SWEET POTATO

PROCEEDINGS OF
THE FIRST INTERNATIONAL SYMPOSIUM

Ruben L. Villareal and T. D. Griggs, Editors

PN AAA-078
1455

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Edited by

Ruben L. Villareal *
Plant Breeder
and
Sweet Potato Research Coordinator

T. D. Griggs
Associate Information Officer
and
Head, Office of Information Services

Asian Vegetable Research and Development Center
Shanhua, Tainan, Taiwan, China

1982

* *Presently Professor of Horticulture and Deputy Director, Institute of Plant Breeding, College of Agriculture, University of the Philippines at Los Banos*

Layout

L. S. Cheng and Fred Tsai

Typing

Anna L. C. Tai

Art work and cover design

L. S. Cheng

AVRDC Publication No. 82-172

Printed by

Hong Wen Printing Works, Tainan

SYMPOSIUM OVERVIEW

In the quest for food and the struggle for human survival, the sweet potato has historically played an important role. It has been accepted as a staple crop in several countries, such as Papua New Guinea and certain parts of the Philippines. Years ago sweet potato was recognized as a staple crop in Taiwan.

Daily consumption of the starchy staple type of sweet potato provides sufficient vitamin A to prevent the debilitating diseases caused by deficiency of this vitamin. An intake of only about 13 gm/day of the dessert types, which are higher still in vitamin A, is sufficient to meet the human body's requirements.

Orange-fleshed varieties are utilized for desserts either baked, boiled or canned, and have found a place in the commercial canning industry.

Not only the roots are rich in nutrients. The tender shoots of the sweet potato serve as an important source of vegetable fiber and food in Papua New Guinea and the Philippines. Studies in Taiwan have shown that the tops contain total nutrients equivalent to beef or pork.

Sweet potato is also widely used as an animal feed. In the most primitive situations, roots are cooked by the farmer before being fed to animals. Where more sophisticated technology is available, roots are processed into chips which are more nutritious than corn in hog rations and more nutritious than soybeans in beef rations.

Sweet potato is one of the world's highest yielding crops with total food production per unit area exceeding that of rice and with higher food value. Moreover, it requires only low inputs. Tolerance for limited water and little fertilizer permits production in semi-arid conditions. Acceptable yields of sweet potato are frequently produced with residual fertilizer remaining from a previous rice crop. Because of its high level of nutrition, high productivity and low input requirement, it is a useful component of home or kitchen gardens. In the sub-tropics and tropics, sweet potato is a crop that can be grown the year round, an important factor for struggling families with little real income. It is very adaptable to systems of relay-cropping, intercropping and rotations of various crops. It will flourish in the shade of tree crops.

Looking to the future, there is potential for developing a sweet potato with useful levels of protein. Lines of sweet potatoes currently can contain as little as 0.5% and as much as 23% protein on a dry-weight basis.

Home or cottage industries can easily be adapted to sweet potato. Candies, cookies or rolls can be prepared in one-man operations and sold on a street corner as a source of ready income. The next logical step is the distribution of home or cottage industry products for sale in other areas. This has already been done in Taiwan. The sweet potato is adaptable to more sophisticated technology in which products are canned for desserts, or processed into starch or distilled into butinol or ethanol, with the waste products providing a source of protein for animal feed. Other products,

such as carotene, pectin, and a kind of tempeh which can be produced from sweet potato are of commercial interest in certain areas of the world.

Research in genetics and plant breeding is being conducted in several parts of the world: in the USA at several locations, at AVRDC in Taiwan, in north, west and south Africa. Every effort should be made for germplasm to be available at a central location so that national breeding projects need not worry about the problems of collection. Expeditions should be made to the home of the sweet potato in South and Central America to augment the limited variability of the world's germplasm.

One of the problems in exchanging germplasm, particularly since the sweet potato is propagated asexually, is the potential for exporting disease. Sweet potato pests are not ubiquitous and particular care should be taken to distribute pest-free germplasm. There should be much wider use of tissue culture and meristem culture as a means of developing and exporting propagules with a minimum risk of introducing disease.

Plant breeding is bedeviled with the problems of sterility and incompatibility. Fortunately, some plant breeders have made excellent progress in unraveling some of these mechanisms. Breeding for high protein varieties would seem to be a useful project considering the quite high levels of protein available in certain lines. Further breeding to improve staple types and dessert types as well as types for animal feed could make a significant contribution in certain areas of the world.

An important problem often ignored is the rapidity with which a variety loses its desirable characteristics. It has been considered an advantage that propagules can be collected from a crop and replanted, saving the expense of purchasing high quality seed stock. This can be a serious disadvantage through which inferior, sub-standard low-yield sweet potato entities are propagated. There is a great need for institutions to take on the responsibility of providing high quality propagules and either certified or registered seed to growers in order to maintain high quality germplasm and high levels of production.

Breeding for disease and insect resistance is particularly important in developing countries where the cost of pesticides is often prohibitive. Experiments on weevil resistance started over 40 years ago, but the lack of consistently weevil-resistant germplasm has complicated the research and resulted in slow progress. Nevertheless, there appear to be varieties with significantly higher resistance than others and because of the severity of the problem, breeding programs for improved weevil resistance should continue. The instability and variability of resistance in various plant parts are presumably affected by the rigors of environment. These vagaries necessitate highly sophisticated methods for determining the level of resistance and its reliability. The development of methods for improved reliability would be an important contribution.

The development of a bush-type sweet potato would seem to have some merit: in some trials staking the vines doubled yields. In other trials, there is evidence that pod-borer is less prevalent on erect than on prone vegetative growth.

After a long history of vegetative reproduction of the white potato, research has shown that production from seed shows considerable promise. Has this approach been seriously investigated for sweet potato?

Plant physiologists appear to be making good progress in unraveling mechanisms which control storage of photosynthate in the root, and factors which trigger these processes. Similarily, research has been done on those physiological processes which are altered by plant virus diseases and their vectors. In future, the fruits of this research should permit manipulation of environmental factors for improved production efficiency and higher yields.

The use of rice straw residue as a source of nutrients has stimulated significant increases in yields of sweet potato. Improved utilization of crop residues and compost as sources of crop nutrients is very important. The high cost of fertilizer already prevents its use in some developing countries and escalating energy prices will result in even higher costs in the future.

These are mainly important in that they prevent optimum production of vegetables in general and sweet potatoes in particular. Problems of marketing are generally individual to a situation. The inhibiting factor may be high production costs, high transport costs, inadequate transportation or communication, inadequate packing or an under-developed marketing structure. Economic incentives to the producer are very important in the development of a crop.

Other factors may prevent the sweet potato from being accepted as an important food. These may be lack of expertise in preparation and cooking, or eating habits which do not include sweet potato. Such problems, be they technical, economic, social or historical, must be attacked on a case-by-case basis. Social scientists can make an important contribution in this field by encouraging consumption of vegetables in general and sweet potato in particular.

Considerable technological effort has been put into storing and conserving the sweet potato and its products. It is important that the appropriate technology be identified and promoted in specific areas. Simple solar dryers, for example, could be used in dry seasons in some developing countries. Bulk storage experiments have succeeded in preserving sweet potatoes for five to six months even in sub-tropical environments.

A great deal of technology exists for production and processing and the development of new products from the sweet potato. But in developing countries there is a lack of trained and dedicated people active in extension programs to help transfer this technology. Too often, the basic structure for an extention organization is lacking. Or if not, research and extension are often left uncoordinated. Research is important, but without a means of transferring information to people who need it in a way that is understandable, the practical impact of technology is lost.

A great deal of technology is already available and practical at various levels of development. We need economists, anthropologists, sociologists, nutritionists, teachers and extension people to collect and distribute techniques to appropriate areas. Questions about what to grow, how to grow it, how to prepare and how to cook it, how to process and how to store and dry it, must be answered.

Vegetables in general and sweet potato in particular should rarely be promoted independently from staple crops, but should complement staple crop

production. Crop rotations and integrated crop production have been re-discovered many times during the history of man. In the western world, crop rotation was found to be very important in Europe during the tenth century. It has been forgotten from time to time, was re-discovered in the US during the 1930s and neglected again until the last decade. If agricultural output per unit area is even to come close to meeting the demands of the world's increasing population, still further emphasis will need to be placed on crop rotations and integrated crop production.

There are many advantages of crop rotations, multiple cropping, inter-cropping and relay-cropping. Here are some:

- maximized food production per unit area
- food of higher nutritional quality
- utilization of excess labor (putting people to work and allowing them to eat)
- improved utilization of crop residues and compost as plant nutrients (and thus economy of fertilizers)
- improvement of soil fertility and increased capacity for crop production
- improved soil conservation, reduced water erosion and improved soil stability
- Improved quality of human life. Too often, developing countries emphasize production of staple crops to fill bellies and ignore the need for balanced diets, resulting in an aftermath of widespread nutritional disease. Once a staple food is in good supply, there is usually a program several years later to introduce legumes and vegetables into the rotation. This is inefficient, often encounters resistance, requires expensive re-education and needs decades to accomplish. It can be avoided by introducing an integrated cropping system in the early stages.

There should be increased cooperation between national and international research organizations on sweet potato in order to pool resources on common projects where technology can be benefitted, improved and transferred.

I am convinced that this International Symposium on Sweet Potato raised the level of the data base and the level of understanding of the sweet potato and its value. This will prepare the way for the next giant step in the development of technology. In the meantime, we need to do our very best to disseminate this valuable information for the benefit of the farmer and the people he feeds. He urgently needs our help.

Dr G. W. Selleck
Director, AVRDC

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Sweet Potato in the Tropics — Progress and Problems

R. L. VILLAREAL

Asian Vegetable Research and Development Center, P.O. BOX 42, Shanhua, Tainan741, Taiwan.

INTRODUCTION

After poverty itself, the Third World's most pressing problem is food scarcity. The International Food Policy Research Institute (1977) predicted a bleak future for the world food situation "... the food deficit in the developing market economies is projected to rise from 12 million metric tons in 1975 to 70-85 million by 1990 ... Asia accounts for 40% of the total projected deficit, North Africa/Middle East about 25%, sub-Saharan Africa over 20%, and Latin America over 10%." Equally alarming is the fate of some 15 million of the world's children who die each year of malnutrition and related diseases. Most of this mortality is concentrated in the developing countries, which are home to about 75% of the world's population. Tropical Asia alone has more than half a billion people, without counting those in China and India. Throw in the Chinese and Indian populations (neither China nor India is entirely in the tropical zone) and the figure is about two billion people, one half of the world's population. Even where the "green revolution" has made its mark, many children are malnourished. This is because their diets are largely based on such commodities as cereal grains, cassava, and bananas, all starchy and low in protein. A child's small stomach cannot hold enough of such food to provide the protein the body needs, let alone the necessary vitamins and minerals. It is imperative that man and food should be brought into better equilibrium to avert the threat of starvation and malnutrition on a massive scale.

Food production specialists are generally agreed on four conventional ways to increase food supply and meet the dietary requirements of the people within any country:

1. Increase the amount of land under cultivation.

2. Increase the output of food crops per unit of cultivated land and decrease postharvest loss.

3. Purchase food from outside the country and attract foreign aid.

4. Make use of wild plants.

In the next four days, we shall focus our attention on recommendation number 2 for sweet potato, which is considered to be the world's most underrated crop. I don't intend to labor the point that sweet potato has tremendous yield potential, high nutrient yields per hectare per day and can survive a wide range of adverse environments (Villareal 1977). Rather, I plan to analyze current sweet potato production statistics, examine reasons why it is underrated, review some highlights of work done so far and suggest what work remains to be done on this sadly undervalued crop. In other words, I shall attempt to set the stage for discussion so that the subsequent papers can be better appreciated and understood.

AN ASIAN CROP

Of all the world's root and tuber crops, sweet potato is second only to white potato in importance. It occupied about 13.6 million hectares in 1979 compared to white potato's 18.3 million hectares. Cassava ranked third. In Asia, however, sweet potato is the most important root crop. It was grown on about 12.3 million hectares, representing 92 of the world's sweet potato area, and Asia also accounted for 92 of total production, amounting to 105 million metric tons (Table 1). For that reason the average production per

Table 1. Areas of production, percentage of total world production and average yields of the most important roots and tubers in Asia, 1979

Roots & tubers	Area (1000 ha)	Production (1000 MT)	Yield (kg/ha)
Sweet potato	12,330 (92)	104,617 (92)	8485
White potato	3268 (18)	36,928 (13)	11,300
Cassava	3737 (28)	41,036 (35)	10,980

Source: FAO Production Yearbook 1980

hectare (8485 kg/ha) in Asia is about the same as the world's average (8355 kg/ha). Of the three crops, sweet potato is the least productive on a per hectare basis. It should be mentioned, however, that most if not all of the white potatoes are grown in more favorable environments in the highlands whereas sweet potatoes are generally grown in the hot lowland tropics. Cassava is harvested over about a 12-month period while sweet potato is harvested in less than half that time.

Sweet potato is basically an Asian crop: let us examine then some data on the progress of increasing its productivity in the region. The progress achieved in increasing rice productivity in Asia is very dramatic - 1.5 to 4.2 increase per year (Table 2). In the case of sweet potato, productivity

Table 2. Yield increases of rice and sweet potato over a 16-year period in selected countries in Asia

Country	1963		1979		Change	
	Rice	Sweet potato	Rice	Sweet potato	Rice	Sweet potato
	(t/ha)				( )	
China	2.8	8.5	3.7	8.5	32	1
India	1.4	7.3	1.8	6.9	29	-6
Indonesia	1.8	6.3	3.0	7.6	67	21
Japan	5.0	21.2	6.2	20.0	24	-6
Philippines	1.3	5.0	2.0	4.6	54	-8
Avg	2.5	9.7	3.3	9.5	32	-2

Source: FAO Production Yearbook 1964 and 1980

in most Asian countries except China and Indonesia registered a decrease in yield. China had a negligible 1 increase over 16 years whereas Indonesia increased its national average by 21 over the same period. Among Asian countries, only Japan has an average yield of above 20 t/ha. The lower productivity of sweet potato compared to rice is understandable since most of these countries need staple food to meet the demands of their rapidly increasing populations. Therefore, national programs devote their limited resources to research and extension activities of priority crops like rice. Sweet potato has temporarily attained the status of a staple food in many poor countries unfortunately only in time of war, calamity, and famine. To my knowledge it is only in Papua New Guinea, on Orchid Island off Taiwan and in certain locations in the Philippines where sweet potato is accorded the status of a staple food.

The high yield potential of sweet potato has been mentioned as an important reason why this crop deserves attention. Nevertheless, there is a big gap between experimental yields and farmers' yields of sweet potato, whether it is grown in tropical or temperate environments (Table 3).

Table 3. Sweet potato yields obtained in experimental stations compared with the national average

Country	Potential yield[a]	Farmer's yield[b]	Yield gap	Possible improvement
	(t/ha)			( )
Tropical				
India	37	7	30	428
Philippines	35	5	30	600
Nigeria	32	13	19	146
Temperate				
Japan	35	20	15	75
Korea	43	20	23	115
USA	45	13	32	246

[a]Based on yields obtained from experimental stations (Anonymous 1980; Collins and Pope 1979; Fugise 1970; IITA 1979; Kamalan et al. 1979 and Park et al. 1971)
[b]1979 national average (Source: FAO Production Yearbook 1980)

Realization of experimental yields could mean an improvement of between 75% and 600 . I shall not try to identify the reasons for this yield gap in affluent countries such as Japan and the USA. In poor countries, however, this gap is typical not only for sweet potato but also for other crops, including cereals. Gomez (1980) and Garcia and Gomez (1980) in the Philippines claimed that this could be due to biophysical and socio-economic problems. I think the sweet potato situation fits into this model. The specific constraints on this crop are presented in Figure 1. So what progress has been made to solve or minimize these problems?

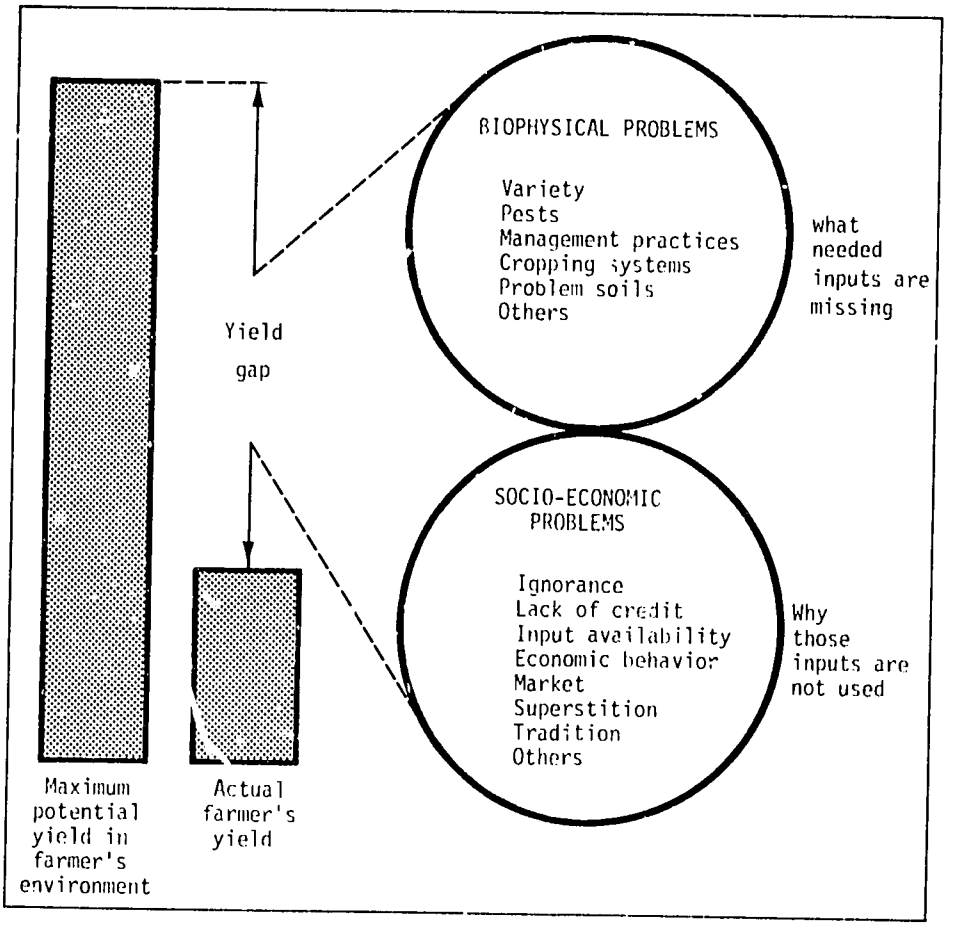

Figure 1. Both yield potential and actual farmers' yields are due to both biophysical and socio-economic problems (Garcia and Gomez 1980; Gomez 1980)

PROGRESS SO FAR

Even before the establishment of the International Institute of Tropical Agriculture (IITA) and the Asian Vegetable Research and Development Center (AVRDC), both basic and applied research on sweet potatoes were being conducted by scores of agricultural experiment stations and universities in affluent nations, and by a few in the tropics. The creation of IITA and AVRDC, however, strengthened research on this crop especially under tropical conditions. These research institutions have significantly contributed to sweet potato improvement.

Biophysical problems

Biophysical barriers to sweet potato production can be overcome using a number of approaches. The variety to be grown must be carefully chosen; protection against diseases, insect pests and weeds must be ensured; and appropriate management practices - land preparation, mulching, fertilizer application and cropping systems - must be selected. I will draw attention to some developments in these areas, but I will leave more detailed discussion to other speakers.

Choice of variety: - One significant breakthrough has been made which has resulted in the rapid progress of the sweet potato industry on the American continent. Methods and techniques have been developed to induce the sweet potato to flower and set seed (Miller 1937, 1939). This technology has enabled sweet potato scientists around the world to study sterility and incompatibility, and the inheritance of various traits such as yield, flesh color, skin color, dry matter, and disease and insect resistance. A fuller understanding of the genetic mechanism of inheritance allows breeders to identify the appropriate breeding technique for the transfer of a useful trait to a commercially acceptable sweet potato line. American scientists should be proud of the numerous outstanding varieties they have released and grown commercially in the United States (Harmon *et al* 1970). Most of these varieties are moist-fleshed and nutritionally high in beta-carotene, a precursor of vitamin A.

In Africa, IITA's sweet potato breeding program has been successful in producing improved sweet potato cultivars which are high yielding, resistant to weevil, virus diseases and drought, and which exhibit good keeping quality under ambient conditions, and high adaptabilities to different environments (Hahn 1979). These improved breeding lines have been distributed to many national programs, for example those in Sierra Leone, Liberia, Cameroon, Zaire, Burundi, the Seychelles, Indonesia and Nigeria.

Japanese plant breeders in Kyushu National Agricultural Experiment Station have succeeded in developing one variety and 17 strains of sweet potato by crossing *Ipomoea batatas* with its wild relative *I. trifida* (Sakamoto 1979). Most of these hybrid materials posses high resistance to rootknot and root lesion nematodes - resistance which was transferred from the wild species. A well-known high starch variety, Koganesengan, with resistance to rootknot nematode, was also developed in Japan (Kawakami and Fuji 1980).

Since the establishment of AVRDC in 1971, its scientists have been involved in the development of more nutritious sweet potato roots and tips, high in beta-carotene and protein, which can be grown with minimum input. We have also experimented with sweet potato varieties for intensive cropping systems such as intercropping, relay cropping and multiple cropping. In 1979, we described in chemical terms our breeding goals for various nutrients (Table 4).

Staple crops are not normally sweet, and we believe that the sugar content of sweet potato may work against its acceptance as a staple crop. Rice contains less than 1% sugar, and wheat and white potato 2%, compared with sweet potato which contains between 8% and 40% sugar on a dry weight basis. We therefore embarked on a program to develop low sugar sweet potato (between 3% and 5% on a dry weight basis). Low sugar sweet potatoes should be more acceptable as a staple, have longer storage life and be more useful as food or animal feed. We now have some high yielding, moderately low sugar lines that await evaluation in several tropical environments. Sweet potato intended to be eaten as a dessert should contain high levels of beta-carotene, and in addition have a texture acceptable to most Asians, who normally prefer dry-fleshed varieties to moist-fleshed ones. Although we have developed several orange sweet potatoes which scored high in eating quality evaluation tests in the Philippines, Bangladesh, Taiwan and Thailand, there is still room for improvement. We have also a series of breeding lines

Table 4. AVRDC breeding goals for various sweet potato nutrients

Nutrients	Sweet potato type[a]			
	staple	dessert	animal feed	industrial
Beta-carotene (mg/100 g fresh wt)	<1	10-15	<1	0
Protein (% dry wt)	5-8	-[x]	5-8	<3
Starch (% fresh wt)	>20[y]	-[x]	>20	>20
Sugar (% dry wt)	3-5	>20	3-5	3-5
Dry matter (%)	23-35	-[x]	25-35	25-35

[a]All types should have white to yellow flesh except dessert type which should have orange flesh
[y]Preliminary goal
[x]Amount is not critical

that appear to meet our criteria for varieties to be used as animal feed and for industrial uses. Several of them have been under evaluation at various locations in the Asian tropics.

AVRDC's philosophy in developing sweet potato breeding lines which require minimum input and which fit intensive cropping systems is compatible with the Center's mandate to serve the rural poor of the Third World countries. The high cost of fertilizers and other inputs necessitate a search for vegetable varieties which can efficiently utilize residue nutrients in the soil after a principal crop has been grown. Several studies indicate that some vegetable crops - especially celery, beans and tomatoes - are more efficient than others in the uptake of mineral nutrients (Gableman and Gerloff 1978). This suggests that nutritional capabilities of vegetable crops can be manipulated genetically. Villareal *et al* (1979) at AVRDC found a number of sweet potato accessions capable of yielding at least 15 t/ha when grown following a rice crop, without extensive soil preparation, irrigation or use of costly inputs. High yielding genotypes survived, yielded and matured more efficiently under these conditions than did low yielding genotypes. Preliminary results indicate that high yielding lines accumulate 45% more dry matter than low yielding ones (AVRDC unpublished data). The impact of a heavy sweet potato crop on the soil and its influence on subsequent crop yields remains to be determined.

Economic pressures force the small farmer to adopt intensive cropping systems. For years, such farmers have been intercropping vegetables, using varieties which have been developed under monoculture. Consequently, their yield levels are generally low. Villareal and Lai (1977) at AVRDC pioneered a study on this problem, concentrating on tomatoes and sweet potatoes. Shading may be the main problem. Large yield reductions occur when sweet potato is relayed instead of being grown in a monoculture. The relayed crop receives only 40-60% of the prevailing solar radiation. Our data suggest that it is possible to select and breed genotypes that can tolerate partial shading and therefore perform better than those varieties bred specifically for monoculture.

It is clear that many outstanding varieties are now available to sweet

potato growers around the world. These varieties, however, require appropriate pest control, management practices and production systems to exploit their yield potential.

Pests: - Sweet potatoes are attacked by various insect pests (Kantack and Cuthbert 1970) and diseases (Martin [illegible] 1970; Martin 1970; Morrison 1970 and Steinbauer and Kushman 1971), but the most serious of them all, particularly in the tropics, is the sweet potato weevil ([illegible] and [illegible]). [illegible] is mainly present in Asia, Pacific Islands and the Americas whereas [illegible] is predominantly found in Africa. Weevil is the only sweet potato pest which seems to have attracted major research attention among scientists. Because of the prohibitive cost of insecticides which can adequately control this pest, the identification and development of resistance to the weevil offers a practical solution. Scientists at IITA have obtained through breeding a number of breeding lines with good resistance to [illegible] (Leuschner 1979), but scientists at AVRDC have not found materials with satisfactory resistance to [illegible]. Thus, developing varieties with immunity or relative resistance to sweet potato weevil, and finding an inexpensive effective control, remain formidable problems for sweet potato scientists.

Among leaf diseases, scientists from AVRDC and IITA have stressed studies on witch's broom and virus diseases (Terry 1979), respectively. Both groups have identified fairly good sources of resistance to these pathogens and these are now being incorporated into various breeding materials.

Management practices: - Sweet potatoes are seldom fertilized or irrigated, and are generally neglected in most parts of the tropics. However, in order to produce a satisfactory crop, the optimum conditions for growth and root development must be provided. For instance, investigations on the nutrient uptake of sweet potato indicate that a crop yielding 15 t/ha removes from the soil about 70 kg of nitrogen, 20 kg of phosphoric acid and 110 kg of potash per hectare (Jacob and von Uexkull 1963) which indicates that at least the same amount of nutrient should be returned to the soil in one form or another. Scientists generally agree that for maximum sweet potato yields the level of potassium in the soil should be increased several times more than the level of nitrogen. AVRDC scientists have observed that rototilled land, compared with land under rice-stubble culture, produces highly significant increases in average root yield, and a highly significant decrease in vine/root ratio (Luh and Moomaw 1979). Fertilizer and weed control significantly increase total root yield, vine weight and the number of roots. Vine turning has no effect. Banking of the soil, compared with no banking, significantly increases total and marketable root yield. During the wet season in 1977, sweet potatoes exhibited excessive vine growth and failed to produce large, fleshy roots. Pruning at one month after planting produced the highest root yields (33% greater than the check). The vine to root ratio for this treatment was 31% lower than the ratio for the check. In a study of the effect of top growth retardation on sweet potato yield, pruning to 20 cm length of the vine appeared to increase root yields during the wet season.

One experiment indicated clearly that the level of soil compaction produced highly significant differences in root yields (Table 5). There was a highly significant interaction between soil texture and compactness. Both AVRDC 35-2 and Tainung 57 cultivars yielded better on compact rather than on non-compact sand, but a non-compact loam gave the highest root yield.

Table 5. Mean root weight (g/flat) as affected by soil texture and compaction, AVRDC, 1978

Cultivar	Sand[a]		Loam		Mean
	Compact	Non-compact	Compact	Non-compact	
	g/flat				
Tainung 57	228	134	144	356	215
AIS 35-2	297	276	161	406	285

[a]Bulk density of the two soils without compaction were 1.6 (sand) and 1.4 (loam)

Cropping systems: - Perhaps it is only in Taiwan where the role of the sweet potato in intensive cropping is fully exploited. It has been a popular intercrop with either rice or sugarcane (FFTC 1974). Local scientists have established the appropriate cultural requirements (such as the type of soil required, the arrangement of planting rows, the time and method of planting, the rate and time of fertilizer application, and field management) to ensure good yield for either combination of crops. In other countries, techniques are not well developed for the commercial cultivation of sweet potato in intensive cropping systems. Nevertheless, there is growing interest among scientists of developing countries in cropping systems involving sweet potato.

Socio-economic problems

Unavailability of inputs or the lack of an adequate distribution system can limit the farmer's yield just as much as the lack of appropriate management practices or the prospect of infestation from weevil. In other words, both the biophysical and socio-economic problems must be dealt with in such a way as to narrow the yield gap between experimental stations and farmers' fields. For scientists (especially for those from the developing countries) it is not enough that we develop the appropriate technology to grow sweet potatoes. We should also encourage farmers to use this technology as producers. To do so they should forget such indulgences as superstition and tradition. We should also make local governments understand the need to introduce practical innovations such as farm credit arrangements and cooperatives, irrigation systems, roads from farms to markets, information networks, and marketing systems for agricultural produce, particularly processing and storage facilities.

WHAT REMAINS TO BE DONE?

Sweet potato scientists and development specialists still have much to do to make sweet potato a popular, productive crop. Problems associated with yield stability, post harvest loss, flower synchronization, diseases other than witch's broom and virus diseases, weevils, management practices in various soil types and environments in the tropics remain to be solved. In addition, there is a need for work on the more effective utilization of sweet potato roots and tips. Along these lines, we should pay attention to problems such as that of sweet potato's trypsin inhibitor content, the flatulence it causes, the difficulty of finding efficient drying methods, the loss of quality in storage, and so on. The answers to most of these pro-

blems will undoubtedly be discussed formally or informally in the next four days of our symposium.

In some Third World countries, development projects are necessary to bring this nutritious root crop to public attention. Luh and Moomaw (1979) summarized some aspects of these needs:

"1. Adequate supply of quality planting materials, to be propagated by dependable sources of named varieties, with varietal description as the first step of development.

2. A well organized scheme through which the transmission of research findings can be effectively applied for profitable crop production. Trained manpower, as well as information prepared in many forms, become indispensable to successful implementation.

3. The appreciation of food value of the sweet potato by the public through various educational processes is an important requirement for development. For example, the nutritive value of sweet potatoes and their contribution to human health should be made more widely known to the general public and the traditional attitude of regarding sweet potatoes as a low-status food for the poor would change.

4. Food scientists, nutrition specialists, biochemists and home economists need to create innovative ways to prepare more appetizing and appealing sweet potato dishes. This will undoubtedly help change people's attitude and encourage their acceptance of the sweet potato.

5. Re-evaluation of the sweet potato in the social and economic context of world hunger may reveal techniques useful to a successful development of the sweet potato around the globe."

THE TAIWAN EXPERIENCE

There are many lessons to be learned from the Taiwan experience that may be useful in food production programs of other countries. In 1952 when Taiwan's yearly per capita income was US$124, 25% of sweet potato utilization went to human consumption, and 60% to animal feed and manufacture (Table 6). In 1939, when Taiwan's yearly per capita income was less than

Table 6. Sweet potato utilization in Taiwan, 1952 and 1978

Use	1952 (1000 MT)	% of Total	1978 (1000 MT)	% of Total
Food	522.6	25	99.6	6.8
Animal feed	933.2	45	919.5	63
Manufacture	313.6	15	291.9	20
Seed	112.1	5	2.6	0.2
Waste	209.0	10	145.9	10
Total	2090.5		1459.5	

Source: Taiwan Food Balance Sheet, 1952 and 1978, JCRR

US$100, about 40% of sweet potato produced was used as human food. In 1978, the increase in per capita income to US$1271 was accompanied by a decrease in the use of sweet potato for food to 6.8% and an increase in its use for animal feed and in industry to 83%. This suggests that as the standard of living has improved, dependence on low-cost food has decreased. It is true that it is called a 'poor man's food' but unfortunately there are a great many poor men who go to bed hungry each night. Based on the Taiwan experience, it appears that sweet potato is a crop that can be relied upon to help alleviate food supply and nutritional problems in countries with low per capita income.

In the past, farmers prepared hog feed from sweet potato using a small hand-operated machine which chipped the roots and chopped the tops. This product was then sundried and stored. Dried roots or tops were then mixed with either commercial feeds or kitchen leftovers and fed to the hogs. More recently, however, labor shortages have meant that an increasingly large number of farmers prefer to buy commercially mixed animal feeds. Although there are still farmers using sweet potato for animal feed, the trend is towards the use of readily available commercial feeds. This is one reason why the area planted to sweet potatoes has gradually decreased from 233,502 hectares in 1952 to 91,749 hectares in 1978 - a 61% reduction - though yields increased from about 9 to 16 t/ha (78%) over the same period. This suggests that in countries where labor is still cheap, sweet potato can economically be used as animal feed as well as for human food, especially by backyard livestock raisers. Naturally, a wider range of uses enlarges the market for sweet potatoes.

To change the status of sweet potato from subsistence crop to market-oriented crop requires a fresh approach aimed at getting this food back onto people's tables. Dr Samson C. S. Tsou (personal communication), AVRDC biochemist, suggests four strategies:

1. Reduce production costs. This means that planting and harvesting (the most labor-intensive operations) should be mechanized as far as possible.

2. Improve yield per hectare in the farmer's field. In 1978, Taiwan's national average was about 16 t/ha, whereas scientists obtained about 52 t/ha in their experimental plots. Dr Tsou believes that a consistent yield of 25 t/ha in the farmer's field would make sweet potato competitive with dry matter yield of other crops.

3. Extend present utilization. As human food for urban centers, sweet potato should be available packaged and ready for cooking with minimum preparation. For feed use, some innovations are needed, such as low-cost drying, an efficient system for collecting produce in a form easily mixed with other feed ingredients, and practical storage facilities which will permit minimum deterioration in quality. Starch yield and quality should be improved so that they will be competitive with other starch-producing crops.

4. Initiate a vigorous program to develop new products. The food processing industry of Taiwan can play a dominant role in pursuing this strategy.

Again, these strategies could be useful to any country where sweet potato may soon become a market-oriented crop.

CONCLUSION

In closing, I wish to reiterate a statement in an earlier paper (Villareal 1977). I share the optimism of my fellow sweet potato scientists that we can contribute to the alleviation of food problems in the developing nations. Certainly, there is no single practical answer to the complex problem of food and population. However, I think Dr Robert F. Chandler, Jr, former director of IRRI and AVRDC, best summarized what he thought could be and should be done, "... The solutions will require intelligent and dedicated leadership by governments, educators and religious leaders, and, of course, most improtantly, the solid cooperation of the general public. Such indulgences as bigotry, superstitution, and even mere parochialism are too costly to human progress to be allowed a place in mankind's scheme. They must be supplanted by liberal, yet realistic, unselfish thinking, unswervingly directed toward the wellbeing of mankind."

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INTERNATIONAL SYMPOSIUM
ON SWEET POTATO
March 23-27 1981-Taiwan ROC

Sweet Potato in Historical Perspective

D. E. YEN

Department of Prehistory Research School of Pacific Studies, Australian National University, Canberra, ACT, Australia. (on leave from Bishop Museum, Honolulu, Hawaii, USA)

INTRODUCTION

The seventh ranking of sweet potato production in world crop statistics (FAO 1978) after wheat, rice, maize, potato, barley and cassava, has been accepted by the International Board for Plant Genetic Resources (IBPGR 1981) as one basis of a proposal for a germplasm conservation system. There are a number of collections in tropical countries that are often of restricted, local varietal interest, or limited in their representation of the potential genetic range of the *Ipomoea batatas* species. Certainly there are allied species that could be of value in breeding research. So the working group on sweet potato of the IBPGR recommended in 1980 a field campaign for conservation of this crop. This approach takes into account both phylogeny and the history of sweet potato dispersal in the world as a major factor in the planning of field collections. The historical theme is the one that will be developed here.

PHYLOGENY

With the development of taxonomic and cytological studies on sweet potato in the early 20th century, it is now seldom questioned that the species originated on the American continent. Botanical genealogy however, is far from settled, and more research is necessary on the wild *Ipomoea* species. The revision of Nishiyama (1971) based on chromosome number and genome analysis defined a *batatas* group in which sweet potato (2n = 90), *I. trifida* (2n = 90), *I. tiliacea* (2n = 60) and *I. leucantha* (2n = 30) form an apparently autoploid series of hexaploid to diploid and provided support to Nishiyama's earlier contention that *I. batatas* was a direct descendant of the wild *I. trifida*. An anatomically differentiated group of different genome constitution was also recognized, comprising the diploids (2n = 30) *I. [illegible]*, *I. [illegible]*, *I. [illegible]* and *I. [illegible]*, while the tetraploids *I. [illegible]* and *I. [illegible]* remain unassigned in terms of genome composition. On two grounds, the relevance of this reorganization to the issue of sweet potato ancestry is questioned.

Cytologically, chromosome behavior in *I. batatas* as demonstrated by multivalency, univalency and secondary association indicates some interspecific hybridization in that species' ancestry (Ting and Kehr 1953; Yen 1974).

Morphologically, the studies of Martin and Jones (1972) on most of the species named above do not demonstrate the direct evolutionary mechanism that Nishiyama's revision suggests, and especially the direct descent of *I. batatas*. The recent taxonomic revision of the *Ipomoea batatas* complex of species incorporates nearly all of the species named by Nishiyama within a single group on anatomical grounds. However, referring to previous work on these species, Austin (1978) indicates the problems that misidentification has posed to theorizing on sweet potato ancestry. As an example, Austin

(1977a) cites the erroneous recognition as tetraploids of *I.* [illegible] (an Australian species) and *I.* [illegible]. Based on revised taxonomic, field and hybridization studies, Austin accounts for these polyploids as results of natural hybridization of the cultivated *I.* [illegible] with a diploid weed, probably *I.* [illegible]. And the hexaploid *I.* [illegible] of Nishiyama is, on Austin's model, the product of the rehybridization of the cultigen with the wild alloploid weed species.

Wider issues of phylogeny are involved in the distribution of the genus *Ipomoea* outside the Americas. Perhaps the most interesting group of species is that recorded for Australia in the tropical north of the continent, Arnhem Land and Cape York, and in the desert region of central Australia. In his review of plants used as food by the aboriginal hunters and gatherers, Golson (1971) lists eight species gathered for their roots or leaves, with two of them, interestingly, for their seeds (Table 1). Meehan and Jones (personal communication) have noted a further and as yet unidentified species exploited for its roots as a secondary food by the Anbara of Northern Australia. Latz (unpublished data) describes the use of three *Ipomoea* species as food among the desert dwellers of the central continent: *I.* [illegible] and a further unnamed species often producing large roots (Figure 1), and *I.* [illegible], the utilized roots of which have no tuberous characters, and of which the seeds are said to be eaten by one tribal group. There is considerable ethnobotanical interest to these species, for two of them, *I.* [illegible] and the unnamed species, are culturally significant. The former is a totemic plant often

Figure 1. *Ipomoea* of the Central Australian desert.
A) A flowering plant of *I.* [illegible]. Diameter of open flower approximately 8 cm
B) Darby Jampiginpa holding the result of 15 minutes' labor, harvesting *I.* [illegible] roots
C) Edible roots of an unknown *Ipomoea* species. Length of largest approximately 16 cm (Photographs: Peter Latz)

Table 1. *Ipomoea* species gathered for food by the Australian aborigines

Species	Region	Environment	Plant part used[a]
I. costata F Muell	Central Australia	desert	tuber
I. coccinea R Br	Cape York (east)	tropic rain forest	root
I. gracilis R Br	Arnhem Land	stream, marsh	root
I. muelleri Benth	Central Australia	desert	root, seed
I. pes-caprae (L) Sweet	Cape York (east)	coast	root
I. pes-caprae ssp *brasiliensis* Oostr	Arnhem Land	coast	root
I. polymorpha Roem and Schult or *I. heterophylla* R Br	Central Australia	desert	root, seed
I. velutina R Br	Arnhem Land	savannah, coast	root
I. spp	Central Australia	desert	greens, tuber
I. sp	Arnhem Land	coast, inland	root
I. graminea R Br	Arnhem Land (northeast)	coastal	tuber
I. abrupta R Br or *I. tuba* (Schlect) G Don	Arnhem Land (northeast)	savannah	root

[a]Differentiation tuberized forms from non-tuberized roots
(Source: Golson (1971) with additional information from personal communications with R. Jones, P. Latz, B. Meehan, N. Scarlett and N. White)

featured in aboriginal myths, and the latter figures in the related phenomenon of 'dreaming', defined by Stanner (1979) as the evocation 'of a sacred, heroic time long ago when man and nature came to be as they are.' Such cultural associations, of course, suggest considerable antiquity for the link between these species and Australian man.

It is unpredictable what contributions that such comparatively distant and isolated relatives could make to future plant breeding for the improvement of sweet potato. And indeed, we do not know how far such species could be domesticated or adapted to often stressful environmental conditions; for agriculture in pastoral and arable forms in Australia has only been developed with the coming of the Europeans. In 40,000 years of prehistory during which populations subsisted as hunter-gatherers, there was a considerable reliance on wild plant foods. Distributed over a wide ecological range, the wild *Ipomoea* represent possible world economic food resources that may remain unassessed for their potential adaptation to desert, savannah and tropical forest regions outside Australia. With the modern trends towards intensive development, particularly mining, in Australia, the aboriginal food plants as part of the natural flora are likely to become endangered species.

SWEET POTATO HISTORY

The construction of the tripartite hypothesis to account for the distribution of sweet potato to Oceania (Yen 1974) is inseparable from the story of its global diffusion from an American origin. Concentrating on the *batatas* section of *Ipomoea* species, Austin (1977b) has suggested that sweet potato originated in the region bounded by the Yucatan Peninsula to the north and the Orinoco River to the south, within which the four major American taxa of the *batatas* group are distributed. My work on variation in *I. batatas* indicated maximum diversity in northwest South America (Colombia, Equador and northern Peru), an area which falls within the origin center postulated by Austin, who also identifies secondary centers of high diversity for Guatemala and southern Peru.

From the ethnohistorical records of Columbus in Hispaniola, of the Spanish explorers and missionaries in Mexico and Peru, and of the Portuguese in Brazil, it is obvious that sweet potato was widely spread through the American tropics considerably before 1492. The plant was further spread by Iberian explorers, and particularly the Spanish in the Pacific in the sixteenth century (Frederici 1929; Brand 1971). With the support of linguistic evidence, these lines of transmission can be traced as follows (Figure 2):

1. The *batatas* line: Portuguese explorers transferred West Indian clones grown in western Mediterranean Europe to Africa, India and the East Indies.

2. The 'kamote' line: Spanish trading galleons between Acalpulco and Manila spread sweet potato clones from Mexico.

These two introductions of the same species from America were to spread, respectively, into New Guinea and the western Pacific Islands, and into China and Japan. The possibility that *batatas* reached China by an overland route through south or southeast Asia cannot be discounted, for by 159[illegible] the plant was recorded in south China (although reported to be from the Philippines), in Taiwan and the Ryukyu Islands by 1597 and 1605, and in southern Japan by 1698.

