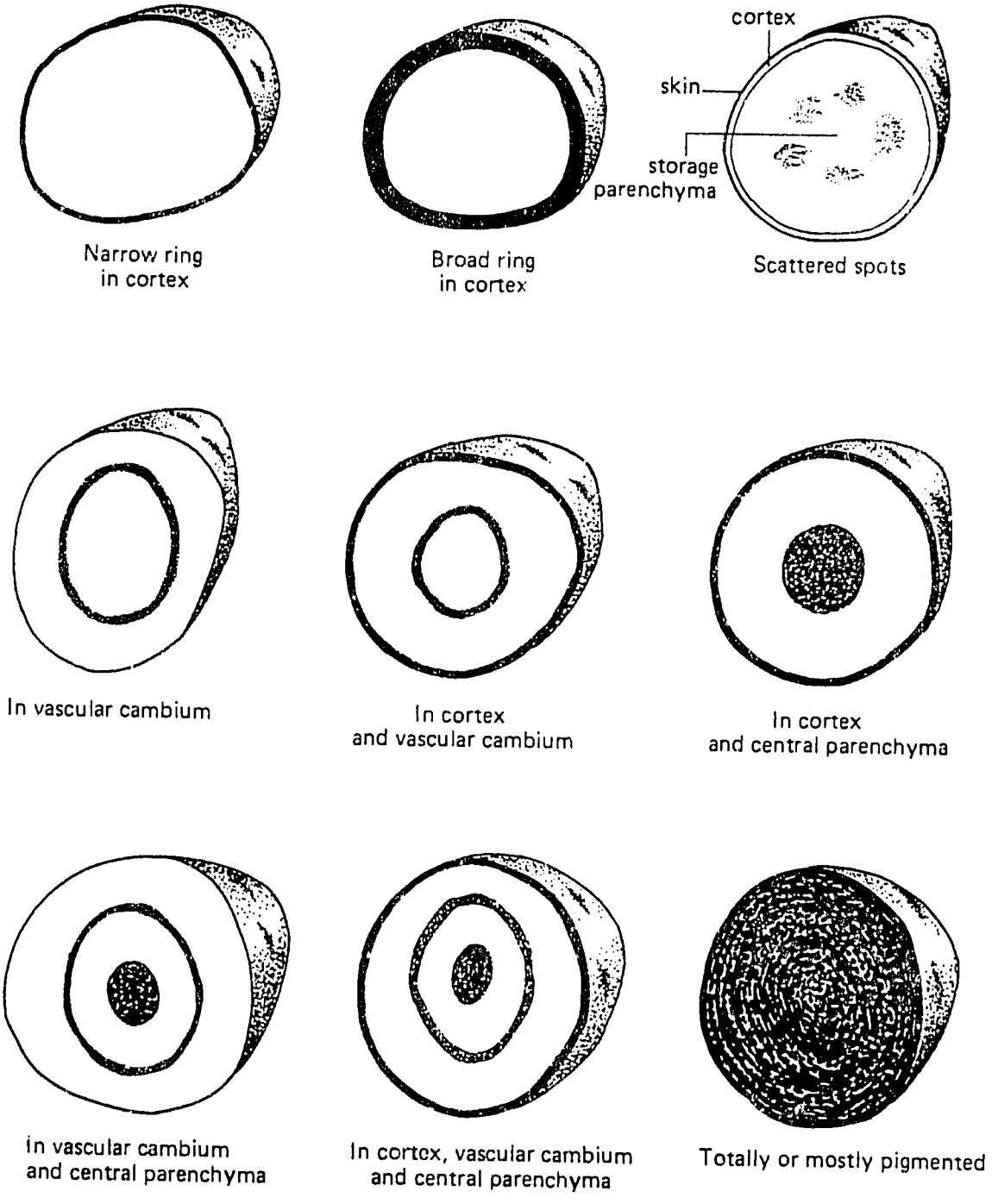


Fig. 8. Parts of a sweet potatc flower

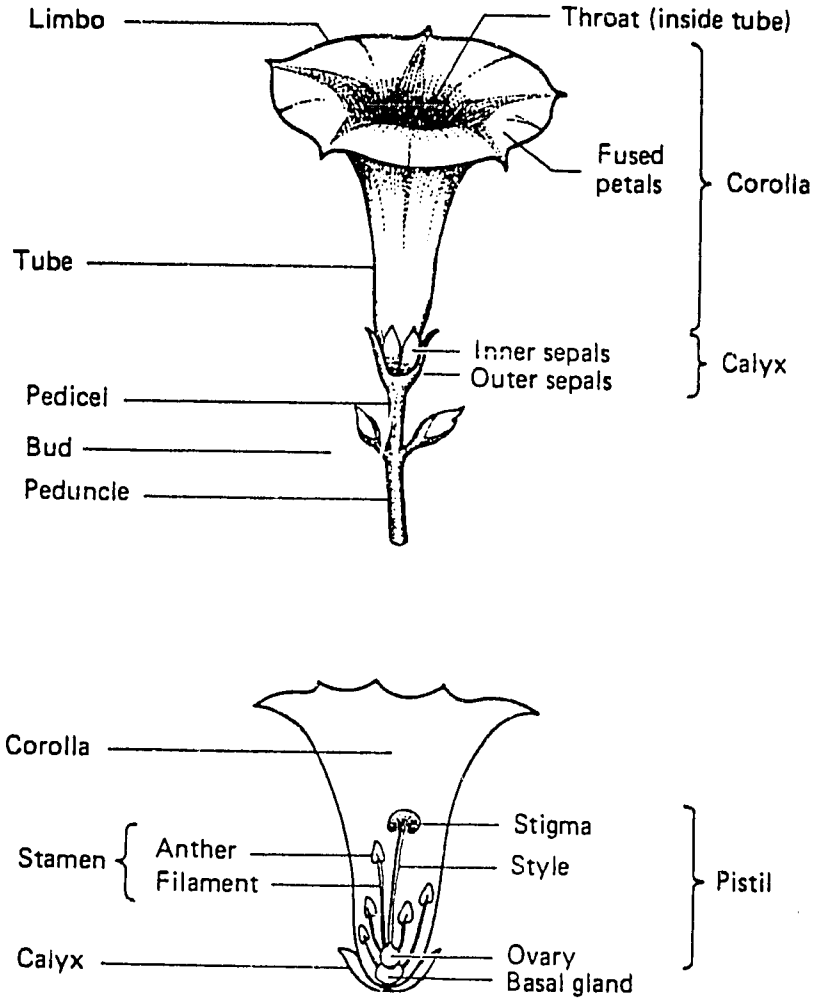
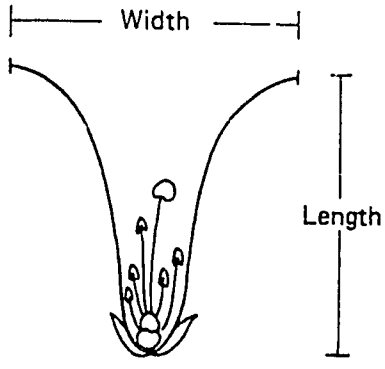


Fig. 9. Flower lenght and width



4.20 FLOWERING HABIT

0 None
1 Scarce
3 Sparse
5 Moderate
7 Profuse
9 Very profuse

4.21 FLOWER COLOR

1 White
2 White limb with purple throat
3 White limb with pale purple ring and purple throat
4 Pale purple limb with purple throat
5 Purple
6 Other (specify)

4.22 FLOWER LENGTH AND WIDTH

Average length and width of ten typical flowers and expressed in centimeters (see Fig. 9).

4.23 SHAPE OF LIMB

See Fig. 10

3 Semi-stellate
5 Pentagonal
7 Rotate

4.24 EQUALITY OF SEPAL LENGTH

1 Outer two shorter
2 Equal

4.25 NUMBER OF SEPAL VEINS

Count of the number of veins observed in the sepals. The most frequent number in ten typical flowers should be recorded.

Fig. 10. Shape of Limb

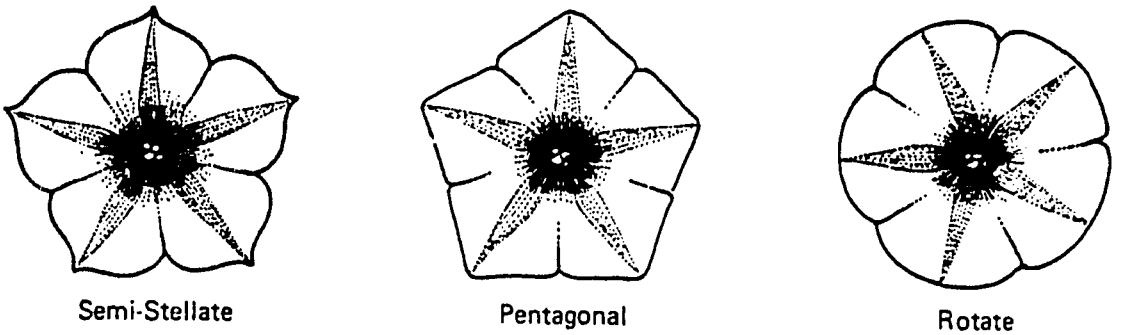


Fig. 11. Sepal shape

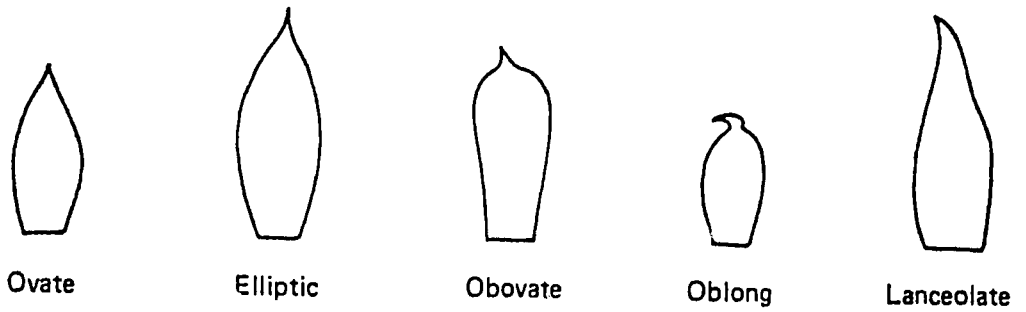
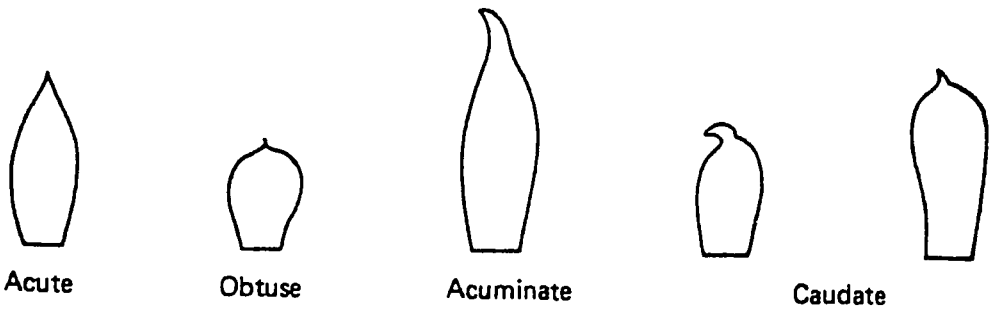


Fig. 12. Sepal apex



4.26 SEPAL SHAPE

See Fig. 11

1 Ovate
3 Elliptic
5 Obovate
7 Oblong
9 Lanceolate

4.27 SEPAL APEX

See Fig. 12

1 Acute
3 Obtuse
5 Acuminate
7 Caudate

4.28 SEPAL PUBESCENCE

0 Absent
1 Very sparse
3 Sparse
5 Moderate
7 Heavy
9 Very heavy

4.29 SEPAL COLOR

1 Green
2 Green with pigmented edge
3 Lightly pigmented
5 Moderately pigmented
6 Some sepals green, others pigmented
7 Totally pigmented - red
9 Totally pigmented - purple