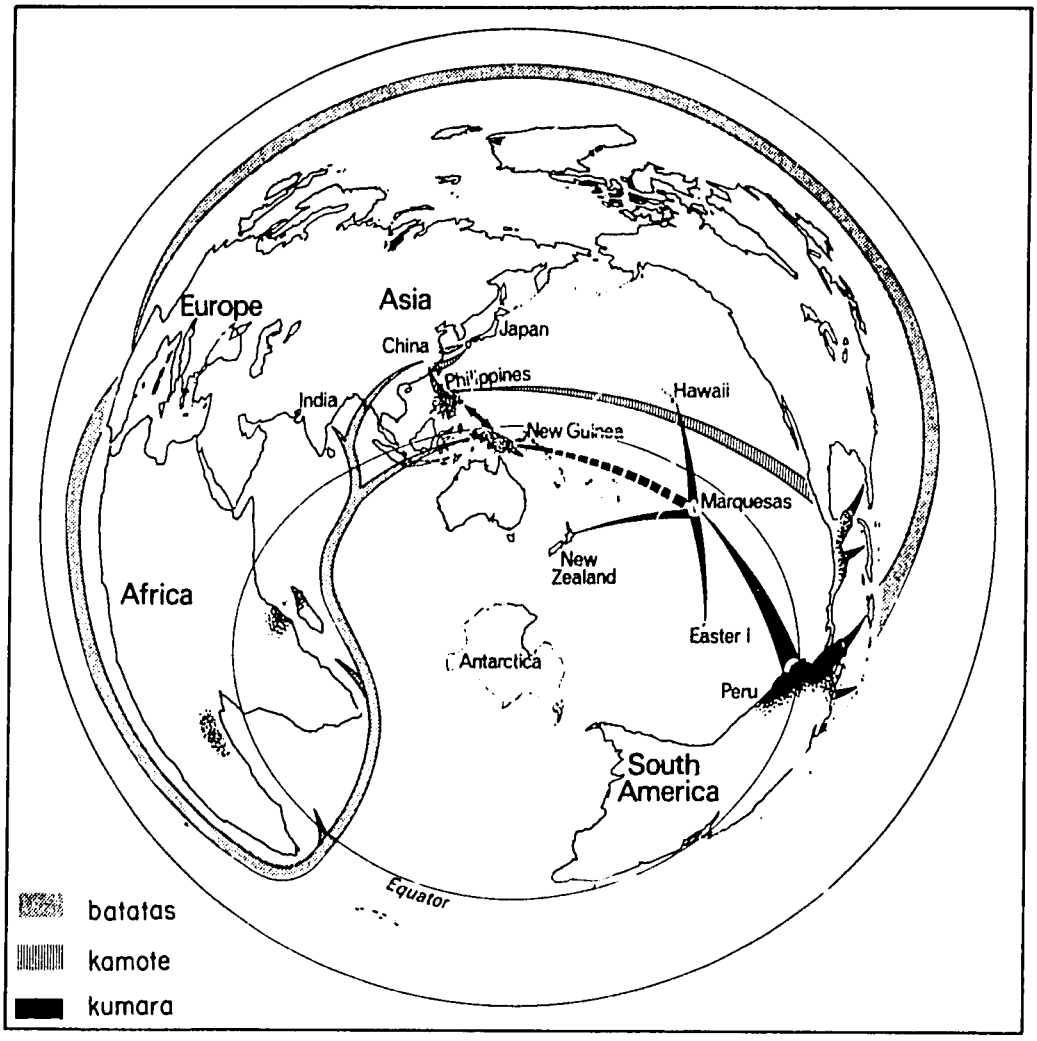

Figure 2. The history of dispersal of the sweet potato from America. The kumara lines are prehistoric, with the transfer from northern South America to eastern Polynesia dated at c 400 AD. The extension of this line to Melanesia through western Polynesia before European contact is the subject of contention. The time-depth of the transfer to the Antilles is unknown. The *batatas* line dates from the first voyage of Columbus, 1492, introducing the plant to western Europe; this line continued after 1500 AD with the exploration and colonization of Africa, Asia and western Melanesia. The kamote line represents the direct transfer by the Manila galleons from Mexico to the Philippines in the 16th century. In the east Asian and western Melanesian area, there have been complex interchanges of sweet potato after early introductions. (Diagram by Winifred Mumford)

The third line is the prehistoric transmission of the 'kumara' line. Here the main and unresolved argument centers on the identity of the carriers of the plant from South America to eastern Polynesia. Lexical parallels between a Quechua name and the Polynesian word kumara suggest human transfer, but whether Peruvian or Polynesian voyagers were responsible is in doubt. The Kon Tiki theory of a Peruvian origin for the population of Polynesia

(Heyerdahl 1952) still retains popular support even though archaeological study in Easter Island, the Marquesas, and the Society and the Tuamotu archipelagoes has done little or nothing to confirm it. Archaeological work throughout the Pacific has in fact tended to consolidate the opposite view that the islands were settled from the west (Asia) at various times in prehistory, and that there was no American Indian input to Polynesian culture. Thus, by this circuituous elimination process, the advent of the American sweet potato into the Pacific in prehistory is associated with Polynesian voyagers in, again, unattested extensions of their exploratory probing across the ocean.

SECONDARY DISTRIBUTION - A MAJOR QUESTION IN HISTORY

The accepted view has been that the prehistoric introduction of the sweet potato into Polynesia never penetrated the Melanesian region, nor indeed western Polynesia and Micronesia. However, a major study into prehistoric agriculture of the Wahgi Valley in the New Guinea highlands by Professor Jack Golson and his colleagues has resurrected the whole issue. Golson (1976a) and Golson and Hughes (1976) have delineated the sequence of agricultural drainage that, since 9000 years ago, has many implications of adaptive evolution of technology to a changing swamp environment. The successive erosional depositions in the swamp within this drainage sequence from upland soils, together with vegetational changes indicated by pollen analysis, have been interpreted as the result of intensifications of slash-and-burn agriculture that have complemented or succeeded periods of intensive swamp cultivation. In the later stages of this sequence, there was a long cessation of drainage of the swamp between 1200 and 350 years ago. With the resumption of drainage at the latter date, the pattern of water control that emerged was similar to the drainage systems still in use today in the New Guinea highlands for sweet potato production (Figure 3). Earlier and simpler forms of drainage have been attributed to cultivation of *Colocasia*, so that the 350-year-old conversion of the aims of water control fit with the

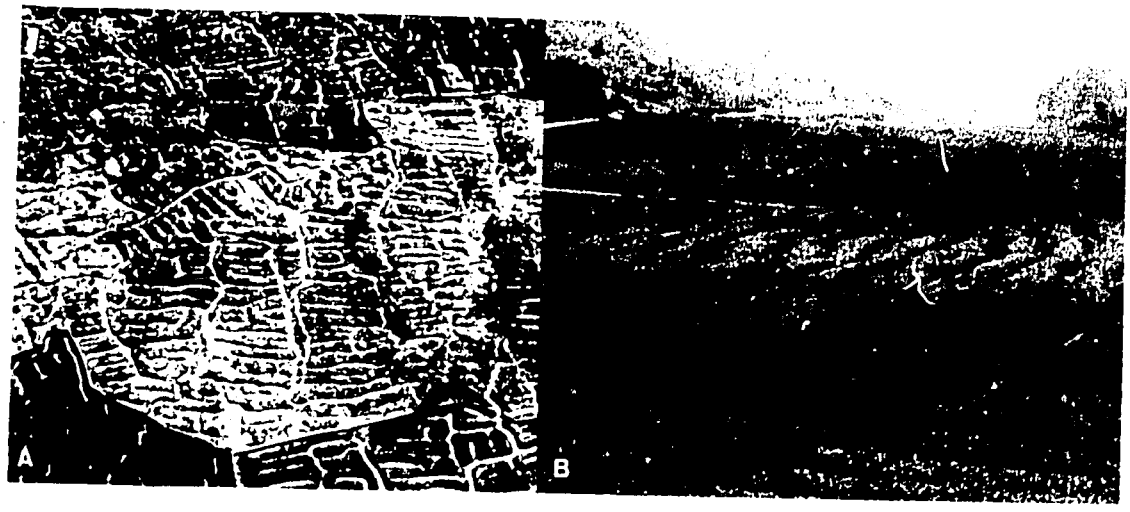

Figure 3. Indigenous cultivation of sweet potato under drainage.
A) The Baliem Valley of central West Irian, Indonesia. An aerial photograph of the complex drainage patterns forming 'island gardens' for the planting of sweet potato. (Photo: J. Golson)
B) Sweet potato fields in Rwanda, Africa, with drainage technique similar to New Guinea systems. (Photo: S. K. Hahn)

putative post-1500 AD introduction of sweet potato through the *batatas* line (Figure 2). However, in a paper presented at the Waigani Seminar in New Guinea in 1975, Golson exploded a minor bombshell for Oceanic archaeology, by stating that some 1200 years ago, sweet potato had already reached the New Guinea highlands. Using the evidence from the Wahgi Valley excavations, the major features of the re-interpretation were:

a. Palynological evidence at 1200 years ago suggested significant increase in the clearance of natural forest that resulted in the rise in importance of species that are now planted or conserved in garden fallows under sweet potato cultivation regimes.

b. Such clearing could coincide with the advent of sweet potato, which would extend the scope of cultivation because of its adaptations to sloping ground and relatively higher altitudes than the more traditional cultigens such as *Colocasia* and *Dioscorea*.

c. The soil depositional evidence that marks the cessation of drainage at 1200 years ago is interpreted to be a consequence of widespread forest clearance for sweet potato production.

Fuller expositions of the evidence are available in Powell *et al* (1975) and in Golson (1976b). In the latter paper however, Golson cautions against the complete acceptance of the earlier advent of the sweet potato in New Guinea, but indicates that future interdisciplinary work could settle the question.

The conservative view of recent introduction into Melanesia (Hendren 1976; Green 1976) has undoubtedly been spurred by my own rather equivocal treatment of a combination of plant variation study and data from historical sources (Yen 1974). However, in the face of Golson's hypothesis, though as yet unproven, it may be instructive to test the plant and re-examine other ethnobotanical lines of evidence to see if there is support for an extension of the prehistoric introduction of sweet potato from Polynesia to Melanesia. For without this possibility, it would be difficult to account for the presence of the plant in the Wahgi Valley 1200 years ago.

Plant variation

In a survey of 42 characters, Yen (1974, 1971) indicated that differences which might distinguish the Polynesian and Melanesian cultivar populations are obscured in the border islands because of the exchange of germplasm. The most plausible explanation for this mixture seems to be found in the plant introduction activities of missionaries, often recruited in western Polynesia for the Melanesian missions.

Lexicology

The same missionary source has been attributed to the variants on the Polynesian word kumara for sweet potato recorded in the Melanesian islands, including Tawala in the Louisiade Archipelago, eastern New Guinea (Yen 1974). It may be contended that the name accompanied the plant in prehistoric times.

Historical records

Sweet potato does not figure in early European records of western Polynesia, though other root crops like *Dioscorea* yam and *Colocasia* taro are specified. The exception however, is Tonga, where a European settler called Mariner (1818) specified the presence of 'kumala' in the late 18th century. The records of Cook's 1773 landings on Tonga (Beaglehole 1961), and the account (Heeres 1898) of Abel Tasman's discovery of the island in 1643 make no reference to sweet potato, so that its presence at that time cannot be substantiated, though unspecified roots other than yam are mentioned by earlier chroniclers.

There are some Spanish records from first landfalls in the Pacific that may have been unjustly dismissed as misidentifications. The eyewitness account of Magellan's discovery of Guam and the Philippines in 1521 (Pigafetta 1969) includes reference to kamote as an agricultural product at both landfalls. Mendana's illfated 1595 expedition to Santa Cruz in the eastern Solomons offers a description by Quiros (Markham 1904) of 'three or four kinds of roots', one of which 'has a sweet taste, the other two prick a little when eaten'. It is difficult to relate this to any Oceanic root crop other than sweet potato. In Legaspi's account of the discovery of Majit, an island in the northern Marshall Islands in eastern Micronesia (Sharp 1960), the plant is mentioned again. However, in another translation (Blair and Robertson 1965) the relevant passage is translated as 'they are engaged in vegetable gardening from which they got some roots with which they make bread'.

Ethnographic record

In recent fieldwork in the eastern Solomons, informants on Santa Cruz and Polynesian-speaking Tikopia claimed independently that the present forms of sweet potato are of recent introduction, but previously there were inferior varieties of unknown origin. This information is not uniform throughout the area and might well be ignored, but together with the reports mentioned above it could support the idea of a prehistoric penetration of sweet potato from Polynesia to Melanesia.

SWEET POTATO ADAPTATION

The adaptability of the sweet potato in the tropics to a wide range of edaphic and climatic conditions is amply demonstrated in Oceania. On atolls, raised coral reef islands, volcanic islands and continental land masses, the plant is seldom absent from cultigen rosters. The human element, however, has been important in the history of adaptation, both socially and technologically.

The technologies applied to the cultivation of sweet potato, in keeping with its adaptability, are usually simple and fit well into the common shifting mode of slash-and-burn and digging stick agriculture. Nevertheless, there are cases of environmental modification through more intensive methods of cultivation that seem to be correlated with situations of natural ecological stress. One conspicuous example is the drainage system in the swamps of highland New Guinea (Figure 3a) mentioned above. In such environments, which may be described as marginal for tropical agriculture, drainage systems thought to be developed for the culture of *Colocasia* taro were further deve-

loped for sweet potato. The crop was finally to dominate the more permanent drained fields as well as hillside shifting agriculture in New Guinea.

There is an interesting case of parallel agricultural development in Africa. Hahn (personal communication) has observed similar drainage practices for sweet potato in the inland valleys of Rwanda (Figure 3b). Is this also a case of a post-Columbian development? Again, history gives us a cloudy answer, for Columbus (Jane 1960) says that the roots that tasted like chestnuts in Haiti in 1492 he had already found earlier in Guinea, implying an older, trans-Atlantic introduction from America.

The highlands of New Guinea offer the greatest variety of agronomic adaptations for growing sweet potato in permanent and semi-permanent or long rotational fields, as well as in shifting fields (Figure 4a) usually on montane slopes (Brookfield 1962).

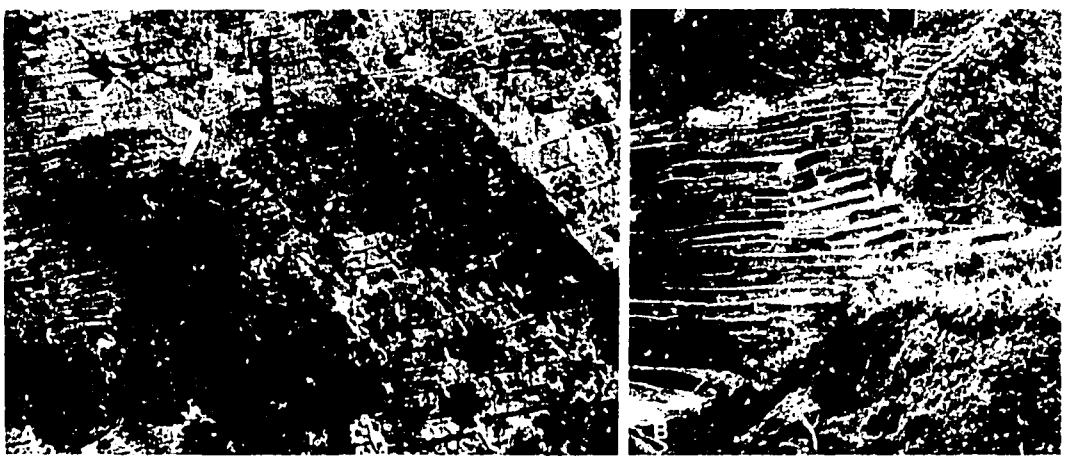

Figure 4. Mountain slope cultivation of sweet potato.
A) The walled gardens of the mountain slopes of the Baliem Valley, West Irian, complementing production of sweet potato on the valley swamps (Photo: J. Golson)
B) The integration of slope production of sweet potato with irrigated rice terracing in Ifugao, Philippines. Secondary growth vegetation on the slopes marks earlier sweet potato fields, while current plantings can be seen on right upper part of photograph, marked by rows across the slopes. (Photo: H. C. Conklin)

In New Zealand, the Maori overcome the problem of cold by growing sweet potato strictly as an annual crop. Roots are kept in ground pits for winter consumption and as propagation material. This is an early development of postharvest treatment of the crop. Also, the Maori have developed 'kao', a dried product from cooked roots, as a storable food. The potential of processed roots was probably most fully realized in south China, for in addition to a kao-like product used there as a confection, farmers developed storable forms of flour, sago-like granules and dried flakes.

The most important human-influenced adaptation of sweet potato has been its integration into agricultural systems the diversity of which is only hinted at by the variations of environments. It is a comparatively easy crop to grow, and in the tropics it exhibits no strict seasonality, so that it can be combined in mixed fields with other tubers or roots, vegetable species and

even grain, as in the rice swiddens of the Hanunoo (Conklin 1957) in the Philippines. It is a constant provider of farinaceous staple, and is often integrated into indigenous cultivation cycles with a secondary role as a feed for livestock, often occupying inferior land. A number of examples of such integration have been described (Yen 1974), but recent research on the Ifugao people of central Luzon merits special notice. In what must be one of the most sophisticated subsistence systems extant, sweet potato occupies a key role in a food production cycle which emphasizes, both technologically and ritually, the spectacular pondfield rice (Figure 4b). Conklin (1980), in his household survey, records an average consumption ratio of 40 rice: 38 sweet potato. In the richest central valleys he calculates that the proportion may reach 5:1 in favor of rice, but in the more marginal steeper territories, this ratio is reversed to show a marked sweet potato dominance of the diet. The contribution of the root and green tops to pig husbandry is not taken into account in these calculations: the importance of the sweet potato to this economy is clearly very great.

The positive, if indirect, cultural role of the sweet potato is patent in this example as it is in pig-raising in Papua New Guinea, for the pig figures as a major material constituent in the ceremonial cycles in both regions, albeit in different manifestations. However, in many parts of Oceania, and particularly in tropical Polynesia, the status of sweet potato as human food is often as low as in Asia. We have already observed that in Polynesia, the plant only achieved dominance at the apices of the Polynesian triangle. It was the one tropical crop brought to New Zealand from the tropics by the Maori that could be adapted to the temperate seasonal conditions, and was thus to lose its inferior food status immediately. Easter Island was a somewhat similar case, for although taro and yam grow there, sweet potato was a more reliable producer in the inclement although subtropical climate. Hawaii, on the tropical margin, presents a more complex situation that is partially shared by New Zealand and Easter Island; as one of the last archipelagoes to be settled in Polynesia, the sweet potato probably arrived with the first men from eastern Polynesia, at the same time as taro and yam. In such competitive circumstances, the relative merits of the three root crops were more easily recognized. By contrast, in the case of tropical Polynesia, the sweet potato entered into already established systems emphasizing the traditionally important yam-taro complex that so fitted into the environmental dry-wet categorization of adaptation that Barrau (1965) has pointed out. In Hawaii, the formed systems incorporated pondfield taro and specialized areas for yam-growing, while sweet potato shared a dominant role as human and animal food (Handy 1940; Handy and Handy 1972) in more marginal areas. It is significant that in Hawaii, Easter Island and New Zealand, though not elsewhere in Polynesia, sweet potato is embedded within native tradition and origin stories, and was the subject of agricultural ritual. It is an interesting confirmation of the effect of crop precedence, that from the New Guinea highlands to island Melanesia, there are only a very few examples of the entry of sweet potato into folklore that may still be recorded for yam and taro. A similar situation obtains in Ifugao, where rice and taro are the principal symbolic plants in ritual (Conklin 1980), again reflecting precedence over sweet potato. In more highly stratified societies such as pre-revolutionary China (Yang 1945) the low status of sweet potato as a food mirrored directly the economic level of consumer classes.

In 25 years of fieldwork in tropical Oceania, this writer has observed an increasing dependence on sweet potato in the subsistence sectors of the

changing economies. The shift from subsistence to commercial agriculture (Yen 1980) has emphasized the qualities of sweet potato over the other traditional crops, largely in terms of relative labor inputs and the proportion of that input that can be diverted to cropping for cash. Where populations are increasing, the productive capacity of sweet potato is testified to by the preference shown to it over previously important root and tree crops, now often only secondary components in cropping systems. Where populations are decreasing due to emigration as on the Cook Islands (Ward and Proctor 1980), sweet potato is grown because it requires less labor than other root crops such as taro.

While difficult to quantify, it appears that prejudice against the human consumption of sweet potato, at least in Oceania, is declining in the face of continuing economic change. Already, production has become commercialized on a small scale in many places and sweet potato, and that other great American root crop, manioc, are likely to become dominant as prejudice against them declines. Papua New Guinea however, provides an interesting example of change in food prejudices. While sweet potato, sago and taro were the dominant, predevelopment food, preference is now changing with increasing cash earning and urbanization, to imported rice. This is a noticeable trend in many Pacific countries (Castle 1980), and efforts to counteract it by increasing acreages of root crops, especially sweet potato, by processing to add the storage of quality of rice to tuberous crops, and even by import control, have so far met with little success.

The potential of root crops to produce energy is a topic that figures in most reviews for economic development in the Pacific. But in the case of the small islands, the problems of production scale and of achieving self-sufficiency in food perhaps overshadow the economics of conversion technology. On the larger land surfaces, and especially New Guinea, the choices are wider, with the uses of *Metroxylon* sago and other palm sources in wild and cultivated swamp stands as the most conspicuous alternatives for energy production that will detract little from other agricultural development.

SECONDARY CENTERS OF VARIATION

Genetic adaptation of sweet potato is also significant. Although its distribution through the tropics is recent in terms of world agricultural history, and its reproduction in cultivation is universally vegetative, the potential for occurrence and selection of new variations may be quite high in regions where the plant has become widely adapted. There is no evidence for the loss of sexual reproductive capacity, and accidental seedling selection has been recorded in many instances from the Pacific region, from Asia and from America. Indeed, the hundreds of varieties recorded among subsistence farmers in areas like the Philippines and New Guinea owe their existence to accidental seeding, rather than to somatic mutation, or to varietal exchange between areas, and certainly more than to original introduction. The heterozygous nature of sweet potato clones, and the virtually obligatory outcrossing breeding system together allow for a wide range of genetic recombinants with natural seed production. The biological nature of the species combines with its agronomic treatment in areas of dominance (high plant population) to allow for the preservation of new and perhaps unmarked variation in local gene pools. Such variation may be the result of mutation or the effect of genetic drift from relatively narrow variability in the original founder populations. Vegetative propagation is a conservative

mechanism, but accidental seedling selection has the opposite effect. The alternation of generations in sweet potato is considerably affected by the fact that, in the tropics, two and three plantings per year are common, so that the opportunities are greater for mutation and for new variability from other sources than in strictly annual crops. However, this process has not led to geographic speciation - nor indeed has the influence of sexual reproduction led to greater diploidization of chromosomes in meiosis anywhere except in some of the highly bred and selected North American cultivated varieties.

In Yen's (1974) analysis of cytological, morphological and physiological characters in his sweet potato collection, there is some evidence for new variation in the species. In both American and Polynesian collections, glabrous reproductive organs were absent, while this character was evident in Asian and Melanesian varieties. With the more economic character of specific gravity of roots, one variety from eastern Polynesia showed a significantly lower reading than any in the entire collection. Of course two aberrants out of 42 characters measured may be due to sampling, or simply to the unusual expression of multifactorial inheritance affecting those characters. But they could signify the possibility of new genetic variation, some of which might be peculiarly adaptive to the new environments to which the species was transported.

Considerations like these have formed the basis for the planning of the world collection of sweet potato germplasm (IBPGR 1981), in which secondary centers of variability - New Guinea, the Philippines, and parts of Africa - will be the focus after initial exploration in Central and South America is completed.

CONCLUSION

Plant improvement and inheritance studies could both benefit from a knowledge of the history of sweet potato distribution. With developments in genetic engineering, possibilities of incorporating desirable traits from other species seem less remote than they once were.

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Sweet Potato as A Supplemental Staple Food

T. H. YANG

Department of Agricultural Chemistry, College of Agriculture, National Taiwan University, Taipei, Taiwan.

INTRODUCTION

Sweet potato, rice and sugarcane were for many years the three main crops in Taiwan. Sweet potato supplied 11% of the average caloric intake of Taiwan people in 1958 (Yang and Blackwell 1961). Its importance was especially marked in the rural areas where sweet potato supplied 44% of the total caloric intake. Sweet potato was cooked alone or cooked with rice and served as a staple food. In addition, sweet potato in the past has been the main food energy source for animal production. The importance of sweet potato as human food has been gradually replaced by imported wheat. Increasing consumption of animal products (Yang *et al* 1975a, 1977), fruits and vegetables also cut down the consumption of sweet potato and rice. According to a recent dietary survey (Hsieh *et al* 1976) the consumption of sweet potato as part of the human diet in Taiwan has decreased to less than one-third of its former level. Accordingly, the annual production of sweet potato has decreased to less than half of its peak level (JCRR 1976; PDAF 1978).

PROTEIN CONTENT AS AFFECTED BY VARIETIES AND CULTIVATION PRACTICES

The protein content of sweet potato and its quality are two of the most important factors that deserve attention in using sweet potato as supplemental staple food and feed. In 1967, my laboratory assistants collected locally-produced sweet potato from many agricultural stations and analyzed them for crude protein (Yang *et al* 1967a). Among the varieties evaluated, Okinawa 100 had the highest crude protein (4.8 to 7.5% dry weight). Other examples are: Tainung 57 (3 to 6.3%), Tainung 60 (3.1 to 6%), Hong-Hsin Wei (3 to 4.7%), Tainung 45 (2.5 to 4.9%), Tainung 31 (3.2 to 4.3%), Hsin-Tsu 1 (2.9 to 4.7%), and Tainung 59 (4.2 to 2.9%). In a separate experiment, our results indicated that the crude protein and lysine - first limiting amino acid in cereals - levels were significantly influenced by variety and location of cultivation. The lysine level of sweet potato crude protein varied from 2.5 to 5.7% and threonine - the second limiting amino acid in cereals - from 2.6 to 4.9% (Yang *et al* 1975b).

We noted a wide variation of the above data even for the same variety. Therefore, to minimize the variation due to location and cultivation practices another study was carried out under controlled conditions in one location (Yang *et al* 1976). Five varieties of sweet potato (Tainung 60, Tainung 57, Hong-Hsin Wei, 70 Ju-Chao and Okinawa 100) were grown under four fertility levels as shown below:

Code	Fertilizer rate kg/ha
Control	Zero
Low	40 N - 20 P - 80 K
Medium	80 N - 40 P - 160 K
High	120 N - 60 P - 240 K

The sweet potatoes were harvested at 161 days (short term) and 192 days (long term). In four of the five varieties, the highest root production both on fresh and dry weight bases was obtained at the medium fertility level, with one variety reaching highest root yield under low fertility. On the other hand, the crude protein content of the root was proportional to the level of fertilizer. Root production was increased by delaying the harvesting to 192 days. However, the crude protein content was decreased by this delay. Starch accumulation was mainly responsible for the higher yield of the 192-day crop compared with the 161-day crop.

The lysine level was decreased with increasing levels of fertilizer, in spite of the increase of crude protein content in the high fertility treatments. Prolongation of the cultivation period decreased protein lysine and threonine content. On the other hand, the aspartate distribution was increased as the level of fertilizer was increased in the short term crop. The results indicated that the increased crude protein content with increasing amount of fertilizer may be explained mainly as an increase of protein with relatively higher aspartate level. In the long term crop, three of the five varieties (Tainung 60, Hong-Hsin Wei and 70 Ju-Chao) showed a drop of aspartate level. This phenomenon indicated that considerable amount of protein decomposition with relatively higher aspartate occurred with prolonged crop duration. The methionine level increased with increasing fertility levels and by prolonging crop duration. Results of these studies also revealed that the lysine level of sweet potato is higher than that of rice and wheat flour.

Free amino acid content levels showed the same response as that of methionine. Ammonia N/total N ranged from 0.03 to 0.06% in three of the five tested varieties, and the other two varieties ranged from 0.11 to 0.17%. Ammonia decreased with extended crop duration. Nitrate N/total N ranged from 0.06 to 0.3% among the varieties and cultivation conditions. Nitrite N/total N ranged from 0.002 to 0.007% in the short term crop and from 0.004 to 0.01% in the long term crop.

BIOLOGICAL VALUE OF SWEET POTATO PROTEIN

Protein quality of the staple food is another important aspect of nutrition. Therefore, we decided to determine the biological value of dietary protein by feeding six-week-old male and female rats with a sweet potato diet supplemented with either a high level of wheat flour or of rice.

Protein true digestibility of precooked high rice and precooked high wheat flour diets slightly decreased with the substitution of 30% precooked sweet potato. The use of 30% dried sweet potato corresponded to substituting 25.5% crude protein of rice, wheat flour or their mixture. The biological value increased from 72 to 80 for male and 65 to 71 for female rats when 30% of wheat flour was replaced by sweet potato. The same trend was observed when part of a high rice diet was replaced with sweet potato; there was an increase in biological value from 87 to 89 for male and 80 to 83 for female rats. The results paralleled the earlier observation by showing that sweet potato roots have a higher lysine level than either rice or wheat flour - especially than the latter. Lysine is the first limiting amino acid of rice or wheat flour protein.

Our nutritional study on rice and sweet potato for the improvement of

the Taiwanese diet indicated that 13% equicalorie sweet potato substitution in place of rice enhanced human nitrogen balance (Yang 1966; Yang *et al* 1967b). The same treatment prolonged the longevity of tested male and female rats (Yang 1977).

EFFECT OF PREHEATING RAW SWEET POTATO FOR THE ELIMINATION OF TRYPSIN INHIBITOR

A study on the effect of heat treatment on the nutritive value of sweet potato was conducted with a view to enhancing the utility of locally produced sweet potato (Hseu *et al* 1979). The results obtained from pair-fed rats and rats fed *ad libitum* revealed that the feed containing preheated sweet potato resulted in higher feed efficiency, nitrogen retention and growth rate than the feed containing unheated sweet potato. The raw sweet potato contained trypsin inhibitor and thus lowered protein digestibility of the feed mix containing soybean oil meal, wheat bran and raw sweet potato material. This trypsin inhibitor could be destroyed by preheating raw sweet potato. The times needed for the destruction of the inhibitor in raw sweet potato extract were 120, 60, 30, 15 and 10 minutes when heated at temperatures of 90°, 100° and 120°C, respectively.

ENHANCEMENT OF SWEET POTATO AS A SUPPLEMENTAL STAPLE FOOD

Several studies were conducted in Taiwan to enhance the intake of sweet potato together with rice and wheat flour in the form of dumplings, cakes, cookies and other pastries (Lu 1977; National Taiwan University unpublished data).

CONCLUSION

Sweet potato has contributed to the Taiwan diet as a staple food in the past. Potentially it could be a very valuable supplemental staple in other developing countries. Our studies have shown that sweet potato is an excellent supplemental staple food to cereals such as rice and wheat flour. Although the crude protein content and the amino acid pattern of sweet potato protein varies depending upon cultivar, environment, cultural management and growth duration, it is generally high in lysine and is a good supplemental protein to cereals. A high protein sweet potato line given optimal fertilizer application can promote the role of sweet potato in the human diet as a supplemental staple. Studies further support the view that substituting 30% of rice and wheat diets with sweet potato enhances the biological value of dietary protein. Although a slight decrease in protein digestibility is also observed, replacing 13% dietary energy from rice by sweet potato enhances human nitrogen balance in the Taiwanese diet. This treatment also prolonged the longevity of tested male and female rats. Cooking sweet potato, however, is necessary for good digestibility. It is proposed that the low digestibility of raw sweet potato could be due to the trypsin inhibitor present in the root.

ACKNOWLEDGEMENT

The author wishes to express his profound appreciation to the following for their inspiration, guidance, assistance and cooperation in the conduct of his studies in sweet potatoes: Dr Shih-Liang Chien, Dr Chen-Hsing Yen, Dr Ko-Chang Hsieh, Dr Ching-Chung Hsu and all agricultural professionals of

Taiwan. The author is also grateful to the National Science Council, Joint Commission of Rural Reconstruction, US Department of Agriculture and US Naval Medical Research Unit No. 2 for their financial aid in his studies.

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Nutritive Value of Sweet Potato

P. C. HUANG

Department of Biochemistry, National Taiwan University, Taipei, Taiwan

INTRODUCTION

Sweet potato contains approximately 20% starch and 5% simple sugar, and is generally considered as a high energy food. In some parts of the world it is the staple crop. It also provides a considerable amount of vitamin C (20-30 mg/100g), and deep yellow varieties of sweet potato can provide sufficient pro-vitamin A carotenoids for health, if eaten in quantity. However, overall the variation in carotene content is great (0-8000 IU/100g). Vitamin B_1 (thiamin) is also present in adequate amounts in terms of calories, 0.8-1.0 mg/1000 kcal, about twice the level required by humans. Potassium (200-300 mg/100g) is known to be the predominant mineral present, and iron content (0.8 mg/100g) is sufficient for sweet potato eaters who consume 2 kg or more per day. However, sweet potato is a starch root and contains very little fat (0.1-0.2%). The content of protein (mainly in the form of a kind of globulin) is generally low, providing about 4-6% of the total calories (1-2% on a wet weight basis), although sweet potato's essential amino acid pattern is reasonable (chemical score: 80) and the limiting amino acid is leucine. According to some food analysis tables, sweet potato is giving a chemical score of 65, with sulfur-containing amino acids listed as the limiting ones if compared with the FAO/WHO reference pattern (1973). It is reasonable to assume therefore, if sweet potato contributes more than 90% of the total calories intake in any diet, protein deficiency is likely to occur. Therefore, sweet potato eaters have to supplement their diets with some protein-rich food such as fish, a practice adopted by aboriginal Lan-Yu tribesmen living on Orchid Island - a small island southeast of Taiwan.

Between 1960 and 1970, several studies conducted in New Guinea reported that the sweet potato eaters of the New Guinea highlands were healthy, although a considerable negative nitrogen balance was recorded for them every day. The investigators proposed that the intestinal bacterial flora of these sweet potato eaters were able to fix gaseous nitrogen and provide amino acids for the host; an interesting story but hard to accept. Our studies have indicated that this conclusion was erroneous (Huang et al. 1979).

We enlisted the help of nine young Yami tribesmen from Orchid Island between 16 and 24 years of age. They were given sweet potato diets (steamed sweet potato of variety Tainung 57) which supplied 80 to 99% of the total calories and 75 to 91% of the total protein in two separate experiments. Experiment 1 lasted 32 days and Experiment 2 lasted 53 days. In Experiment 1 and during the first 36 days of Experiment 2, nitrogen (N) balance studies with the seven teenage boys in the group were conducted with 0.67 and 0.71 g of protein per kg of body weight, respectively. Theoretically teenagers should show positive N balances. However, results of the N balance study, taking into account skin N loss, were -0.5 mg N/kg/day in Experiment 1 and -3.2 mg N/kg/day in Experiment 2. Protein digestibility was about 70%. Plasma urea N decreased from between 8 and 11 to between 2 and 3 mg/100 ml, and the plasma free amino acid pattern showed some abnormality, in that valine, isoleucine and leucine decreased significantly. This indicates some degree of protein depletion in the teenagers. On the other hand the two

adults who were given 0.63 g/kg of protein did not show such results. In other words adults may be able to get enough protein to meet their minimum requirement when fed about 2.5 kg of sweet potato per day, supplemented by a small amount of fish and vegetables. We were also able to show that the feces of the sweet potato eating subjects were not able to fix N under either aerobic or anerobic conditions. The conclusion of this study is that sweet potato alone is not able to maintain adequate protein nutrition in subjects of growing age. But it is not as deficient as some people consider, who feel that it has no value at all from the viewpoint of protein nutrition. The extent of negative N balance is not as great as reported by some investigators. For adult sweet potato eaters the protein nutrition status is marginal, and no apparent sign of protein deficiency, except a tendency to tire easily, may be seen after feeding for as long as two months. However, due to high dietary fiber content the fecal volume was huge, averaging about 800 g on a wet weight basis per day.

Recently, we have tested the hypocholesterolemic effect of various dietary fiber-rich vegetable foods in rats and found many of them, including leafy vegetables, legumes and bamboo shoots, were able to lower serum and liver cholesterol if given in sufficient amounts. Therefore, we also tested four varieties of sweet potato for this effect. Dry sweet potato powder was incorporated into 20 casein rat diets at a level of 20% together with 1% cholesterol. After a four-week feeding period, rats were killed and blood and liver were collected for analysis. Sweet potato did not cut down on serum cholesterol and total lipids as much as other vegetables. However, one variety of sweet potato, Peng Hu, was found to decrease both serum cholesterol and total lipids significantly.

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Resistance to Eating Sweet Potato

S. C. S. TSOU and R. L. VILLAREAL

Asian Vegetable Research and Development Center, PO Box 42, Shanhua, Tainan 741, Taiwan.

INTRODUCTION

There are barriers against the consumption of sweet potato particularly in the developing countries, where the crop could be most beneficial in alleviating malnutrition and starvation. Food preference is a complex subject and cannot be analyzed simply. Sweet potato is one of many nutritious foods which are overlooked by consumers in underdeveloped countries. Most of these foods fail to meet certain important requirements in their production, processing, distribution, storage, preparation or cultural acceptance. Utilization of these crops is less advanced than that of cereals, and the factors working against their consumption vary from crop to crop. Sweet potato has been consumed in many parts of the world for centuries, yet it remains a 'survival crop', or a food for the last resort. People will eat it only when they are on the verge of starvation. When better fed, consumers shift to other crops.

The primary purpose of this paper is to analyze the resistance to eating sweet potato.

STAPLE OR VEGETABLE?

A question that has been repeatedly asked is whether sweet potato is a staple or a vegetable. It can be considered either depending on the point of view. For example, eaten with simple kitchen preparation and as a supplement to other foods, it is classified as a vegetable. When used as the principal food, it falls into the staple crop category. Since this is controversial and sweet potato is primarily an Asian food, we will follow the Asian way of food classification into three groups: main food, supplementary food, and luxury food (sometimes called food for pleasure). Main foods are staples like rice, wheat or corn which provide energy and are included in almost every meal. In most parts of Asia the main food is rice, whereas wheat is the staple in Europe and North America and parts of India and China. Supplementary foods like meat, eggs and vegetables are eaten with the main food and supply protein, minerals and vitamins. These vary from meal to meal, season by season. Luxury food is considered non-essential and includes those items such as cakes, icecreams, candied foods, beverages, and so forth (Riley and Moomaw 1979). Following this classification, sweet potato can fall into three groups depending on the method of preparation or the level of consumption. For example, white-fleshed and high-starch sweet potato eaten in large quantities is considered a staple. Many inhabitants of Papua New Guinea have been reported to eat 3 to 5 kg of sweet potatoes every day. On the other hand hand, since sweet potato is rich in beta-carotene, vitamin C, minerals and dietary fiber, it also can be considered as a typical vegetable. A sweet potato high in sugar or with an attractive color can be made into candied products and other delicacies, therefore becoming a luxury food. In our discussion, however, we will regard sweet potato as a staple food.

TRENDS IN SWEET POTATO CONSUMPTION

Sweet potato's status as a survival crop is apparent from a study of the situation in Taiwan. The relative per capita availabilities of major food groups during the period 1962-1977 are shown in Figure 1. We are using the food availability of 1962 as our base for comparison. As a staple food it contributed 6.55% of the available food energy in the people's diet in 1962. However, it also formed an important source of vitamin A and minerals. The

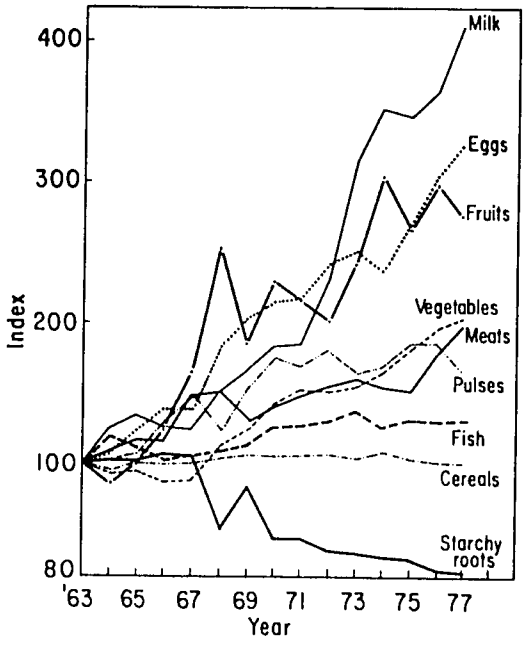

Figure 1. Change in relative consumption of selected food products in Taiwan, 1963-1977 (1963 as 100)

consumption of rice remained constant during the period of 1963-1977, whereas the consumption of all other food groups increased, and that of starchy roots decreased. Sweet potato was the principal starchy root referred to in these figures. In 1977 the per capita availability of sweet potato was only 6.93 kg per year, contributing only 0.73% of the total daily energy intake (JCRR 1978).

In 1977 AVRDC economists surveyed food patterns of five cities in Taiwan. Sweet potato consumption responded to income levels, with the low income group having higher frequency of sweet potato in their diet (Calkins 1978).

We do not have sufficient data to do similar calculations for other countries. However, trends appear to be similar. Table 1 lists the availability of food energy and sweet potato in 1964-66 and 1972-74 of selected Asian countries (FAO 1971 and 1977). With the exception of China and India, most countries in Asia were able to improve their available food energy during this period. These figures suggest a greater availability of food as a source of calories and probably a better standard of living. Again, except for China and India, reduction in sweet potato consumption in these countries is very noticeable. This trend indicates a discrimination against eating sweet potato. Similar trends can be observed in the case of African and Latin American countries (Table 2 and 3).

Table 1. Food energy and sweet potato availability in selected Asian countries in 1964-66 and 1972-74

Country	1964-66		1972-74	
	energy (cal/caput/day)	sweet potato (kg/caput/year)	energy (cal/caput/day)	sweet potato (kg/caput/year)
China	2379	68.9	2278	80.2
India	1964	2.1	1967	3.0
Indonesia	1760	25.4	2301	17.1
Rep of Korea	2329	76.1	2749	28.7
Malaysia	2200	3.7	2539	1.0
Pakistan	1995	3.7	2128	2.0
Philippines	1911	20.4	1957	5.1
Thailand	2226	16.2	2302	7.2

Source: FAO food balance sheets

Table 2. Food energy and sweet potato availability in selected Latin American countries in 1964-66 and 1972-74

Country	1964-66		1972-74	
	energy (cal/caput/day)	sweet potato (kg/caput/year)	energy (cal/caput/day)	sweet potato (kg/caput/year)
Argentina	1885	14.2	3280	13.6
Bolivia	1765	45.8	1858	48.4
Brazil	2541	15.1	2537	13.3
Chile	2516	65.4	2734	73.6
Ecuador	1848	1.4	2084	1.0
Paraguay	2723	37.9	2714	27.6
Peru	2271	10.2	2322	9.8
Uruguay	3023	26.4	2969	20.3
Venezuela	2367	8.9	2388	2.4

Source: FAO food balance sheets

If the same approach is used to study the consumption of cassava, the trend is less marked (Table 4) indicating cassava to be more acceptable as a staple than sweet potato.

WHY THE RESISTANCE?

Food preference is a complex social phenomenon, caused by many factors. We believe that some of the major reasons contributing to the resistance to eating sweet potatoes are negative psychological associations, seasonal fluctuation of supplies, high sugar content, and flatulence.

Table 3. Food energy and sweet potato availability in selected African countries in 1964-66 and 1972-74

Country	1964-66		1972-74	
	energy (cal/caput/day)	sweet potato (kg/caput/year)	energy (cal/caput/day)	sweet potato (kg/caput/year)
Angola	1911	22.6	1993	23.8
Burundi	2017	199.2	2324	186.5
Cameroon	2228	39.8	2379	21.0
Central African Republic	2172	25.5	2318	28.9
Congo	2036	64.3	2261	62.7
Guinea	2059	20.4	1992	17.4
Kenya	2243	29.5	2137	26.3
Liberia	2287	6.5	1973	7.6
Mali	2131	12.1	1756	5.5
Niger	2178	4.4	1857	3.0
Rwanda	1910	67.5	2101	109.4
Sierra Leone	2155	3.4	2248	3.0
Sudan	2091	20.4	2067	1.6
Tanzania	2144	19.5	1956	18.1
Uganda	2157	141.5	2140	42.9
Zambia	2246	7.2	2014	3.4

Source: FAO food balance sheets

Psychological

Resistance to eating sweet potato is partly psychological. For example, those Filipinos and Taiwanese who survived on this crop during the Second World War seldom eat sweet potatoes now because of unpleasant memories of suffering and hardship. Because sweet potatoes are considered a survival, or poor man's food, they are also considered a low prestige food. The situation is further aggravated in some countries like the ROC where sweet potato is used as hog feed. Also, it is natural that any farmer shifting from sweet potato to rice as a source of income will also eat more rice and less sweet potato.