4.30 COLOR OF STIGMA

1 White
5 Pale purple
9 Purple

4.31 COLOR OF STYLE

1 White
3 White with purple at the base
5 White with purple at the top
7 White with purple spots throughout
9 Purple

4.32 STIGMA EXSERTION

The relative position of the stigma as compared to the highest anther (see figure 13).

1 Inserted (shorter than longest anther)
3 Same height as highest anther
5 Slightly exserted
7 Exserted (longer than longest anther)

4.33 SEED CAPSULE SET

0 None
1 Scarce
3 Sparse
5 Moderate
7 Heavy

5. PRELIMINARY EVALUATION

5.1 STORAGE ROOT FORMATION

Description of the arrangement of the storage roots on the underground stems of plants propagated by vine cuttings (see Fig. 14).

1 Closed cluster
3 Open cluster
5 Disperse
7 Very disperse

5.2 STORAGE ROOT STALK

Description of the length of the stalk joining the storage roots to the stems.

Fig. 13. Stigma exsertion

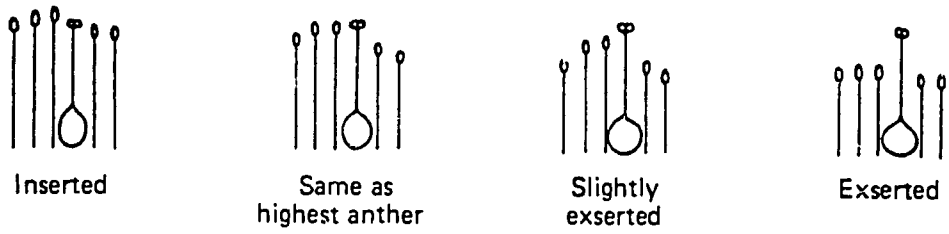
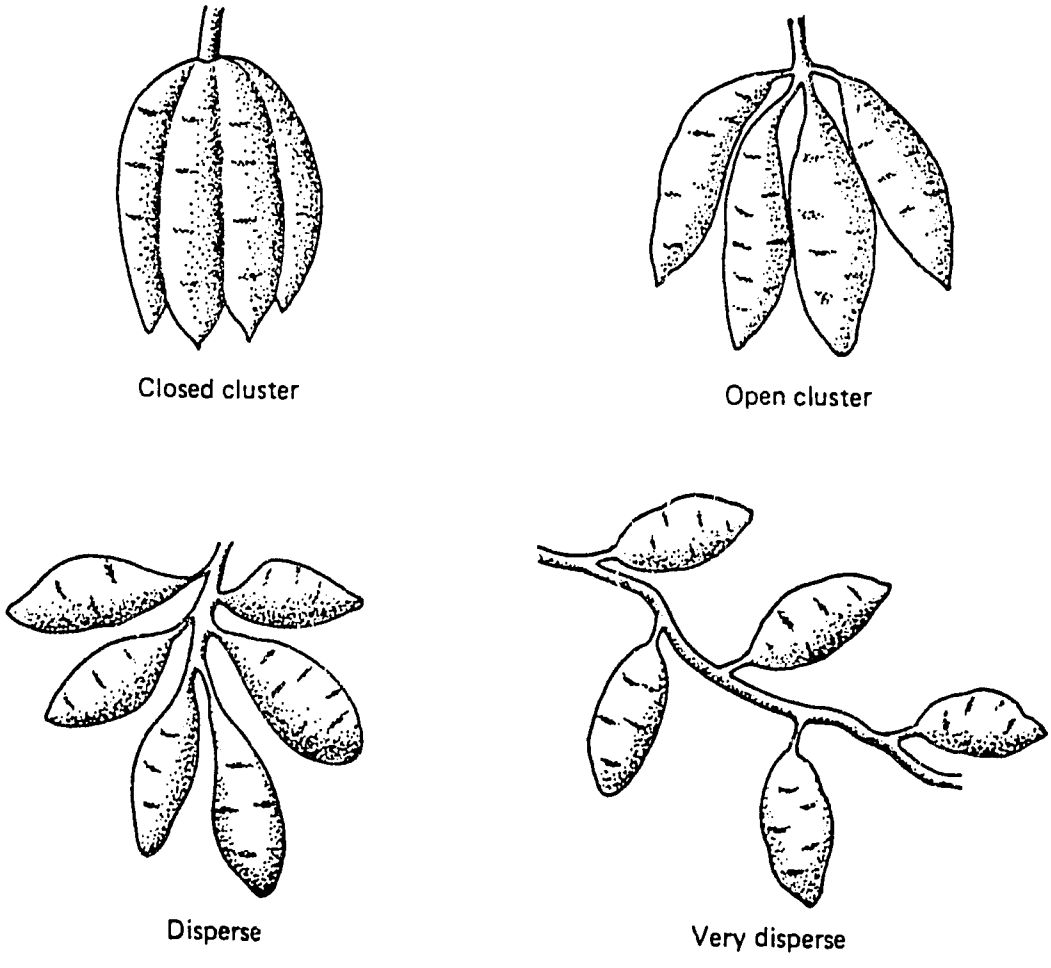