Seasonal fluctuation of supplies

Earlier we mentioned that a staple food is included in almost every meal. To meet that criterion, sweet potato should be available the year round. This is not the case because of production, distribution and post-harvest problems. Although a tropical root crop, sweet potato harvest in Taiwan is generally lower in July to September than in February to April (Lee 1978). Consequently, the limited supply from July to September results in

Table 4. Food energy and cassava availability in selected African countries in 1964-66 and 1972-74

Country	1964-66		1972-74	
	energy (cal/caput/day)	cassava (kg/caput/year)	energy (cal/caput/day)	cassava (kg/caput/year)
Angola	1911	182.9	1993	174.8
Burundi	2017	11.8	2342	95.4
Cameroon	2228	104.0	2479	80.2
Central African Republic	2172	353.9	2318	158.3
Congo	2036	241.7	2261	313.3
Gabon	2182	192.8	2226	269.6
Gambia	2315	15.5	2305	13.6
Ghana	2084	104.8	2291	112.5
Guinea	2059	86.5	1992	76.2
Ivory Coast	2430	71.7	2621	79.0
Kenya	2243	41.7	2137	35.5
Liberia	2287	200.7	1973	163.0
Madagascar	2387	74.2	2361	59.6
Malawi	2131	11.4	1756	1.5
Mozambique	2127	301.6	1987	243.2
Niger	2178	23.0	1857	29.4
Nigeria	2166	102.6	2071	114.2
Rwanda	1901	15.8	2101	24.3
Senegal	2299	41.9	2180	23.7
Sierra Leone	2155	25.8	2248	24.8
Somalia	1770	6.8	1915	7.9
Sudan	2091	126.3	2067	57.6
Tanzania	2144	86.8	1956	65.2
Uganda	2157	260.0	2140	65.6
Zambia	2246	35.3	2014	33.2

Source: FAO food balance sheets

high sweet potato prices. High moisture and free sugar content make sweet potato susceptible to rapid deterioration in storage, complicating preservation of large quantities during off-season production. However, sweet potato can be stored for one to six months with proper curing and adequate storage facilities (Ryal and Lipton 1979).

The sweet potato weevil also prohibits effective storage of roots. This pest is not only a problem in production, but riddles sweet potato roots reducing their value as human food. Weevil-infested sweet potatoes have a strong bitter taste due to production of ipomeamarone (Akazawa *et al* 1960). Regardless of the toxicity of this compound, the unpleasant flavor makes sweet potato less acceptable for humans. Unfortunately, there are still no economical ways of controlling this insect in developing countries.

High sugar content

Sweet potato may not be acceptable as a staple food because of high sugar content (Villareal 1981). A staple high in free sugar could elevate blood sugar in a short period and reduce the appetite (personal communication, T. H. Yang, professor, National Taiwan University). Furthermore, there is a tendency for sweet foods to dominate the flavor of others.

Flatulence

Flatulence or 'gas' problems that occur after eating large quantities of sweet potatoes have been mentioned in a joking manner as a reason for low acceptability of sweet potato. This problem, however, has not been studied. Undigestible carbohydrate could be involved in this process.

SUGGESTED APPROACHES

There are situations and areas in the world where it should be practical to promote sweet potato as a staple food. In many rice areas it would seem feasible to promote sweet potato as a supplementary staple food. The following approaches are recommended to accomplish this goal.

1. Media promotion. A massive campaign should be made through the use of the press, radio, television, and attractive posters. Coupled with the campaign, a strong and highly trained corps of extension nutritionists should carry information to schools and potential consumers (Villareal 1977).

The present program to develop sweet potatoes specialized for human food, animal feed or industrial uses in starch and alcohol production should help dispel psychological barriers against the status of sweet potato.

At AVRDC, we consider that a staple type of sweet potato should possess the following characters: high dry matter content, low sugar, high protein, dry texture and a white flesh color (Villareal 1981). A variety high in dry matter will store better as well as having better eating quality. The dry matter content of sweet potato grown under Taiwan conditions varies from 13.6 to 35.1 (AVRDC, unpublished data). The sugar content of our germplasm varies from 8 to 40 on a dry weight basis. The lines with the lowest sugar, however, exceed the sugar content of other staple foods. Nevertheless, after intercrossing low sugar lines, we reduced the mean sugar content from 13.4 in the germplasm to 10.2 in our breeding lines indicating that it may be possible to reduce it further through breeding. The protein contents of most popular Asian sweet potato cultivars are low. A nutrition study has shown that this amount of protein is sufficient to balance the metabolic needs of an adult if sweet potatoes are eaten in sufficient quantity to supply calorie needs (Lee 1978). Sweet potato germplasm at AVRDC ranges from about 2.5 to 12 protein on a dry weight basis (AVRDC 1975). It appears possible to im-

prove this level without sacrificing yield levels. Although a positive correlation was observed between protein content and antiproteiase factor activity, it is not considered a serious problem for human consumption since this factor is destroyed by cooking.

2. Although sweet potato can be grown the year round in the tropics (Santos 1977), yields during the wet season are much lower than in the dry season (Li 1979). For this reason, high yielding varieties for wet season plantings need to be developed.

3. Food processing needs to be emphasized in any sweet potato research undertaking. For example, a low-cost drying process will surely improve storability and maintain good eating quality. Current techniques used in Taiwan to prepare sweet potato chips for animal feed are not adequate to develop products acceptable for human consumption.

Fortification of conventional foods with sweet potato flour is one area that deserves more attention. The work at the National Taiwan University experimental farm and TARI's Chiayi Agricultural Experiment Station demonstrate that breads made with up to 20% sweet potato flour are tasty and of good quality. Additional vitamin A can be supplied to the diet if orange-fleshed sweet potato varieties are used. This technology would be practical in countries where sweet potatoes are available and importation of wheat has drained precious foreign exchange.

4. Other new products need to be developed depending on the country. In Taiwan, for instance, the electric cooker is an essential household utensil. Precooked sweet potato flakes recently introduced to the US market (Hoover 1966) may have potential in Taiwan but will be too expensive for certain less developed countries.

5. A low-cost postharvest handling system is another way of assuring consumers of a continuous supply of sweet potato.

6. On the problem of flatulence, studies on the following area should be considered:

a. the nature of flatulence-causing substances in sweet potato.
b. breeding and selection for low-flatulence lines.
c. storage techniques and processing methods which can eliminate or reduce flatulence.

CONCLUSION

Despite many advantages, sweet potato is a low prestige food. Its value has been as a survival food but it has the potential to play a fuller role in many developing countries. We believe the resistance to eating sweet potato, particularly in poor countries, is both psychological and technical in nature. National governments can probably play a dominant role in removing the psychological barriers. The world's scientists can cooperate in developing improved varieties, appropriate management practices, and postharvest handling and processing technology to improve sweet potato as a supplementary staple food. Simply by trying these approaches, we have everything to gain in feeding a hungry world, and nothing to lose.

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Sweet Potato in Papua New Guinea

R. M. BOURKE

Highlands Agricultural Experiment Station, Aiyura, PO Box 384, Kainantu, EHP, Papua New Guinea

SWEET POTATO CULTIVATION

Significance and distribution

Sweet potato (*Ipomoea batatas* (L) Lam) is by far the most important food crop in Papua New Guinea (PNG). The only production estimates are now 20 years old. Walters (1963) gives the annual production as 1,223,000 tons from an approximate area of 72,000 ha. If this is valued at a conservative 15 US cents/kg, crop production is worth over US$180 million per year. Present production is probably worth over US$200 million per year. The only other crop that approaches this value is coffee which is grown as an export crop. Sweet potato is a very important cash crop and large quantities are grown for sale. It is the most important crop grown at schools and similar institutions.

The principal product is the root which is baked or boiled. Small roots are used as pig feed and large pig herds are maintained on sweet potato roots, particularly in the highlands. The vines and leaves are occasionally eaten by people as a green vegetable, but their main use is as pig food.

Sweet potato is cultivated extensively in the highlands between 1200 m and 2700 m where it is generally the staple food. Various authors have calculated that it provides between 60% and 90% of energy needs for highlanders. It also provides a significant proportion of people's protein intake. In the lowlands (0-600 m) and intermediate altitude areas (600-1200 m), sweet potato is increasing in importance in subsistence agriculture. In some areas, such as on Bougainville Island, it has completely displaced the traditional staple taro. Sweet potato production is in general increasing, together with *Xanthosoma* taro and cassava, at the expense of the traditional staples of *Colocasia* taro, yams and bananas. This is occurring because of the loss of fertile forest land which is necessary for taro cultivation, the ease of cultivation of sweet potato, pest and disease problems in other crops, and the loss of traditional values associated with other staples.

Introduction to PNG

It is generally accepted that sweet potato was introduced to PNG sometime in the past 400 years following European exploration in the New World. Yen (1974) has proposed that it came to PNG from the West Indies via Africa, India and the East Indies (Indonesia). Various authors have estimated that sweet potato has been in the highlands for 200 to 300 years. Some examples are: Upper Kaugel Valley, minimum 170 years (Bowers 1968); Kainantu, 200 to 300 years (Watson 1965); Waghi Valley, 250 years (Golson); Tari Basin, 250 years (personal communication with B. J. Allen, Office of Environment, PNG).

The effect of the comparatively recent introduction of sweet potato into the highlands has been the subject of controversy. Watson (personal

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communication) has suggested that a subsistence revolution occurred following its introduction. Aspects of this revolution include radical changes in gardening patterns, an increase in the importance of pigs, a human population explosion, a change in the relationship between the sexes among highlanders, changes in social structure and an increase in warfare. Other workers in the highlands have rejected this hypothesis (Brookfield and White 1968). They suggest instead that the introduction of the sweet potato was not of major relevance to the development of agriculture in the highlands, although its introduction has had some effects, such as an expansion of cultivation into areas of higher altitude, the clearing of montane forest and the resulting wider planting of casuarina trees to provide wood in deforested areas.

Farming systems

The crop is grown from sea level to the altitudinal limit of agriculture. This is usually at about 2700 m, but occurs as high as 2850 m in parts of Enga Province. The crop attains its greatest importance above 1400 m. Above 2350 m, regular frost damage occurs. It is the staple crop in areas with mean annual rainfall ranging from 1700 mm to over 5000 mm. It is grown on a very wide range of soil types ranging from sandy loams to heavy clays and peat soils. In the highlands where the crop is most important, the soils are generally clays. It is grown on flatlands and on slopes up to 40°. The wide range of ecological conditions under which the crop is grown reflect both the adaptability of the crop and the wide genetic base within the country.

The farming systems in which the crop is grown are equally diverse. It is grown in systems ranging from those where a single crop is followed by a very long forest fallow to those involving continuous cultivation in which the crop has been cultivated for over 200 years with fallows of only 2-3 months between crops (Wood 1981). It is grown in systems using both grass and forest fallows, although grass fallows are more common, particularly in the highlands. Cultivation techniques in grassland areas may be classified as follows:

1. Planted without mounding or in small mounds (30-50 cm diameter). Little soil cultivation. Generally practiced on steep hillsides, especially in Simbu Province, where soil retention devices are common.

2. Planted in small mounds (30-80 cm diameter) on drained beds. Soil cultivated by hand prior to mounding. Beds are long and rectangular in the drier Eastern Highlands and square in shape where the rainfall is higher (Waghi and Baiyer Valleys, parts of Simbu).

3. Planted in large mounds (1 to 5 m in diameter) with up to 30 planting positions per mound, with 2-3 plants per position. Compost is placed in mounds prior to planting. This is the traditional system in most of Enga Province and adjoining parts of the Western and Southern Highlands.

4. Mechanical cultivation systems. Mounds or ridges formed by hand or mechanically after mechanical soil cultivation. On flat or gently sloping land in grassland areas in the lowlands and highlands, especially by commercial or institutional farmers.

In forest areas, little soil cultivation is practiced and mounds are

small, if they are built at all. This is the common system in the lowlands and intermediate altitude areas and also at high altitudes as new land is opened up for agriculture.

Cultivars and cultural techniques

Cultivars are very numerous in PNG. Yen (1974) suggests that more cultivars could be collected in PNG than from any other area in the world. There are probably in the order of 5000 cultivars grown. About 500 cultivars (including some duplicates) are maintained on research stations. The available information on cultivars held by various groups is summarized in Table 1. The number of cultivars held by any one group of people ranges from six to 71, with a mean of 33. Some of the lower figures are almost certainly underestimates. In the lowlands the number of cultivars held by any group of people is generally smaller than in the highlands. Spontaneous germination of true seed gives rise to potential new cultivars, some of which are retained and may eventually replace existing ones. This process, and cultural isolation of growers, explains the large number of cultivars (Yen 1974; Powell [illegible] 1975). Cultivars introduced since European contact are rapidly replacing traditional ones and many traditional cultivars are now being lost (Table 1).

The crop is always propagated by stem cuttings. These are almost always taken from the apical portion of the vine and cuttings from mature plants are preferred (Kimber 1972a). Vine and root pruning are both practiced. Cultivation of sweet potato in the highlands is mainly the responsibility of women. Men clear new areas, and do the heaviest work such as removing the basal parts of cane grass and fencing whilst the women prepare the soil, plant, weed and harvest the crop. Crop planting is somewhat seasonal in the highlands with more planting taking place at the beginning of the wet season.

Systems of harvest and crop yield

The most common harvest system is progressive harvesting: large roots are removed from the soil as they are needed. Up to four harvests may be made from individual plants over a period of a year or more. In the Dom area of Simbu Province, villagers claim that harvesting of individual plants may extend for as long as 3-4 years (Wohlt, personal communication). On Bougainville (Mitchell 1976) and in other lowland areas, a single harvest is taken and all roots are removed at the same time, regardless of size. Roots are occasionally stored in holes in the ground filled with sand (Kimber 1972a) or are also stored in houses for a few days before consumption (Siki 1981).

The available information on subsistence yields is summarized in Table 2. Reported subsistence yields range from 2 to 50 t/ha, with most values in the range 5 to 25 t/ha. Values of over 25 t/ha are unlikely to be accurate indications of subsistence yields. Experimental yields have ranged from crop failure to 71.2 t/ha (Enyi 1977). Experimental yields usually lie between 10 and 30 t/ha. In the lowlands yields of 10-20 t/ha are the rule, whilst in the highlands yields are often in the range 20-40 t/ha. Time to maturity is 5-6 months in the lowlands, 6-8 months in the highlands and 7-12 months (and longer) at high altitudes.

Table 1. Number of sweet potato cultivars grown by various groups in Papua New Guinea

Location and approximate altitude	Cultivars now grown: total number	Cultivars now grown: traditional cultivars	Cultivars now grown: Post-contact introductions	Traditional cultivars now lost	Source
Upper Chimbu Valley, Simbu Prov[#] (c. 2200 m)	71	45	26	-	Sterly (1978)
Grand Valley, Baliem River, Irian Jaya[#] (1650 m)[¢]	70+	-	-	-	Heider (1970)
Sinasina area, Simbu Prov[#] (1800-2500 m)	67[x]	28	32	36	Hide *et al* (1979)
Tari Basin[#] (1600 m)	53	-	-	-	Powell (1981)
Upper Mendi Valley, SHP[#] (2000 m)	49	30	19	-	Simpson (1978)
Simbai area, Madang Prov[#] (1500-2300 m)	48[ψ]	43	5	-	Bulmer (1981)
Upper Mendi Valley, SHP[#] (2100 m)	42	-	Most cvs	22	Harrison (1976)
Mt Hagen area, WHP[#] (1600-1900 m)	40-50	-	-	30-40	Powell *et al* (1975)
Lai Valley, Enga[#] (1800 m)	35	-	-	-	Waddell (1972)
Upper Lai Valley, Enga[#] (2100 m)	31	25	6	-	Meggitt (1958)
Simbu Province[#] (1500-2700 m)	30+	-	-	-	Brookfield and Brown (1963)
Simbai area, Madang Prov[#] (1500-2300 m)	29[ψ]	21	8	22	Bulmer (1981)
Upper Simbu Valley, Simbu Prov[#] (1900 m)	29	-	-	-	Komba (1978)
Kainantu area, EHP[#] (1550-1800 m)	27	20	7	-	Watson (1967)
Nembi Plateau, SHP[#] (1650 m)	25	11	14	25	R. M. Bourke (unpub. data)
Simbai River, Madang Prov (1300-1600 m)	24	-	-	-	Rappaport (1968)
Sirunki Plateau Enga[#] (1900-2700 m)	24	-	-	-	Sinnett (1975)
Kagua area, SHP[#] (1600 m)	17	11	6	-	Abaya (1978)
Simbai River area, Madang Prov (700-1100 m)	15+	-	-	-	Clarke (1971)
Sirunki Plateau, Enga[#] (2600 m)	13	11	2	-	Walker (1966)
Pangia area, SHP[#] (1500-1600 m)	10	-	-	16	Paia (nd)
Markham Valley (300 m)	7	-	-	-	Langley (1950)
Snake River, Morobe Prov[#] (1100 m)	6	-	-	-	Langley (1950)

[#]Sweet potato is the main staple food
[¢]Irian Jaya (West New Guinea) is a province of Indonesia
[x]Includes 7 varieties of unknown origin
[ψ]Situation in 1963-64
[ϕ]Situation in 1980

Table 2. Sweet potato yields recorded in subsistence gardens in Papua New Guinea

Location and approximate altitude	Yield (t/ha)	Sources	Notes
Snake River area, Morobe Prov (1100 m)	37.7-50.3	Conroy and Bridgland (1950)	
Tsak Valley, Enga Prov (1500-1900 m)	33.2-37.0	Bureau of Statistics (1967b)	Average over all soil types and slope classes
Tsak Valley, Enga Prov (1900-2300 m)	31.3-34.9	Bureau of Statistics (1967b)	
Tsak Valley, Enga Prov (> 2300 m)	27.6-30.7	Bureau of Statistics (1967b)	
Simbu Prov (1900-2300 m)	24.0-26.6	Bureau of Statistics (1967a)	
Kaugel Valley, WHP (2200 m)	23.5	Bowers (1968)	River terraces
Simbu Prov (< 1900 m)	22.5-24.9	Bureau of Statistics (1967a)	Average over all soil types and slope classes
Enga Prov (1500-1900 m)	22.4-25.0	Bureau of Statistics (1967b)	Average over all soil types and slope classes
Lai Valley, Enga Prov (1800 m)	20.9	Waddell (1972)	Small mounds
Enga Prov (1900-2300 m)	21.2-23.6	Bureau of Statistics (1967b)	Average over all soil types and slope classes
Enga Prov (> 2300 m)	18.6-20.7	Bureau of Statistics (1967b)	
Mt Hagen (1600 m)	18.4	Clarke (1977)	Good soil. After 8 year fallow
Lai Valley, Enga Prov (1800 m)	17.4	Waddell (1972)	Large mounds
Upper Lai Valley, Enga Prov (2100 m)	15.7	Meggitt (1958)	First crop on best soil
Simbu Province (> 2300 m)	15.0-16.6	Bureau of Statistics (1967a)	Average over all soil types and slope classes
Oksapmin area, WSP (1800 m)	14.8	Cape (personal communication)	After 35 year fallow on limestone soil
Upper Wage Valley, Enga Prov (2650 m)	c.14.0	Wohlt (1978)	Per year
Tari Basin, SHP (1600 m)	13.1-13.3	Wood (1981)	Peaty soils
SW Bougainville Island (100 m)	12.2/8.5	Mitchell (1976)	First and fifth crops respectively. Other crops intermediate
Tari Basin, SHP (1600 m)	11.2-11.3	Wood (1981)	Alluvial soils
Siane area, Simbu Prov (1900 m)	10.6	Salisbury (1962)	Estimate only

Table 2.

Upper Lai Valley, Enga Prov (2100 m)	c.10.0	Meggitt (1958)	Average yield, all soil types
Oksapmin area, WSP (1800 m)	9.7	Cape (personal communication)	After 15 year fallow on mudstone soil
Mt Hagen (1600 m)	9.3	Clarke (1977)	Poor soil. In cultivation for 10-15 years
Kamu Valley, Irian Jaya (1500 m)	7.1	Pospisil (1963)	Intensive valley cultivation
Simbai River, Madang Prov (1300-1600 m)	6.5	Rappaport (1968)	Over 1200 weeks in mixed garden. Total garden production 15.5 t/ha
Nembi Plateau, SHP (1650 m)	6.3	Bourke (unpublished data)	Soil fertility reduced by many years of cropping
Kamu Valley, Irian Jaya (1500 m)	6.2	Pospisil (1963)	Valley shifting cultivation
Tari area, SHP (1600-1800 m)	5.4-8.5	Wood (1981)	Volcanic ash soils
Kamu Valley, Irian Jaya (1700 m?)	4.2	Pospisil (1963)	Mountainside garden
Manus Island (100 m)	c.2.0	Rooney (1981)	Following taro blight epidemic, people changed briefly to a sweet potato staple

Pest and disease problems

Rats cause much damage to roots. Villagers often turn the vines to expose the soil to the sun and thus reduce rat damage by making the soil harder. Women and children hunt and eat the rats. Domestic and wild pigs can do much damage. In most parts of PNG, individual gardens or groups of gardens are fenced in to keep pigs out. The sweet potato weevil (*Cylas formicarius* F) can be a major problem at times. It is only serious in areas with a marked dry season, such as around Port Moresby, or in very dry years. The recommended control measure is crop rotation and use of uninfested planting material (Kimber 1972b).

Hawkmoth (*Agrius convolvuli* (L)) has been recorded as attacking sweet potato leaves, mainly in the lowlands, but the damage is generally not severe. The pest is controlled by the introduced cane toad (*Bufo marinus* (L)) (Dept Agric 1941). The sweet potato leafminer (*Bedellia somnulentella* (Zell)) has reduced yields in the highlands and the lowlands in some years (Kimber 1972b). Sweet potato littleleaf is a condition caused by a mycoplasma-like organism (Pearson 1981). It is a serious problem in village gardens in Central Province and has caused severe yield loss in experimental plots on New Britain in the past. Leafscab, caused by the fungus *Elsinoe batatas* Jenkins and Viegas, is common on sweet potato vines and leaves. The condition is worse in the highlands than in the lowlands. Cultivars vary

widely in resistance to the condition. It is not believed to cause much yield loss in most cultivars. In the Upper Mendi area of the Southern Highlands sweet potato yields were severely reduced in 1980 by a condition associated with nematode damage and the fungus *Fusarium oxysporum* Schlecht *ex* Fr (Anders, personal communication).

Future prospects

Continuing expansion of production is likely in both the subsistence and commercial sectors. Courses for farmers in commercial sweet potato production are being run at Aiyura in the highlands and at Laloki near Port Moresby to encourage commercial production. Use of irrigation in the dry Port Moresby area should facilitate expansion of production to meet the high demand there. It is likely that sweet potato will continue to replace the traditional staples in the lowlands and intermediate altitute areas. The spread of littleleaf disease is the most serious threat to production.

RESEARCH WORK

Research on sweet potato in PNG has concentrated on crop agronomy, farming systems studies, use of the roots for stockfeed, the littleleaf condition and production of a dried sweet potato product. Some 150 agronomic field trials have been undertaken, mostly by staff of the Department of Primary Industry. The research work is briefly reviewed below.

Agronomic trials

Cultivar trials: Some 50 cultivar trials have been conducted at 11 locations. In these, yield, taste, resistance to leafscab and weevil, and protein content have been evaluated. Cultivars have been released mainly on the basis of high yields and acceptable taste. Current releases are Ma'alua, Markham, Merikan, Naveto, Serenta and Wanmun Kabiufa for the highlands; Milne Bay and Okinawa for Central Province; and K 9 and K 13 for other lowland areas. Introductions from Peru, the USA and IITA in Nigeria have been evaluated. The Peruvian varieties were imported from New Zealand in an attempt to obtain frost resistant material. They performed poorly and were not frost resistant. Material from the USA has not performed particularly well and the soft orange-colored root is not acceptable to local taste. Some of the IITA varieties have outyielded local material at Aiyura (1600 m) and Tambul (2300 m). Their evaluation is continuing.

Fertilizer trials: Over 50 inorganic and organic fertilizer trials have been carried out on sweet potato in PNG, many of them in the highlands. Results with inorganic fertilizer in the highlands have not been consistent. In some trials fertilizer increased root yield with responses recorded in various trials to nitrogen, phosphate and potassium. In other trials yield was depressed and in others there was no response (Dept Agric Stock and Fisheries 1972 ; Clarke and Street 1967). The variable response is likely to reflect different soil types, but may have been caused by a nitrogen by cultivar interaction. Seventeen field and six pot trials have been undertaken on a young volcanic soil on New Britain in the lowlands (Bourke 1977). In these trials nitrogen gave large yield increases, especially in grassland sites. Potassium increased yield in a depleted forest soil. In most trials nitrogen increased tuber yield, but in others it depressed yield. This appears to have occurred because of the use of different cultivars.

Nine organic fertilizer experiments have been performed in the highlands and lowlands (Table 3). In all trials, except one using chicken manure, organic fertilizer increased root yield. In the trial where no response was recorded, yield levels were already very high (Velayutham *et al.* 1981). These results suggest that yield responses are more likely with organic fertilizer than with inorganic fertilizer.

Table 3. Sweet potato organic fertilizer trials in Papua New Guinea

Organic fertilizer	Level of application (t/ha)	Crop yield (t/ha)	Level of significance	Source
Pig manure	0	13.4	*	Kimber (1973)
	22	17.0		
	44	15.9		
Chicken manure	0	40.7	ns	Velayutham *et al.* 1981
	15	42.7		
Chicken namure[a]	0	18.2	**	Thiagalingam and Bourke (1981)
	5	16.6		
	10	24.9		
	15	19.2		
	20	18.8		
Coffee pulp[b]	0	9.3	**	Siki (1980)
	15	12.1		
	30	13.0		
	45	12.9		
	60	15.8		
	75	15.6		
Compost placed in mounds	0	8.9	p = .1	Bourke and D'Souza (1981)
	12	11.9		
	24	13.7		
	36	14.1		
Compost placed in mounds	0	7.5	**	Bourke and D'Souza (1981)
	10	10.3		
	20	12.7		
	30	12.0		
Compost placed in mounds	0	6.6	**	Wood (personal communication)
	18	10.1		

[a]Manure applied to a preceding crop of winged bean
[b]Average of three trials

Method of cultivation: In a trial on a sandy loam at Keravat (20 m) on new Britain, large hills and ridges gave a yield of 37.7 t/ha compared with 11.3 t/ha using the local method of small ridges and probably a lower planting density (Dept. Agric. 1941). At Aiyura, Kimber (1970) compared flatland plantings with mounds and ridges of various sizes in five trials on mostly heavy soils. Flatland planting gave yields which were very much inferior in most trials. Mounds gave higher yields than ridges of corresponding size. On the other hand, Rose (1978 personal communication) found no significant yield difference between large and small mounds and ridges on a light soil at Piwa (1700 m).

Plant density: In seven trials at Aiyura plant densities ranging from 11,000 plants to 110,000 plants/ha were compared. There was very little difference in yield of marketable roots (over 100 g weight) between treatments, but yield of stockfeed roots (under 100 g) increased with increasing density (Kimber, personal communication).

Effect of weeds and herbicides: Four herbicide trials and one trial examining the effect of weeds on yield have been carried out at Aiyura (Dept Agric Stock and Fisheries 1973). It was found that yield was increased as the weed-free period after planting was extended from 0 to 8 weeks. Gramoxone at 0.7 liters/500 liters water/ha applied at two and four weeks after planting gave good weed control.

Time to maturity: Jamieson (1968) examined various crop characteristics on one soil type with varied pre-crop histories using successive row-by-row harvesting of plots. He found that maxima in crop yield, number of roots and flowers occurred earlier in more depleted soil, and that maximum flowering is a useful indicator of time of achievement of maximum yield.

Method of harvesting: Two comparisons have been made of single harvesting of all roots versus progressive harvesting of large roots. The latter technique is the universal practice in the highlands. A. J. Kimber compared the two techniques for two cultivars over three plantings at Aiyura. Rose (1979) used two cultivars over one planting. Both workers found that root yield was the same when compared on a per day basis.

Tuber protein content: Because of the importance of sweet potato in highlanders' diets, root protein content can have a major effect on the amount of protein people eat. The protein content of roots from 11 cultivar trials done by DPI have been analyzed. In addition six authors have reported on root protein content. These are reviewed by Heywood and Nakikus (1981). The published and unpublished analyses indicate that root protein content varies markedly between cultivars. Where the same cultivars have been analyzed from different experiments, the ranking of the various cultivars was not very consistent from analysis to analysis. It is not clear whether this is because of variation in root protein content between plantings or because of problems in the techniques used. In a series of experiments, the protein content of three cultivars was increased by N or NPK fertilizer (Kimber 1976).

Storage trials: Trials comparing various techniques of storing roots in clamps have been carried out at Kandep (2350 m) and Kuk (1600 m) by Aldous (1976) and at Keravat (20 m) by Bourke (unpublished data). It was found that it was possible to store roots successfully in clamps for up to 50 days at Kandep, 40 days at Kuk and 30 days at Keravat.

Other agronomic studies: Sweet potato has been the main indicator crop used in various farming system trials in the lowlands and highlands. These include trials to assess the effect of soil exhaustion, crop rotation and type of fallow. Intercropping trials at UPNG using sweet potato with maize or sorghum have shown that a sweet potato/maize combination increases yield and economic return (Kesavan 1981). Growth analysis studies have been done by Bourke (1978) and Enyi (1977). Uniformity studies by A. J. Kimber have resulted in a recommended plot size of 16 x 2.5 m for trial work. Other work has examined vine pruning and the effect of frost under simulated conditions.

Other research work

'Kaukau rice': Experimental work has been done on producing a dried sweet potato product known as 'kaukau rice'. Siki (1981) and Thomas (1981) describe the process. The experimental work was done in 1977 but no further production was carried out because of an inadequate supply of roots and low sales due to high cost, low consumer acceptance and poor marketing (Thomas 1981).

Littleleaf disease: Some work has been done on identification of the causal organism of littleleaf condition. This is reviewed by Pearson (1981).

Stockfeed: Sweet potato roots and foliage have been evaluated as pig and chicken feed. Malynicz (1971) found that raw sweet potato and a 53% crude protein concentrate gave satisfactory returns for growing pigs. Supplementation of standard rations with sweet potato foliage was not found to improve pig performance (Malynica and Nad 1973). A tethering system of pigs grazing a sweet potato crop has been found to be successful (Rose 1976). Watt (1973) has summarized the results of this and other research work on feeding sweet potato to pigs. He includes the findings that giving pigs cooked sweet potato increased live weight gain when compared with raw sweet potato, and that pigs grazing sweet potato required protein supplement of 500 g concentrate per pig per day. Turner [illegible] (1976) examined various diets based on sweet potato and a protein supplement as chicken feed. They concluded that unless concentrate prices are low and sweet potato is considered a free food, it is more economic to use a fully prepared ration.

Current research

Germplasm collections at Aiyura, Keravat and Laloki are being steadily expanded. Evaluation of both PNG cultivars and introduced ones is continuing at Aiyura, Keravat, Laloki and throughout the highlands. The interaction of nitrogen fertilizer and cultivar is being examined at Aiyura and Keravat. Lime fertilizer studies are under way at Laloki. Trials with various organic fertilizers (pig manure, coffee pulp, [illegible] and compost) are being undertaken on the Nembi Plateau (1700 m) in the Southern Highlands Province. Seasonality of production is being studied by market and garden surveys and by time of planting trials at Aiyura and on the Nembi Plateau. Cultivars are being screened for weevil resistance and the effect of littleleaf on crop yield is being examined in field trials at Laloki.

Much research work has been and is being done on sweet potato in PNG. The challenge is to make the results available to the scientific community, and more particularly, to the country's subsistence and commercial sweet potato producers.

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Early maturing AVRDC swee+ potato breeding lines.

Sweet Potato and Its Potential Impact in Liberia

M. A. AS-SAQUI

Central Agricultural Research Institute, Ministry of Agriculture, PO Box 32, Gharnga, Bong County, Liberia

INTRODUCTION

In Liberia, sweet potato covers 2000 ha of land. Although this crop is generally grown for its roots, there are large groups of people in the world who eat the leaves and the tops of the vines. In Liberia, the leaves are more extensively used than the roots and many people grow sweet potato in the their backyards mainly for the leaves. Sweet potato leaves and cassava leaves together provide the population of Liberia with more than 25% of its daily calorie intake. With the widespread incidence of protein-calorie malnutrition in many areas where sweet potatoes can be grown, the tops of the vines and leaves of this crop could serve as a most valuable supplement for other carbohydrate food (Dahniya 1979). Furthermore, the crop is considered useful as a famine reserve (Brooke 1972) in case of locust attack. It is also more drought tolerant than cassava (Culwick 1941).

World production figures (Table 1) show Asia as the major sweet potato producing area with Africa as the second, producing roughly 4% of the total world output (FAO 1980). The reason for the low production levels in Africa in general, as well as in Liberia in particular, has not been thoroughly ascertained but the sweet taste of the root (which most natives find unpalatable) may be an important factor. The highly perishable nature of the crop in regions where economic home processing techniques have not been developed and commercial processing is not available may also keep its popularity low. The crop, however, has great potential in Liberia, as in other parts of the tropics, and production practices are developing in anticipation of wider acceptance.

Table 1. World sweet potato production 1979

Zone	Area 1000 ha	Yield t/ha	Production 1000 t
World	13,638	8.4	113,954
Asia	12,422	8.5	104,617
Africa	782	6.5	5,053
South America	225	10.1	2,263
North America	178	7.2	1,293
Oceania	110	5.4	593
Europe	13	10.4	135

(Source: FAO 1980)

RESEARCH FOR IMPROVEMENT

Realizing the importance and potential of sweet potato as a source of energy food to tide people over food crises, a sweet potato improvement program was initiated at the Central Agricultural Research Institute (CARI) of the Ministry of Agriculture in 1978 in close collaboration with the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

The main objective of the program is to evolve high yielding, good quality, disease and pest resistant/tolerant varieties together with improved cultural practices for high production.

Sweet potato research at CARI is at a preliminary stage. However, the following progress has been made since the program gained cooperation from IITA.

Germplasm: A nationwide tour was conducted from October to December 1978 to collect local germplasm materials of sweet potato and other root and tuber crops. A total of 172 accessions was collected out of which 52 were sweet potato. A live germplasm bank has been established with these at CARI and they are being evaluated against introduced varieties from IITA. Most of the local types are disease and insect susceptible and have low yield potential. The collected sweet potatoes have varying combinations of pigmentation of root peel and flesh, and of petiole and the under-surface of leaves, and of leaf shape and size. The germplasm bank will be maintained for future plant breeding works.

Varietal improvement: Two hundred seeds of different varieties were received from the IITA breeding program. They were planted in 1980 and a seedling nursery has been established. The germination percentage has been 80% and the plants are healthy, with no disease symptoms, and show vigorous growth. They will be harvested in 1981 and a preliminary yield trial will be established with selected plants. In 1979 a few hundred seeds of 11 varieties of sweet potato were received also from IITA to establish a second seedling nursery. The varieties were TIS 2328, TIS 3290, TIB 8, TIS 5125, TIS 3247, TIS 5061, TIS 3030, TIS 5239, TIS 2532, TIS 2330, and TIS 3017. They were studied in the seedling nursery, screened for diseases, insects and yield. Among them eight clones were initially selected to establish a preliminary yield trial. Table 2 shows the performances of all the varieties. Among them six are very promising and most of these are of leafy type which will be easily acceptable to the consumers.

With these six best performing varieties, an advanced yield trial (replicated four times) has been established this year. The root/leaf yield and quality will be studied.

During the wet season (June-October) the six varieties will undergo different agronomic practice trials to evaluate their performance in the farmers' fields. The varieties are also undergoing multilocational testing in two ecological zones of the country.

Introduction, selection and evaluation of different varieties of seeds will continue every year from different national and international organizations and more personnel will be involved in breeding, agronomy, physiology, plant protection and nutrition studies.

Table 2. Preliminary yield results of sweet potato roots and tips tested at CARI during 1980

Varieties[a]	Root yield t/ha	Leaf (tip) yield t/ha
TIS 2330	25.7	10.1
TIB 8	23.8	9.3
TIS 3030	22.1	8.7
TIS 5016	20.2	9.8
TIS 3290	19.6	11.2
TIS 3247	18.7	7.0
TIS 3017	18.3	9.1
TIS 5125	17.5	10.7
TIS 2532	15.3	7.9
TIS 2328	13.7	8.7
TIS 5239	10.3	9.3
Local check	10.0	12.3

[a]Source of materials IITA, Ibadan, Nigeria

POTENTIAL IMPACT

Sweet potato ranks fourth after rice, cassava and cocoyam as a staple carbohydrate food crop in Liberia. The leaves provide substantial protein while the roots supply starch and vitamin A.

Sweet potato leaves are nutritionally valuable and could go a long way towards improving the nutritional status of its consumers. Li (1974) reported considerable variation in the crude protein level on a dry weight basis of the stems and leaves of sweet potato ranging from 12.1 to 10.7 but most cultivars contained between 19.5 and 20.5 . Purseglove (1974) stated that on a fresh weight basis, the leaves contain 86 water, 3.2 protein, 0.3 fat and 8.5 carbohydrate.

Oyenuga (1968) reported the average chemical composition of young sweet potato leaves as a percent of dry matter as follows: crude protein, 24.6 ; crude fiber, 9.1 ; and total ash, 11.5 . The leaves had a dry matter content of 12.5 .

Investigations by Ruinard (1961) revealed that on a fresh weight basis, the leaves of sweet potato contain almost three times as much actual protein and from ten to 100 times more carotene than the roots. Kay (1973) reported that a typical analysis of the tops of the vines (100 g edible portion) is: moisture, 81.7 g; nitrogen, 0.57 g; ether extract, 0.67 g, crude fiber, 1.4 g; ash, 1.59 g (of which 81.2 mg is calcium, 67.3 mg phosphorus and 10.37 mg iron). The vitamin content is 3.61 mg carotene, 0.06 mg thiamine, 0.17 mg riboflavin, 0.94 mg niacin and 25.0 mg ascorbic acid.

Sweet potato has a tremendous potential as a carbohydrate source for both humans and animals. Its development may however depend on development of processing and preservation methods which will be commercially feasible within the region.

Agronomic research aims at developing production techniques in anticipation of expected wider acceptance and increased usage. The predominance of intercropping in the region indicates the need for integrating sweet potato into crop combinations and sequences especially with crops that are already popular. As a minor crop with drought tolerance the crop should be better able than most to exploit the environmental resources during the late rains. Such exploitation will depend however on weevil resistant cultivars and improved management.

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Status of Sweet Potato Cultivation in East Africa and Its Future

R. E. JANA

Faculty of Agriculture, University of Dar es Salaam, PO Box 643, Morogoro, Tanzania

INTRODUCTION

Three countries - Tanzania, Kenya and Uganda - comprise East Africa. The area is situated between the Indian Ocean in the east and the Rift Valley in the west and is bordered by Sudan and Ethiopia in the north, and Zambia, Malawi and Mozambique in the south. East Africa extends from latitudes 4°45' north to 11°50' south. Table 1 gives the land area of the East African countries. Tanzania mainland accounts for over one-half of the total land area of the region; Kenya comprises just over one-third and Uganda about 13%. The physical features of the region vary greatly from the permanent snows on Mount Kilimanjaro and Mount Kenya to the humid coastal belt and from the arid deserts of Kenya's Northern Province to the lush parkland of the high plateau. Climatic conditions are also very variable particularly in Tanzania and Kenya. They range from those of the tropical coastal belt which has mean temperatures of over 27°C, high humidity and narrow temperature ranges, to those of the temperate climates of the highlands, where mean temperatures vary between 10°C and 21°C. In Uganda climatic variations are less marked. Mean temperatures are for the most part between 21°C and 25°C.

Table 1. Land area of East Africa (including swamps)

	Uganda	Kenya	Tanzania (mainland)	Total
Land area square miles	80,292	219,789	341,150	641,231
Land area square kms	208,759	571,451	886,990	1,667,200
Percent of total	13	34	53	100

Source: J. G. C. Blacker. The Demography of East Africa. Hawkins Ltd, Nairobi 1962

The mean annual rainfall in East Africa varies from less than 250 mm to over 1500 mm. Some parts of Kenya's Northern Province only receive about 125 mm of rainfall annually. In contrast, in some of the mountainous areas, precipitation is as much as 2500 mm per annum. In addition to this considerable range of annual total rainfall, the other important consideration is the distribution of rainfall over the year. In some areas, the rainfall occurs in two distinct seasons each year; in others the total annual rainfall is concentrated in such a short period that the production of many kinds of agricultural crops is impossible. A good example of such an area is the Northern Province of Kenya. Here, agricultural production is limited to small areas of drought resistant crops such as cassava, sorghum and millet, grown for subsistence purposes. Their hardiness in withstanding unfavorable climatic conditions makes them particularly important as an insurance against

Table 2. Percentage of land area receiving selected amounts of annual rainfall four years of every five

Rainfall (inches or mm)	Uganda %	Tanzania %	Kenya %	East Africa %
Less than 20" (500 mm)	12	16	72	35
20-30" (500-750 mm)	10	33	13	20
30-50" (750-1250 mm)	72	47	12	41
Over 50" (1250 mm)	6	4	3	4

Source: J. F. Griffiths. The Climate of East Africa. Hawkins Ltd, Nairobi 1962

crop failure and famine. Another important factor which influences the growth of crops is the reliability of rainfall. Table 2 gives the minimum annual rainfall to be expected in four years out of five. This shows that on average during four years out of five, 72% of the land area of Kenya receives less than 500 mm of rainfall annually, compared with 16% of Tanzania mainland (Tanganyika) and 12% of Uganda. In contrast, 72% of the land area of Uganda receives, on average, between 750 mm and 1250 mm of rain four years out of five, compared with 47% of Tanzania mainland and only 12% of Kenya. The unreliability of rainfall, particularly in Kenya, emphasizes the vital need for a strict and sensible agricultural and forestry policy if the best use is to be made of the land within such severe climatic restrictions. Despite the wide variation in both the climatic and physical features of the region it is nevertheless possible to divide East Africa into four main divisions: the Coastal Belt, the Coastal Hinterland Plain, the main East African Plateau and the Lake Victoria Depression (Oloya 1969).

IMPORTANCE AND DISTRIBUTION OF SWEET POTATOES IN EAST AFRICA

In East Africa sweet potatoes and cassava are the most important root crops. Of the two, sweet potato is the more widely distributed. It is grown in areas below 2100 m so long as such areas do not experience a dry period so long that vines cannot survive from one season to another. In some places - such as the Central Province of Kenya and on the slopes of Mount Kilimanjaro in Tanzania - where standards of smallholder stock husbandry are high, sweet potatoes are an important animal feed especially during the dry season because they are resistant to drought. In these places many varieties produce large amounts of vine and few roots and are specifically grown for feeding the stock.

According to the Uganda Census of Agriculture (1963/64) 86,000 ha of sweet potato were planted in 1963 of which 74,000 ha were grown in pure stand and 12,000 ha were mixed with other crops. They are invariably grown by women. As a supplementary food crop sweet potatoes are widely cultivated in almost all parts of Uganda so that their distribution relates quite closely to that of population. The most marked concentration is in South Kigozi. In south Uganda sweet potatoes have a more entrenched status in traditional agriculture than has the comparable crop cassava which is limited by altitude. Before 1900 sweet potatoes were important in Buganda, Bwamba and amongst the Bakonjo of Ruwenzori. The spread northwards within Uganda has

been more recent since the crop only arrived in Lango shortly before 1923. It seems possible that there has been a decline in importance in south Uganda in recent years probably due to banana plantings (Dunbar 1975). In other areas, where they are less important, they are found growing on small plots around homes, being treated as a garden vegetable crop. In these circumstances, sweet potatoes may be grown on the same plot of land for several years in succession.

In most areas with a pronounced dry season they are grown in swampy areas during the dry months. This is partly to ensure a supply of planting material for the following season's crop and partly to provide food prior to the harvesting of the main rains crop - a season of the year in which food is in short supply. These plots may be individually or communally owned and in some districts in Uganda their planting is compulsory under legislation aimed at providing famine reserves.

In Uganda as a whole sweet potatoes occupied about 9% of the food crops area (Table 3) and ranked as the fourth most important food crop, after *Eleusine* millet, bananas and cassava. Kigezi in Uganda is an area in which sweet potatoes have been increasing in importance over the past 50 years and it may well be that the pressure of population on land in that district has dictated a trend toward replacement of the traditional staple cereals by a high yielding root crop. This hypothesis gains support from the fact that the main centers of sweet potato production in East Africa, namely Kigezi and the Kampala area in Uganda, Sukumaland in Tanzania and the Kikuyu reserve in Kenya, are all centers of high population pressure.

The present status of sweet potato cultivation in East Africa is presented in Table 4. At present little more than 3% of arable land in Uganda is under sweet potato cultivation according to FAO estimates. In Tanzania and Kenya the land under sweet potato cultivation is about 1% of the arable land. At the same time it is interesting to note that the yield of sweet potatoes per unit area is relatively less in Uganda compared to Tanzania and Kenya (Table 5), although area under cultivation in Uganda is the highest. This is attributed primarily to diseases, insects and lack of suitable varieties.

SWEET POTATO CULTIVATION IN DIFFERENT PARTS OF EAST AFRICA

PLANT CHARACTERISTICS

Although the sweet potato is often treated as an annual crop, the plant is a perennial vine. Each plant produces many trailing stems which seldom rise more than 45 cm above the ground. Sweet potatoes have herbaceous, creeping or trailing stems (vines) with adventitious roots that end in swollen roots. Where nodes touch the ground or when they are buried during weeding they may produce roots although these are usually much smaller than those from the buried end of the planting material. The plants are grown as annuals and are propagated vegetatively from stem cuttings, rarely from roots. The cuttings are usually withered in the shade for two days. This makes them root easily. Most East African sweet potato varieties flower freely and it has been observed in Uganda that seedlings often grow in the field. Most varieties are self-sterile but will sometimes set seed when grown alongside other varieties or when artificially pollinated. Roots of different varieties vary in size, shape and color and food quality. Leaf

shape, root shape, root color and root:vine ratio all differ widely from one variety to another.

The first roots can usually be harvested between four and five months after planting. The crop duration (planting to harvesting) depends on the

Table 3. The acreage of sweet potatoes expressed as a percentage of the food crop acreage (mean of 1957 and 1958 acreage statistics)

	Food crop acreage	Sweet potato acreage	Sweet potato acreage as % of food crop acreage
	(x 103 ha)		
Buganda			
Mengo	286	32	11.0
Masaka	104	6	5.7
Mubende	38	5	13.2
Total	428	43	10.0
Eastern Province			
Busoga	248	32	13.0
Bukedi	208	13	6.2
Bugisu	162	6	3.7
Teso	323	23	7.1
Total	941	74	7.9
Western Province			
Ankole	163	11	6.8
Bunyoro	49	5	10.0
Kigezi	219	49	22.3
Toro	72	6	8.3
Total	503	71	14.1
Northern Province			
Lango	251	13	5.3
Acholi	141	7	5.0
W. Nile and Madi	155	12	7.8
Karamoja	48	<1	<1
Total	595	32	5.4
Total Uganda	2,467	220	8.9

Source: Based on Acreage Statistics from Uganda Prot Dept Agric, Annual Report 1958

Table 4. Land use in East Africa (1978)

	Tanzania	Kenya	Uganda
	---------	(x 10^3 ha)	----------
Total	94,509	58,265	23,604
Land area	88,604	56,925	19,971
Arable and permanent crops	5,140[‡]	2,270[‡]	5,610[‡]
Arable land	4,110[‡]	1,790[‡]	4,080[‡]
Permanent crops	1,030[‡]	480[‡]	1,530[‡]
Permanent pasture	44,680[‡]	3,770[‡]	5,000[‡]
Forest and woodland	31,074	1,874	2,759[‡]
Other land	7,710	49,011	6,602

Source: FAO Production Yearbook, 1979 (Vol 33)
[‡]FAO estimate
[‡]Unofficial figure

Table 5. Status of sweet potato production in East Africa with reference to Africa

	Tanzania	Kenya	Uganda	Africa
		Area (x 10^3 ha)		
1969-71	39	30	133	675
1977	54[‡]	36	137[‡]	749
1978	53[‡]	37	139[‡]	768
1979	53	38[‡]	140[‡]	782
		Yield (kg/ha)		
1969-71	6053	7753	5200	5954
1977	6204	7176	4818	6258
1978	6226	8884	4865	6383
1979	6226	8947	4912	6459
		Total Production (x 10^3 mt)		
1969-71	234	230	693	4020
1977	335[‡]	258	660[‡]	4688
1978	330[‡]	330	674[‡]	4905
1979	330[‡]	340[‡]	689[‡]	5053

Source: FAO Production Yearbook 1979 (Vol 33)
[‡]FAO estimate

variety, the climate and the local custom. In Uganda, Tanzania and western parts of Kenya sweet potatoes are seldom left in the ground for longer than a year, in the Central Province of Kenya where the rainfall distribution is favorable, they usually remain in the ground for two years, sometimes for as many as six.

ECOLOGY

Rainfall and water requirements

Sweet potatoes are very drought resistant. The vines remain green and healthy during severe droughts although root growth is negligible. Sweet potato grows well in areas with an average annual rainfall of 750 mm or more. In areas with a long dry period - like many parts of Tanzania - it is grown as an annual and is replanted near swamps, rivers or seepage areas during the drought. Where the rainfall is high and well distributed, as in Central Province in Kenya, it is usually a perennial crop.

Altitude and temperature

Sweet potatoes grow well both in the warm and the cool areas of East Africa. A warm, humid climate with reliable rainfall gives best yields. The crop will stand a fair amount of drought but yields will be less. It tolerates shadowing but no dense shade. It grows best at temperatures greater than 24°C. Sweet potatoes are widely grown from sea level up to 2100 m and some are found as high as 2400 m. They therefore replace cassava, which is seldom grown over 1500 m, at the higher altitudes.

Soil requirements

The soil needs of sweet potatoes in East Africa are poorly documented. They are grown in a wide variety of soils, from swamps to eroded areas. Based on the good responses which sweet potatoes show to farmyard manure, they need fertile soils for good yields: although the crop can stand a poor soil, yields will be less.

FIELD OPERATIONS

Land preparation

In Africa methods of land preparation differ widely. In Uganda and the lakeshores of Kenya sweet potatoes are often grown on mounds which are about 0.9 m apart and about four cuttings are planted on each. In Central Province in Kenya they are almost always grown on the flat. Ridges are the general rule in Tanzania and are sometimes seen in Uganda and western Kenya. Mounds and ridges provide ideal soil conditions for root expansion. Where sweet potatoes are grown on the flat the soil is usually sufficiently friable and well drained to make mounds or ridges unnecessary. Thus deep cultivation is required so that the roots have plenty of room for growth and consequently for best yields. All troublesome weeds - such as *Digitaria scalarum* - must be destroyed.

Time of planting

There is little experimental evidence to suggest the best time for

planting sweet potatoes. Thus growers very seldom give them priority over cereals or important cash crops such as cotton. They plant at any convenient time when there is sufficient soil moisture for establishment.

Where rainfall is evenly distributed throughout the year, as in Buganda, planting can be done nearly every month. Where there is a pronounced rainy season, as in Teso, planting is done at the beginning of the rains on the high ground and at the end of the rains in the swamps.

Planting material

Propagation by seed is possible but is only likely to be used by breeders; vegetative propagation is the only method practiced by small holders. Throughout East Africa apical pieces of vine (the pieces furthest from the base of the plant) are preferred and are taken from mature plants. Local custom and individual preference dictate the length of the planting material; pieces may be anything from 23 cm to 90 cm long. When planting material is in short supply it may be taken from the middle or even the basal parts of vines. In some parts of East Africa - such as Uganda, the lakeshore areas of Kenya and the southern highlands of Tanzania - the planting material is commonly wilted for a few days before planting to encourage root initiation; it may be covered with a layer of soil or vegetation or may be kept in the shade with no direct cover. In other areas the plants are planted without wilting.

Planting methods

Cuttings (or slips) about 30-45 cm long, of the apical part of the vine, about pencil thickness at the base, are taken from a mature plant. These are usually withered in the shade for two days to encourage root formation. Cuttings are planted at an angle with between one-half and two-thirds of their length, including the cut end, buried in the soil. However, long cuttings are usually planted almost flat with the end pointing up and out of the soil at an angle. Sometimes, as in Central Province in Kenya, cuttings are planted with both ends exposed and only the middle part buried. In Teso and Bukedi (in Uganda) they are planted directly on the mound and covered with soil, which is removed two days later. They should be free of virus disease. The traditional method of planting is on mounds, which consist of thoroughly cultivated soil made into a heap. The height, size and distance apart of the mounds vary from tribe to tribe. The use of a forked stick is common in north Uganda and is convenient for planting large numbers of cuttings. Elsewhere the cuttings are inserted by hand or covered with soil. Usually 2, 3, 4 or 6 cuttings are inserted in each mound. Yields per hectare vary little with spacing but larger roots are obtained from wider spacings. The modern method of planting is on ridges, which if they follow the contour, prevent soil erosion and can be made by an ox-or tractor-drawn ridger. The flat method of planting is used in perennial crops when ground cover is required.

Spacing

Sweet potato is usually planted in pure stands or with perennial crop . It spreads so rapidly that it is seldom interplanted with annual crops and when it is, planting is usually delayed until the other crops are well established. When pure stands are planted on the flat a random spacing is

adopted. When grown on ridges the ridges are 0.9-1.5 m apart and the vines are not an important factor in achieving good yields.

Fertilizers and manures

N fertilizers have not given good results in East Africa; vine yields are sometimes increased but root yields are not improved and are sometimes even depressed. P and K are not encouraging when used; farmyard manure always gives good responses but it is very seldom applied.

Varieties

There is a large number of varieties varying in taste, food value, size, shape and color of roots, maturity period, yield, resistance to pests and diseases, leaf structure, and so on. At Ukiriguru in Tanzania collections of over 2000 clones were made in the past. There is great scope for selecting, breeding and issuing improved varieties. New varieties are periodically found, probably from self-sown seedlings, the seed resulting from cross-fertilization between flowering varieties. New varieties are grown in 10-20 years. One of the problems of sweet potato growing in East Africa is that varieties often degenerate over the years. The cause of this degeneration is suspected to be virus diseases. Seedlings are thought to be the source of new varieties.

Rotations

The crop is often grown in small plots around houses or on swamp fringes and often is not included in the rotation - otherwise it usually comes near the end. Occasionally it may be used as an opening crop for cleaning land. When sweet potatoes are planted in a pure stand, as they usually are, they may be grown in a crop rotation. Examples of continuous cultivation occur on steep slopes (where sweet potatoes cover the ground and prevent erosion better than most other crops), on small plots near the homestead (conveniently situated for ease of transport), along roadsides (especially true in parts of Kenya where local bye-laws prohibit growing tall crops such as maize directly alongside roads), and in valley bottoms. Unlike Uganda and the western parts of Kenya where sweet potatoes are often grown in a crop rotation as the first crop after clearing the land from grass, in Central Province in Kenya sweet potatoes are often grown on land which has been exhausted by previous crops of maize and beans.

Weed control

With this crop weeding is not a great problem. The crop is so aggressive that it covers the soil quickly and suppresses most weeds. Two or three thorough weedings can be done in the first two months of the crop but once sufficient ground cover has been established most weeds will be smothered. Sometimes no weeding is necessary at all.

Harvesting and storage

Sweet potatoes are usually harvested piecemeal because few are needed at a time for domestic use and compared to other crops they cannot be stored fresh for more than a few days. Only if they are sliced and dried can they be stored for a considerable period, but this is not commonly practiced. One

or two roots are removed from a plant leaving the rest of plant undisturbed. A sharpened stick is often used for harvesting; if on the other hand a 'jembe' or a hand hoe is used then the chances of damaging the roots increase. When the roots are dried about 2/3 of the weight is lost.

Yields

Exact data are difficult to obtain locally because of the method of harvesting. They may vary between 2.5-15 t/ha of fresh roots. In addition 2.5-10 t/ha of tops are produced which are a valuable feed for cattle.

Pests and diseases

Sweet potato weevils are the most damaging pests of sweet potatoes in East Africa. There are two species, [illegible] and [illegible]. The former is more common. The larvae tunnel inside vines and roots causing discoloration and bitterness in the roots and dwarfing and yellowing of the vines. Sweet potato virus B causes the only disease that poses a great threat to sweet potato cultivation in East Africa. It causes stunting, excessive branching and yellowing of the vines, and cork symptoms may develop in the roots. Virus B is spread by whiteflies ([illegible] spp). Another virus, sweet potato virus A, which is transmitted by aphids, is of very little significance except in Western Tanzania.

Utilization

The commonly practiced method of preparing sweet potato roots is to boil them unpeeled; they are then peeled immediately before eating. A popular alternative in Central and Eastern Provinces in Kenya is to roast them unpeeled in the ashes of a fire. A less common method of cooking is to peel and slice the roots before boiling or frying with other root crops, cereals, legumes or vegetables. In a few areas - like Nyanza in Kenya and Western Tanzania - sweet potatoes are peeled, sliced, dried, and then ground into a flour with sorghum or maize for making 'ugali' or 'uji' (Acland 1975; Dunbar 1975).

RESEARCH ACTIVITIES ON SWEET POTATOES IN EAST AFRICA

Although sweet potato is one of the most important food crops in East Africa, research activities on it at the present time are lacking. In the past, some research work was done in Uganda and Kenya in the 1960s by expatriate staff (Aldrich 1963; Ingram 1967; MacDonald 1963; Wheatley 1961), but due to political changes in Uganda the work was not followed up.

In Tanzania research work on sweet potato was initiated in 1967 at Ukiriguru Research Station (Western Tanzania near Lake Victoria). The research work covered collection of varieties, time of planting, spacing, effect of leaf size and shape on variety tolerance to late planting and so on. Due to turnover of expatriate staff and shortage of local manpower most of the work was discontinued. Further, many varieties collected from inside and outside the country were not maintained and several others died due to drought, pests and diseases (Annual Reports 1970, 1972).

Recently, the Tanzania National Root and Tuber Crop Improvement Programme was established at Ukiriguru and given the responsibility of improving the

production of sweet potatoes in the country by identifying the limiting factors in their production. Some of these include: continued use of poor yielding varieties; poor crop husbandry; insect and disease problems; poor storage facilities; processing problems; and inadequate crop utilization. Although the local varieties of sweet potato have continuously shown low capacities of root production and resistance to disease and pests, farmers continue to grow them under their environmental conditions and poor cultural practices. The reasons for this may be that most farmers do not get improved varieties and packages of practices from the agricultural research stations, and that some farmers who do have access to improved varieties and practices do not use them because they are something new and they have not seen them grown or used (Annual Reports 1978, 1979).

From the preceding paragraphs it is clear that a strong coordinated research programme on sweet potato is urgently needed in the three countries of East Africa. It is satisfying to note that such a program has already been initiated and is gathering momentum particularly in Tanzania.

SWEET POTATOES AND ITS FUTURE IN EAST AFRICA

In recent years there have been acute food shortages in East African countries. Cereal production is also not increasing because of a number of factors. It has been observed that sweet potatoes are grown in almost all parts of East Africa and it is a popular crop in traditional farming systems.

Since the yield potential of sweet potato is extremely high and it is not a new crop in the region, there is no doubt that it has bright future in East Africa to supplement the food needs of the region.

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General Discussion

(Session I)

URITANI: Please explain whether sweet potato will be better than cassava in the tropics for the future.

VILLAREAL: Sweet potato scientists believe that sweet potato has better potential than cassava primarily because of its shorter growing season and higher nutritional content.

SALIRE: Is sweet potato better than cassava in terms of alcohol production?

VILLAREAL: I think they have comparable yield on a hectare basis but sweet potato seems a little better if yield is expressed on a daily basis. As you know sweet potato has a shorter growing period than cassava.

SALIRE: In Bicol Region, the Philippines, some farmers prefer to plant sweet potato on Ash Wednesday in the belief that more and bigger roots can be produced. Is there any scientific reason for this practice?

VILLAREAL: It is a superstitious belief for which I am not aware of any scientific explanation.

KAYS: On compacted soils, the two primary components of yield reduction appear to be decreased: soil oxygen concentration and mechanical impedance. Which of the two do you believe to be the more important in sweet potato production?

VILLAREAL: I think both are important. Which one is more important I am not sure. Dr Sajjapongse will give a paper on soil compaction on Thursday but he may wish to comment on this matter now.

SAJJAPONGSE: In our experiment oxygen was not limiting. Therefore mechanical impedance was more important. Under flooded conditions, however, soil oxygen becomes a critical factor.

ANONYMOUS: Are there any reports or studies on the domestication of sweet potato on any of the Pacific islands?

YEN: No. The possibilities are being researched by me in such genera as *Canarium*, *Burckella*, *Pandanus* and so on but there is no evidence for the origin of sweet potato other than diffusion and varietal formation by genetic recombination and mutation.

VILLAREAL: Which part of the Philippines is considered a secondary center of variation of sweet potato?

YEN: I would say that the center of mountainous Luzon - among the Ifugao and Bontoc peoples, judging from the great range of varieties, seed production and ethnographic examples of seedling selection.

VILLAREAL: Any evidence to indicate what form or kind of sweet potato was grown about 300 years ago?

YEN: I presume you mean in the Pacific as a whole. The indications from relatively isolated areas like Easter Island, New Zealand, and the Eastern Solomons is that early varieties were white-skinned, white- or near white-fleshed, and lower yielding than more recent introduction. Also they were more bushy in growth habit.

ANONYMOUS: From your point of view, which is better - long cultivation or short cultivation?

YANG: From the standpoint of solar energy fixation efficiency, long term cultivation is better than short term cultivation. The following points should also be considered in determining which is better: crop rotation, market price of sweet potato at harvest time, favorable climate for sun-drying of sweet potato chips, and economic conditions of farmers.

WINARNO: How were the physical conditions of rats which received sweet potato supplementation?

YANG: No differences in the physical appearance of rats were observed between those fed with a rice diet alone and those fed with a rice diet supplemented with sweet potato.

ANONYMOUS: Please comment on the use of fertilizer to increase protein content in sweet potato especially to increase aspartate content.

YANG: Aspartate levels of sweet potato root crude protein were remarkably increased by increasing the amount of fertilizer under short term cultivation. A remarkable decrease of aspartate levels was observed together with a decrease of protein content, when cultivation was prolonged by 31 more days and during this period free amino acid increases were observed. Therefore, I conclude that proteins with relatively high aspartate level were broken down during the prolonged harvesting period.

WINARNO: Is there any future possibility of incorporating sweet potato into weaning diets?

HUANG: It is not possible to use sweet potato as the main weaning food because an infant's stomach capacity is small and cannot contain enough to get sufficient calories and protein. The high-carotene variety, however, can be used as a supplement to provide pro-vitamin A to prevent xerophthalmia.

WINARNO: What were the physical characteristics of your younger subjects after sweet potato eating?

HUANG: They are shorter and lighter for their age as compared to Chinese.

ANONYMOUS: Is it possible that the different results obtained in the New Guinean study and in your study are due to genetic factors?

HUANG: The New Guinean study was conducted in the subjects' houses in the highlands, and therefore the dietary N intake measurements, urinary and

fecal collection and so on, were probably inaccurate. Our study was conducted in a metabolic ward under strict control. Our previous studies on Chinese protein requirements showed some difference between Chinese and US whites. Therefore, the possibility exists but it is difficult to assume from the present study that the differences are due to genetic factors.

ANONYMOUS: Sweet potato consumption patterns in the US have followed a pattern similar to that described for Taiwan but not as drastic. Decline is generally attributed to its survival food status gained during the Great Depression. However even this is not entirely accurate. A recent survey of major markets in midwestern and eastern states indicates it is served as holiday food at Thanksgiving, Christmas and Easter.

JONES: I know little of nutrition research and therefore I am a little out of my area of expertise here. However, Taiwan and other areas may learn something from our American experiences. I think one reason for reduced consumption of sweet potato in the US was that at a time when we had a rather large migration of people from the farms to the cities the price of sweet potato also rose rapidly. These people from farm backgrounds liked sweet potato but simply could not afford it as a staple food. So they treated themselves to it on special holiday occasions. As the price went up, future markets were thus reduced. The lesson is if you want the sweet potato to remain a staple food you must keep the price low enough to compete with other staple foods.

YUH: Is it possible to breed a cultivar of sweet potato comparable to rice as main staple food? What is the limiting factor on this problem?

TSOU: We try to improve sweet potato as a better supplementary staple rather than as a staple food on its own. We think high sugar content of the present cultivar is one of the factors working against sweet potato as a supplementary staple.

MOY: Toward the end of your presentation, you suggested several desirable characteristics of sweet potato for product development and increased utilization. Do you have a certain type of processed product in mind?

TSOU: I am thinking of partially dehydrated sweet potato cubes that can be easily stored and cooked directly with rice using an electric cooker.

GEA: How old is sweet potato cultivation in Papua New Guinea? Give us a brief history.

ARUS: It is generally accepted that sweet potato was introduced into Papua New Guinea from the West Indies via Africa in the past 400 years following European exploration of the New World. However, archeologists in PNG increasingly suspect that sweet potato may have been growing in PNG for a much longer period than 400 years.

URIAHI: Sweet potato produces phytoalexins in response to fungal infection or weevil infestation. Do you have some problems with the production of phytoalexins, which are toxic and bitter?

ARUS: Our problem with the sweet potato weevil is restricted to the unimportant sweet potato growing area in the lowlands. This has not forced us to do

an indepth study on sweet potato weevil and the related problems. However with time we will look into it.

ANONYMOUS: Can sweet potato be planted by row instead of by heap in Papua New Guinea?

AKUS: Sweet potato in Papua New Guinea is grown in many ways. It is grown on flat land, small mounds, large mounds and on ridges. Of all the methods used the best yield is obtained from large mounds (1.5 x 1 m).

LEE: Why do you plant sweet potato in a pile of soil instead of using the traditional ridge method? Do you have any yield data on these two planting methods?

AKUS: The two methods have been tried and it was found that yields obtained from mounds were far superior to those obtained from ridges. Mounds yielded 28% more roots than ridges. However, it is more work building mounds than ridges.

URITANI: Please explain how sweet potato roots are stored under natural conditions as foods or seeds.

AKUS: As food, sweet potato is best stored by our method of harvesting. We harvest large roots as they are required. Sweet potato in Papua New Guinea is not grown from seed. All sweet potato varieties are propagated vegetatively.

ANONYMOUS: Your sweet potatoes are grown from low to high elevation. Do you have data about varieties including maturity time for low, medium or high elevations?

AKUS: Our region is divided into two: the highlands and the lowlands. There are six varieties that are being recommended for the highlands. The lowlands have their own varieties. Sweet potatoes are harvested in 5-6 months in the lowlands, 6-8 months at the intermediate elevation and 8-12 months or more in the highlands.

SESSION II

Tuberization in Sweet Potato (*Ipomoea batatas* (L) Lam)

L. A. WILSON

Department of Crop Science, The University of the West Indies, St Augustine, Trinidad, West Indies

INTRODUCTION

Root tuberization is here defined as the sum total of all the processes leading to the formation of mature roots in sweet potato. It developed at some point during the phylogenetic evolution of the genus *Ipomoea* to give rise to the characteristically tuberous *Ipomoea batatas*. It is repeated during the cropping of the several modern sweet potato varieties and cultivars now grown throughout the tropical and subtropical world. Different hypotheses on the origin of the sweet potato species are briefly described and biological processes involved in tuberous root initiation, development and growth to maturity reviewed. Variations in yield and yield components within the species is briefly outlined and achievement of potential photosynthetic productivity discussed.

TUBER INITIATION

Wilson (1970) defined the sweet potato tuber as the localized lateral swelling that develops in certain roots in the sweet potato root system. Later Wilson and Lowe (1973a) designated such roots potential tuber-bearing organs by analogy with the stolons of *Solanum* potato. The significance of such a designation is that the genesis of the tuber-bearing organ might indeed be considered an integral part of the process of tuber initiation. In reviewing the gross morphology of the sweet potato root system, Wilson (1970) listed ten root types (Figure 1). In addition, adventitious roots may be of nodal or internodal origin and in some sweet potato varieties, pigmented and non-pigmented roots are observed (Wilson and Lowe 1973b). In sweet potato plants grown from stem cuttings, positively geotropic thick roots, designated potential tuber-bearing organs, give rise to string roots, pencil roots or tuber-bearing roots (Wilson 1970). In sweet potato plants grown from tuber sets, certain tuber roots give rise to daughter tubers. Diageotropic, adventitious roots, lateral roots and tuber roots do not normally give rise to tubers. However, tubers generate lateral tuber roots and the root constituting the proximal extension of the tuber is designated the tuber end root.

Wilson (1970) suggested that the interpretation of thick roots as tuber-bearing organs depended upon:

(i) their different form and function from other root types

(ii) the control of the process of tuber initiation on thick roots by different factors from those leading to growth and development of the thick roots.

Accordingly, thick roots were found to differ from thin roots in the greater size and more rapid growth of their apical meristems and their origin in nodes nearer the stem apex and in those nodes containing few root primordia

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1. Adventitious roots (those roots developed on the stem)
   (A) Positively geotropic roots
      (I) thin roots (Togari 1950; Wilson 1970)
      (II) thick roots (Togari 1950)
      (III) string roots (Wilson 1970)
      (IV) pencil roots (Togari 1950)
      (V) tuber-bearing roots (Wilson 1970)
   (B) Diageotropic roots (surface roots of Fujise and Tsuno 1967)
      (VI) thin roots
      (VII) thick roots
2. Lateral roots (roots developed on existing roots)
3. Tuber roots (roots developed on tuber):
   (A) Tuber end root (Wilson and Lowe 1973a)
   (B) Lateral tuber root

Figure 1. Root types in the sweet potato root system

(Togari 1950). Alternatively, roots of internodal origin were almost exclusively thin roots (Togari 1950). The most important functional difference between the root types is the capacity for tuber initiation in a specific subapical region of thick roots. That such tuber initiation is subject to different controlling factors from those controlling the continuing growth of the thick root was supported by evidence that the following specific conditions promoted root development but apparently inhibited tuber initiation or at least early tuber growth:

1) exposure of the root system to light (Tsuno and Fujise 1965)
2) growth of roots in water culture even when well aerated (Wilson 1969)
3) growth of roots in waterlogged soils with oxygen deficiency or in dry and compact soils (Togari 1950)
4) exposure of roots to high levels of NO_3-N supply (Wilson 1973a, 1973b).

Wilson (1970) pointed out that the positive geotropism of the tuber-bearing root and its capacity for alternative development of shoots (albeit lateral rather than terminal) under conditions of high nitrogen supply (Wilson 1973b) completed an apparent analogy between the tuber-bearing root of the sweet potato and the stolon of *Solanum* potato. In dark subterranean conditions, in a well aerated solid medium with low levels of nitrogen supply, apparent tuber initiation as judged by localized, subapical lateral swelling of the tuber-bearing root occurs. The tuber divides the otherwise unthickened root into the distal 'tuber stalk' and the proximal tuber end root.

Anatomical considerations on tuber initiation have been concerned with

(a) the initiation of the tuber-bearing organ (thick roots)

(b) tuber initiation on this organ.

Artschwager (1924) and Togari (1950) reported that tetrarch thin roots could be distinguished from thick roots which were either pentarch or hexarch. It was further observed that tuber initiation occurred in such thick roots which, in addition, contained a central pith, with or without a central metaxylem cell. Wilson and Lowe (1973a) later confirmed these findings for Caribbean sweet potato cultivars but maintained that although tetrarch tuberous roots did not occur, many pentarch and hexarch roots were not tuberous. Also, roots which were pentarch or hexarch and tuberous in their distal regions sometimes became tetrarch at their proximal or root tip ends to give rise to the tuber end root. However, there is agreement that the process of tuber initiation involves the genesis of anomalous primary cambia in the central pith surrounding the central metaxylem cell, as well as a vascular cambium with capacity for centripetal generation of storage parenchymatous cells instead of xylem cells (Artschwager 1924; Togari 1950; Wilson and Lowe 1973a). The earlier report by McCormick (1916) that tuber initiation occurred in roots with complete centripetal development of the stele, later to be broken up by meristematic activity in adjacent parenchyma cells and in the vascular cambium, was not supported by the later studies. Wilson and Lowe (1973a) further pointed out that such renewal of meristematicity gave rise to anomalous primary and secondary cambia surrounding primary and secondary xylem elements respectively. Also, complete but not incomplete centripetal development of the primary xylem elements leading to lignification of the central pith frustrated the process of tuber initiation, characterized by the generation of secondary parenchyma from the vascular cambium. Such progressive lignification led to development of uniformly, secondarily thickened, string roots and pencil roots and later in tuber ontogeny, delimited the tuber at the tuber stalk and tuber end root regions of the tuberous root.

Tuber initiation, as so described, takes place at two to eight weeks after planting of stem cuttings of Caribbean cultivars and at this time is not recognizable by the lateral swelling commonly called the tuber. Little work has been done on the physiology and biochemistry of tuber initiation defined at the anatomical level, presumably because of the tedious sectioning of roots involved in recognition of the process. Instead, studies have been conducted on factors affecting the process which will be described as early tuber growth, that is, the early lateral expansion of the tuber. However, it should be mentioned that Wilson and Duncan (1968) found that the location of pith cells could be recognized in the undifferentiated region of the root by the absence of peroxidase activity compared with surrounding 'pre-xylem' cells, suggesting that pith formation (and hence tuber initiation) might indeed be determined prior to visible cell differentiation. Also auxins are known to increase the number of xylem elements in ferns and higher plants (Wardlaw 1968), as well as in *Pisum sativum* root tips grown in asceptic culture (Torrey 1955). Such an effect of auxin on the early ontogeny of sweet potato roots might mean that auxin supply was critical for the pentarch and hexarch condition of roots found to be a prerequisite for tuber initiation.

TUBER DEVELOPMENT

Tuber development is here defined as the qualitative changes in growth

which take place in the sweet potato root system in the course of the transformation of potentially tuberous roots into mature tubers. These changes, which are interpreted to include those resulting in the frustration of tuberization leading to formation of pencil roots and string roots, as shown below:

tuber initiation and early growth

formation of alternative root types eg pencil and string roots

tuber stalk development

determination of tuber shape

development of buds

development of lateral tuber roots

These processes have not been studied in detail and hence only brief statements on available information on each of them are given below.

Tuber initiation and early growth

Although the process of tuber initiation has been previously described, it is here noted that if the process is defined on the basis of the primary stelar structure of thick roots, then it occurs at root initiation. However, definition of the process on the basis of meristematicity of primary cells in the subapical region of the thick, tuberous root means that tuber initiation commences later in root ontogeny. In any event, Lowe and Wilson (1974a) found that the process was completed by eight weeks after planting stem cuttings, at which time typical tuber numbers of the six cultivars studied could be discerned. The following events were recognized in the tuber initiation process:

1. rapid increase in the number of pigmented and non-pigmented roots over the period, between week 1 and week 4 after planting.

2. increase in the thickened root number and decline in total root number over the period weeks 4-12; but with a significant mean increase in thickened root number of 117 over the period weeks 8-12.

3. increase in tuber number to maximum values in five of the six cultivars studied by week 8 (Lowe and Wilson 1974a).

Since tubers were recognized in this study by their morphological appearance as lateral swellings rather than by anatomical observation, then the process of early tuber growth, which is realized by active meristemacity of primary, secondary and tertiary meristems, was included in the definition of tuber initiation.

Formation of alternative root types

The period weeks 8-12 appeared to be critical for the genesis of alternative tuberous root types, that is, pencil and string roots, through progressive lignification of secondary stelar tissues, leading to the definition of tuber number (Lowe and Wilson 1974a). Thus, when the total number of tuberous roots was defined as potential tuberization index and the percentage of these roots which tuberized as percentage tuberization index then there

were major reductions in percentage tuberization indices in the period weeks 8-12 after planting, indicative of the frustration of the tuberization process by the formation of uniformly thickened string roots. As a result, there were only marginal increases in tuber number after week 8. However, in one of the six cultivars studied (I 62) tuber initiation continued over the entire 24-week growth period.

Tuber stalk development

At the completion of tuber initiation at week 8, Lowe and Wilson (1974b) found that maximum tuber stalk length was virtually achieved in two cultivars (AI 6/15, C 9/9) and percentage increases in the other four cultivars at final harvest (24 weeks after planting) ranged from 15-34%. Final tuber stalk lengths ranged from 2.4-7.6 cm suggesting that stalk length was a varietal character. The anatomy of the tuber stalk (Wilson and Lowe 1973a, c) showed that secondary xylem elements had the structure either of string roots with complete centripetal lignification or of pencil roots with incomplete lignification, medullary rays and secondary xylem parenchyma. It follows therefore that the subapical region of the tuberous root along which tuber initiation occurred, varied in different sweet potato cultivars. Although tuber stalk length is virtually determined at the completion of tuber initiation eight weeks after planting, there is progressive secondary thickening of the stalk with tuber development to diameters of up to 5-6 mm in cv A 28/7 (Wilson and Lowe 1973c). Such secondary thickening results in the formation of extensive secondary phloem as well as genesis of phloic bundles within secondary phloem parenchyma and cortical tissues (Wilson and Lowe 1973c). Such phloem development results in the specialization of the tuber stalk as an organ of translocation for the transport of assimilate from the stem to the tuber. At tuber maturity, Wilson and Lowe (1973c) found that phloem tissues occupied up to one-third of the cross sectional area of the tuber stalk in a high yielding sweet potato cultivar, A 28/7.

Determination of tuber shape

Different rates of longitudinal and lateral growth result in characteristic changes in shape with tuber development. Thus Lowe and Wilson (1974b) found that 92-100% of final tuber length was established by 16 weeks after planting in six sweet potato cultivars but only 49-77% of final tuber width developed in the same time (Lowe 1971). Accordingly, rates of increase in tuber length were 2.6-8.3 mm/week in the 8-16 week period and 0-0.1 mm/week in the 16-24 week period, but the corresponding figures for increases in tuber width were 1.1-2.3 and 1.1-3.3 mm/week respectively. Final tuber lengths and widths ranged from 7.4-15.6 cm and 3.0-5.3 cm respectively and length/width ratios varied from 1.5-4.4 in the six cultivars studied. Since tuber stalk length was fixed early in tuber ontogeny (by week 8) then increase in tuber length over the period weeks 8-16 must have taken place at the tuber end root region of the tuber and mediated through lateral expansion in the initiated region of the root. Definition of tuber length at this end of the tuber was determined by development of a typical, secondarily thickened string root by secondary lignification of the stele (Wilson and Lowe 1973a). Variations in the rate of increase in tuber width in different cultivars was effected either through major contributions of the vascular cambium, as in cv AI 6/15 with narrowly uniform tubers, or through contributions from both this cambium as well as successively formed secondary and tertiary tuber meristems for example in cv 049 with globular tubers (Wilson and Lowe

1973a). In the latter cultivar, there was up to a 1.7 fold increase in the rate of tuber width increase in the 16-24 week period compared with the 8-16 week period (Lowe and Wilson 1974b). Anatomical evidence (Wilson and Lowe 1973a) further demonstrated that tuber shape was largely determined by the shape of the stele. As the tuber expands, a phellogen increases in girth to accommodate its increasing width producing an external layer of tuberized cells.

Development of buds and lateral tuber roots

Wilson and Lowe (1973a) established that early in tuberous root ontogeny, adventitious buds were produced in the tuber stalk, pencil and string roots as well as on the tuber, either singly or in groups of up to four. Such buds occurred in the primary cortex opposite xylem rays and were distinguishable from lateral tuber root primordia by their exogenous origin. Wilson (1973b) showed that adventitious buds produced on thickened roots of detached rooted leaves could be stimulated to develop into shoots by high levels of nitrate-nitrogen supply.

Therefore tuber development involved a series of qualitative changes in growth, the most important of which appears to be the relative activity of cell division and cell expansion versus cell lignification. Such relative activity leads to either tuber initiation or the generation of alternative root types such as pencil roots, delimits the tuber stalk, defines the length of the tuber, and later determines its rate of lateral growth to give rise to tubers of different shapes. However, in addition, normal tuber development includes development of a unique translocatory system in the tuber stalk and development of lateral tuber roots. Light dry and compact soil (Akita *et al* 1960), as well as waterlogged soil conditions (Togari 1950), high levels of nitrogen supply (Wilson 1973b), gibberellin and long days (McDavid and Alamu 1980a,b) are known to encourage lignification and frustrate tuber development. Alternatively, dark conditions (Akita *et al* 1960; Fujise and Tsuno 1967), high potassium supply (Tsuno and Fujise 1967), well aerated soil conditions, low temperature (Togari 1950 and Kim 1961) short days and kinetin (Spence and Humphries 1972; McDavid and Alamu 1980a,b) have been shown to encourage tuber development. Apart from the work of Spence and Humphries (1972) and McDavid and Alamu (1980a,b) few investigations on the role of plant growth substances and growth inhibitors in sweet potato tuberization have been reported. However Sirju (1977) showed that in addition to IAA, gibberellic acid (GA) and benzyl amino purine (BAP) both stimulated and inhibited, and abscissic acid (ABA) inhibited, IAA oxidase genesis during ageing of sweet potato tuber discs.

The process of tuber development therefore results in the realization of tubers with specific characteristics with respect to number, subapical location on the tuber-bearing root, length and function of tuber stalk, shape and the relative contribution of the vascular meristem and anomalous secondary and tertiary meristems to tuber growth. These characteristics vary considerably between sweet potato cultivars and appear to be under genetic control. It will be shown that capacity for expression of these characteristics resides in the root system rather than in the foliage of sweet potato plants and also that these qualitative development characteristics of the tuber influence its capacity for quantitative growth.

TUBER GROWTH

In contrast to tuber development, tuber growth is defined as the quantitative changes in the size and weight of tubers which take place in the course of transformation of sweet potato tuberous roots into mature tubers, that is: tuber yield. Increase in tuber size is mediated through increases in cell number and cell size and in tuber weight through accumulation of assimilate in tuber cells (Wilson 1967, 1969, 1974, 1977). Increases in tuber cell number and cell size are under hormonal control whilst increase in tuber weight depends upon leaf photosynthesis. Moreover, the transport of assimilate to the tuber via the petiole, stem and tuber stalk is an active process known to be influenced by tuber growth in sweet potato (Fujise and Tsuno 1967). Therefore, there is a morphogenetic or cellular component versus a photosynthetic or weight component in tuber growth. Since tuber cells must first be formed and then expand before they can store assimilate and since the cell division component of tuber growth continues throughout tuber ontogeny (Wilson and Lowe 1973a) it appears that the morphogenetic component of tuber growth must first be realized in order to accommodate the photosynthetic component (Wilson 1969). However, if it is accepted that cellular growth is a prerequisite for increase in tuber dry weight, then the growth component might be assessed by comparison of the distribution of dry matter between the tuber and alternative growing organs of the plant such as stem and leaves.

Tuber yield depends upon the rate of increase and duration of tuber growth and hence tuber growth also includes rate and time components. In addition the terminal, physical components of tuber yield are the number and mean size of tubers at final harvest and therefore increases of tuber number and tuber size components with tuber growth are physical expressions of tuber growth. Considerations on these various components of tuber growth are presented under the following headings:

a) Interrelationships between foliage characteristics and tuber yield

b) Patterns of tuber growth

c) Mean tuber weight, tuber shape and tuber growth

d) Possible mechanisms of tuber growth.

Interrelationships between foliage characteristics and tuber yield

A most remarkable feature of the sweet potato species is the wide range of morphological characteristics of foliage and tuber that exist in cultivars and varieties. However, several attempts to demonstrate clear relationships between yield and either morphological or physiological characteristics of the crop foliage have been unsuccessful, eg Jones (1966).

Cowling (1964) and Chapman and Cowling (1965) reported that staking resulted in dramatic increases in yield of a low yielding, high leaf area index (LAI) cultivar A 138 (maximum LAI > 7) and suggested that vertical leaf display and by inference photosynthesis might be directly involved in sweet potato yield. However, Wilson (1969, 1975) pointed out that these yield increases were due more to increases in harvest indices (HI) than to increase in total dry matter (TDM). Thus, in the presence of applied N, percentage increases in yield, HI and TDM were 480, 222 and 64 and in its absence 158, 82 and 41 respectively. It might also be mentioned that the

low light intensity conditions in shaded leaves of unstaked plants could also have led to reduced cellular growth of tubers (Togari 1950) and so have a morphogenetic effect.

In reciprocal graft (phytomodel) experiments with three sweet potato cultivars of different yield (sink for assimilate) capacity and foliage (source of assimilate) characteristics, Wilson (1967) showed that rootstocks with the high yielding cv 049 gave higher average tuber yield/plant after eight weeks of growth (65 g) than cv C9 (29 g) and the low yielding R 38 (4 g) respectively. However, scions of cv C9 and cv R 38 (both low leaf area cultivars) gave higher yields on 049 rootstocks than cv 049 itself. The preeminence of C9 as a scion was also illustrated by the superior yield of C9/C9 phytomodels compared with 049/C9 and R 38/C9 models. However this latter effect was not obvious at final harvest. It was concluded that early tuber growth in the cultivars examined, providing a sink for assimilate, was a function of their capacities to tuberize, a characteristic associated with the rootstock. Moreover these capacities were transferable to the scion of other varieties by reciprocal grafting. It was also suggested that intervarietal differences in tuber yield were related to tuber growth (Wilson 1967).

Subsequently Hozyo (1970), and Hozyo and Park (1971) confirmed that early (and late) tuber enlargement characteristics were inherent properties of the rootstock, in reciprocal grafts with six improved Japanese sweet potato varieties. They also reported that in reciprocal grafts between cv Okinawa 100 and *I. trifida*, photosynthesis of the non-tuberous *I. trifida* scions was increased by 50% (approximately) on Okinawa 100 rootstocks compared with controls of self graft *I. trifida* phytomodels.

Later, a mathematical analysis of yield in reciprocal graft phytomodels with four sweet potato varieties was done by Hahn (1977) who found that high tuber growth varieties (TIS 1499 and TIB 10) responded to increase in the source as the sink demand increased. However, increased sink demand increased the production of the source. It was concluded on the results of standard partial regression coefficients, that the sink appeared to be more important than the source in determining dry tuberous root yield. Hahn's data showed that the productivity of the scion of the low yielding variety TIb 5 (a self-graft phytomodel TIb 5/Tib/5, 7.28 g/plant) was increased some 259 in the TIb 5/TIb 10 phytomodel and 181% in the TIb 5/TIS 1499 model demonstrating clearly the capacity of tuber growth to increase dry matter productivity of sweet potato foliage.