Fig. 14. Storage root formation



0 Sessile or absent
1 Very short (less than 2 cm)
3 Short (2-5 cm)
5 Intermediate (5-8 cm)
7 Long (9-12 cm)
9 Very long (more than 12 cm)

5.3 STORAGE ROOT LENGTH

Storage root dimensions should be recorded on the most predominant size of storage roots produced by ten plants.

Average length of ten storage roots in centimeters.

5.4 STORAGE ROOT DIAMETER

Average of largest diameter of ten storage roots in centimeters.

5.5 NUMBER OF STORAGE ROOTS PER PLANT

Average of ten plants.

5.6 STORAGE ROOT SHAPE VARIABILITY

3 Uniform
5 Slightly variable
7 Moderately variable
9 Highly variable

5.7 STORAGE ROOT SIZE VARIABILITY

3 Uniform
5 Slightly variable
7 Moderately variable
9 Highly variable

5.8 STORAGE ROOT CRACKING

Description of the average cracking shown in ten plants. Consider all cracks caused by growth and/or water stress.

0 Absent
3 Few cracks
7 Many cracks

5.9 LATEX PRODUCTION IN STORAGE ROOTS

Description of the relative amount of latex observed about 5 seconds after the cross section is made in medium sized storage roots.

0 None
1 Very little
3 Little
5 Some
7 Abundant
9 Very abundant

5.10 OXIDATION IN STORAGE ROOTS

Description of the relative amount of oxidation observed 5 minutes after the cross section is made in medium sized storage roots.

0 None
1 Very little
3 Little
5 Some
7 Abundant
9 Very abundant

FURTHER EVALUATION

6. STORAGE ROOT DATA

6.1 STORAGE ROOT DRY MATTER PERCENTAGE

6.2 STORAGE ROOT NITROGEN

6.3 STORAGE ROOT FIBER PERCENTAGE

American Official Analytical Chemistry on cooked roots of at least 3 cm diameter.

6.4 STORAGE ROOT STARCH PERCENTAGE

6.5 STORAGE ROOT WATER SOLUBLE SUGAR PERCENTAGE

6.6 STORAGE ROOT CAROTENE CONTENT

In milligramme per 100 g fresh weight.

6.7 KEEPING QUALITY OF STORAGE ROOTS

3 Poor
5 Medium
7 Good

6.8 SPROUTING ABILITY IN BEDS

3 Poor
5 Medium
7 Good

BOILED STORAGE ROOTS CHARACTERS

Description of these characters should be made on commercial size storage roots of approximately the same dimensions. Roots should be totally inmersed in boiling water for approximately the same time for all accessions compared. The average score of at least 3 people should be recorded.