Using rooted leaf phytomodels, Wilson (1967) also demonstrated that in the absence of nitrogen in the culture solutions used for growth, phytomodels reached the point of starch storage in leaves on exposure to light before models grown in the presence of nitrogen, leading to a 41% increase in specific lamina weight after three weeks of growth (Table 1). Moreover, at this time, -N phytomodels assumed the state of permanent accumulation of starch in laminae, a state which was not alleviated after 72 hours in the dark. These results were interpreted to mean that the -N induced cessation of root extension growth and resulted in increased starch accumulation in leaves with photosynthesis. Later, using rooted leaf phytomodels, Spence and Humphries (1972) demonstrated similar increases in specific lamina weight. Tuber growth was restricted by moisture supply and root temperature. There was also up to 81% increase in dry matter productivity at 25°

Table 1. Increases in specific lamina weight in sweet potato rooted leaf phytomodels induced by reduced root and tuber growth

Specific lamina wt[z] g fresh wt/100 sq cm			Specific lamina wt[y] g dry wt/100 sq cm[x]		
+N	-N	% increase	25° RT	15° RT	% increase
12.7	17.9	40.9	0.50	0.68	36.0

[z]Adapted from Wilson (1967)
[y]Adapted from Spence and Humphries (1972)
[x]RT = Root temperature

root temperature compared with 15° induced by up to 205% increase in tuber growth at the higher temperature (Spence and Humphries 1972).

Therefore, it is here concluded that the capacity of tubers for growth is a major factor in determining sweet potato yield in view not only of its effect on the realization of the size component of tuber growth, but also because it results both in increased rate of photosynthesis and dry matter productivity of the sweet potato plant through sink effects both in dry matter production and distribution to tubers. The data also demonstrated that nitrogen and staking had positive effects on dry matter distribution. However further experimentation is needed in order to separate morphogenetic from photosynthetic effects of light on tuber development.

Patterns of tuber growth

Lowe and Wilson (1974a) and Wilson (1975) examined patterns of tuber bulking in six sweet potato cultivars of different yield potential and foliage characteristics and recognized three bulking phases (Table 2, Figure 2) as follows:

Table 2. Early and linear bulking rates in six sweet potato cultivars over a 24-week crop (Lowe 1971; Wilson 1975)

	Sweet potato cultivars						Means
	A 28/7	O 49	I 62	C 9/9	AI 6/15	03/62	
Early bulking rates (0-8 wks) (g/plant/wk)	7.6	4.5	0.4	2.6	6.1	1.9	3.9
Duration of linear bulking (wk)	16	8	16	16	8	12	13
Linear bulking rates (g/plant/wk)	36	47	30	26	34	26	33
% yield formed in linear bulking	90	84	99	95	76	96	90

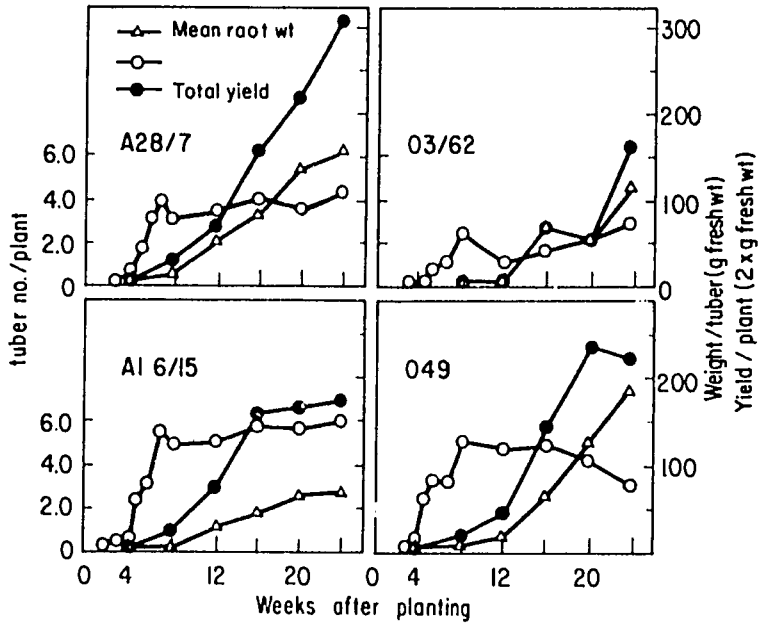

Figure 2. Typical growth patterns in sweet potato cultivars (Lowe and Wilson 1974a)

1. The period up to week 8 when tuber initiation was being completed and tuber bulking was slow (0.4-6.1 g/plant/week)
2. The linear phase of rapid bulking (16-34 g/plant/week)
3. The phase of late tuber bulking

In Phase 1, there were relatively rapid rates of tuber bulking in cv A 28/7, AI 6/15 and 049, slower rates in cv C9/9 and 03/62 and a very slow rate of bulking in cv I 62 in which tuber initiation continued up to week 16 (Table 2). The linear phase extended for 16 weeks (8-24) in cv A 28/7, I 62 and C9/9; 12 weeks (12-14) in cv 03/62 and eight weeks (12-20 and 8-16) in cv 049 and AI 6/15 respectively. Some 90-99% of final tuber yield was formed in cultivars with 12-16 weeks of linear bulking and 76-84% in the eight-week bulking cultivars. This phase was clearly the most important for final yield determination. However there were low and high yielding cultivars within eight and 16 weeks bulking groups determined by different bulking rates. Thus in the 16-week bulking group cv A 28/7 had a bulking rate of 36 g fresh weight/plant/week and was higher yielding than cv I 62 and C9/9 with bulking rates of 30 and 26 g/fresh weight/plant/week (Table 2). Similarly, in the eight-week bulking group cv 049 had a higher bulking rate and yield than cv AI 6/15.

Tuber dry weight data showed similar tuber bulking patterns to those for fresh weight (Lowe and Wilson 1974a). Additionally, it was illustrated that in those cultivars with rapid early (up to week 8) shoot growth (cv I 62, 049, 03/62), tuber bulking was delayed compared with the remaining cultivars (cv C9/9, A 28/7, AI 6/15) with slower early shoot growth. This result was interpreted to mean that the shoot system functioned as an alternative sink for assimilate during early growth. Peak shoot dry weights occurred at week 12 in five of the six cultivars studied and at week 16 in

cv C9/9 and there were rapid rates of decline in shoot dry weight thereafter in cv C9/9, I 62, 049, and A 28/7 compared with the remaining cultivars (AI 6/15, 03/62). Highest shoot growth in the period weeks 8-12 was recorded in cv I 62 and 049 but only in the latter cultivars was there a slower rate of tuber bulking. Moreover, only in the late bulking rate when competitive effects of the alternative shoot sinks were released by cessation of shoot growth. In cv C9/9, A 28/7 and I 62 tuber bulking continued at similar rates up to final harvest and in cv 049 and AI 6/15 it decreased after weeks 20 and 16 respectively. In the latter cultivar, (AI 6/15), rate of decline of shoot dry weight after week 12 was slower than in any other, suggesting that slow tuber growth in this cultivar at this time was not caused by lack of assimilate.

Therefore it is concluded that tuber yield was determined by the duration and rate of tuber bulking achieved during tuber ontogeny. Thus, the high yielding cultivar A 28/7 had a high bulking rate over a long period. Cultivars 049, I 62 and C9/9 with intermediate yields had a high bulking rate for a short duration (049) or lower bulking rates for longer durations (C9/9, I 62). Of the low yielding cultivars, AI 6/15 had a relatively high bulking rate for a very short duration and 03/62 a slower rate for a long duration. The duration of tuber bulking was short in the late bulking cultivars 049 and 03/62 where bulking was apparently delayed by rapid early shoot growth. However, in the former cultivar (049) rapid late bulking resulted in increased yield, but such high bulking rate was not achieved in the low yielding cv 03/62, in which bulking was erratic. Therefore a highly competitive shoot sink early in ontogeny resulted in low yield only when there was poor distribution of assimilate to tubers during later growth.

Mean tuber weight, tuber shape and tuber growth

Wilson (1975) proposed that tuber weight per plant which was the product of mean tuber number and mean tuber weight was a measure of the total tuber sink capacity, that is, the sum total of meristematic cells and expanding cells capable of assimilate storage. Therefore, since tuber initiation was completed early (by week 8) in the course of tuberization and curves for increase in tuber yield and mean tuber weight after this time were similar (Lowe and Wilson 1974a) then mean tuber weight values, particularly during the phase of linear bulking, appeared to be a measure of the capacity of the plant for further tuber growth, that is, sink capacity. Data Figure 2 showed that mean tuber weight values continued to increase up to final harvest in the late bulking cultivar 049, where there was a reduction in tuber number at final harvest. However, in cv C9/9, I 62, A 28/7 and particularly AI 6/15 there were reductions in the rate of increase of mean tuber weight between weeks 20 and 24.

In a comparison of changes in tuber shape (length/width ratios) and mean tuber weight with development in two sweet potato cultivars, cv 049 with globular tubers and cv AI 6/15 with narrowly fusiform tubers, Lowe and Wilson (1974b) showed that there was close similarity between curves for increase in tuber width and mean tuber weight in the two cultivars, and also that length/width ratios were inversely related to yield. It was also shown (Wilson and Lowe 1973a) that reduced capacity for lateral tuber growth in the low yielding cv AI 6/15 was associated with reduced numbers of secondary and tertiary meristems, resulting in tuber expansion being mediated at a slower rate mainly by the vascular cambium. This finding was interpreted as an illustra-

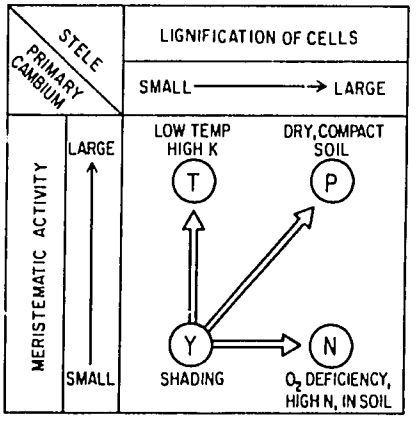

Figure 3. Control of cellular events in sweet potato tuber development, Togari (1950); Y = young root; P = pencil-like root; T = tuberous root; N = not-tuberous root

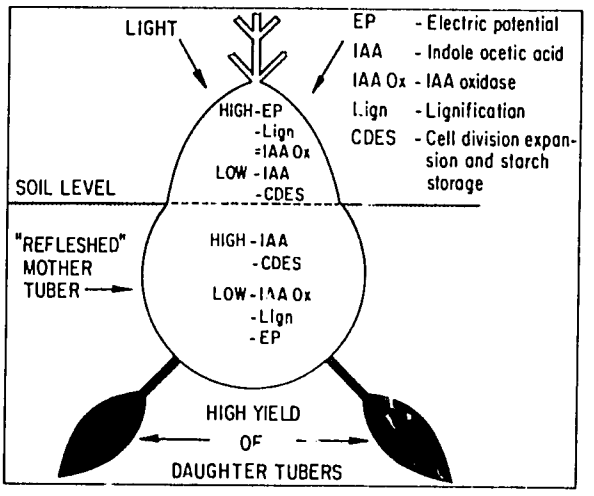

Figure 4. Possible roles of IAA and IAA oxidase in tuber growth (Akita *et al* 1962)

tion of the necessity for increased meristematic capacity and high rates of cell number increase towards generation of sink capacity first for tuber growth and then for assimilate distribution to tubers. Given the growth pattern of the sweet potato tuber whereby growth in length is completed before growth in width, such meristematic capacity would be higher in globular than in narrowly fusiform tubers. It was previously explained that such tuber capacity for growth led to increased photosynthesis, increased translocation of assimilate and increased dry matter productivity as demonstrated in staking trials and phytomodel experiments.

Possible mechanisms of tuber growth

Togari (1950) proposed a classical mechanism for tuber development and growth whereby initiation and growth of the tuberous root were promoted by active cambial meristematicity to produce starch storing parenchyma instead of lignification of stelar cells (Figure 3) as already explained in the section on tuber development. Akita *et al* (1962) showed that partial exposure of mother tubers to light in tuber set cultivation induced lignification, low IAA levels, high IAA oxidase activities and high electrical potential leading to limited 'refleshing' and increased capacity for translocation of assimilate in the exposed section of the mother tubers. In the dark, subterranean section, there was increased cell division and expansion, starch storage and tuber growth associated with high IAA levels as well as low electrical potential and IAA oxidase activities (Figure 4). Fujise and Tsuno (1967) emphasized the importance of critical K_2O/N ratios for increased water content, respiration rate and tuber growth leading to accelerated translocation of photosynthate from leaves and higher photosynthetic rates. These authors proposed that high potassium supply and the K_2O/N ratios in tubers might also be associated with increased protein synthesis leading to enhanced tuber growth. Although this interpretation appeared to be contrary to the nitrogen requirement for protein synthesis, it is in accord with N-induced increases in tuber growth and dry matter distribution to tubers in staking and reciprocal graft experiments. However, the dramatic effect of potassium

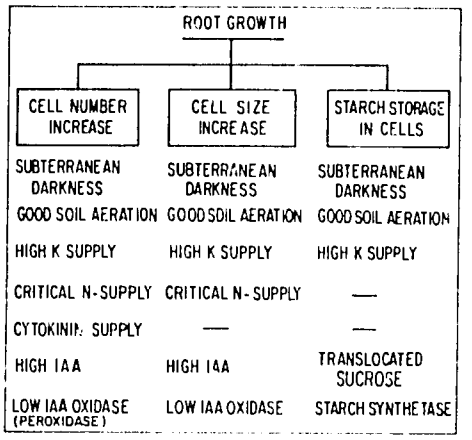

Figure 5. Some factors affecting three major components of tuber growth

concentration in increasing sweet potato tuber starch synthetase activities (Murata and Akazawa 1968) suggests that potassium supply would play a critical role in starch synthesis in sweet potato tubers. On the basis of demonstration of stimulatory/inhibitory effects of scopoletin and IAA on IAA oxidase activity (Imbert and Wilson 1970, 1972) and genesis (Sirju and Wilson 1974) regulatory roles for IAA and scopoletion are envisaged in a mechanism of tuber growth which separates the growth components of cell division, cell expansion and starch storage which shows some of the factors affecting these components (Figure 5).

TUBER PRODUCTIVITY

In studies on final tuber yield conducted with six sweet potato cultivars over two crops, Lowe and Wilson (1975a) found average yield, mean tuber number and tuber weight per plant to be 23.4 t/ha, 4.7 tubers and 129 g respectively and highest and lowest yields of 31.6 and 16.3 t/ha.

However, in later experiments (Ochuba and Wilson 1981) with 56 unselected open-pollinated seedling lines from seven female parents of International Institute for Tropical Agriculture (IITA) and University of West Indies (UWI) origin, yield of the highest yielding line (TIS 2328/6) was 68.1 t/ha, with a mean tuber number of 8.5 and mean tuber weight of 168 g. Therefore it might be concluded that the yield potential of the cultivars studied by Lowe and Wilson (1975a, b) was limited by failure to combine high tuber numbers and mean tuber weights in the same cultivar, a combination later achieved in TIS 2328/6. Two other selections TIS 2525/6 and C 26/7 outyielded the commercial cultivar cv 049 by 60% and 37% respectively (Ochuba and Wilson 1981).

Using an average net potential dry matter production of 550 x 10^3 cal/ha/day and a harvest index of 80%, potential tuber yield productivity for sweet potato of 44 x 10^3 cal/ha/day was calculated by De Vries *et al* (1967). This level of productivity equates to tuber yields of the order 150 t/ha/year, 69 t/ha for a 24-week crop or 46 t/ha for a 16-week crop. Yields of greater than 46 t/ha in 16-week crops in three UWI cultivars TIS 2328/6, TIS 2525/6 and C 26/7 suggested that the predicted photosynthetic potential of the species might have been achieved. However, in view of the demonstrated capacity of growing tubers to increase dry matter productivity in reciprocal grafts up to 259% (Hahn 1977) it is suggested that further optimization of the relationship between yield components consistent with

even higher tuber yield capacity might be sought before attempting to improve the photosynthetic potential of the species.

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Assimilation Patterns of Carbon in Developing Sweet Potatoes Using ^{11}C and ^{14}C

S. J. KAYS[a], C. E. MAGNUSON and Y. FARES[b]

[a]Department of Horticulture, University of Georgia, Athens, GA 30602, USA
[b]Biosystems Research Division, Department of Industrial Engineering, Texas A & M University, College Station, TX 77840, USA

INTRODUCTION

The biological concept of the 'rate limiting step' is an outgrowth of kinetic studies of the enzymatic control in a series of reactions. When this concept is applied to general processes within a plant, it becomes apparent that different processes may be more or less limiting under changing conditions. For example, the lack of light energy limits the acquisition of carbon during darkness, while at normal daylight energy levels, other steps are probably rate limiting. In addition, the rate limiting step in a process may be a physical factor, for example sieve tube diameter, rather than a biochemical one.

A genetic engineering approach to the enhancement of productivity functions most effectively through a) analyzing individual steps within a series of reactions or processes, b) ascertaining which step is most limiting, and c) screening genetic material and subsequent crosses for improvement of this step. The major problems associated with this approach have been the inability to isolate and measure crucial steps and to predict what alteration of the step will do to subsequent interrelated processes. In addition, an assumption made in the genetic engineering approach is that there are a relatively limited number of major rate controlling points.

The purpose of this paper is to a) outline briefly what is currently known about carbon assimilation in the sweet potato, b) look at patterns of carbon deposition in the storage roots and c) outline a technique which may enhance isolation and measurement of specific processes of carbon assimilation which may be rate limiting under normal production conditions.

INTERNAL FACTORS AFFECTING STORAGE ROOT DEVELOPMENT

Net photosynthetic rate

The net photosynthetic rate for sweet potato exhibits a cyclic pattern during a normal light period (Fujise and Tsuno 1962). Under natural conditions, the rate of photosynthesis was approximately 12 mg CO_2/sq dm/hr between the hours of 0900 and 1300, declining to 2 mg CO_2/sq dm/hr by 1700. Under constant environmental conditions, however, photosynthesis is high and relatively stable during the morning and mid-day, only declining toward the later afternoon (Tsuno and Fujise 1965). Typical net photosynthetic rates range from 14 to 20 mg CO_2/sq dm/hr, however, apparent photosynthetic rates of 35-36 mg CO_2/sq dm/hr have been reported (Kato [illegible] 1979). The photosynthetic process is thought to saturate at around 30 Klux of light energy (Fujise and Tsuno 1962). In addition, the rate of photosynthesis of individual leaves varies with position on the plant (leaf plastochron indice, LPI)

(Kato *et al* 1979) and stage of development of the plant.

It has been over a century since Boussingault (1868) presented the hypothesis that '... the accumulation of assimilates in an illuminated leaf may be responsible for a reduction in the net photosynthesis rate of that leaf'. While the hypothesis has been supported by considerable experimental evidence, it has not been strictly proven (see review by Neales and Incoll 1968). In the sweet potato considerable correlative evidence, based primarily on altering sink strength or source potential, points in favor of the hypothesis. For example, if storage root development is inhibited by its exposure to sunlight, leaf photosynthesis is reduced (Tsuno and Fujise 1965). When comparing reciprocal grafts between plants with substantially different sink potentials, plants having stocks which exhibited strong sink potential normally fixed more carbon (Hahn 1977; Hozyo and Kato 1976; Hozyo [illegible] 1971; Hozyo and Park 1971; Kato [illegible] 1979). This suggests that sink potential is typically more limiting than source potential in the sweet potato.

Photosynthate export rate and direction

Phloem loading: After sucrose that is to be exported from the leaf is synthesized in the cytoplasm of a leaf chlorenchyma cell, it must pass through a series of steps prior to transport. The inicial step involves transversing the plasmalemma of the cell in which it originates and movement into the apoplast. Then molecules of sucrose diffuse in the apoplastic solution to phloem cells. At which time it is transported across the plasmalemma against a concentration gradient into the phloem cell (termed phloem loading). Loading is an active process requiring energy and is thought to function in many plants through a sucrose-proton cotransport system (Giaguinta 1979).

Transport direction: The direction of flow of photosynthate from individual leaves appears to be controlled by both the individual leaf's position on the plant and the hierarchy of demand for photosynthates within the plant at any given moment. Typically fibrous roots and lateral buds are much lower in the hierarchical chain of control of photosynthate partitioning than are storage roots and shoots. In addition, neither leaf position relative to the apex nor photosynthate demand are static. As a consequence, directional flow of carbon may change radically in response to changing conditions.

Sweet potato leaves ranging in position on the plant from LPI 4 to 19 display bidirectional transport (Kato [illegible] 1979). The lower leaves (LPI 19) transport a greater percentage of their fixed carbon in a basipetal direction. Altering the size of the storage root sink demand through grafting the same scion on different stocks had a distinct effect on the directional flow of carbon. Transport direction of carbon from leaves of LPI 4 and LPI 19 were not affected by stock type, that is, storage root sink potential; however, leaves of LPI 7 had a substantial increase in the proportion of their translocated carbon which was directed toward the stock.

Movement of photosynthate to developing organs can be limited in part by orthostichy and vascular connections. As illustrated in a number of species, lateral movement of carbon may be quite limited (Wardlaw 1968). As a consequence, the loss of photosynthate supply potential through defoliation or shading of one side of the plant may have an extreme effect on developing organs or organ parts on the affected side. In [illegible] var [illegible]-

fera DC, vascular connections reflect the plants 5/13 phyllotaxy with ^{14}carbon flow exhibiting little lateral movement (Kays, unpublished data). The relationship of vascular connections in relation to leaf phyllotaxy and photosynthate allocation has not been closely studied in the sweet potato. Problems dealing with storage root hierarchy may prove to be closely tied to the extent of vascular connections and lateral movement of carbon from the vascular system. Moreover, the structural relationships of the phloem transport system such as sieve tube cross-sectional diameter and number have not been explored relative to transport volume and velocity.

Transport velocity and volume: The importance of phloem transport velocities in relation to leaf photosynthetic rate has been stressed in several studies (Fujise and Tsuno 1967; Tsuno 1970). Based on field dry matter production rates, Austin and Aung (1973) also suggest that the rate by which assimilates move appears to be more important for storage root growth than increases in leaf area. Kato and Hozyo (1976) have described the transport velocities and coefficients of transport of ^{14}C-photosynthates in both the acropetal and basipetal direction using reciprocal grafts to alter both source and sink potential. Transport velocities of carbon toward the apex were not as substantially affected as were the velocities toward the root system when the storage root sink potential was altered. Using the improved cultivar Okinawa No. 100 (0-100) which has a strong storage root sink potential and the wild type, *Ipomoea trifida* HBK (T-15) which has a limited storage root sink potential, 0-100/0-100 (scion/stock) grafts had a mean apical transport velocity of 0.80 cm/min while 0-100/T-15 grafts were 0.70 cm/min and T-15/0-100 and T-15/T-15 grafts were 0.77 and 0.52 cm/min, respectively. Basipetal transport, in contrast, was very strongly affected by storage root sink strength. Zero-100/0-100 grafts had a mean velocity of 2.13 cm/min while 0-100/T-15 grafts had a velocity of 0.62 cm/min. It is concluded by Kato and Hozyo that sink activity affects the speed of translocation and the coefficient of translocation. It should be noted, however, based on the close rates of basipetal transport between 0/100/T-15 (0.62 cm/min) and T-15/0-100 (0.52 cm/min) grafts, that factors other than storage root sink strength have a pronounced effect on transport velocity.

Storage root sink potential

Attempts made to resolve the inherent factors contributory toward final yield in the sweet potato revolve around the source-sink relationship (Hahn 1977; Hozyo 1970; Spence and Humphries 1972; Wilson 1967). The relationship between photosynthesis and carbohydrate sinks is well documented in a wide variety of plants (Humphries 1967; Neales and Incoll 1968).

Spence and Humphries (1972) manipulated environmental conditions surrounding rooted single sweet potato leaves and related increases in net assimilation rate to increasing storage root growth. Their interpretation was that the rate of photosynthesis depends on the capacity of sinks to accept photosynthate.

Using reciprocal grafts, it has been inferred (Hozyo 1970; Wilson 1967) that yield is determined primarily by the rootstock rather than the foliar portion of the sweet potato plant. However, both photosynthetic source potential and storage root sink capacity can be rate limiting (Hahn 1977). Thus it is likely that a series of processes, from carbohydrate production in the leaves to final carbohydrate polymerization in the storage root of the

sweet potato, can each under appropriate conditions be rate limiting.

Deposition of carbon at sink sites: If one accepts, based on substantial correlative evidence in the sweet potato (Hahn 1977; Hozyo 1970; Wilson 1967) and other plants (Neales and Incoll 1968), that sink potential is of major importance in the net rate at which carbon is fixed by the plant, then processes dealing with the deposition of carbon at active sink sites become of critical interest. These processes can be grouped under three very general headings: (a) phloem unloading (b) transfer of the carbon to the site of polymerization, and (c) starch synthesis. Each of these general processes is composed of secondary and tertiary subprocesses or steps.

In general, when contrasted with phloem loading and transport, little is known about the specific steps in the pathway of photosynthates upon reachnig a major sink such as a storage root. One might anticipate a sweet potato storage root to function is some ways similarly to wheat grains where the rate of starch synthesis in the endosperm is closely related to the concentration of sucrose in the tissue. In this case, regulation is not predominantly due to the supply of sucrose to the grain (Jenner and Rathjen 1972a, 1972b), but rather to processes operating within the grain itself. Factors regulating the movement of sucrose into and through the grain and influencing its conversion to starch appear to be major controlling steps (Jenner 1974). In addition, declining deposition of carbon as the plant approaches maturity may more accurately reflect a decline in the sink's capacity to accept or metabolize sucrose rather than a decline in supply potential from the source (Jenner and Rathjen 1975). Although there are obvious places where this analogy between a wheat grain and a storage root does not hold, it does promise to serve as a useful model for comparison.

Other evidence concerning the relationship of the sink to the carbon acquisition-transport systems can be inferred using mathematical models. Goeschl *et al* (1976) described the response of a concentration-dependent unloading mechanism in a steady state Münch pressure flow model of phloem transport to varying input parameters. If loading rate was held constant and the value of the unloading coefficient increased, then the velocity of sucrose toward the sink increased and the concentration of sucrose throughout the sieve tube decreased.

Pattern of carbon deposition: Little is known about the pattern of carbohydrate deposition in the sweet potato storage root over the course of its development. Our present understanding of the nature of storage root growth in the sweet potato is based primarily on evidence from anatomical studies. The general concensus is that the development of the storage root in the sweet potato involves cell proliferation resulting from both the meristematic activity of the localized vascular cambium, as well as the activity of the anomalous cambina (Artschwager 1924; Esau 1960; McCormick 1916; Takatori and Purnell 1961; Tsuno 1970). The anomalous cambium is recognized as a general phenomena in the storage root (Artschwager 1924).

Comparative anatomical studies of West Indian cultivars (Wilson and Lowe 1972) indicate that the relative contribution of cells derived from the activity of the vascular cambium versus the anomalous cambia, to the overall size of the mature storage root was a cultivar characteristic. In some cases the vascular cambium accounted for about half of the total storage root size.

Studies using starch staining techniques (Indira and Kurian 1973), show that in the initial stage of storage root development, starch is localized in the cortical tissues. However, the contribution of the primary cortex to the total volume of the developed storage root is negligible.

Starch is the major storage compound in the storage root of the sweet potato (Onwueme 1978). In the cultivar Red Jewel, it accounts for 27% of the storage root dry weight (Chang 1979). At the histological level, starch is located in storage parenchyma cells. Artschwager (1924) discerns two types of storage parenchyma. There is the normal bundle parenchyma, rich in starch and whose cells are the product of the cambium. It is the major type of storage parenchyma. The other type is the interstitial parenchyma, a filler between groups of bundles, relatively poor in starch and considered to be directly derived from the original parenchymatous sheath of the young rootlet. Considering these facts, one would expect the starch deposition pattern to reflect to a large extent the nature of storage root development.

There has been some work involving the use of labelled $^{14}CO_2$ to monitor carbohydrate distribution patterns in other underground crops. In the potato tuber, assimilated ^{14}C accumulated most in the periderm with weak radioactivity evenly distribued inner to this layer (Badenhuizen and Dutton 1956). In a ^{14}C tracer study on the Jerusalem artichoke, where polymerized fructose is the major storage compound in the tuber, it was suggested that carbohydrate was deposited mainly in the cells newly formed by a sub-epidermal cambium and, therefore, the tuber grows in the outer layers (Edelman 1963).

Storage root sink hierarchy: Control of the allocation of carbon to competitive sinks is not well understood. A number of mechanisms can influence the preferential movement of carbon to one sink over another. Variations in the ability of one sink to deplete the supply of photosynthates in the phloem (unloading coefficient) causes a concentration gradient which enhances subsequent movement of carbon to the sink. Variation in the chronological order of inception of the sink is also a factor (hence, large storage roots will have more cells which increases the potential to deplete the level of carbon in the phloem). The position of a sink relative to the source of assimilate production can also be significant. Using mass flow models, sinks with identical unloading coefficients (strength) but at different distances from the source loading zone can be shown to have differences in the absolute amount and percentage of the total photosynthate unloaded into each; sinks closer to the source having the advantage (Goeschl, unpublished data). Finally, vascular connections and lateral transport potential, may also be important in the establishment of a hierarchy of carbon allocation between competitive storage root sinks. Current breeding programs for edible sweet potatoes have selected toward minimizing variation in the patterns carbon allocation to the roots. As a consequence, desirable new cultivars tend to have a number of roots of uniform size.

EXTERNAL FACTORS AFFECTING STORAGE ROOT INDUCTION AND DEVELOPMENT

External factors affecting storage root induction and development can in general be classed into two groups: those over which we have minimal control (radiation, temperature and carbon dioxide concentration for example), and those over which we have the potential to exert substantial control (such as soil nutrition, soil type and moisture level).

Several studies have been directed toward ascertaining the effect of temperature on assimilate partitioning and storage root development (Kim 1961; Sakr 1943; Sekioka 1970; Spence and Humphries 1972). For example, Kim (1961) demonstrated that sweet potato plants, when subjected to an air temperature of 20°C during the period of darkness alternated with a temperature of 29°C during the light period (16 hr), produced more storage roots and an increased storage root weight than plants subjected to a constant temperature of 29°C throughout the cycle. Storage roots were also formed earlier in the treatment incorporating the 20°C temperature. This may suggest a possible role for a thermoperiodic effect in storage root induction, although in the tropics sweet potato yields abundantly in spite of much smaller differences between day and night temperatures.

Soil temperature also affects sweet potato storage root formation and development (Spence and Humphries 1972). In rooted single leaves, optimum storage root formation and development resulted when the soil temperature was 25°C, whereas soil temperatures of 15°C and 35°C were inhibitory to storage root formation (Spence and Humphries 1972). Sekioka (1970) found that sweet potato plants produced the largest increase in storage root weight when they were subjected to a constant soil temperature of 30°C combined with air temperatures of 25°C during the night compared to other temperature treatment combinations.

According to Tsuno (nd), Togari attempted an integrated explanation for the effects of the environment in influencing the various root types produced. Low temperatures (22°-24°C as against normal temperatures of 24°-29°C) and heavy K application promote storage root induction. On the other hand, soil oxygen deficiency and heavy N application increased lignification of stele cells and inhibited the activity of the cambium. Therefore, young roots tend to develop into fibrous (thick) roots instead of storage roots.

Soil aeration when limiting can also have a pronounced effect on storage root induction and/or development. Sweet potatoes grown under waterlogged conditions or in solution culture (Wilson 1970) typically fail to produce storage roots. In addition, with field production of sweet potatoes on many soils, yields are markedly improved by ridging (Edmond et al. 1950). Preliminary work by Watanabe, Ozaki and Yashiki (1968) and a recent study by Chua and Kays (1981) suggest that low storage root yields under field conditions of excess moisture are due largely to inadequate oxygen in the root zone. Exposure of the storage root production zone, separated from the fibrous root system, to 2.5% oxygen decreased the number of storage roots/plant from 6.2 to 0.8 and the dry weight of storage roots formed per plant by 97.5% when compared to 21% oxygen controls. Shifting the storage root production zone from 2.5% oxygen to 21% oxygen on the 81st day of growth, resulted in a rapid increase in storage root number and carbon allocation rate. This would suggest that low soil oxygen is probably more detrimental late in the growing season after the storage roots have formed and attained some size. Initial estimates for threshold levels of oxygen for shifting of storage roots to anaerobic fermentation are in the 5 to 7% range (Chang and Kays 1981; Hasselbring and Hawkins 1915).

Under field conditions, soil water, aeration and bulk density are closely related. Adequate water supply through rainfall or irrigation is essential for maximum development of storage roots (Anderson 1941; Onwueme 1978; Peterson 1961). However, excess water in the soil results in poor aeration.

The use of mounds or ridges in sweet potato cultivation results in better yields (Edmond *et al* 1950; Kimber 1970). This can be partly attributed to better drainage and aeration, but also to decreased physical resistance of the soil for lateral expansion of the storage roots. Since the storage root displaces its volume equivalent of soil by deforming the soil adjacent to it, elevated physical resistance of the soil surrounding the root can, if sufficiently high, decrease storage root growth. Decreases in storage root growth due to soil compaction have been documented (Watanabe *et al* 1968). Its restriction of the allocation of carbon in the storage roots did not, however, cause a corresponding decrease in the top and fibrous root growth.

The nutritional status of the plant also influences the allocation of carbon. Nitrogen, P, K, S, Mg, Ca and Fe below critical levels resulted in deficiency symptoms in sweet potato plants, with inadequate K, Mg or Ca resulting in no storage root formation (Spence and Ahmad 1967). Storage root induction occurred in N-deficient plants in spite of severely restricted top growth (Spence and Ahmad 1967).

It is well established that K is required for storage root development (Fujise and Tsuno 1967; Scott 1950; Stino and Lashin 1953; Tsuno 1970, Tsuno nd). Conversely, a high nitrogen supply favors top growth that would serve as a competitive sink for carbohydrate supply. Thus a high N supply would have an adverse effect on storage root development under low K conditions (Samuels 1967). Tsuno and Fujise (Fujise and Tsuno 1970, Tsuno nd) hold that a high K_2O/N ratio in the storage root results in a higher water content in the storage root and this increases the respiratory rate. To the extent that the resultant energy is used for cell division and starch synthesis, storage root growth is facilitated.

Though seldom a problem in the field, the exposure of storage roots to light inhibits their development (Fujise and Tsuno 1970; Hozyo and Kato 1976). When subjected to light (Hozyo and Kato 1976), the starch content of the storage root decreased, beginning from the cortex inwards. Lignification of parenchymatous cells as well as an increase in the number of xylem vessels in the vicinity of the vascular cambium were found. The amount of parenchymatous tissue in the stele decreased. When the light treatment was withdrawn, storage root development resumed together with an accompanying increase in starch.

REDISTRIBUTION OF CARBON FROM STORAGE ROOTS

Because of intense agricultural interest in the sweet potato storage root as an edible commodity, the primary biological purpose of the root as a reproductive organ is often obscured. This has resulted in little being known about the pattern of carbohydrate remobilization from the storage root for the sustenance of the sprouts that develop from it. It is known that sprouts develop from the vascular cambium zone of the storage root (Schlimme 1966) or in its vicinity (Wilson and Lowe 1973) and that the size of sprouts produced from root pieces used in plant propagation varies with the size of the root pieces used (Kays and Stutte 1979; Takatori and Purnell 1961). Larger-sized sprouts are produced from larger root pieces, with whole roots producing the largest sprouts. This suggests that carbohydrate remobilization from the root piece has an important role in sprout vigor and growth. Among other considerations, carbohydrate remobilization would depend on factors such as the site, the amount, and the availability of carbohydrate reserves in the storage root.

In the Jerusalem artichoke, where the major storage carbohydrate (inulin) is a straight chain molecule composed of approximately 38 to 40 fructose subunits, it has been shown that the carbohydrates are initially remobilized for shoot growth in a region a few millimeters beneath the epidermis (Jefford and Edelman 1960). Subsequent hydrolysis of the stored carbohydrate progresses inward. Whether hydrolysis of stored carbohydrates in the sweet potato is localized as in the artichoke or is a general phenomenon is not currently known.

USE OF ^{11}C AND ^{14}C ISOTOPES FOR STUDIES OF SWEET POTATO PHOTOSYNTHESIS, TRANSPORT AND METABOLISM

^{14}C has been used extensively in the study of carbon metabolism in many organisms. In the past few years a wealth of new information about the growth and development of the sweet potato has been generated with this isotope (Kato and Hozyo 1972, 1974, 1976, 1978; Kato *et al* 1979, 1972). Along with many advantages (such as long half-life, low cost and relative safety) are a number of disadvantages which limit its potential uses especially in live, intact plants. Many of these limitations can be circumvented, however, with the use of the unstable isotope of carbon, ^{11}C.

The use of ^{11}C in CO_2 studies was first suggested in the 1930s (Ruben *et al* 1939; Ruben and Kamen 1940) because of its several significant advantages. First, it decays by positron ($\beta+$) emission followed by positron-electron annihilation with the emission of two oppositely-directed 0.511 MeV gamma (γ) rays. Gamma emission allows for measurement *in vivo* through essentially any thickness of live plant tissue in real time. In addition, coincidence detection of both γ rays allows for precise localization of the decaying carbon atom. Secondly, ^{11}C has a half-life of 20.4 minutes. Therefore, several experiments can be run daily on the same plant and throughout its growth cycle. The recent development by Fares *et al* (1978) of a technique for continuous rather than batch production of ^{11}C, allows for steady-state labelling and negative pulse labelling.

METHODS AND MATERIALS

^{11}C experiments

Sweet potato plants, variety Centennial, were grown in 29.4 cm diameter pots containing a 1:1:1 ratio of Terface, vermiculite and gravel. Lateral buds were removed from the main stems to prevent the formation of secondary sink sites. Plants were grown at the Duke University Phytotron for the majority of their growth period under the following conditions: 24°C day - 20°C night temperatures, 16-hour photoperiod of 40 Klx combined fluorescent-incandescent light, ambient CO_2 concentration (350 ppm). During ^{11}C experiments the CO_2 concentration to the treated leaf was 450 ppm. The plants described in the following ^{11}C experiments were six-week-old vine cuttings which had not yet developed distinct storage roots.

^{11}C production

^{11}C was continuously produced during the course of an experiment to allow for steady-state kinetic analysis of transport phenomena (for a detailed description see Fares *et al* 1978). Production consisted of accelerating ^{3}He with a 4 MeV Van de Graaff accelerator using gaseous $^{12}CO_2$ as the

target. This yielded the following reaction: $^{12}C(^{3}He, ^{4}He)^{11}C$. The target effluent was then transported to the phytotron through a Teflon capillary tube with an inner diameter of about 1.3 cm and 120 meter length. Upon arrival, the effluent gas was passed through a soda lime trap to remove $^{12}CO_2$, leaving predominantly ^{11}CO. ^{11}CO was then passed over a cupric oxide furnace (≈600°C) and oxidized to $^{11}CO_2$. Using this technique $^{11}CO_2$ of a constant, known specific activity was administered to the plant.

Administering $^{11}CO_2$ to the plant and subsequent monitoring of the flow of carbon: A detailed description of the experimental set-up is provided by Fares (1978). Briefly, $^{11}CO_2$ was fed to an individual leaf using a standard leaf chamber (10 cm^2) with the CO_2 input/output ratio monitored by infra-red gas analysis. Coincident scintillation detectors were positioned at the leaf, on the petiole, and various locations up and down the stem. This technique allowed pulse labelling, steady-state labelling and negative pulse labelling.

Data for each of coincident detectors and inlet, outlet, line and leaf detectors were collected over each 60 sec period, as were continuous measurements of leaf net photosynthetic rate. Data collected was plotted as collected in 'real time' on a Hewlett Packard model 9845 computer. Tapes of each run were later corrected for detector variation, isotope half-life and background. Transport velocities were calculated from the arrival time of the labelled front moving up and down the stem and the distance between the leaf source and stem detectors. Use of coincidence detectors allowed for precise measurement of the ^{11}C front position.

^{14}C experiments

Three sets of ten plants of variety Red Jewel, grown individually in pots of 29.4 cm diameter, were treated with ^{14}C-labelled CO_2 at the 44, 74 and 105-day growth stage with a fourth set serving as control. The above ground portion of each plant was exposed in a standard plant treatment chamber for two hours to 14.4 μCi $^{14}CO_2$ from Ba $^{14}CO_3$ released with H_3PO_4. The atmosphere within the chamber was circulated during the treatment period with an air circulation pump. Remaining $^{14}CO_2$ was removed at the end of the labelling period by the insertion of an Ascarite column into the circulation system.

Plants treated at the 44, 74 and 105 day stage as well as the control plants were harvested on day 106. Two plants, however, from each of the sets treated at the 44 day stage and at the 74 day stage were for the preparation of storage root sections 24 hours after their respective treatment periods.

Freshly harvested storage roots were used in the preparation of 1.5 mm thick cross sections. They were obtained from the proximal, medial and distal portions of the storage root. Longitudinal sections were made from separate roots. Samples were pressed between cardboard, frozen and lyophylized, after which they were mounted on paper for autoradiography (Kodak X-Omat RP film, D-19 developer, 2-4 week exposure time). After autoradiography individual samples were quantified by oxidation of 20 mg samples and subsequent trapping in 10 ml of ethanolamine-ethanol (1:2, v:v). A 1 ml aliquot was added to a 15 ml scintillation cocktail (0.6 gm PPO and 6 gm POPOP/l toluene) with 1 ml of absolute and counted in a Beckman LS-100C liquid scintillation counter.

Distribution of radioactivity of cross sections was determined by quantitatively measuring samples taken from four areas of the storage root. These were designated: area 1 - the periderm-outer cortical region; area 2 - the vascular cambium ring and tissues in its immediate vicinity, extending no more than 1 mm on either side of the cambium ring; area 3 - the peripheral stele, which is adjacent to but inner to area 2 and corresponds to the area of the stele showing radial xylem files; and area 4 - the inner stele, which is the innermost portion of the storage root, and is where the xylem vessels are randomly distributed within it.

Remobilization of labelled substrate upon sprouting was monitored in sprouts from replanted storage roots obtained from the four sets of plants harvested at the 106 day growth stage. Storage roots were planted 2 cm below the surface in 294 cm diameter pots of soil (Cecil clay loam) in the greenhouse. No more than three sprouts were allowed to develop at the proximal end of each storage root. Entire sprouts at the two, four, six and eight leaf stage were harvested, pressed, oven-dried at 70°C for 18 hours, mounted on drawing paper and autoradiographed as previously described.

RESULTS

Fixation and translocation of ^{11}C photosynthates

A typical response of a sweet potato to a square wave input of $^{11}CO_2$ to a single leaf is presented in Figure 1A. Numbers on the figure refer to the position of specific sets of detectors on the plant and the corresponding data output (log of the radioactivity). Detector 1 was stationed on the petiole just below the blade of the treatment leaf. Detectors 2 and 3 were 16 and 37 cm below the leaf blade on the main stem. For the first 23 minutes of the experiment, $^{11}CO_2$ from the accelerator (marked line) was vented until reading a steady state. During this time the leaf was exposed to $^{12}CO_2$ at 350 ppm. Between 23 and 139 minutes, $^{11}CO_2$ + $^{12}CO_2$ were supplied to the leaf at 460 ppm. The level of radioactivity in the leaf increases rapidly until it approaches a steady state, at which time export due to translocation and respiration equals incorporation. Line #1 represents the export of carbon down the petiole. The rate of arrival of the ^{11}C front at various detectors (such as 2, 3, 4) down the stem can be used, knowing their distance from the source, to calculate the basipetal transport velocity. In this case (Figure 1A) the velocity of phloem transport of photosynthates was 1.04 cm/min. This can be done similarly for acropetal transport with appropriate detector positioning, although this was not done in this study. In addition, by knowing the specific activity of the sucrose formed, and with appropriate corrections for half-life, detector sensitivity and 'view' of the stem and the volume of sieve tubes containing ^{11}C, the moles of sucrose/cm^3 can be calculated.