6.9 CONSISTENCY OF BOILED STORAGE ROOT

1 Watery
2 Extremely soft
3 Very soft
4 Soft
5 Slightly hard
6 Moderately hard
7 Hard
8 Very hard
9 Very hard and non-cooked.

6.10 UNDESIRABLE BOILED STORAGE ROOT FLESH COLOR

0 None
1 Some beige
2 Much beige
3 Slightly green or gray
4 Green
5 Gray
6 Beige and green
7 Beige and gray
8 Beige and pigmented
9 Pigmented

6.11 TEXTURE OF BOILED STORAGE ROOT FLESH

1 Dry
3 Somewhat dry
5 Intermediate
7 Moist
9 Very moist

6.12 SWEETNESS OF BOILED STORAGE ROOT FLESH

1 Not sweet
3 Slightly sweet
5 Moderately sweet
7 Sweet
9 Very sweet

7. PEST REACTION

See IBPGR list.

8. DISEASE REACTION

See IBPGR list.

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GENETIC RESOURCES OF SWEET POTATO - IBPGR RESEARCH

J.T. Williams and D.H. van Sloten

The International Board for Plant Genetic Resources (IBPGR) initiated concerted activities on the genetic resources of sweet potato in 1980 because of the importance of the crop. In order to define scientific priorities, an IBPGR Working Group was convened in Charleston, South Carolina, USA from 5-7 August, 1980 with participation of world experts on the genus. Representatives of other International Agricultural Research Centres (IITA, AVRDC) with active programmes on sweet potato were present. The recommendations of this Working Group, published in 1981 (IBPGR, 1981), served as a basis for IBPGR's activities on sweet potato during the next five years. The report also contains a sweet potato descriptor list.

Collecting efforts during the period 1980 through 1984 largely concentrated on primitive cultivars of sweet potato from Latin America, Africa, Asia and the Pacific. During this period a total of around 5,000 samples was collected from 13 countries (Burkina Faso, Burundi, Guatemala, Indonesia, Malaysia, Mexico, Papua New Guinea, Peru, Philippines, Solomon Islands, Thailand, Uganda and Zaire). When the International Potato Center (CIP) started a programme on sweet potato in 1985, IBPGR was jointly involved through the funding and appointment of a full-time IBPGR/CIP Sweet Potato Collector, who commenced his work on 1 January 1985. IBPGR has agreed to fund this Collector for a 3-year period (1985 through 1987), whereby emphasis is given to the collection of the wild Ipomoea species in Latin America. Areas visited included those in the primary centre of diversity.

In relation to the wider genepool, a research project was supported 1982-85 to study diagnostic characters of species allied to the cultigen and to the use of morphological characters in relation to characterization. The results were valuable in describing ranges of variation (Austin, 1985).

The Asian Vegetable Research and Development Center (AVRDC) has been designated by the IBPGR to maintain a field genebank of sweet potato cultivars from Asia and the Pacific. In order to facilitate the introduction of vegetative material, the IBPGR has provided AVRDC with a post-entry quarantine screenhouse. IBPGR intends to proceed further with the designation of field genebanks at IITA and CIP.

For conservation of genetic diversity of sweet potato, the IBPGR strongly emphasizes the conservation of seed. The following institutions are currently engaged in the conservation of sweet potato seeds.

- National Seed Storage Laboratory, Colorado State University, Fort Collins, Colorado, USA.

Global collection - National Institute of Agrobiological Resources, Tsukuba Science City, Japan

Asian/Pacific - Asian Vegetable Research and Development Center, Taiwan, China

Of course these seed conservation collections will be supplemented by active seed collections in centres where breeding is ongoing.