After stopping the flow of $^{11}CO_2$ to the leaf, a characteristic decay curve develops. The difference between the calculated decay of ^{11}C (20.4 min half-life) and the measured decay indicates the amount of ^{11}C photosynthates available for export (transport + respiration) (Figure 1A). The remaining count rate is equal to the rate of ^{11}C photosynthate stored in products such as starch in the leaf. By measuring the turnover time of the mobile ^{11}C photosynthate pool, the half-life for the pool can be calculated.

Figure 1B represents the effect of exposing a 1 cm long section of the

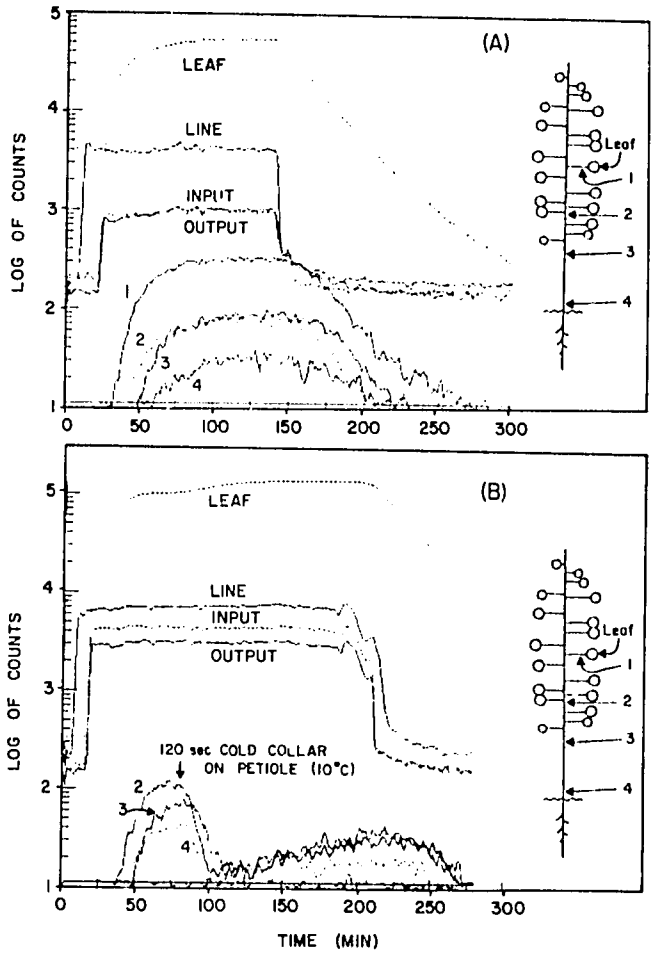

Figure 1. Comparison of a normal square wave ^{11}C treatment (A) with the effect of a 120 sec petiole cold collar pulse (10°C) on the transport of ^{11}C photosynthate from the leaf and basipetally in the stem of a sweet potato plant (B)

petiole of the treatment leaf to 120 sec at 10°C with rapid (≈30 sec) rewarming to the ambient temperature, 24°C. Transport of ^{11}C photosynthate down the stem is stopped almost immediately, with subsequent effects on transport at positions lower down on the stem. While recovery begins to occur approximately 55 minutes after the end of the temperature treatment, it is extremely slow, never approaching (note log scale) pretreatment levels during the remaining 80 min of the test period. In addition, the level of ^{11}C staying in the leaf increased simultaneously with the decreased transport.

The effect of a slight physical perturbation on the acquisition and transport of ^{11}C-photosynthates can be seen in Figure 2A-F. The treatment involved lifting the potted plant from the floor of the growth chamber and setting it on the bench used to hold the detectors and positioning the individual detectors. This small amount of agitation resulted in extreme alternations in the carbon transport system of the sweet potato. The ^{11}C experiment was initiated 2 hrs after the agitation and by 275 minutes after the initial exposure of the plant to $^{11}CO_2$, no ^{11}carbon could be detected leaving the leaf (Figure 2A) via the petiole and stem (detectors 1-4). The photosynthetic rate of the leaf, however, remained relatively high (18 mg $CO_2/dm^2/hr$ as measured by infra-red gas analysis) relative to the rate of photosynthesis of the leaf during the period of recovery of the transport function over the next 48 hours. $^{11}CO_2$ fixed by the leaf after agitation

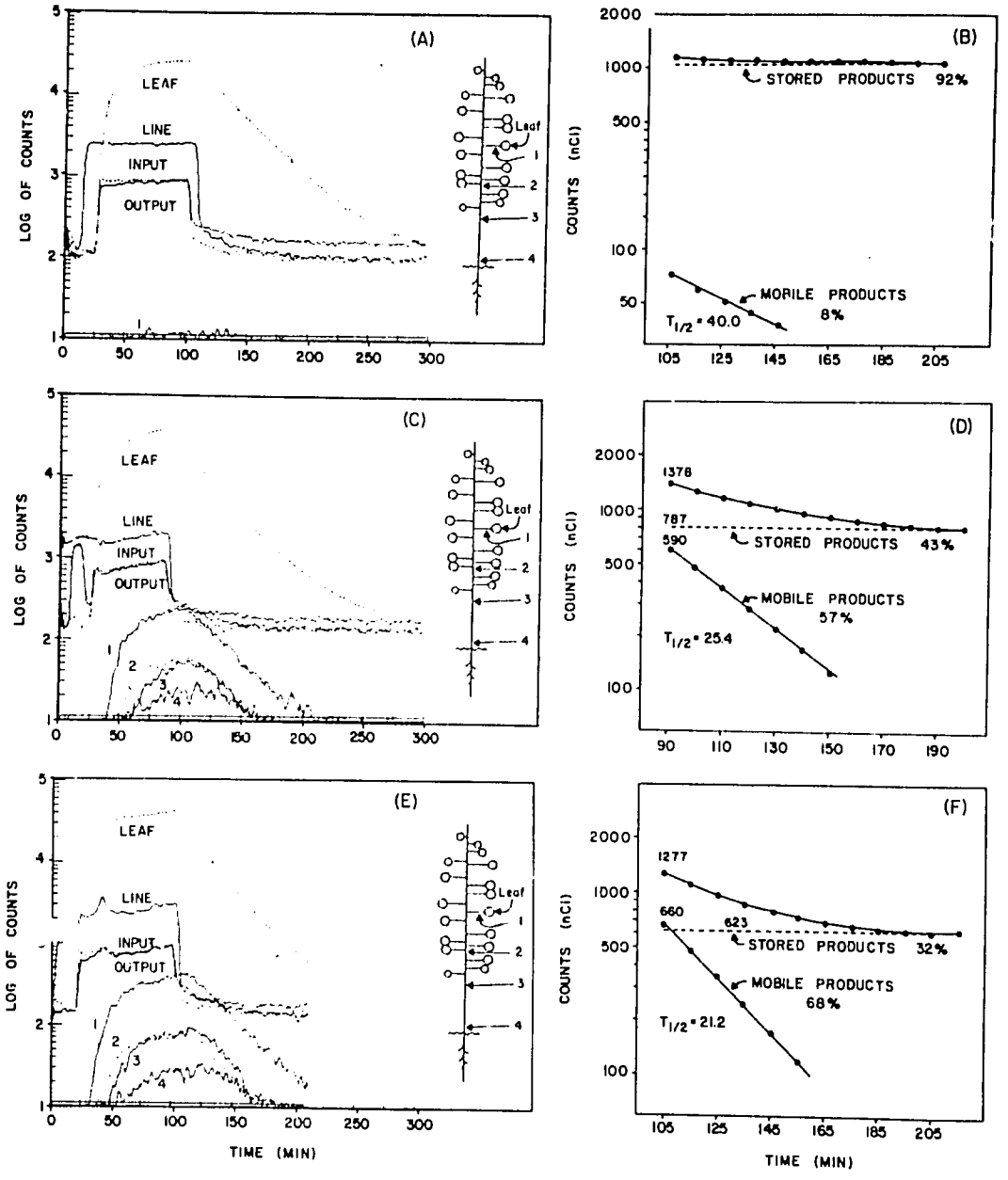

Figure 2. The effect of slight movement of an entire sweet potato plant on the transport of ^{11}C photosynthate. A) ^{11}C fixation and transport, B) mobile and non-mobile pools, C) ^{11}C fixation and transport 24 hr after perturbation, D) mobile and non-mobile pools 24 hr after perturbation, E) C^{11} fixation and transport 48 hr after perturbation, and F) mobile and non-mobile pools 48 hr perturbation.

(≈1 hr) remained almost exclusively (92%) in the leaf as starch or other non-translocated products (Figure 2B). The pool of mobile products represented 8% of the ^{11}C fixed, nearly all of which left the leaf via light and dark respiration. The turnover time for the mobile pool of ^{11}C was 80 min ($T_{1/2}$ = 40 min). By the second day the plant had significantly recovered from the

perturbation (Figure 2C). Transport of ^{11}C from the leaf was occurring at a substantial rate and could be monitored at the petiole and at each position down the stem. Phloem transport velocity of photosynthates had increased from 0 to 0.86 cm/min. On day 2, the storage pool of ^{11}C represented only 43% of the fixed carbon, with the mobile pool increasing to 57% (Figure 2D). In addition, the turnover time of the mobile pool had shortened substantially ($T_{\frac{1}{2}}$ = 25.4 min). By day 3 (48 hours after perturbation) the plant had returned to what appears to be a normal carbon fixation-transport system (Figure 2E). The storage pool represented 32% of the fixed carbon while 68% was found in the mobile pool (translocation + respiration). $T_{\frac{1}{2}}$ had decreased 4.2 min from the previous day to 21.2 min and phloem transport velocity of photosynthates had reached 1.13 cm/min.

Deposition of ^{14}C-photosynthate in storage roots and redistribution in sprouts

Autoradiographs of cross sections of storage roots from plants treated at the 44 day stage and harvested at the 106 day stage showed radioactivity throughout the cross section except along a somewhat circular band (Figure 3). This band is in the vicinity of the vascular cambium ring, and includes the vascular cambium ring itself, as well as tissues differentiated from it on both its inner as well as outer surface. Although the outer cortical region shows radioactivity, the phloem-secondary cortex region adjacent to the vascular cambium ring does not. The bulk of the cross sectional area showing radioactivity is in the center of the stele. The periphery of the stele, contiguous to the vascular cambium ring is, however, within the band where the radioactivity is less discernible. This band is much broader in the proximal section (Figure 3A) than in the distal section (Figure 3C). Its width is somewhat intermediate in the medial section (Figure 3B).

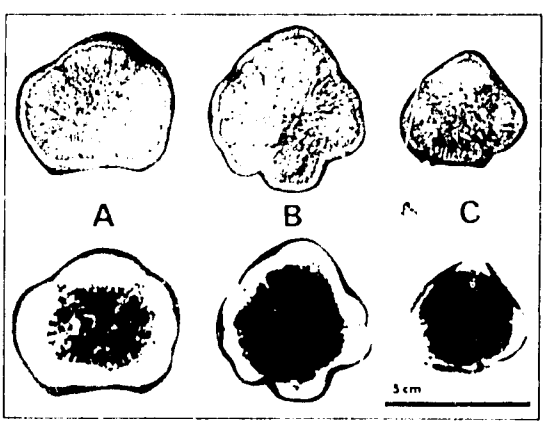

Figure 3. Distribution of assimilated $^{14}CO_2$ in cross sections of a storage root obtained from a plant treated at the 44-day stage and harvested for autoradiography at the 106-day stage. A) Section from proximal portion, B) section from medial portion, C) section from distal portion. (Mounted specimens on top, autoradiographs below)

Distribution of radioactivity within the central stele is not uniform. This is especially the case in the proximal section (Figure 3A). In the cortex, the labelled region shows uniform distribution of radioactivity within each individual section. The labelled portion of the cortex in the medial section (Figure 3B) accounts for about 50% of the total area external to the vascular cambium ring.

Autoradiographs of cross sections of storage roots from plants treated at the 74 day stage and harvested at the 106 day stage show a second distinct pattern (Figure 4). Again, there is a circular band extending from both

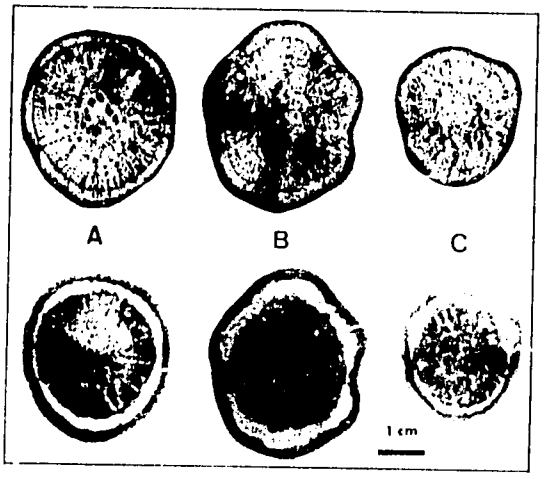

Figure 4. Distribution of assimilated $^{14}CO_2$ in cross sections of a storage root obtained from a plant treated at the 74-day stage and harvested for autoradiography at the 106-day stage. A) Section from proximal portion, B) section from medial portion, C) section from distal portion.
(Mounted specimens on top, autoradiographs below)

sides of the vascular cambium ring, where the radioactivity is much less distinct than that in the other portions of the cross section. This band, however, is relatively much narrower than the one in the first pattern previously described in Figure 3. The band is again broader in the proximal section (Figure 4A) than in the distal section (Figure 4C). The width of the band in the medial section (Figure 4B) occupies an intermediate position.

Radioactivity in the outer cortical area appears uniformly distributed. In the section across the medial portion of the storage root (Figure 4B), the portion of the cortical region that appears labelled accounts for about 70% of the area external to the vascular cambium ring.

A larger portion of the stele shows discernible radioactivity than in the first pattern previously described. Distribution of radioactivity within the center of the stele appears non-uniform. This is especially true in the case of the proximal section (Figure 4A). The non-uniformity of radioactivity distribution in the central stele is, however, not as obvious as that observed in the first pattern described in Figure 3.

Autoradiographs of cross sections of storage roots from plants treated at the 105 day stage and harvested at the 106 day stage (Figure 5) show a radioactivity distribution pattern distinctly different from the other patterns described earlier.

In this case, radioactivity is concentrated in a clearly defined ring which corresponds exactly to the location of the vascular cambium ring. The

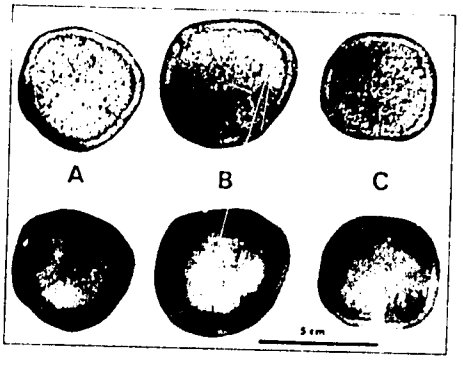

Figure 5. Distribution of assimilated $^{14}CO_2$ in cross sections of a storage root obtained from a plant treated at the 105-day stage and harvested for autoradiography at the 106-day stage. A) Section from proximal portion, B) section from medial portion, C) section from distal portion.
(Mounted specimens on top, autoradiographs below)

remaining portions of the cross section appear labelled, with the cortex and the periphery of the stele appearing to have a higher concentration of radioactivity than the center of the stele. Within each of these areas, however, distribution of radioactivity was uniform.

There was essentially no difference in this pattern of distribution between the proximal (Figure 5A), the medial (Figure 5B) and the distal (Figure 5C) sections of the same storage root.

The longitudinal sections (Figure 6) further demonstrate the differences between the three patterns resulting from the different times of treatment. The longitudinal section of a storage root from a plant treated at the 44 day stage and harvested for autoradiography at the 106 day stage, is shown in Figure 6A. The relative tissue area that appears radioactive follows a gradation along the longitudinal axis of the storage root with the distal end showing more of its tissue area being radioactive than the proximal end.

The longitudinal section of a storage root from a plant treated at the 74 day stage and harvested at the 106 day stage (Figure 6B) shows that the band where radioactivity is not readily discernible is widest towards the proximal end and tapers towards the distal end. At the extreme distal end the band is absent. The band in this case (Figure 6B) is on the whole relatively narrower than in the previous case (Figure 6A).

The longitudinal section of a storage root from a plant treated at the 105 day stage and harvested at the 106 day stage (Figure 4C) shows that the vascular cambium has a much higher concentration of radioactivity than other areas of the storage root.

Results of the quantitative analysis for radioactivity concentration in

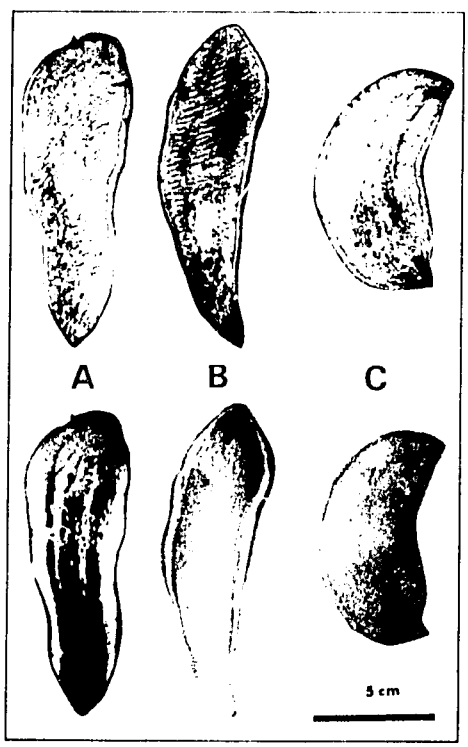

Figure 6. Distribution of assimilated $^{14}CO_2$ in longitudinal sections of storage roots obtained from plants treated at three different growth stages and simultaneously harvested for autoradiography at the 106-day stage. A) Section from storage root labelled at the 44-day stage, B) section from storage root labelled at the 74-day stage. C) section from storage root labelled at the 105-day stage. (Mounted specimens on top, autoradiographs at bottom, top end of storage root is the proximal end)

Table 1. Distribution of radioactivity in cross sections of storage roots obtained from plants treated at the 44, 74 and 105 days stage and harvested at the 106 day stage (in cpm/20 mg dry wt)

Stage of development	Room area**	Position of cross section in root*		
		Proximal	Medial	Distal
44 day	1	274 (44)	251 (42)	448 (105)
	2	36 (6)	50 (14)	459 (50)
	3	77 (10)	98 (25)	705 (107)
	4	246 (27)	520 (15)	815 (41)
74 day	1	218 (7)	295 (6)	220 (45)
	2	173 (23)	108 (12)	191 (10)
	3	313 (23)	153 (10)	250 (8)
	4	333 (16)	196 (4)	253 (21)
105 day	1	84 (14)	151 (13)	88 (2)
	2	197 (16)	198 (11)	103 (32)
	3	114 (40)	143 (16)	59 (3)
	4	53 (28)	35 (8)	50 (10)

**Area 1 - periderm-outer cortex
Area 2 - vascular cambium ring and its imediate vicinity
Area 3 - peripheral stele
Area 4 - central stele
*Figure in brackets ( ) denotes standard deviation

various areas within the cross sections are presented in Table 1. These results essentially confirm those shown by the autoradiographs.

For the storage root cross sections obtained from plants treated at the 44 day stage and harvested at the 106 day stage, the vascular cambium ring and its immediate vicinity shows the lowest radioactivity count per unit dry weight compared to the other areas in the cross section. This is true for the proximal, medial as well as the distal portion of the root. However, the amount of radioactivity in any area of the distal section was higher than the corresponding area in either the proximal or medial section.

The data for the storage root cross section obtained from plants treated at the 74 day stage and harvested at the 106 day stage indicate that the lowest radioactivity count per unit dry weight was recorded in the vascular cambium ring and its immediate vicinity. This was true for all three of the proximal, medial, and distal sections.

In the case of storage root sections from plants treated at the 105 day stage, the highest radioactivity count was recorded in the vascular cambium region, the lowest in the central stele, with the other two areas in the cross section showing intermediate counts. This pattern of radioactivity concentration within the cross section was the same in the proximal, as well as the medial and distal portions of the storage root.

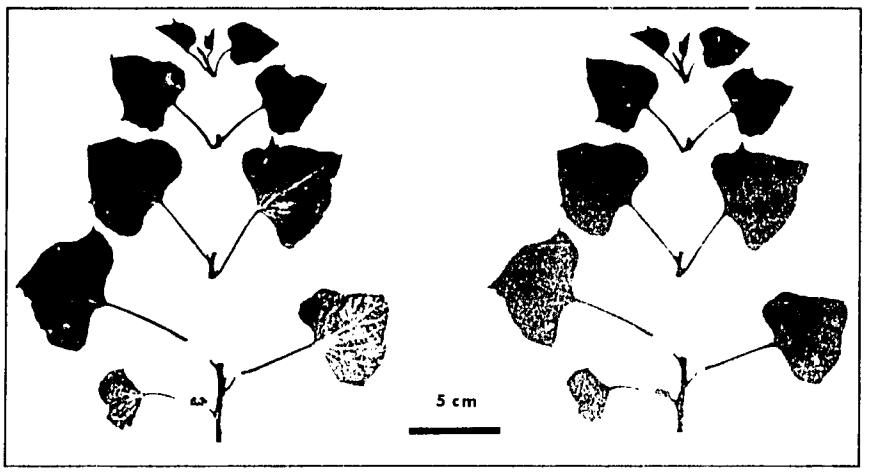

Figure 7. Redistribution of assimilated ^{14}C into an eight leaf stage sprout growing from storage root previously harvested when plant was at the 106-day stage after treatment at the 105-day stage.
(Mounted specimen on left, autoradiography on right; fibrous roots are not shown)

Radioactivity in storage roots of plants treated at the 44 day and 74 day stages, but harvested for autoradiography 24 hours after treatment is concentrated in the vascular cambium ring (data not shown). The other areas in the cross sections are labelled more or less uniformly, but to a lesser extent. This is the same general pattern exhibited by storage roots of plants treated at day 105 and harvested 24 hours later.

Autoradiographs of sprouts removed from storage roots exhibiting three distinct root labelling patterns of ^{14}C (44, 75 or 105 day treatment stage) produced essentially identically labelled autoradiographs whether they were pulled at the 2nd, 4th, 6th or 8th leaf stage (only 105 day, 8th leaf autoradiograph is shown, Figure 7). Radioactivity was uniformly detected throughout the plant with the highest concentration found in the leaf veins.

DISCUSSION

Fixation and translocation of ^{11}C photosynthates in response to external stimuli

We have demonstrated, using the rates of fixation and translocation of ^{11}C, that brief periods of exposure to low temperature and mechanical stresses have a pronounced effect on the carbon transport system of the sweet potato. The plant responded to a petiole cold collar (10°C for 120 sec) by rapidly decreasing the translocation of ^{11}C-photosynthates through the petiole of the treated leaf and down the stem. The slow recovery rate of the transport system indicates that substantial stress occurred, rather than simply rate changes in specific transport steps.

The magnitude of the stress imposed by the treatment is difficult, at present, to place in perspective from a field culture standpoint. While prolonged exposure of very young sweet potato plants to 10°C can cause death (Harter and Whitney 1926), it is not uncommon in the temperate zone for fields of sweet potatoes to be exposed to 10°C night temperatures during the

late fall without apparent damage. This would suggest that plant age, pre-conditioning and length of exposure are of considerable importance in addition to absolute temperature.

Mechanical stress (thigmomorphogenesis) to portions of plants is known to cause significant changes in plant growth (Boyer 1967; Hiraki and Ota 1975; Jaffe 1973; Neel and Harris 1971; Russell and Grace 1978). For example, wind (7.4 m s^{-1}) has been shown to alter the rate of leaf expansion and subsequently the whole plant structure of grasses (Russell and Grace 1978). In the present study, very slight mechanical stress, possibly in part caused by the plants alteration of its position in the gravitational field, resulted in complete cessation of the transport of carbon from the leaves. In addition, the rate of photosynthesis by the leaf was not substantially affected. This resulted in a major shift in the sizes of mobile and non-mobile pools of fixed ^{11}C, and in the turnover rate of the mobile pool.

It has been known for some time that plants, in response to stress of sufficient magnitude to cause large internal pressure changes rapidly (for example), form callose around the pores of sieve plates in the phloem. This constriction of the pores results in a pronounced effect on the flow through the sieve tube. For example, a decrease in the diameter of the pores from 1 μm to 0.2 μm results in a 600-fold decrease in flow rate through the pores. A callose response to mechanical stresses imposed by wind or other movement has been thought to be unlikely, since it would appear to place the plant at an evolutionary disadvantage (Canny 1973). This argument could be circumvented, however, if the response did not have a significant effect on net carbon acquisition by the plant. Neither our results nor those by Russell and Grace (1978) showed a substantial effect on photosynthetic rate due to agitation. While it is premature to speculate on a possible operative mechanism for the pronounced changes in carbon translocation caused by movement of a sweet potato plant, the response was considerable and perhaps significant in the overall control of carbon movement in plants. In addition, the effects of pre-conditioning of the plant, severity of stress and species need to be addressed.

It is also evident from the data presented that the use of ^{11}C has excellent potential for monitoring rate limiting steps in plant growth. Net photosynthetic rate, incorporation rate of photosynthates in the leaf, export rate, mobile and non-mobile pool size, export pool turnover rate, velocity or mean speed of phloem transport, unloading at sinks and other processes can be readily and non-destructively measured. The integration of this potential and a mechanistic modelling system into a sweet potato genetic engineering program will have a pronounced effect on the rate at which sweet potato productivity can be enhanced.

Deposition of ^{14}C photosynthate in storage roots

For all the three growth stages investigated, the labelled carbohydrate assimilates accumulate most along the vascular cambium ring of the storage roots, 24 hours after treatment. The assimilates at this point would most likely occur in a form other than starch, as no starch grains were observed in the vascular cambium. The accumulation of recent carbohydrate assimilates in the vascular cambium ring could to a large extent be related to the vascular cambium being a metabolically active site, it being the zone of maximum meristematic activity in the storage root.

All the remaining areas of the storage roots show discernible radioactivity. The ^{14}C-labelled material at this point in time probably exists in a hydrolyzed form, allowing it to be distributed throughout the storage root.

In storage roots from plants treated at the 105 day stage and harvested 24 hours later, the radioactivity count was highest per unit dry weight in the vascular cambium, somewhat less in both the periderm-outer cortical region and the peripheral stele, and lowest in the inner stele. This indicates that part of the assimilates upon phloem unloading would concentrate around the vascular cambium ring (which is near the phloem region) with the remainder moving out toward the external surface and in toward the center of the storage root. Since the inner stele is furthest from the unloading zone, it shows the least amount of radioactivity count per unit dry weight.

The concentration of recently assimilated carbohydrates along the vascular cambium ring immediately after treatment is no longer observed upon further development of the storage root. The accumulated carbohydrate is either expended in such metabolic activities as respiration or else transferred to other regions in the storage root. Both processes may be involved. Transfer to other regions may either involve the actual movement of the assimilates to other parts of the storage root or else involve a relative shifting of location due to cell division and subsequent differentiation of tissues from the vascular cambium. This latter process is unlikely to be major contributory factor, as autoradiographs of storage roots labelled at the 44 day or 74 day stage and harvested at the 106 day stage do not show a distinct ring of radioactivity inner to the vascular cambium ring. It is noted that the final depository for starch in the storage root is mainly in the bundle parenchyma, which is a general rather than a localized occurrence (Artschwager 1924).

The area spread of discernible radioactivity in the inner stele of storage roots labelled at the 44 day stage and harvested at the 106 day stage is much larger than the entire cross sectional area of storage roots harvested at the 45 day stage. Similarly the area spread of discernible radioactivity in the inner stele of cross sections of storage roots labelled at the 74 day stage and harvested at the 106 day stage is much larger than the total cross sectional area of storage roots harvested at the 75 day stage. It is noted that the entire cross sections of storage roots harvested at the 45 day stage or at the 75 day stage show discernible radioactivity distributed evenly in areas other than the vascular cambium raing.

The above comparisons indicate that either the deposition of $^{14}CO_2$ assimilates in the storage root continues far beyond the 24 hour period after treatment, or else an outward redistribution of the deposited material from the center of the root occurs. Kato *et al* (1972) reported that 20% of ^{14}C-photosynthate was translocated from the treated rooted leaf after 30 min of ^{14}C-labelling. Movement of ^{14}C-photosynthate was predominantly to the roots. About 50% of total ^{14}C-photosynthate was lost via respiration by 24 hours. They were, however, working with the single rooted leaf. It is more likely that once located in a region other than the vascular cambium ring, the labelled assimilates polymerize and do not move readily into newly developed areas differentiated from the vascular cambium. Otherwise, the fully developed storage roots labelled at the earlier dates would not show such distinct radioactivity differences between the different areas in the same cross section.

Elsewhere, it is proposed that the role of the vascular cambium ring versus the anomalous cambium, in determining storage root growth is a cultivar characteristic (Wilson and Lowe 1973). In the Red Jewel cultivar investigated here, the region of growth attributable to the activity of the vascular cambium ring from the 44th day onwards accounts for at least half of the cross sectional area in the proximal section of the storage root. It is probable that a still larger area of growth may be attributable to the vascular cambium ring, though this cannot be shown in the evidence presented here, because either the transport of $^{14}CO_2$ assimilates into the root extends for a relatively long period after treatment, or redistribution of labelled material occurs from the central core to its periphery.

Storage roots from plants treated at the 44 and 74 day stage and harvested for autoradiography at the 106 day stage, show that distribution of radioactivity in the central stele area does not appear uniform. This is especially the case with storage roots from plants treated at the 44 day stage, where a somewhat speckled pattern is discerned. Ordinarily in a storage root section, xylem groups and vessels are randomly distributed in an otherwise uniformly appearing inner stele. Anomalous cambium mainly arises in the vicinity of xylem groups (Artschwager 1924). Thus, it is probable that areas within the inner stele that show lesser amounts of radioactivity, would be cells of the anomalous cambium or cells recently differentiated from it. If such is the case, the areas showing lesser radioactivity within the core indicate the relative contribution of the anomalous cambium to the overall bulk of the storage root, from the date of labelling.

When plants are treated at different growth stages but harvested for autoradiography of the storage root at the 106 day growth stage, the thickness of the labelled cortical zone varied with the date of treatment. Storage roots from the earlier treated plants show a thinner zone of radioactivity. This indicates that growth of the secondary phloem-cortex region occurs and that the carbohydrate deposited in the older cortical region is not appreciably moved inwards into the zone recently differentiated from the outer margin of the vascular cambium ring. It may also indicate that the older cortical region may be compressed to some degree by the underlying expanding bulk.

The results suggest that invaginations along the surface of the storage root are related to different parts of the vascular cambium ring showing different rates of meristematic activity; the depth of invagination to an extent depending on when this difference in rate first arises.

The results show that the earlier deposited carbohydrates are concentrated towards the distal end of the storage root. To the extent that the deposition of carbohydrate is directly related to bulk growth of the storage root, this is interpreted to mean that growth along the longitudinal axis of the storage root starts at the distal end and progresses towards the proximal end as the storage root develops.

Anatomical studies (Wilson and Lowe 1973) have shown that early in storage root ontogeny, specialized tissues at the root end of the storage root allow for the longitudinal extension of the storage root and that later these tissues assume the structure and presumably functions of normal secondary thickened roots, thus delimiting the storage root at this end. The implication that longitudinal growth would then progress towards the proximal end is verified by the results presented here.

Redistribution of stored ^{14}C photosynthates out of the storage root into sprouts

The autoradiographs of the sprouts suggest that while attached to the storage root, sprouts will draw food reserves from the storage root and at least up to the eight-leaf stage, the amount drawn into the last opened leaf is comparable to that drawn into the first opened leaf. It is conceivable that a sprout continues using carbohydrate reserves from the storage root indefinitely so long as it remains attached to the storage root although carbon export to the storage root may occur simultaneously once the sprout is of sufficient size.

In root piece culture of sweet potatoes, smaller root pieces give rise to less vigorous sprouts (Kays and Stutte 1979; Takatori and Purnell 1961; Tsuno and Fujise 1965). The results presented here indicate that this is due to limited food reserves in the smaller root pieces. The nutrient physiology of the plant growing attached to the storage root from which it sprouts, as distinct from the detached independent plant, remains to be studied.

It has been demonstrated that sprouts originate in the vascular cambium region (Schlimme 1966), or in the cortical region adjacent to it (Wilson and Lowe 1973). The storage roots used for sprouting in the experiment were from plants treated at different dates and, therefore, showing different patterns in the deposition of labelled materials. This difference is not reflected in the redistribution pattern of labelled material into the sprouts. This would suggest that the hydrolysis of starch for remobilization into the sprouts occurs as a general phenomenon throughout the root rather than in localized regions. Additional evidence will be essential to establish if this is in fact the case.

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The Characteristics of Dry Matter and Yield Production in Sweet Potato Under Field Conditions

W. AGATA

Faculty of Agriculture, Kyushu University, Hakozaki, Higashi-Ku, Fukuoka 812, Japan

INTRODUCTION

Sweet potato produces the highest amount of calories per unit land area of all useful crops in Japan, and it has been grown as a most important food crop since the 18th century. Recently, this crop has also come to be considered most promising as an industrial raw material, in particular with reference to biomass energy. Because of the importance of this crop, a lot of research on cultivation methods has been carried out since the Meiji period in this country, but not much research has been undertaken from the viewpoint of matter production (Boysen-Jensen 1932). Tsuno and Fujise (1965) made the first studies based on matter production, and they also provided the theoretical foundation for sweet potato cultivation method. In their study, however, CO_2 balance in the field and also the relationship between climatic factors and dry matter production throughout the growth period were not clarified.

This investigation was carried out to make clear the characteristics of dry matter and yield production during the whole growth period in relation to climatic factors, based on growth analysis and on investigation of the CO_2 balance under field conditions.

MATERIALS AND METHOD

Nursery stocks of sweet potato (*Ipomoea batatas*, cultivar Koganesengan) used in this experiment were obtained from the National Kyushu Agricultural Experiment Station, Kumanoto, Japan. The cultivar is a recommended variety for food and as an industrial raw material in Japan. The plants were grown in a field inside the campus of Kyushu University under standard cultural conditions from 11 June 1979 (planting date) to 14 November 1979 (harvesting date).

Basal dressing 6, 6, and 19 kg/r ha of NPK was applied ten days before planting. Planting density was 4938 plants/4 ha (one plant/45 cm x 45 cm). About 0.8 ha was used for this experiment. From August to September, irrigation was carried out frequently to minimize moisture stress. During the growing period, sampling was carried out ten times at about two-week intervals. Three plots were sampled at each time. The samples were taken from a 90 cm x 90 cm plot and sampling was done at random. After sampling, the leaf area was measured and the dry weight was measured after drying in a forced-air drying oven for more than 48 hours at 80°C.

Growth analysis followed Watson's method (1952). Crop growth rate (CGR), net assimilation rate (NAR), maximum crop growth rate (CGR_{max}) and optimum leaf area index (LAI_{opt}) were calculated, based on the data of dry weight and leaf area measured at each sampling time.

The CO_2 exchange in population was measured six times using an open system assimilation chamber method under field conditions during the whole growth period. The assimilation chamber was made of transparent acrylyl resin and measured 45 x 45 x 40 cm. It was constructed on a metal frame which rested on stolons soil was heaped up around the frame.

The air temperature inside the chamber was regulated by adjusting the flow of cooling water which was poured continuously over the chamber. Whenever the CO_2 concentration in the chamber dropped, it was boosted to within 20% of the ordinary atmospheric level by pumping air into the chamber with a compressor. The light intensity in the chamber was adjusted by covering it with a number of layers of cheese cloth. The dark respiration under field conditions was measured by covering the chamber with dark curtain cloth.

The photosynthetic rates were expressed as gross photosynthetic rates (g DW/sq m/hr) which included the dark respiratory rates and apparent photosynthetic rates both of which were measured under field conditions. The dark respiration in each organ of the plant was also measured periodically using the chamber method at 25 ± 0.5°C. All CO_2 gases sampled were analyzed with an infra-red gas analyzer. A factor of 0.61 was used for conversion of CO_2 to dry matter.

The efficiency for solar radiation utilization (E_u) shows the ratio of fixed energy calculated as 3.75 kcal/g of dry matter to the total amount of incident radiation (Monteith 1966). All climatic data, such as air temperature, solar radiation and precipitation during the growing period were obtained from the Fukuoka Meteorological Observatory Station in Fukuoka City.

RESULTS AND DISCUSSION

General conditions of climate and growth

The mean daily air temperature, mean daily solar radiation and the amount of rainfall in each growth period from 11 June to 14 November in 1979 are given in Table 1. Mean values of air temperature and solar radiation during the whole growth period were 24.2 ± 3.6°C and 319 ± 85 cal/sq m/day, respectively. Both air temperature and solar radiation tended to increase till the end of July, and then to decrease until November. In the case of radiation, however, fluctuations were mainly noticed in the latter half of this period. The amount of precipitation differed in each growth period. Generally speaking, climatic conditions in 1979 were quite favorable for sweet potato growth, and yields were high.

Dry weight of total and of tuberous root

Changes in total dry weight and in tuberous root dry weight with time are shown in Figure 1. Total dry weight showed a sigmoid growth curve also typical of other crop plants. The highest value, at harvesting time, was 2047 g/sq m. Formation of the tuberous root started at 30-35 days after planting and its dry weight increased almost linearly till harvesting time. The yield at harvest was 1754 g/sq m and the ratio of yield to total dry weight (harvest index) was 84.6%. This value was larger than those obtained by Tsuno and Fujise (1965). The reason for this may be that the growth period was longer and climatic conditions were more favorable in this experiment.

Table 1. Mean daily air temperature, mean daily solar radiation and precipitation at each growth period of sweet potato (1979 in Fukuoka)

Sampling period	Mean air temperature °C	Mean solar radiation cal/sq cm/day	Precipitation mm
11 Jun - 22 Jun	24.5	251	127
23 Jun - 5 Jul	24.5	244	497
6 Jul - 21 Jul	25.4	386	96
22 Jul - 2 Aug	29.0	501	7
3 Aug - 20 Aug	28.2	422	66
21 Aug - 4 Sept	26.7	330	68
5 Sept - 19 Sept	24.6	407	44
20 Sept - 4 Oct	23.2	296	6
5 Oct - 24 Oct	18.8	329	99
25 Oct - 14 Nov	16.7	226	27
Mean	24.2 ± 3.6	399 ± 85	-

Leaf area index

Changes of leaf area index (LAI) with time are also shown in Figure 1. After planting, LAI increased rapidly till early August and then decreased gradually towards November. But LAI remained above 4.0 throughout the latter half of the growth period.

Growth analysis

Growth analysis was carried out based on the data of total dry weight and LAI shown in Figure 1. The results are shown in Figure 2.

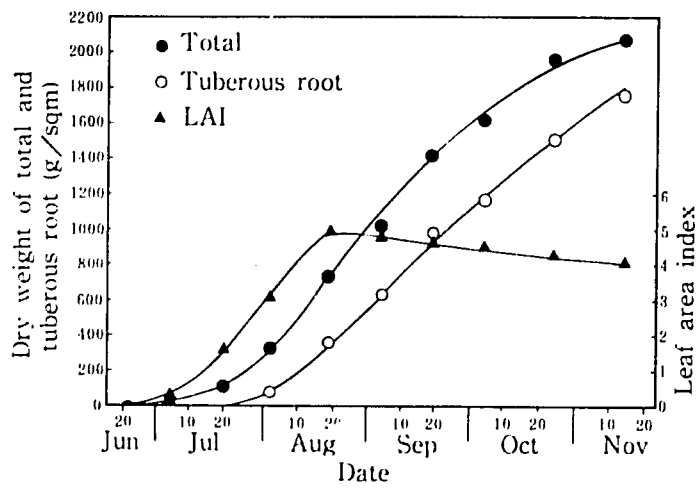

Figure 1. Changes with time in total dry weight, tuberous root dry weight (yield) and leaf area index (LAI) in sweet potato under field conditions

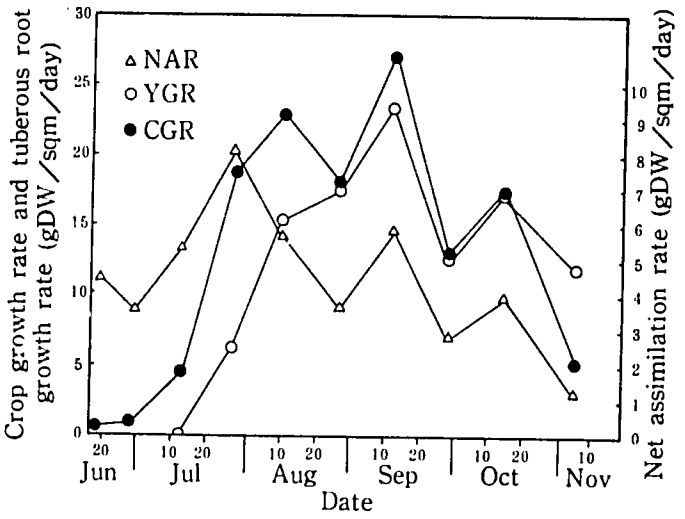

Figure 2. Changes with time in crop growth rate (YGR), net assimilation rate (NAR) and tuberous root growth rate (YGR) in sweet potato under field conditions

CGR increased exponentially till early August, showing a pattern similar to the increasing trend of LAI. Then CGR varied irregularly till November. CGR peaked in September and October. On the other hand, NAR, which is a component of CGR, reached a peak at the end of July. Therefore, it showed a pattern similar to that of CGR till harvesting time.

The changes of CGR, LAI and NAR during the growth period suggest that CGR before and after early August depends mainly on LAI and NAR, respectively. Therefore, analyses as to the correlation of CGR with NAR and LAI in the first half of the period under study (before early August) and in the latter half, were made. As shown in Table 2, CGR in the first half of the period was highly correlated with LAI, but not with NAR. On the other hand, CGR in the latter half of the period was strongly correlated only with NAR. Such results have been reported for many crop populations (Takeda 1961; Murata 1961; Tsuno and Fujise 1965).

Since the LAI-CGR curve shows typical of dry matter production plants in the field, the relation between LAI and CGR was analyzed. The following very close relation was obtained:

$$y = -1.188x^2 + 9.505x - 0.925 \quad (r = 0.778^{**})$$

From this curvilinear regression, it was calculated that CGR_{max} and LAI_{opt} were 23.5 g/sq m/day and 4.0, respectively. These values were a little larger than those reported by Tsuno and Fujise (1965).

Table 2. Correlation coefficients of crop growth rate (CGR) with leaf area index (LAI) and net assimilation rate (NAR) in the first half of the growth period and in the latter half of the growth period

Items	First half period		Latter half period	
	LAI	NAR	LAI	NAR
CGR	0.98 **	0.61	0.72	0.99 **

**Significant at 1% level

Table 3. Correlation coefficients of crop growth rate (CGR), leaf area index (LAI) and net assimilation rate (NAR) with climatic factors in the first half of the growth period and in the latter half of the growth period.

Items	First half period		Latter half period	
	Mean air temperature	Mean solar radiation	Mean air temperature	Mean solar radiation
CGR	0.96*	0.85	0.66	1.00**
LAI	0.88*	0.76	0.98**	0.71
NAR	0.75	0.92*	0.62	1.00*

*Significant at 5% level, **Significant at 1% level

To make clear the differences of influence of LAI and NAR on CGR in the first half and the latter half of the period, it was necessary to make analysis with regard to climatic factors. The mean air temperature and solar radiation are considered to be the main climatic factors affecting CGR. The results of these analyses are given in Table 3.

CGR in the first half period was more highly correlated with temperature than with solar radiation. However, in the latter half of the period CGR displayed highly significant correlation only with solar radiation. Further, LAI in the first half of the period was highly correlated with air temperature, and NAR in the latter half was highly correlated with solar radiation. These results indicate that CGR in the first half and the latter half of the period depended closely on the relationships between temperature and LAI, and between solar radiation and NAR, respectively.