Sweet potato clones are cultured in vitro in IITA, at AVRDC, at CIP, in Japan and in the United States. The IBPGR further supported this work through research which looks at methods suitable for the widest possible range of genotypes. This research at Clemson University, South Carolina, USA is in association with Dr. A. Jones, Chairman, IBPGR Working Group on Sweet Potato, with USDA-supported work on disease indexing (Dr. J. Moyer, North Carolina). A technical manual, essential for the transfer of material to collections, is in press and an input to this has come from scientists involved in tissue culture in the Centres. Ultimately, when techniques are available, there will be the need for crop preservation facilities for base in vitro genebanks which will hold a limited number of clones. Other clones will need to be held in active in vitro genebanks but to date no such collection exists which follows the minimum scientific standards for genetic conservation (IBPGR, 1986b). They need the urgent incorporation of monitoring for genetic stability and disease indexing.

In accordance with recent IBPGR policy, more emphasis is being given to the characterization and documentation of the collected materials. This is an integral part of a number of the above-mentioned collecting activities. Specific funds for the multiplication, characterization and documentation of sweet potato germplasm already collected have been provided by the IBPGR to national programmes in Guatemala and Thailand. The IBPGR also placed an Assistant in Papua New Guinea from 1984 to 1986 to characterize and document the large sweet potato collections in that country, and IBPGR Interns are assisting the national programme in the Solomon Islands for the same purpose.

In 1980, IBPGR published a Directory of Germplasm Collections of Root Crops (including sweet potato). This Directory was expanded and updated in 1986 and provides detailed information on over 60 sweet potato germplasm collections around the world (IBPGR, 1986a). In addition, an IBPGR Consultant prepared an inventory of existing root crop collections in the Pacific.

In addition to its regular training courses, IBPGR organized a specific training course on sweet potato genetic resources in 1984 for

scientists of national programmes in Latin America. These scientists are now the major contacts for the collecting work carried out by the IBPGR/CIP Collector.

In conclusion these activities can be summarized:

(i) a fairly representative sample of the genetic diversity of cultivated sweet potato of Africa, Asia and the Pacific has been collected, and a start has been made with the characterization of these collections as well as their duplication in designated collections. It is expected that both IITA and AVRDC will continue the latter activity;

(ii) CIP, with IBPGR support in the form of an IBPGR/CIP Collector, has made an excellent start in assembling existing collections in Latin America as well as in collecting substantial diversity of cultivated sweet potato and of its wild relatives. IBPGR support will end at 1 January 1988 and CIP will assume major responsibility for the continuation of sweet potato genetic resources activities in Latin America;

(iii) a major effort has been made by the IBPGR in research on in vitro active conservation and transfer of tissues in vitro (Withers & Williams, 1985).

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A G E N D A

Monday, February 23

Chairman: J. Valle Riestra

08:00 Welcome and Introductory Remarks.
R.L. Sawyer, Director General

08:20 Sweet potato research at CIP.
P. Gregory, Director of Research

08:35 World patterns and trends in sweet potato production and use.
D. Horton

PRIORITIES FOR GERM PLASM EXPLORATION AND COLLECTION

Chairman: W. Collins

09:00 The taxonomy, evolution and genetic diversity of sweet potatoes and related wild species.
D.F. Austin

09:30 Genomic structure and the gene flow in sweet potato and related species.
I. Shiotani

10:00 Break

10:30 Progress in explorations and collections of sweet potato genetic resources - The IBPGR-CIP project.
F. De la Puente

11:00 Discussion - Priorities for germplasm exploration and collection in the Americas.

12:30 Lunch

Monday afternoon

AVAILABILITY OF SWEET POTATO GENETIC RESOURCES

Chairman: A. Jones

14:00 Current status on the maintenance of sweet potato germplasm at CIP.
Z. Huamán

14:20 The U.S. sweet potato germplasm repository.
R. Jarret

14:40 Status of sweet potato collections maintained at AVRDC.
G. Fernández

15:00 Status of sweet potato collections maintained at IITA.
S.Y.C. Ng

15:20 Report on the scope of sweet potato collections maintained in Japan.
S. Sakamoto

15:40 Sweet Potato Collections in Papua New Guinea.
H. Takagi

16:00 Discussion

Tuesday, February 24

STRATEGIES FOR SWEET POTATO GENETIC RESOURCES CONSERVATION

Chairman: R.T. Opeña

08:30 Preservation of sweet potato germplasm as populations.
F.W. Martin

09:00 Current strategies for conservation of sweet potato germplasm at AVRDC.
G. Fernández

09:15 Current strategies for conservation of sweet potato germplasm at IITA.
S.Y.C. Ng

09:30 Review of strategies for overcoming incompatibility and sterility of sweet potatoes.
H. Beaufort-Murphy

10:00 Review of *in vitro* propagation and maintenance of sweet potato germplasm.
J. Dodds

10:30 Break

11:00 Discussion - Guidelines for sweet potato germplasm conservation.

11:45 Discussion - Genetic Resources conservation, collaboration among International Centers.

12:30 Lunch

Tuesday afternoon

UTILIZATION OF SWEET POTATO GENETIC RESOURCES

Chairman: H. Mendoza

14:00 Strategies in sweet potato breeding.
A. Jones

14:30 Use of wild germplasm in sweet potato breeding.
M. Iwanaga

15:00 Breeding sweet potatoes resistant to stress: techniques and results.
F.W. Martin

15:30 Improvement of nutritional and edible qualities of sweet potato for human consumption.
W. Collins

16:00 Review of sweet potato breeding in Japan.
S. Sakamoto

Wednesday, February 25

CONSTRAINTS IN SWEET POTATO PRODUCTION AND UTILIZATION

Chairman: F.W. Martin

08:30 Sweet potato breeding at AVRDC to overcome production constraints and use in Asia.
R. Opeña

09:00 The goals of sweet potato breeding in China.
Shuy Yun Lu and Bo Fu Song

09:30 Sweet potato breeding in a developing country - The Philippines.
F. Saladaga

10:00 Break

10:30 Discussion: Short and long term breeding objectives for sweet potato.

11:30 Discussion: Evaluation needed and strategies for utilization of CIP's sweet potato collections.

12:30 Lunch

Wednesday afternoon

INTERNATIONAL TRANSFER OF SWEET POTATO GENETIC RESOURCES

Chairman: E. French

13:30 Principal bacterial and fungal diseases of sweet potatoes and their control.
C. Clark

14:00 Complex virus diseases of sweet potato.
H.W. Rossel

14:30 Principal virus diseases of sweet potatoes, their control and eradication.
J. Moyer

15:00 AVRDC virus elimination and indexing procedures for international exchange of sweet potatoes germplasm.
S.K. Green

15:30 Importance of nematodes and insects in the international transfer of sweet potato germplasm.
P. Jatala and K.V. Raman

16:00 *In vitro* methods for pathogen elimination and international distribution of sweet potato germplasm.
S.Y.C. Ng and J. H. Dodds

17:00 Discussion - Plant health, quarantine and transfer of sweet potato genetic resources.
E. French / L. Salazar, Chairmen

Thursday, February 26

DOCUMENTATION OF SWEET POTATO GENETIC RESOURCES

Chairman: D.F. Austin

08:00 Genetic resources of sweet potato - IBPGR research.
J.T. Williams

08:30 Descriptors for the characterization and preliminary evaluation of sweet potato genetic resources.
Z. Huamán

09:00 Discussion - Addition or modification of descriptor list for sweet potatoes. Determination of minimum descriptor list for breeder's use.

10:00 Setting up of committees to make recommendations on:

1. Taxonomy, exploration, collection and maintenance of sweet potato genetic resources.

2. Conservation and utilization of sweet potato genetic resources.

3. Quarantine and international transfer of sweet potato germplasm.

P. Gregory, Chairman

10:15 Break

10:30 Formulation of recommendations.

12:30 Lunch

13:30 Visit to the sweet potato collection at La Molina.

14:45 Formulation of recommendations, continued.

Friday, February 27

08:30 Discussion, modification and approval of the recommendations.
P. Gregory, Chairman

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