Relation between tuberous root growth rate and growth parameters

In the case of sweet potatoes, tuberous root production is equal to yield. Therefore, the growth rate of the tuberous root (YGR) is one of the most important growth parameters. As shown in Figure 2, the variation of YGR during the growth period was similar to that of CGR. However, the difference between CGR and YGR became smaller and smaller after August, and YGR exceeded CGR after the middle of October. This indicates the translocation of matter from other organs to the tuberous root.

Table 4 shows the correlation coefficient of YGR with climatic factors and growth parameters. It is obvious that YGR was more highly correlated with CGR and NAR than with LAI, and was correlated closely with solar radiation. These results indicate that YGR is strongly influenced by solar radiation through NAR and CGR when LAI is above the optimum value.

Table 4. Correlation coefficients of tuberous root growth rate (YGR) with climatic factors and growth parameters

Item	Climatic factors		Growth parameters		
	mean air temperature	mean solar radiation	CGR	LAI	NAR
YGR	0.52	0.94*	0.95*	0.56	0.95*

*Significant at 1% level

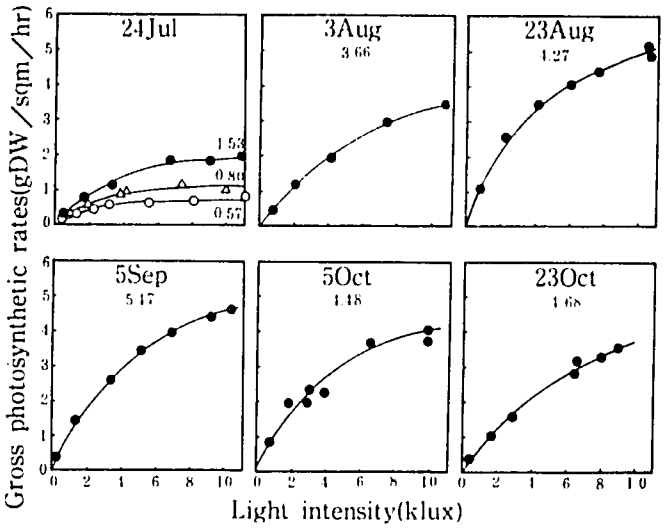

Figure 3. Light-gross photosynthetic rate curve at different growth stages of sweet potato under field conditions (numbers indicate LAI value)

Photosynthesis in plant population

The relationships between light intensity and gross photosynthetic rate measured in each growth period, are shown in Figure 3.

The gross photosynthetic rate under strong light intensity increased rapidly in proportion to LAI increase from 24 July to 23 August, and then it decreased gradually towards 23 October in spite of the fact that LAI was above 4.0. The highest value of the gross photosynthetic rate was 5 g DW/sq m/hr on 23 August. This value was higher than those recorded by Tsuno and Fujise (1965).

The response of gross photosynthetic rate to light intensity showed a saturated curve at the stage when LAI was low, but a fairly non-saturated curve when LAI was above 3.0. Such a result has been found in other crop populations (Takeda 1961; Murata 1961; Shimizu and Tsuno 1957; Kubota *et al* 1972).

Dark respiration in plants

Dark respiratory rates of each organ at various growth stages are shown in Table 5. These values differed for each organ. The value for leaf was

Table 5. Respiratory rates of each plant organ at different growth stages of sweet potato[a]

Date	Leaf	Petiole + stolon	Tuberous roots	Root	Whole plant
18 July	4.49	3.36	-	5.09	4.10
4 Aug	4.68	3.07	2.09	2.43	3.27
18 Aug	5.66	2.19	1.09	1.03	2.34
3 Sept	1.12	0.67	0.24	1.42	0.48
1 Oct	1.38	0.66	0.20	1.27	0.48

[a]Values indicate mg CO_2/g/hr at 25°C

the highest, and the values became smaller for petiole and stolon, root and tuberous root, in this order. They also tended to decrease from the early stages to the later stages of growth. The dark respiratory rates of the whole plant were calculated from the respiratory rate and the dry weight of each organ at the same time. Further, Q10 of their rates in the range of 15°C to 30°C was about 1.6 in mean value.

CO_2 balance in sweet potato

Based on the gross photosynthetic rate shown in Figure 3, plant respiratory rate given in Table 5, total dry weight and LAI shown in Figure 1, and air temperature and solar radiation given in Table 1, the gross photosynthesis (Pg) and respiration (R) per day at each growth stage were computed by the method described in previous reports (Agata *et al* 1972; Kubota *et al* 1972). The results are given in Table 6.

Table 6. Changes with time of crop growth rate (CGR), amount of gross photosynthesis (Pg), respiration (R) and net photosynthesis (Pn) per day, and ratios of Pn/Pg, R/Pg and Pn/CGR, and efficiencies for solar energy utilization (Eu) based on Pg, Pn and CGR

Items	11 Jun 22 Jun	23 Jun 4 July	5 July 21 July	22 July 2 Aug	3 Aug 20 Aug	21 Aug 4 Sept	5 Sept 19 Sept	20 Sept 4 Oct	5 Oct 24 Oct	25 Oct 14 Nov	Mean
CGR g/sq m/day	0.45	0.71	4.88	19.59	22.91	18.13	27.13	13.21	17.63	5.19	12.88 ± 9.01
Pg g/sq m/day	1.10	1.87	8.00	27.00	32.40	30.80	30.00	22.00	22.00	11.00	18.62 ± 11.49
R g/sq m/day	0.66	1.01	2.99	9.07	13.09	9.82	8.33	8.20	6.81	5.91	6.59 ± 3.79
Pn g/sq m/day	0.44	0.86	5.01	17.93	19.31	20.98	21.67	13.80	15.19	5.09	12.03 ± 7.94
Pn/Pg	40.0	46.0	62.6	66.4	59.6	68.1	72.2	62.7	69.0	46.3	59.3 ± 10.6
R/Pg	60.0	54.0	37.4	33.6	40.4	31.9	27.8	37.3	31.0	53.7	40.7 ± 10.7
Pn/CGR	97.8	121.1	102.7	96.4	84.3	115.7	79.9	104.5	86.2	98.0	97.7 ± 12.6
Eu of Pg	0.16	0.29	0.78	2.02	2.38	3.50	2.76	2.79	2.51	1.83	1.95 ± 1.11
Eu of Pn	0.07	0.13	0.49	1.34	1.72	2.38	2.00	1.75	1.73	0.84	1.25 ± 0.77
Eu of CGR %	0.07	0.11	0.47	1.39	2.04	2.06	2.50	1.67	2.01	0.86	1.35 ± 0.85

Pg increased from the early stage to the middle stage of growth. The maximum value was 32.41 g/sq m/day in the middle of August. Thereafter, it decreased gradually to November. R also showed seasonal changes similar to Pg. The increase of R in the first half of the period depended on the increase of LAI and air temperature. On the other hand, the decrease of R in the latter half period was correlated with the increase of the ratio of tuberous root weight to total dry weight and the decrease of air temperature.

Net production (Pn), which is determined by subtracting R from Pg, showed an increasing tendency till the middle of September, and then it decreased gradually towards harvesting time. This pattern of Pn was closer to that of Pg than to that of R. This means that Pn depended mainly on Pg. Actually, the ratio of Pn to Pg was greater than that of R to Pg, that is, the the mean ratios of the former and the latter during the whole growth period were 59.3 ± 10.6 and 40.7 ± 10.7, respectively. However, both values differed for each growth period. An R/Pg ratio of 30-40% during the middle period of growth coincides well with Tsuno and Fujise's data (1965), but it is necessary to note that the R/Pg ratio varies according to growth period.

The ratio of Pn to CGR was 98.6 ± 12.5% in mean value during this experiment period. This ratio indicates that the measuring methods of photo-

synthesis and respiration were suitable for analysis of dry matter production of sweet potato under field conditions.

Efficiency for solar energy utilization

Values for solar energy utilization efficiency (Eu) based on Pg, Pn, and CGR are also given in Table 6.

Eu based on Pg averaged about 1.95% throughout the whole growth period, but it differed for each growth stage, and tended to increase with the increase of LAI, reaching a maximum value (3.5%) at the end of August. It then decreased gradually towards November. Eu based on Pn showed almost a similar pattern to Pn and its mean value was 1.35%.

According to the JIBP report (Kanda 1975), the mean Eu of rice, soybean, maize and sugarbeet based on CGR during the growth period are 1.25%, 0.72%, 1.34% and 1.34%, respectively. So the 1.35% Eu of sweet potato in this experiment places near it maize and sugarbeet and above soybean, although it is the same broadleaf plant type. The following factors may explain why this is: a) the sink effect for photosynthesis in root crops is large; b) the yield productive period of root crops is very long.

ACKNOWLEDGEMENT

The author wishes to thank Dr T Takeda, Faculty of Agriculture, Kyushu University, for many useful suggestions, and Dr T Sakamoto, National Kyushu Agricultural Experiment Station, for providing the nursery stocks of sweet potatoes.

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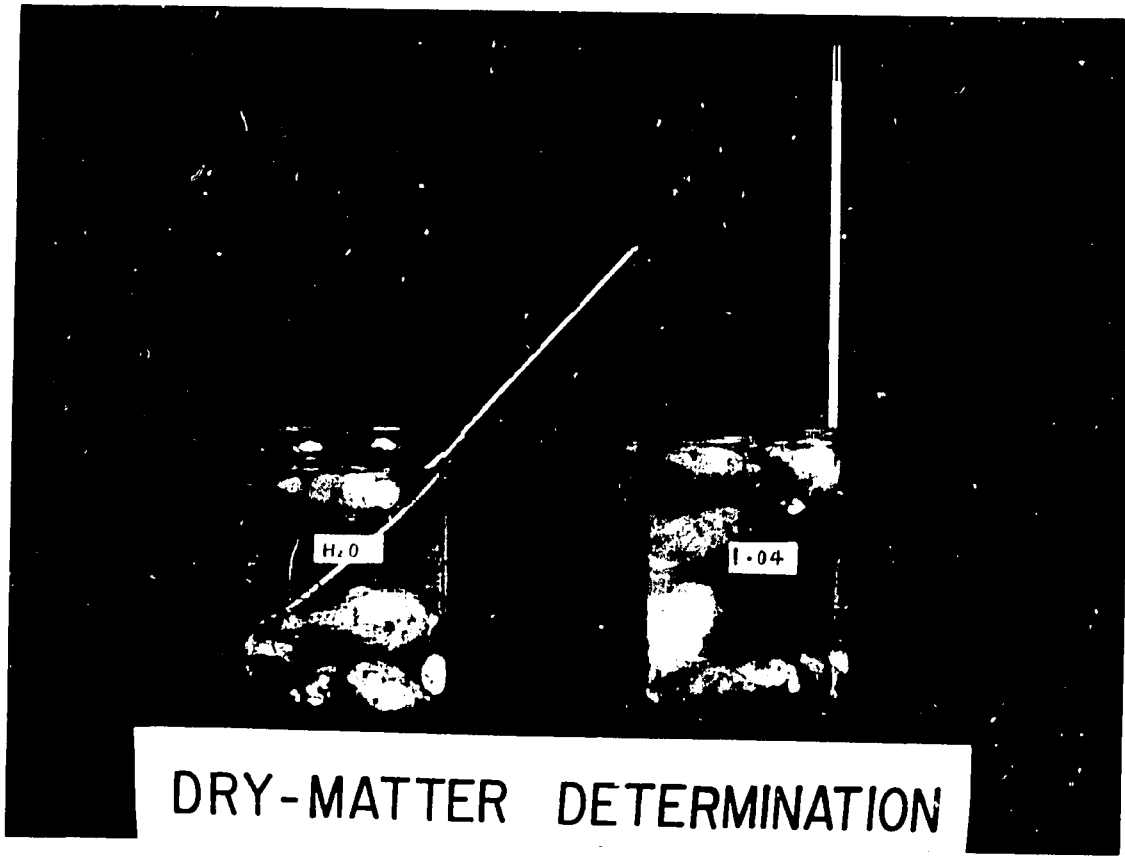


Screening for high dry matter content using specific gravity.

Photosynthetic Activity and Carbon Dioxide Diffusion Resistance as Factors in Plant Production in Sweet Potato Plants

Y. HOZYO

National Institute of Agricultural Sciences, Kannondai, Yatabe, Ibaraki, Japan

INTRODUCTION

The photosynthetic activity and carbon dioxide diffusion resistance of the leaf blade influence dry matter production in sweet potato plants. Measurements of carbon dioxide influx and water vapor efflux indicate that the diffusion resistance to carbon dioxide transfer in the leaf is a rate-limiting process in photosynthesis at saturating irradiance and normal carbon dioxide concentrations.

The aim of this work was to make clear the photosynthetic characters and the diffusion resistance to carbon dioxide transfer in the leaf and to assess their relative significance as the rate-determining processes in tuberous root growth in sweet potato plants.

EXPERIMENTAL METHODS

The photosynthetic activity and transpiration rate of the leaf blade was measured in a leaf photosynthesis chamber and the plants were grown in a controlled airconditioned growth cabinet (Hozyo and Kato 1978). Each measurement was carried out at 25°C, with a relative humidity of 50%. Yoko lamps and incandescent lamps provided the light source. Carbon dioxide diffusion resistance was calculated according to Lamoreax and Chaney (1978). The uptake of carbon dioxide was measured with an infra-red gas analyzer and the water vapor efflux was measured with an infra-red water vapor analyzer. The temperature of the lower leaf surface was measured with a copper-constantan thermocouple. The saturating light intensity for photosynthesis determined at the surface of an intact leaf blade was about 35 klx (Figure 1).

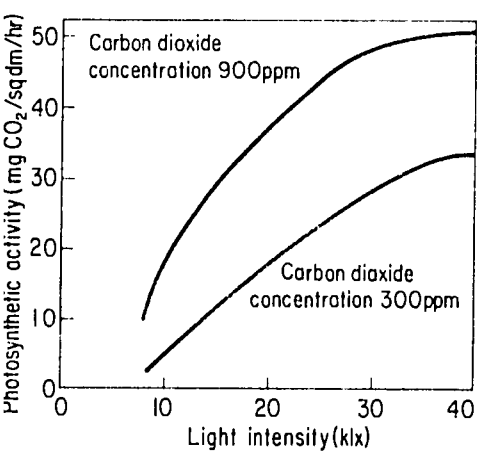


Figure 1. Relation between light intensity and photosynthetic activity. Measurement conducted at following conditions: temp 25°C, 50%. Variety, Okinawa 100. Fifth leaf was used for measuring and leaf position was numbered from the expanded top leaf blade

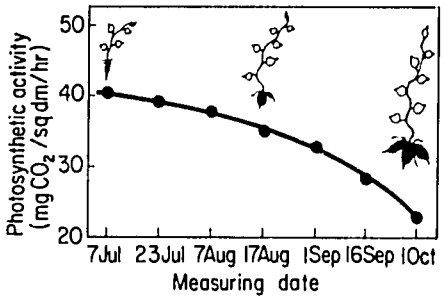


Figure 2. Changes of photosynthetic activity in leaf blade

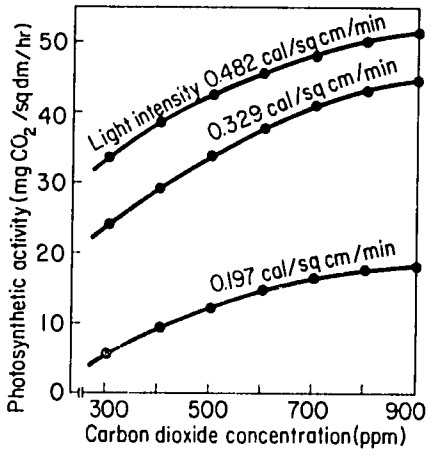


Figure 3. Relation between carbon dioxide concentration and photosynthetic activity

RESULTS AND DISCUSSION

Photosynthetic activity of the leaf blade was high in early growth stages and gradually declined with increasing leaf age. Photosynthetic activity was 30-35 mg CO_2/sq dm/hr in the first growth stage of the tuberous root and 20-25 mg CO_2/sq dm/hr in the final growth stage of the tuberous root (Figure 2) (Hozyo *et al* 1979, 1980).

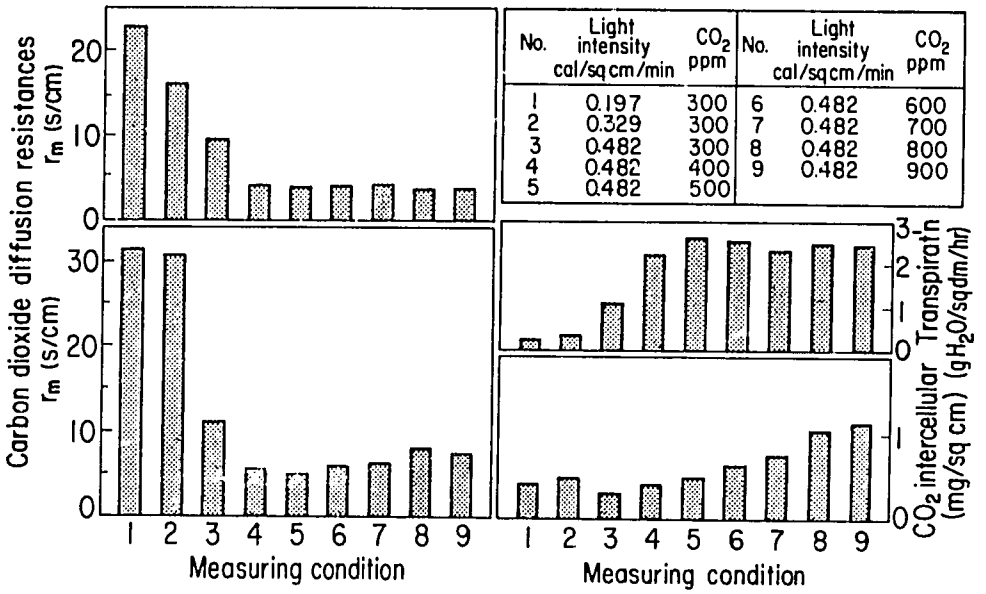
Increase of photosynthetic activity of the leaf blade was observed with the increase of carbon dioxide concentration in the atmosphere. The leaf blade subjected to 800-900 ppm carbon dioxide atmospheric concentration can uptake carbon dioxide 1.5 to two times faster than at a normal concentration of 300 ppm (Figure 3; Hozyo and Kato 1976).

Methophyll and stomatal resistance increased with the ageing of the leaf blade. Photosynthetic activity and transpiration rate decreased at the same rate during the period when the total leaf resistance to carbon dioxide diffusion was increasing.

Stomatal resistance was found to be lower than methophyll resistance under all conditions at which measurement was carried out (Figure 4). The increase in stomatal resistance affected transpiration more than it affected photosynthesis, as evidenced by the increase in the ratio of photosynthesis to transpiration.

Intercellular carbon dioxide concentration remained constant suggesting that the stomatal aperture was imposing some limitation on photosynthesis and that carboxylation was imposing some limitation on photosynthesis.

Of the resistances in the leaf blade, the resistance to transfer of carbon dioxide in the liquid phase through the cell wall and cytoplasm of the methophyll cells to the sites of carboxylation seems to be of overriding importance as indicated by the fact that its value is usually higher than



No.	Light intensity cal/sq cm/min	CO_2 ppm	No.	Light intensity cal/sq cm/min	CO_2 ppm
1	0.197	300	6	0.482	600
2	0.329	300	7	0.482	700
3	0.482	300	8	0.482	800
4	0.482	400	9	0.482	900
5	0.482	500			

Figure 4. Changes in parameters of carbon dioxide and water vapor exchange in different carbon dioxide concentrations ranging from 300 to 900 ppm

stomatal resistances (Catsky *et al* 1976; Goudriaan and Laar 1978; Friedrich and Huffaker 1980).

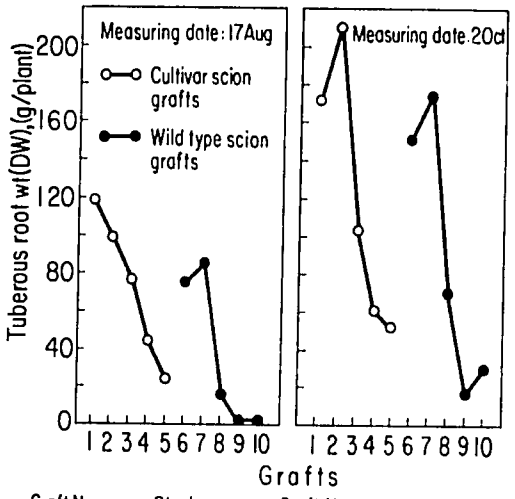
Stomatal resistance was found to remain constant in the range of carbon dioxide concentration 300-900 ppm. The increase of stomatal resistance to carbon dioxide had not been induced simultaneously during the period when the carbon dioxide concentration was increasing.

The interrelationship between photosynthetic activity and tuberous root growth was investigated by grafting plants to cultivated varieties and wild strains of sweet potato. Large values for total plant production were obtained in the grafts where tuberous root growth was superior (Figures 5, 6). The photosynthetic activity of the leaf blade was promoted when the cultivar was used as stock. Photosynthetic activity was better in grafts of large tuberous roots than in grafts of small tuberous roots (Figures 7, 8). A close relationship was thus found between photosynthetic activity and tuberous root growth (Hozyo and Park 1971; Hozyo and Kato 1973, 1976). Methophyll and stomatal resistance increased where wild plants were used as stock and the degree of increase of methophyll resistance was found to be associated with the ageing of grafts (Hozyo *et al* 1979, 1980).

In spite of the decline in photosynthesis, the concentration of soluble sugars and starch increased dramatically with the grafts where wild plants were used as stock (Hozyo *et al* 1979, 1980).

It is possible that the enlarging tuberous roots influence both carbon dioxide diffusion resistance and regulation of carboxylation.

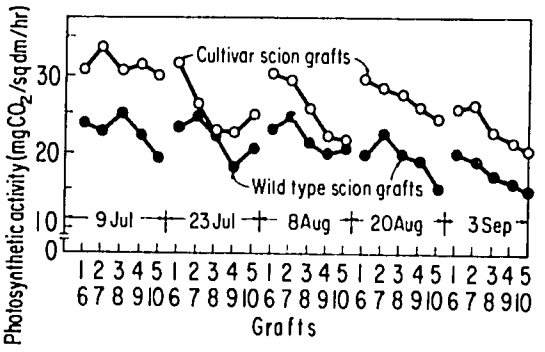
Thus it seems that some metabolic event such as the accumulation of sugars results in a feedback inhibition of photosynthesis, and that the action of endogenous growth substances of tuberous roots on leaf blade controls photosynthesis (Hozyo 1973).



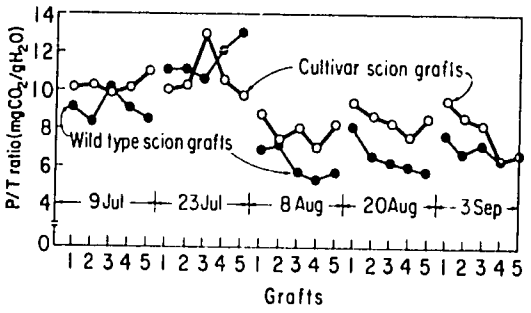
Graft No.	Stock	Graft No.	Stock
1,6	Cultivar-1	4,9	Interspecific hybrid
2,7	Cultivar-2	5,10	Wild type
3,8	Interspecific hybrid/cultivar		

Figure 5. (Left) Changes of tuberous root weight (DW) in the grafts (Hozyo *et al* 1980)

Figure 6. (Below) Relation between photosynthetic activity and tuberous root growth (Hozyo *et al* 1980). The graft codes are the same as Figure 5



It is suggested that the maintenance of high photosynthetic activity and the longevity of the leaf blade are important factors for obtaining high yields in sweet potato plants.



Graft No.	Stock	Graft No.	Stock
1,6	Cultivar-1	4,9	Interspecific hybrid
2,7	Cultivar-2	5,10	Wild type
3,8	Interspecific hybrid/cultivar		

Figure 7. Changes of photosynthesis/transpiration ratio in the grafts (Hozyo *et al* 1980)

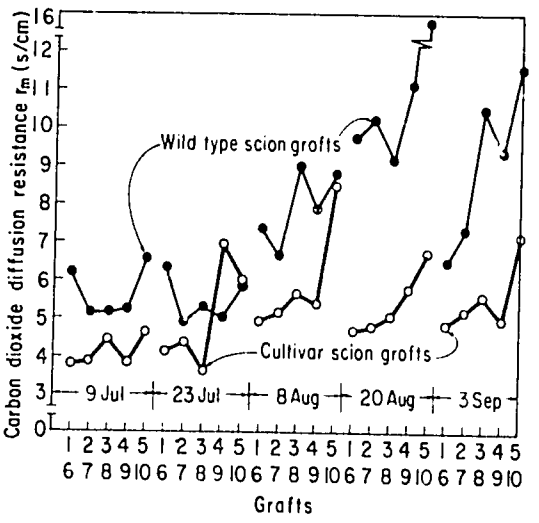


Figure 8. Relation between carbon dioxide diffusion resistances and tuberous root growth (Hozyo *et al* 1980). The graft codes are the same as Figure 5

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Seed set after hand pollination.

Carbohydrates in Sweet Potato

J. K. PALMER

Department of Food Science and Technology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061 USA

INTRODUCTION

This report briefly summarizes information on sweet potato carbohydrates and points out the need for more data on them, especially in relation to their role in defining texture, inducing flatulence and as dietary fiber. The references are not meant to be complete, but were selected only as examples from the extensive literature on sweet potato carbohydrates (Rotar and Bird 1981).

GENERAL CARBOHYDRATE COMPOSITION

Carbohydrates generally make up between 18 and 35% of the fresh weight and 80 to 90% of the dry weight of sweet potatoes. Table 1 presents typical data calculated from two recent publications (Sistrunk 1977; Reddy and Sistrunk 1980) on the carbohydrate fractions in cooked sweet potatoes. Table 2 shows the distribution of sugars in the total sugar fraction of baked sweet potatoes (Buescher, R. W., University of Arkansas, personal communication). The data in Tables 1 and 2 are approximate since sweet potatoes tend to exhibit exceptionally large variations in carbohydrate composition with cultivar, cultivation practice, and cooking, storage, curing, and processing method. Notice the large standard deviations in Table 1. As another example, Hammett and Barrentine (1961) reported nearly 16% starch after baking in one variety of sweet potato, as compared with the 4.1% estimated average in Table 1. In addition, the results obtained in carbohydrate analyses depend to a considerable extent on method of analysis. The data of Table 1 were obtained by a sequential extraction method, measuring sugars in the

Table 1. Approximate carbohydrate composition of cooked sweet potatoes (% fresh wt)

Total sugars	13.2 ± 2.5[a]
Starch	4.1 ± 0.9
Pectins	0.9 ± 0.1
Hemicelluloses	0.7 ± 0.3
Cellulose	1.5 ± 0.4
Total carbohydrate	20.4 ± 3.1

[a]Mean ± standard deviation (n=25) from cooked samples representing a total of 4 cultivars, 5 cooking methods, 2 sizes, bruising, long term (7 month) and short term (4-10 day) storage, and 2 storage temperatures. The data were taken from two separate studies and the standard deviations include the variation between studies as well as the variation with the individual studies

extracts by the phenolsulfuric acid method (Dubois *et al* 1956) or uronic acid by the carbazole method (Dietz and Rouse 1953), as appropriate. Total (free) sugars were extracted with 80% ethanol. A second portion of tissue was treated with diastase and sequentially extracted with 80% ethanol (total sugars plus starch); water and calgon (pectins) and 1N NaOH (hemicelluloses), leaving a cellulose residue. The individual sugars in Table 2 were determined by gas chromatography of trimethysilyl derivatives and identities were confirmed by thin layer chromatography.

Table 2. Composition of the soluble sugars in baked sweet potatoes[a]

Sugar	% of fresh wt
Maltose	5.5
Sucrose	4.4
Fructose	0.9
Glucose	0.8
Raffinose	0.5
TOTAL	12.1

[a]Average data for four varieties - Georgia Jet, Centennial, Jewel and Jasper

No corresponding data could be found on the carbohydrate fractions of uncooked potatoes. Onwueme (1978) reported 8-29% starch, 0.5-2.5% reducing sugars, and 0.5-7.5% non-starch carbohydrates in 'fresh' sweet potato roots. Hammett and Barrentine (1961) reported freshly harvested sweet potatoes to contain about 72% moisture, 1.7% sugars, 26% starch and no dextrins. Sugars increased to about 2.8% and starch decreased to about 25% after curing and storage for 60 days.

It is well known that much of the starch in sweet potatoes is converted during baking or processing into maltose and dextrins (Ali and Jones 1967; Hammett and Barrentine 1961; Walter *et al* 1975). The dextrins would presumably be distributed between the starch and total sugars fractions of Table 1, depending on the degree of polymerization. Walter *et al* (1975) reported that between 42 and 95% of the starch in several cultivars of sweet potato was converted during baking. Between 72 and 99% of the converted starch accumulated as maltose, the remainder accumulating as dextrins. The dextrins were of unspecified chain length, but were solubilized from the 80% alcohol insoluble solids with 10% ethanol and determined as glucose after hydrolysis by amyloglucosidase. The sucrose content of sweet potatoes did not change during baking, suggesting that the sucrose in baked potatoes does not arise as a product of starch hydrolysis (Buescher, R. W., University of Arkansas, personal communication). Deobald *et al* (1971) found sucrose to increase from about 10% at harvest to 20% during 65 days storage of cured or uncured potatoes. This increased sucrose is probably a product of starch hydrolysis.

THE ROLE OF CARBOHYDRATES IN DETERMINING ACCEPTABILITY OF SWEET POTATOES

The composition and properties of the carbohydrates of sweet potatoes are of prime importance in determining the acceptability of sweet potatoes as

food. Three important properties - texture, flatulence induction and dietary fiber source - are discussed below as they relate to carbohydrate composition.

Texture

Since carbohydrates predominate in sweet potatoes, key textural attributes such as firmness, dryness, and 'mouth feel' must be largely determined by the composition and properties of the carbohydrates. Considerable research has been carried out to seek correlations between desirable or undesirable texture and carbohydrate composition. For example, starch and alcohol insoluble solids have been correlated with firmness of canned sweet potatoes (Kattan and Littrell 1963), texture and viscosity of canned sweet potatoes have been correlated with pectic substances (Sistrunk 1971); hardcore (hard, inedible tissue in cooked sweet potatoes attributed to chilling injury) has been correlated with content of particular pectin fractions (Buescher *et al* 1976); mouth feel from eating baked potatoes has been correlated to starch and dextrin content (Walter *et al* 1975); total polysaccharide content has been correlated with softness after cooking (Reddy and Sistrunk 1980); decreases in starch and 'protopectin' (measured as pectic substances solubilized by pectic enzymes) have been correlated with increased moistness of baked potatoes (Swingle 1966).

Several conclusions can be drawn from these and similar studies. Firstly, there is already considerable evidence that the content of particular carbohydrate fractions can be correlated with textural attributes. Secondly, carefully designed experiments are required to single out statistically significant correlations because of extensive variations in carbohydrate composition with cultivar, cultivation practices, handling, cooking, and so on. Thirdly, better chemical and physical characterization of the carbohydrate fractions would no doubt lead to clearer and more specific correlations with textural attributes.

Flatulence caused by sweet potatoes

It seems to be quite generally recognized that ingestion of sweet potatoes causes flatulence and that the flatulence can be severe. However, only one specific reference to flatulence induction by sweet potatoes has been found. In a survey designed to identify social and cultural values leading to acceptance or rejection of sweet potatoes in a North Carolina (USA) community, 14 of 100 respondents mentioned 'indigestion' as a reason for disliking sweet potatoes (Fitzgerald 1976). This was the commonest complaint and Fitzgerald implied that the respondents were in fact referring to flatulence.

Flatulence is induced by carbohydrates which are not digested in the upper digestive tract but which are fermented by colon bacteria to yield flatus gases, primarily H_2 and CO_2. This mechanism has been established for other flatus-generating foods, especially legumes, and the oligosaccharides raffinose, stachyose and verbascose have been demonstrated to induce flatus (Rackis 1975). However, there are other carbohydrates in beans which induce flatus. For example, Olson *et al* (1975) isolated oligosaccharide-free residues from beans which induced flatus in rats. Further, there was an apparent synergistic effect when this residue and stachyose were fed together, the resulting gas (hydrogen) production being about twice the sum of the gas production from feeding the individual test substances. In a more general

sense, it has recently been observed (Salyers *et al* 1979) that colon bacteria can digest a wide variety of polysaccharides typical of those found in plant cell walls, suggesting that virtually any food polysaccharide which finds its way into the colon is a potential source of flatus.

Preliminary data (Table 2) indicate the presence of raffinose in baked sweet potatoes, but at levels (about 0.5% fresh weight) well below those found in legumes. Mature soybeans, for example, contain about 1% raffinose and 2.5% stachyose (Rackis 1975); mature winged beans contain 1-2% raffinose, 2-4% stachyose and 0.2-1% verbascose (Garcia and Palmer 1980). Cooked beans would contain about one-half those concentrations, still well above the levels found in baked sweet potatoes. From these data, it seems unlikely that the raffinose present in sweet potatoes would be sufficient to generate significant flatulence.

Further study will be required to (1) establish the extent and severity of sweet potato induced flatulence and (2) determine which specific sweet potato carbohydrates induce it.

Sweet potatoes as a source of dietary fiber

There has recently been a strong upsurge of interest in the 'indigestible' or dietary fiber components of plant foods. The renewed interest stems from epidemiological studies which indicate that increased fiber in the diet reduces the incidence of a variety of diseases in man, including colon cancer, diabetes, certain kinds of heart disease and a variety of digestive disturbances.

Dietary fiber is presently defined rather loosely to include the non-starch polysaccharides of plant foods - the hemicelluloses, the pectic substances and cellulose - as well as associated structural proteins and lignin. The research on dietary fiber is proceeding in two primary directions. The first involves the detailed chemical and physical characterization of dietary fiber from various sources, with the ultimate goal of better defining and determining dietary fiber. The second involves studies designed to obtain laboratory and chemical evidence for the effectiveness of dietary fiber or particular dietary fiber components in ameliorating disease. It is too early to expect definitive results, but considerable progress has been made in the characterizations, and clinical results with diabetes are promising (Reiser 1979).

Sweet potatoes are potentially a significant source of dietary fiber (Table 1) and should be included in studies of dietary fiber composition and function.

RESEARCH NEEDS

Any additional studies of the role of sweet potato carbohydrates in determining texture, generating flatulence or as dietary fiber, should be preceded by (or should include) detailed studies of the sweet potato carbohydrates. The methodology for determining and characterizing carbohydrates has advanced by leaps and bounds in the past ten years. First, it is now possible to identify unequivocally and quantitate rapidly the individual sugars and oligosaccharides in foods. Second, the detailed structure of even complex polysaccharides can be determined with relative ease. The reports

of Conrad and Palmer (1976), Li *et al* (1977) and Valent *et al* (1980) provide examples of the newer analytical methodologies. The study of Schweiger and Würsch (1979) is an example of the newer methodologies adapted to the analysis of dietary fiber.

Once the sweet potato carbohydrates have been characterized, studies can proceed to elucidate the role of the individual carbohydrates in determining texture or other properties. This information will be the basis for selecting cultivars, cultivation practices and so on, which lead to the desired attributes in the product on the consumer table. If the reduction of flatulence is taken as an example of a desirable goal, the approach would be to identify and characterize the particular carbohydrate(s) responsible for flatus, to develop rapid methods for determining the carbohydrate(s), and then to use these methods to select or breed cultivars with the lowest possible content of the undesirable carbohydrate. Alternatively or simultaneously, it should be possible to develop cultivation, storage, cooking or processing methods which reduce the content or impact of the flatus-generating carbohydrate. The wide variability in carbohydrate composition of sweet potatoes noted earlier will be a positive factor at this stage, providing a greater range of possibilities for eventually producing sweet potatoes with the desired carbohydrate compostion and hence the desired traits.

Additional studies on sweet potato carbohydrates are recommended, as an avenue to ultimately increasing the acceptability and use of this valuable crop, especially in developing areas.

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General Discussion

(Session II)

ANONYMOUS: In general, plant roots accumulate metals absorbed from the soil in quantities several times as high as in the shoot. For instance, if cadmium content in the soil is 1 ppm, how much would be the concentration in the root of sweet potato?

WILSON: I do not know of any studies on cadmium accumulation in sweet potato roots.

ANONYMOUS: What is the best indicator to determine maturity in sweet potato?

WILSON: In the Caribbean, senescense of the foliage is used as an indicator of the time to harvest. Sweet potato maturity is difficult to determine precisely by objective observation.

WINARNO: Is the sweet potato root developmental pattern unique as compared to other tubers such as cassava and carrot?

WILSON: Yes, the sweet potato tuber is unique in terms of its cellular development such as activity of primary, secondary and tertiary meristimatic strips or association with xylem tissue. This pattern is not precisely duplicated in any other root crops.

VON UEXKULL: To what extent is tuber root formation influenced by the nutrient and carbohydrate content of the cutting and to what degree is tuber root formation influenced by external factors (nutrients and other substances) during early stages of root formation? I have seen farmers in Bali planting cuttings into the leaf axils of dead leaves of oil palm for rooting, and then transplanting the rooted cuttings into the field. Farmers claim to get a much larger number of roots this way.

WILSON: The encouragement of rooting by the organic medium in the axils of oil palms probably leads to increased tuber number and growth. However, I cannot guess what specific substance is involved. Nitrate nitrogen is known to promote tuber bulking in sweet potato.

RASHID: Substantial differences in root shape are often observed in sweet potato. To what extent do the plant's internal and environmental factors influence root shape? Will the roots be of identical shape in similar environments?

WILSON: Tuber shape is under genetic control since varieties with typical shapes - such as globular, fusiform and so on - can be recognized. However, environmental conditions do influence shape. For example, waterlogged conditions can lead to fusiform tubers.

TSAY: Are there any plant hormones which can promote tuber initiation and tuber growth of sweet potato except IAA?

WILSON: A number of hormones are more than likely involved in tuber metabolism and growth. My paper dealt with a hypothesis which explains the function of IAA and IAA oxidase in sweet potato.

ANONYMOUS: Inasmuch as your photomicrographs as well as the work of many others show conclusively that the storage organ of the sweet potato is a root, do you agree that it would be much less confusing to a general audience to refer to these storage organs as storage roots or fleshy roots rather than to use the incorrect term tuber?

WILSON: The sweet potato tuber is developed from a specialized root which has many analogies with the potato stolon, such as positive geotropism, anatomical differences from a normal root, the initiation of a storage organ, the capacity for producing buds. If a tuber is defined as a storage organ developed on an organ specialized to initiate it, then the sweet potato storage organ is a root tuber as opposed to the stem tuber of *Solanum* potato. Also the growth of the storage organ is very different from that of a normal root. The growth of the storage root of cassava on the contrary is very similar to that of a normal root except that the storage parenchyma is produced in each of the xylem.

WARRIT: From our discussion this morning, what prospects do we have in terms of plant improvement?

WILSON: The objective of physiological investigations of the determinants and and components of yield is to develop screening tools for selecting elite varieties of sweet potato.

URITANI: According to your picture, ^{14}C does not seem to be incorporated into carbohydrates in the cortex. If so, would you please explain that?

KAYS: ^{14}C is deposited around the vascular cambium; however, with subsequent cellular division new cells adjacent to the cambium are not labelled. Figures 3 (45 days) and 4 (75 days) illustrate this. With plants labelled on day 105 and harvested on day 106 (Figure 5), the ^{14}C is primarily in the vascular cambium region.

ANONYMOUS: In sweet potato, the natural genetic diversity has not been fully exploited. In the light of this, what is the advantage of a genetic engineering approach over conventional plant breeding?

KAYS: Answering this question from a physiologist's point of view, our attempt is to understand the basic plant processes which are limiting yield under normal conditions. This will allow for a more pragmatic program of selection for high yield.

ANONYMOUS: If you use CO_2 from the air how do you calibrate it? How do you measure net assimilation rate?

AGATA: All sampled CO_2 gases were analyzed with infra-red CO_2 gas analyzer. A factor of 0.61 was used to convert CO_2 to dry matter. Net assimilation rate was calculated by Watson's method.

ANONYMOUS: What is the maximum yield potential of sweet potato? Some speakers reported 60 t/ha and 70 t/ha or more. I'd like to know the theoretical maximum yield weight of sweet potato.

AGATA: I obtained maximum yield of about 60 t/ha (fresh weight) in five months. The yield of sweet potatoes is decided by the length of growing period. Based on my experiment I calculated that 120 t/ha can be obtained in eight months and 80 t/ha in six months at Naha, Okinawa, Japan.

URITANI: Would you please show me the effect of water stress on dry matter and yield productivity? Do you have some data on the difference in temperature between day and night, in relation to productivity?

AGATA: I think soil moisture is one of the most important factors for production of sweet potato. I cannot answer your question accurately since I have not studied the effect of water stress on dry matter and yield productivity. However, irrigation was used frequently from August to September to minimize moisture stress in my experiments.

SAJJAPONGSE: When is the best time to plant sweet potatoes in the tropics?

AGATA: I have no experience in the tropics, so I cannot answer your question. However, the best time to plant sweet potato in the temperate region is during the month when air temperature is above 20°C. In my experiment it is in the spring season.

OKA: An increase in CO_2 would increase photosynthesis. However, it is usually accompanied by air pollution with HSO_3, NO_4, etc. How is the sensitivity of sweet potato plants to pollution as compared with other plants?

HOZYO: We don't have specific data concerning the sensitivity of sweet potato to air pollution. From the data of CO_2 effect on photosynthetic activity, however, it is suggested that the sensitivity of sweet potato to air pollution is intermediate compared with other crop plants.

ANONYMOUS: Could you explain the difference of Dr Hozyo's finding of decreasing photosynthesis with ageing and Dr Agata's findings of high NAR (net photosynthesis) at the later stage of plant growth.

HOZYO: My data were obtained from the measurement of photosynthesis from one single intact leaf whereas Dr Agata's data were obtained from dry matter production under experimental field conditions. NAR value does not indicate the CO_2 uptake rate. NAR value means the dry matter production efficiency and also dry matter production is a complicated production process.

URITANI: Would you please explain the effect of temperature and water stress (water content in soil) on photosynthetic activity, in your experiments?

HOZYO: Carbon dioxide uptake rates were found to be almost of the same value at 25-32°C, so the effect of temperature to photosynthetic activity is not severe at temperatures between 20 and 32°C. We don't have data on water stress, but etiolation occurred under soil moisture deficient conditions which suggested that water stress can influence photosynthesis.

LEE: Why was starch content so low after cooking or baking?

CHEN: Conversion of starch into sugars takes place during baking, cooking and storage of sweet potato. This explains the lowered starch content and increased sugar content. The conversion is due to enzymatic hydrolysis. For example, Walter *et al* reported that 42-95% of starch was converted during baking.

VILLORENTE: Kindly explain further why sugar content increased during curing or storage.

CHEN: There are two major sources of commercial β-amylase, sweet potato and barley, which indicates that sweet potato has a high amount of β-amylase. α-amylase also exists in sweet potato. These two amylases contribute to the conversion of starch into sugars.

WINARNO: Is the increase of sugar content due to hydrolysis of other carbohydrates, or due to synthesis from another source?

CHEN: I think this has also been answered in the last question, but I would like to give some more information. According to the report of Walter *et al*, the α-amylase activities of some sweet potato varieties increased from 0.6-2.5 units at harvest to 10-62 units after storage for 71 days, but β-amylase activities remained constant. Furthermore, the taste panel scores correlated significantly with α-amylase activities, but not with β-amylase activities. Therefore, α-amylase activity could be the major contributor to the starch conversion. It should also be noticed that the typical 'dry' varieties of sweet potato had much lower α-amylase activities and percentage of starch converted.

URITANI: When starch is decomposed to maltose during heating, do you think the sweetness decreases the acceptability of sweet potato?

CHEN: As the sugar content increases, the sweetness also increases. This might be a reason for low acceptability of sweet potato, at least when used as the main supplementary food.

SESSION III

A Search for Sources of Resistance to Sweet Potato Weevil

N. S. TALEKAR

Asian Vegetable Research and Development Center, Shanhua, Tainan 741, Taiwan

INTRODUCTION

Among over 40 species of insect pests that infest sweet potato in various parts of the world, the sweet potato weevil, *Cylas formicarius* (F) and a closely related species, *C. puncticollis*, are the most destructive in tropical and subtropical regions. *C. puncticollis* is confined to a dozen or so countries in Africa. Sweet potato weevil, however, is more cosmopolitan, being distributed from West to East Africa, in south Africa, Madagascar, Mauritius, the Seychelles, India, Bangladesh, Sri Lanka, southeast Asia, China, Papua New Guinea, eastern Australia, the Solomon Islands, Hawaii, Samoa, Fiji, the Caroline, Gilbert and Mariana Islands, the southern United States, the Caribbean Islands, Mexico, Guyana, and Venezuela (Hill 1975).

The insect attacks sweet potato roots in the field and in storage. In the field, the adult female lays eggs in the stem or developing roots if they are exposed or accessible. Legless white grubs, which are responsible for most of the damage, tunnel through stems and roots. The tortuous feeding tunnels are filled with excrement, and are characterized by terpene odor noticeable even in slightly damaged roots and making them unfit for human consumption.

The weevil is difficult to control even with insecticides because of the nature of its feeding habit. Cultural control is not uniformly effective and often impractical due to varying cropping practices throughout the world. Use of weevil resistant sweet potato cultivars appears to be more practical and the most economical method for control.

Several attempts have been made during the past forty years to find resistance to this pest and to introduce it into commercial cultivars. One of the earliest studies was initiated in 1939 by Cockerham and Deen (1947) of the United States Department of Agriculture, Bureau of Entomology and Plant Quarantine at Baton Rouge, Louisana. Several cultivars each year were screened from 1939 to 1946. The researchers observed wide variation in infestation levels from year to year and reported that for one line, No.32-10-5, it was 'the first time that any seedling or variety had shown consistent resistance to weevils for two successive years in the presence of sufficient infestation to show significance'. The apparent inconsistency in resistance among cultivars from season to season or location to location which was observed by the authors has constantly frustrated the efforts of workers. Cockerham and Deen (1947) reported, among other characteristics, that the cultivars with long roots from which fleshy roots grow widely separated in the hill were desirable for preventing weevil attack. In further tests during 1949-1950, No. 32-10-5 (renamed L 187) had consistently lower infestations compared with check entries L 225, Porto Rico or Oklahoma (Cockerham and Harrison 1952). Despite these early successes in Louisiana, by 1969 resistant cultivars were still not available (Anon 1970).

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In a non-replicated, small plot field test of ten cultivars, Jayaramaiah (1975) failed to find any significant difference between them in terms of resistance although local cultivars appeared to be less affected than the imported cultivar, Centennial. He noticed that local cultivars possessed thin, hard crowns, stems and tuberous roots. Cockerham and Deen (1947) observed the same character in the resistant cultivar. Jayaramaiah (1975) also found that the local cultivars have long stalks and that the tuberous roots are located deep beneath the soil and are widely spaced. They are therefore not easily accessible to weevil feeding and breeding. Edmond (1971) also mentions that roots developed 10-15 cm below the soil surface are relatively free of weevils.

A concerted effort to breed sweet potato resistant to *C. puncticollis* has been made since 1971 at the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria. Their early resistance screening results indicated that lines TIS 2534, TIS 2328, TIS 2529 and TIS 1499 have field resistance to weevil for one year, but were susceptible the following year (Anon 1975b). In 1976 (Anon 1976) IITA reported 12 new lines least damaged by weevil in the laboratory as well as field screening tests. However, a later report indicated that there are 'yet no major sources of tuber resistance' (Anon 1977). Based on yield trials in 15 environments between 1976 and 1978, TIS 3053, TIS 2328, TIS 2544, TIS 3030, TIS 2532, TIS 2153, TIS 2534 and TIS 3017 were reported to have shown consistent resistance to weevil (Anon 1978). Heritability of resistance was reported to be 82.8 in mid-dry seasons which encounter high weevil population pressure, 39.3 in early dry seasons which encounter low weevil population pressure and 40.3 in rainy seasons (Anon 1978). Further field study at IITA showed that resistant lines TIS 3030, TIS 3017 and TIS 2532 with roots at medium depth (2-4 cm) were less damaged than susceptible Tib 4 with shallow roots (0-2 cm). This confirms observations of Cockerham and Deen (1947) and Jayaramaiah (1975) who reported that deeper-rooted lines are less damaged. IITA's laboratory study indicates antibiosis as the possible resistance mechanism. However, until 1979, no cultivar resistant to the weevil has been developed using previously identified sources of resistance (Anon 1979).

In three field screening tests between 1975 to 1977, Waddill and Conover (1978) tested five cultivars and 34 selections of white-fleshed sweet potato and one orange-fleshed breeding line for resistance to sweet potato weevil. Although they found significant differences in susceptibility, there were inconsistencies in weevil infestations of certain selections between tests. For example selection 32, the least damaged in the second tests, was considerably infested in the first. None of the promising selections from the first two tests, unfortunately, were included in a third to assess their consistency.

Rolston [illegible] (1979) reported an appreciable resistance in some lines during a four-year study of resistance to sweet potato weevil at Louisiana State University, Baton Rouge. Certain lines were consistently resistant when evaluated for two or more years. Line L 3-64, for example, had a low infestation compared to the susceptible lines and was used as a resistant check in later studies. Some of these resistant lines, however, proved to be susceptible in our tests at AVRDC.

Mullen [illegible] (1980a) found five of 79 lines to be resistant at two locations, Savannah, Georgia, and Yoakum, Texas.

Screening sweet potato germplasm for resistance to sweet potato weevil was initiated at the Asian Vegetable Research and Development Center in 1974. Our basic approach was to identify the source of resistance by screening the available germplasm under relatively higher uniform weevil population pressure maintained in the field, and then to incorporate the resistance immediately into high-yielding agronomic cultivars.

METHODOLOGY

Field testing procedure

Routine screening work was carried out at two locations in Taiwan; one at AVRDC's experimental field at Shanhua, in southwestern Taiwan, and the other at a government agricultural research station on Penghu Island in the Taiwan Strait. While the climate in southern Taiwan is typical of humid tropical lowland, Penghu Island represents a semi-arid tropical climate. Screening germplasm at these two locations permits assessment of weevil resistant material under a wider range of environmental conditions. At AVRDC source rows 1 m wide and spaced 2 m apart are planted two to three months prior to screening test material (Figure 1A). These are infested thoroughly two months after planting with weevils from colonies maintained on stored sweet potato roots in the laboratory. Rototilling is carried out between rows at planting and the area is prepared into two 1 m wide beds. Test materials are planted on the top of these beds (Figure 1B). By this method every test entry is located adjacent to a heavily-infested source row. This assures uniform infestation.

Our usual plot size is 5 m long single row beds. The number of replicates depends on the number of lines to be tested and the area available for such tests. Preliminary screening is usually confined to one replicate and advanced tests to two or three. Suggested cultural practices developed for sweet potato at AVRDC are followed, except the use of insecticides. Root yields are recorded at harvest (Figure 1C). All harvested roots per plot up to a maximum root weight of 5 kg are collected for evaluation of weevil infestations. Also collected for evaluation were five 50 cm stems at random from the plot. Each length consisted of about 25 cm of above ground stem and 25 cm of underground stem. The experimental area is then rototilled (Figure 1D), worked into 1 m wide beds and the procedure is repeated (Figure 1E).

Weevil source rows are not maintained at Penghu Island due to extremely dry winter months and limited rainfall from May to September. We plant test materials on 5 m x 1 m beds and release weevils as uniformly as possible eight to ten weeks after planting. Other experimental procedures are similar to those reported above. Screening at Penghu Island is done between April and September.

Resistance evaluation

For various reasons different investigators use different procedures for evaluation of resistance. In some cases (Anon 1975b, 1976, 1977, 1978) procedural details provided are not sufficient for critical evaluation to be made. Cockerham and Deen (1947) and Cockerham and Harrison (1952) used external visual observation of infested crowns and roots, for evaluation of

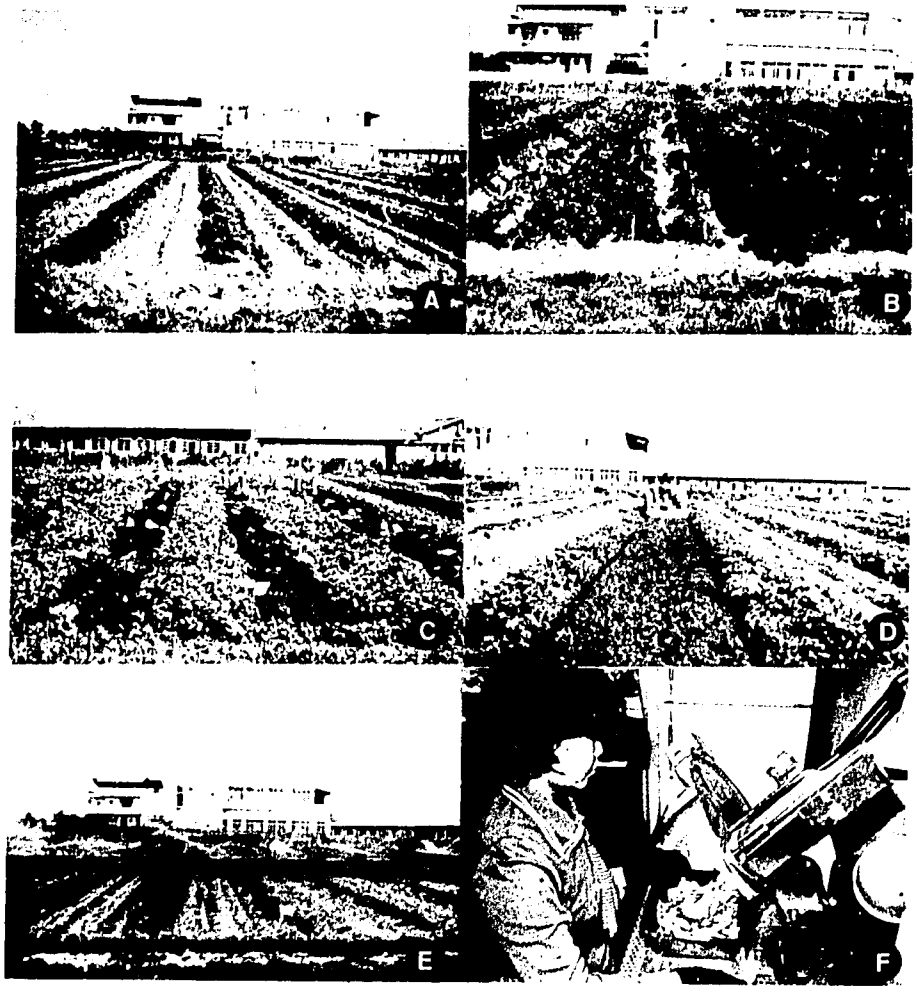

Figure 1. Sweet potato weevil resistance screening procedure. (A) Sweet potato weevil source rows are planted two to three months before field is readied for planting resistance screening materials. (B) Growth of resistance screening materials planted between two source rows about two months later. After harvest of resistance screening materials (C) the testing area between the source rows is rototilled (D) and later planted under new set of resistance screening materials (E). (F) Sweet potato roots are sliced into 2.5 mm thick slices for observing sweet potato weevil and extent of damage

resistance. Jayaramaiah (1975) used percentage damaged roots and vines as the criteria for resistance. At IITA evaluation procedures appear to vary considerably. A damage rating system on a scale of 0 to 5 was adapted in 1975 (Anon 1975b) and supplemented with a weevil damage to stem score and percentage of infested tubers (Anon 1976) or by leaf area consumption by the adult weevil (Anon 1977, 1978). Waddill and Conover (1978) based their resistance rating on the number of weevils emerging from 1.4 kg root samples stored at room temperature (22-26°C) for 30 days.

Rolston *et al* (1979) made their resistance rating by assigning roots to

one of five categories according to the number of punctures: 0, 1-5, 6-10, 11-15 and 16 or more. The number of roots in each category was multiplied by a weighting factor of 1 to 5 and the sum of these products was divided by the number of roots in the sample. The result was an index, with a potential range from 1.00 (no damage) to 5.00 (most damage), which was adaptable to statistical analysis. Mullen *et al* (1980) used crown infestation and hill infestation criteria in judging resistance levels. Crown infestation was measured by the percentage of crown infested and by the severity of the infestation (crown index 1-5 scale). Rating was done by four persons to minimize individual differences. Hill infestation was determined by the number of hills with infested roots and by the number of weevils emerging from roots (22°-26°C for 30 days) returned to the laboratory. Mullen *et al* (1980b) also developed a laboratory screening method consisting of exposing weevils to 1.7 cm diameter plugs corked out of sweet potato roots in the laboratory and recording the feeding punctures. Although the method appears to be simple and less laborious, its utility in extending laboratory results to field conditions is doubtful. After several months of trials we abandoned a similar technique in 1975-76 since we were unable to correlate our laboratory results with field results. This is most probably due to the fact that like other constituents such as carotene (Anon 1975a; Ezell and Wilcox 1958) and proteins (Anon 1975a), resistance factors in the roots may vary from root to root within a single plant or even in different regions of an individual root. Such variations, and they are common in sweet potato, are likely to vitiate any benefit derived from laboratory testing methods.

For resistance evaluation at AVRDC we slice sample roots into 2.5 mm slices using a HDJ-2 Deluxe Ham Slicer (Tokyo Nantsune Shoji Co), (Figure 1F). The number of insects (grubs+pupae+adults) in each sliced root sample is recorded. Insect-damaged slices are separated and weighed to determine the root damage. Relative resistance to weevil is measured as a standard deviation of the mean infestation of all entries in a screening and in terms of the number of weevils per kg roots and the percentage of weevil-damaged roots. In this way entries are classified into various resistance categories (Table 1). Entries that fall into MR or HR categories by all three criteria are tested the following season for confirmation of resistance.

Each screening test includes two standard susceptible cultivars, usually PI 344129 and Tainung 57, and two cultivars which have appeared resistant in earlier tests, usually B 6712 and Red Tuber Tail.

RESULTS AND DISCUSSION

By the end of 1980 we had screened our entire germplasm collection of sweet potato (400 accessions) and several hundred entries of breeding materials derived from the crosses made by our plant breeders. Initially we concentrated our efforts on germplasm. Once accessions showed resistance for two seasons they were incorporated into our breeding program. Germplasm as well as breeding materials was screened for other sources of resistance from crosses in order to study the inheritance of resistance. We have screened all our germplasm at least once and several of our promising accessions as many as eight times at two locations. Like most other workers who have ventured into screening for sweet potato weevil resistance, we encountered tremendous variation in resistance rating from place to place and from season to season. Wide variations between two plots of the same accession are not uncommon. Results of selected accessions indicating promising re-

Table 1. Sweet potato weevil relative resistance ranking methods[a]

1. Based on weevil numbers

I (HR): Highly Resistant = $< (\bar{X})_{wn} - (1sd)_{wn}$

II (MR): Mod. Resistant = $(\bar{X})_{wn} - (1sd)_{wn}$ to $(\bar{X})_{wn}$

III (S): Susceptible = $(\bar{X})_{wn}$ to $(\bar{X})_{wn} + (2sd)_{wn}$

IV (HS): Highly Susceptible = $> (\bar{X})_{wn} + (2sd)_{wn}$

2. Based on % damaged roots

I (HR): Highly Resistant = $< (\bar{X})_{\%d} - (1sd)_{\%d}$

II (MR): Mod. Resistant = $(\bar{X})_{\%d} - (1sd)_{\%d}$ to $(\bar{X})_{\%d}$

III (S): Susceptible = $(\bar{X})_{\%d}$ to $(\bar{X})_{\%d} + (2sd)_{\%d}$

IV (HS): Highly Susceptible = $> (\bar{X})_{\%d} + (2sd)_{\%d}$

3. Based on weevil number + % damaged roots

I (HR): Highly Resistant

$$< ((\bar{X})_{wn} - (1sd)_{wn}) + ((\bar{X})_{\%d} - (1sd)_{\%d})$$

II (MR): Moderately Resistant

$$((\bar{X})_{wn} - (1sd)_{wn}) + ((\bar{X})_{\%d} - (1sd)_{\%d}) \text{ to } ((\bar{X})_{wn} + (\bar{X})_{\%d})$$

III (S): Susceptible

$$((\bar{X})_{wn} + (\bar{X})_{\%d}) \text{ to } ((\bar{X})_{wn} + (2sd)_{wn}) + ((\bar{X})_{\%d} + (2sd)_{\%d})$$

IV (HS): Highly Susceptible

$$> ((\bar{X})_{wn} + (2sd)_{wn}) + ((\bar{X})_{\%d} + (2sd)_{\%d})$$

[a]wn = No. weevils/kg roots, %d = Percent damaged roots, $\bar{X}$ = Mean, sd = standard deviation.

sistance levels are shown in Table 2. In all but two cases, B 6712 and Red Tuber Tail, we discontinued screening once an accession appeared susceptible. We continue to use these two in further tests as well as in our breeding program because they have shown the most consistent resistance during the last five years. Individually they are crossed with a parent carrying desirable agronomic characters (such as high yield and early maturity) and the performance of such a single cross progeny is evaluated. In order to increase the level of resistance, either such a single cross is backcrossed to a weevil resistant accession, or two single crosses, each carrying weevil resistance, are intercrossed. Breeding materials from such crosses are being tested in the field.

Table 2. Summary of resistance reaction of selected sweet potato accessions to sweet potato weevil

AVRDC Acc. No.	Cultivar identification	Resistance screening tests											
		I			II			III			IV		
		place[a] and date	weevils /kg roots	resist-ance rating[b]	place[a] and date	weevils /kg roots	resist-ance rating[b]	place[a] and date	weevils /kg roots	resist-ance rating[b]	place[a] and date	weevils /kg roots	resist-ance rating[b]
I81	PI 286619	AV75/1	6.35	MR	AV75/6	10.8	MR	AV76/10	2.3	MR	PH77/5	169	S
I82	PI 286621	AV75/1	0	HR	AV75/6	1.4	HR	PE76/9	3.5	MR	PH77/5	0	HR
I93	PI 315342	AV75/1	0	HR	AV75/6	5.5	MR	PE76/9	4.7	MR	PH77/5	81.3	MR
I97	PI 315350	AV75/1	13.90	MR	AV75/6	0.6	HR	PE76/9	12.0	MR	PH77/5	160	S
I104	PI 318856	AV75/6	1.7	HR	PE76/9	2.3	MR	PH77/5	66.5	MR	PE77/10	6.54	MR
I123	B 6712	AV75/1	8.15	MR	AV75/6	0	HR	PE76/9	2.5	MR	PE77/10	24.98	MR
I152	Red Tuber Tail	AV75/1	22.49	MR	AV75/6	4.6	HR	PE76/9	10.3	MR	PE77/10	21.57	MR
		V			VI			VII			VIII		
I82	PI 286621	PE78/11	281	S									
I93	PI 315342	PE78/11	306	S									
I97	PI 315350	PE77/10	0	MR									
I104	PI 318856	AV78/11	8	MR	PE78/11	293	S						
I123	B 6712	AV80/5	28	S	AV81/2	0	MR						
I152	Red Tuber Tail	AV78/11	2	HR	AV79/5	13.1	MR	AV80/5	37.6	S	AV81/2	0	MR

[a]AV:AVRDC, PE: Penghu Island, PH: Los Baños, Philippines. Dates shown are year and month of harvest
[b]HR: highly resistant, MR: moderately resistant, S: susceptible

Wide variation in sweet potato is not confined to weevil resistance but extends to many other characteristics. Ezell and Wilcox (1958) recorded as much as 45% variation in total carotenoids and 145% in carotene content within one variety planted over approximately 0.07 ha area and sampled in ten replicates of five roots each. A twofold variation in carotene occurred in the same field from one season to the next. Individual roots from the same plant varied by as much as 47% in carotene content in variety Orange Little Stem, and by 82% in Yellow Jersey. Similar variations were also observed for carotene and protein content of sweet potato at AVRDC (Anon 1975a) and yield performance of six cultivars at eight locations for a three-year period in Korea (Jong and Park 1975).

In an effort to understand the extent and nature of variation in weevil infestation, we performed a uniformity trial during spring 1980. A one-hectare field was planted to cultivar AIS 35-2 and two months later sweet potato weevils were released as uniformly as possible. Three months later, at harvest, roots from a 20 x 20 m area were harvested in 400 lots of 1 sq m each. Roots in each lot were sliced in 2.5 mm slices and the number of weevils and weevil damaged roots were recorded. The coefficient of variation (CV) at each plot size is shown in Figure 2. The CV ranged from 170% for 1 sq m to a minimum of 65% for 20 sq m plots, when weevil number was used as the criterion, and from 132% to 55% respectively when damaged roots was the criterion used. Such variation occurred despite our best efforts in spreading weevils uniformly over the field. A similar or even larger variation can be expected when the resistance rating is based on natural weevil infestation.

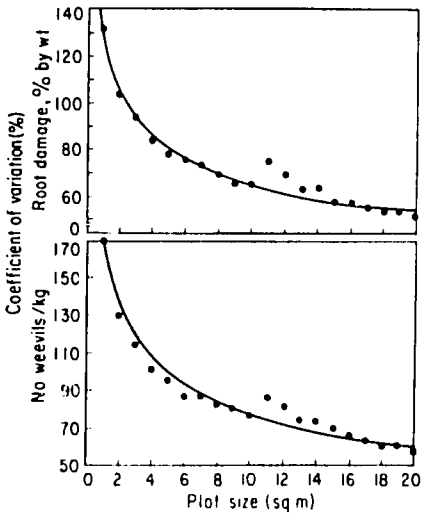

Figure 2. Plots of coefficient of variation (CV) for percent damaged roots and number of sweet potato weevils per kg roots at various plot sizes

It is beyond the scope of this paper to explain the nature of this variation or the influence of environmental factors. Variations between plants and between varieties undoubtedly has been responsible for the failure to develop weevil resistant cultivars since Cockerham and Deen first reported potential sources of resistance almost 40 years ago.

CONCLUSIONS

Host plant-insect pest interaction is based on physiological and environmental factors and on the interaction of both. In sweet potato and sweet potato weevil interaction, environmental factors play a very important role in the expression of resistance. Resistance work should therefore be

carried out over a wide range of environmental conditions. Under given experimental conditions, determination of optimum plot size and the number of replicates should receive prime consideration. Resistance performance based on smaller plots, inadequate number of replicates, and repeated over a limited number of seasons does not provide sufficiently reliable information, especially if such information is to be used for breeding weevil resistant cultivars. Wide variations in a large number of sweet potato characters already documented in the literature, and the failure to breed a commercial cultivar utilizing parents with known sources of resistance to either species of weevil despite years of research, indicate the possibility that an adequate source of resistance to the weevils may not exist in sweet potato germplasm.

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Control of the Sweet Potato Weevil, *Cylas formicarius elegantulus*, by Foliar Application of Insecticides

V. H. WADDILL

University of Florida, IFAS, Agricultural Research and Education Center, Homestead, Florida, USA

INTRODUCTION

The sweet potato weevil, *Cylas formicarius elegantulus* (Summers), was first found in the United States near New Orleans, Louisiana, in 1878 and has since spread throughout the southern states. It is the most serious insect pest of sweet potato in Florida and the coastal areas of Texas, Louisiana, Mississippi, Alabama, and Georgia. The insect produces from six to eight generations a year in southern Louisiana (Cockerham *et al* 1954) and is active all year round in southern Florida (Waddill and Conover 1978).

Wolfenbarger and Walker (1974) stated that granular formulations of insecticides commonly used for control of soil-inhabiting insects were ineffective against *C. formicarius elegantulus*. However, foliar applications of insecticides every three to four weeks substantially reduced numbers of the pest (Pillai and Magoon 1969; Wolfenbarger and Walker 1974; Kung *et al* 1976).

Considering the seriousness of the pest and the lack of economically effective control measures, studies were initiated to determine the efficacy of insecticides against *C. formicarius elegantulus*. This paper presents data from those studies.

MATERIALS AND METHODS

Stem dip test

Fifteen cm stem cuttings of the sweet potato cultivar Nancy Hall were dipped in insecticide solutions on 19 June 1975 and allowed to dry. The cuttings were then placed in cylindrical screen cages (height = 17 cm, diameter = 8.5 cm) and maintained with the lower 2.5 cm of the cutting in a small jar of water. These cages were kept in a greenhouse where each treatment was replicated five times in a completely random design. Ten field-collected *C. formicarius elegantulus* were introduced into each cage at the following post-drying times: 1, 7, 14, 21, 28, and 35 days. The numbers of dead insects were recorded four days after introduction.

Field studies

The *C. formicarius elegantulus* susceptible cultivar Engordo was used in two field trials. Vine cuttings were planted 30.5 cm apart within rows in Rockdale soil. Test 1 was planted 26 August 1975 and plots consisted of single rows on 2.4 m centers and were 7.6 m long. Test 2 was planted 23 June 1978 and plots were single rows on 1.8 m centers and were 9.1 m long. A randomized complete block design with four replications was utilized in both tests. Treatments were applied every three weeks with a tractor-mounted

sprayer having five nozzles per row which delivered 935 liters finished spray /ha. Totals of nine and six applications were made to Tests 1 and 2, respectively.

Test 1 was harvested 26 March 1976 and a sample of 2.7 kg of roots collected per plot. Test 2 was harvested 9 November 1978 and a sample of 3.6 kg of roots taken per plot. The root samples were held at 24°C in paper bags for 30 days, at the end of which the number of adult [illegible] that emerged was counted.

Data were analyzed by analysis of variance and means separated by Duncan's multiple range test ($P < 0.05$).

RESULTS AND DISCUSSION

Stem dip test

All insecticides tested were equally effective against adult [illegible] for the first 14 days (Table 1). However, differences became apparent 21 days after application. Phosmet 1S, methyl parathion 2F, permethrin 25WP, and endosulfan 50WP still induced high mortality (Table 1). Phosmet 1S and permethrin 25WP had the longest residual effectiveness.

Phosmet 1S and methyl parathion 2F are flowable formulations with polymeric microcapsules containing the insecticides. Phosmet 1S caused 100 mortality and phosmet 1E 66 mortality at day 28 (Table 1), indicating that under greenhouse conditions microencapsulation extended the residual effectiveness of the compound.

Table 1. Toxicity of stem cuttings dipped in insecticides to adult [illegible]

Treatment[a]	kg ai[b]	Mortality after 3 days[c] Days post-application that insects were placed on plants					
		1	7	14	21	28	35
Phosmet 1S	0.45	100 a	100 a	100 a	100 a	100 a	100 a
Methyl parathion 2F	0.45	100 a	100 a	100 a	92 ab	-	-
Parathion 8E + Chlordane 8E	0.45 + 0.45	100 a	100 a	92 a	54 b	-	-
Permethrin 25WP	0.09	100 a	90 a	92 a	98 a	76 b	51 b
Parathion 8E	0.45	100 a	100 a	90 a	27 c	-	-
Endosulfan 50WP	0.45	100 a	98 a	89 a	96 a	40 c	
Phosmet 1E	0.45	100 a	100 a	87 a	66 b	-	-
Untreated check	-	22 b	10 b	21 b	14 c	2 d	0 c

[a]Formulations expressed as lbs ai/100 gal
[b]kg ai per 378.5 liters water
[c]Treatment means in columns followed by a common letter are not significantly different ($P>0.05$)
[d]Cuttings destroyed by weevil feeding. The untreated check had fresh cuttings every week

Field studies

All data from the field trials are presented in Table 2. Although there were no significant differences among the insecticides applied to the foliage in Test 1, only treatment with permethrin 25WP and endosulfan 50WP resulted in roots completely free of [illegible]. However, this test was conducted from September - March when the insect population is lower than during the summer months.

Test 2 was conducted during the summer and fall and some adults emerged from all the treatments. Roots from both permethrin and endosulfan plots had significantly fewer adults emerging than did the untreated check.

Table 2. Efficacy of foliar spray applications of insecticides for [illegible] control

Treatment[*]	Kg ai/ha	Number of[**] adults emerging
	Test 1	
Permethrin 25WP	0.22	0.0 a
Endosulfan 50WP	1.12	0.0 a
Phosmet 1E	1.12	0.8 a
Parathion 8E + Chlordane 8E	1.12 + 1.12	1.0 a
Phosmet 1S	1.12	1.5 a
Methyl parathion 2F	1.12	6.8 a
Untreated check	-	16.0 b
	Test 2	
Permethrin 2EC	0.11	1.1 a
Endosulfan 3EC	1.12	2.1 a
Endosulfan 3EC	1.68	4.3 a
Endosulfan 3EC	0.56	5.8 a
Untreated check	-	43.9 b

[*]Formulations expressed as lbs ai/US gal
[**]Numbers of adults emerging from 2.7 and 3.6 kg of roots from Tests 1 and 2, respectively
[***]Treatment means followed by a common letter are not significantly different (P[illegible] 0.05)

CONCLUSION

Data from these two field trials indicate that foliar applications of insecticides do reduce the [illegible] population. Foliar applications of insecticides when used in conjunction with cultural techniques and resistant cultivars should aid in producing marketable sweet potatoes.

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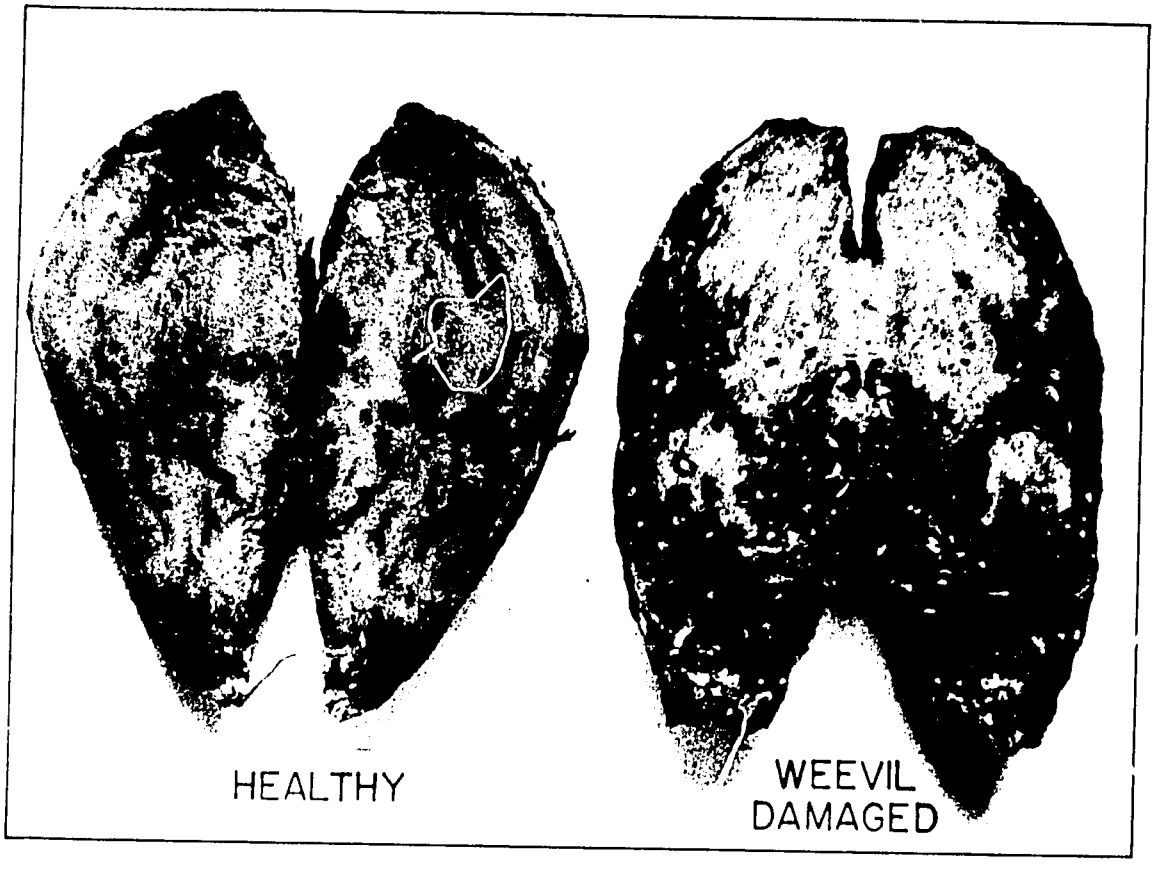

Weevils - the most destructive sweet potato pest in the tropics.

Sweet Potato (*Ipomoea batatas*) Virus Diseases and Their Control

E. R. TERRY

International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

INTRODUCTION

Data on crop losses due to sweet potato (*Ipomoea batatas* L) virus diseases are generally limited. Hildebrand and Cook (1959) reported that the four sweet potato virus diseases which had been recognized accounted for more than half of the total estimated losses of 20% from all causes to the sweet potato crop in the USA. Losses of up to 50 of the crop were attributed to virus diseases in South Africa (Anon 1978). Hahn (1979) reported that yield of fresh roots was reduced by 78 in plants showing sweet potato virus disease symptoms in Nigeria, and Mukiibi (1977) reported that a sweet potato virus disease caused a reduction of 57 in yield both in terms of weight and number of roots in Uganda.

The crop loss figures quoted above indicate that sweet potato virus diseases can constitute a serious constraint to crop production. This article reviews the global distribution of sweet potato virus diseases and the state of our knowledge of these diseases. It also presents some control strategies for minimizing crop losses due to sweet potato virus diseases.

GLOBAL DISTRIBUTION OF SWEET POTATO VIRUS DISEASES

The global distribution of sweet potato virus diseases is presented in Table 1. Since these diseases of sweet potato have been characterized largely through symptomatology, transmissibility and vector relationships, attempts to group them on the basis of their relationships to other sweet potato virus diseases in other parts of the world have been difficult (Terry 1976). Thus we find for example that a virus disease described as sweet potato mild mottle in East Africa (Hollings [illegible] 1976), transmitted by grafting, sap inoculation and a whitefly vector ([illegible]) is caused by a virus whose particles are straight and filamentous and measure 800-950 nm; and, a virus disease described as yellow dwarf in the United States of America (Steinbauer and Kushman 1971), transmitted by whitefly vectors ([illegible] and [illegible]), is caused by a virus whose morphology has not been described.

THE STATE OF KNOWLEDGE OF SWEET POTATO VIRUS DISEASES

Symptomatology and disease development

The names applied to sweet potato virus diseases reflect the symptoms produced in roots (internal cork and russet crack) or on foliage (feathery mottle, mosaic, vein clearing and banding, and chlorotic spotting), or they define changes in plant morphology: littleleaf and witch's broom (Nielsen and Terry 1977).

Table 1. Sweet potato virus diseases

Symptoms	Transmission	Virus particles	Host	Area where the work was carried out	Author
Russet crack - transverse dark lesions with cracking may encircle root. Discolouration due to secondary fungal infection. Grey spots/streaks may occur on vines or petioles	*Myzus persicae*		*I. batatas*	USA	Steinbauer and Kushman (1971)
Sweet potato russet crack		Pinwheel inclusions, bundle inclusions, filamentous particles	*I. batatas* *I. setosa*	USA	Lawson, Hearon and Smith (1971)
Russet crack also feathery mottle	Graft transmission *M. persicae*	flexuous rod-shaped particle 800nm. Member of the potyvirus group (russet crack is regarded as a strain of feathery mottle)	*I. batatas*	USA	Campbell, Hall and Mielinis (1974)
Feathery mottle complex					
i. yellow dwarf	Whitefly *Trialeurodes abutiloneus*		*I. batatas*	USA	Hildebrand (1960)
ii. internal cork	Aphids) *M. persicae*	Not described			
iii. leaf spot	Aphids) *Macrosiphum solanifolii* and others				
Internal cork - yellow spots on younger leaves. Dark brown to black hard, corky spots in roots	Aphids	Not described		USA	Steinbauer and Kushman (1971)
Chlorotic leaf spot - always also occurs when internal cork is present in roots	Not mentioned (but see Hildebrand, 1960)	Not described			
Internal cork		Polyhedral particles 45-47 nm	*I. batatas*		Salama et al (1966)
Vein mosaic - general chlorosis, reduction in size, short internodes, distorted leaves, vein clearing, mosaic	Mechanical sap and *M. persicae*	Flexuous rods 761 x 13 nm	*I. batatas* and other Convolvulaceae	Agentina	Nome (1973)
Variable - mottling and stunting or symptomless sweet potato mild mottle	Grafting, sap inoculation, whitefly *Bemisia tabaci*	Straight filamentous particles 800-950 nm	*I. batatas*	East Africa	Hollings, Stone and Bock (1976)

Yellow dwarf	Whitefly *T. abutilonea* and *B. tabaci*	Not described	*I. batatas*	USA	Steinbauer and Kushman (1971)
Sweet potato vein clearing; sweet potato chlorotic stunt - both separately latent in *I. batatas* cultivars tested in glasshouse conditions, but produce symptoms on *I. setosa*. 2 agents together produce severe symptoms on *I. batatas* (varying with cultivar) and on *I. setosa*	*M. persicae*, *Aphis gossypii*; *B. tabaci*	Filamentous rod 850 nm - non persistent Not detected, probably a virus	*I. batatas* *I. setosa*	Nigeria	Schaefers and Terry (1976)
Virus A - vary with cultivar; chlorotic spots; mosaic may be latent; tends to be mild	*M. persicae*, grafting	Not described	*I. batatas*	East Africa	Sheffield (1957)
Virus B - vary with cultivar - stunting, mottling, distortion; more severe; has different strains	*B. tabaci*, and sap	Not described			
Vein clearing also mosaic, chlorosis and stunting (has different strains)	*B. tabaci*, grafting but not sap	Not described	*I. batatas*	Israel	Loebenstein and Harpaz (1960)
Ring spot, conspicuous ring spots, stunting, chlorosis	*M. persicae*, grafting but not sap	Not described			
Leaf pucker	Not identified	Possibly a virus			

(Source: PANS Manual No. 4 Pest Control in Tropical Root Crops)

It is apparent, however, that even though some of the sweet potato viruses induce distinct and definitive symptoms in roots or foliage, these symptoms are usually but not consistently associated with other minor or transient symptoms in sweet potato plant parts above or below ground. Therefore, these sweet potato virus disease names tend to focus major attention on the definitive symptoms to the mutual exclusion of the other minor but diagnostically equally important symptoms.

Variations in investigation procedures and varying differential reactions to complex infections with two or more sweet potato viruses have led to some confusion with regard to the etiology of sweet potato virus diseases. The dearth of information about viruses infecting sweet potatoes may be attributed largely to the relative instability of the non-persistent viruses (Martin 1970). With few exceptions sweet potato viruses are transmitted manually only with difficulty. (Hildebrand and Smith 1961), and the natural spread of the diseases indicates that vectors are involved, but only a few vector-virus relationships have been studied (Nielson and Terry 1977).

Particle morphology

The disease which is described as russet crack in the United States of America and is sometimes associated with feathery mottle on the foliage has been attributed to a flexous rod-shaped particle measuring 800 nm and a member of the potyvirus group (Campbell [illegible] 1974). On the other hand, the disease described as the feathery mottle complex in the USA (Hildebrand 1960) consists of other associated symptoms viz yellow dwarf, internal cork and leaf spot and has been attributed to a virus whose particle morphology is yet to be described. The virus attributed to internal cork is reported to be polyhedral, measuring 45-47 nm (Salama [illegible] 1966).

Moyer and Kennedy (1978) reported that an isolate of sweet potato feathery mottle recovered from sweet potato plants exhibiting interveinal chlorotic spotting and vein mottling were particles which measured approximately 850 nm in length. On the African continent, Schaefers and Terry (1976) reported evidence of a non-persistent filamentous rod (850 nm) which is latent in sweet potato plants in Nigeria, while Hollings [illegible] (1976) reported straight filamentous particles, 800-950 nm in length, inducing mottling, stunting or symptomlessness in sweet potato in East Africa. Sheffield (1957) had earlier reported that a virus whose particle morphology was not described was known to induce symptoms of mottling, stunting and distortion in sweet potato also in East Africa.

Virus-vector relationships

It has been suggested that feathery mottle is a disease caused by a mixture of the aphid-transmitted leafspot and internal cork viruses and a whitefly-transmitted virus (Hildebrand 1960).

Two whiteflies appear capable of transmitting a virus from the feathery mottle complex. These are [illegible] (Girardeau and Ratcliffe 1960) and [illegible] (Hildebrand 1960). [illegible] also was reported as a vector of a sweet potato virus in Israel (Lobenstein and Harpaz 1960) and in East Africa (Sheffield 1957).

In Nigeria, Schaefers and Terry (1976) separated two infective agents

from a sweet potato virus disease complex. One was a non-persistent virus transmitted efficiently by the aphids *Myzus persicae* and *Aphis gossypii* and less efficiently by *A. craccivora*. This virus was latent in sweet potato, but produces marked vein-clearing in *I. setosa*. A second unidentified agent (suspected to be a virus) was transmitted by the whitefly *B. tabaci*. This agent was also latent in sweet potato but it produces a mild chlorosis in *I. setosa*. In combination, the two disease agents produce severe symptoms in sweet potato.

A virus obtained from sweet potatoes in Kenya, Uganda and Tanzania was transmitted by sap inoculation and by *B. tabaci* to different seedling lines of sweet potatoes which varied significantly in their susceptibility. Hollings *et al* (1976) concluded that the virus was a whitefly-borne filamentous particle (800-950 nm long).

The relationships between the sweet potato viruses described in different parts of the world and those with common aphid or whitefly vectors are not known. The observation by Schaefers and Terry (1976) that the aphid-vectored agent was latent in sweet potato under greenhouse conditions in Nigeria and that dual infection by the aphid and whitefly vectored agents was necessary for symptom expression in sweet potato indicate that some of the sweet potato virus disease syndromes may result from multiple infections by different viruses. This indication is further strengthened by the elimination of some virus symptoms but not others by meristem tip culture (Alconero *et al* 1975).

The use of 'healthy rooted cuttings' as test plants for vector transmission tests by some investigators (Clerk 1960) and the evidence of latent infection in sweet potatoes (Hollings *et al* 1976; Schaefers and Terry 1976; Sheffield 1957) further suggests that symptoms believed to be induced by single sweet potato viruses may indeed be the result of complex or multiple infections. In this connection, the use of sensitive indicators like *I. setosa* to separate the components of a complex infection is a prerequisite in sweet potato virus disease investigations.

THE CONTROL OF SWEET POTATO VIRUS DISEASES

Host plant resistance

Sweet potato varieties range from highly susceptible to very resistant to internal cork, and resistance to this virus disease is readily transmitted to sweet potato progeny (Nielsen and Pope 1960). Resistance in sweet potatoes to the feathery mottle complex has not been reported (Martin 1970).

Hahn *et al* (1981) reported that in field trials at four locations in Nigeria five sweet potato cultivars (TIS 2498, TIS 3228, TIS 3053, TIS 2544 and TIS 2534) were evaluated for field resistance to a sweet potato virus disease (SPVD). A high correlation between field SPVD scores and scores recorded after positively challenging the same test cultivars by the root graft transmission method confirmed the high level of resistance observed in the field trials.

Individual plants of the resistant cultivars were challenged with virus-borne core tissues, and although the test plants expressed symptoms, there was evidence that they had the capacity to grow vigorously and recover from the infection (Terry 1979).

Crop hygiene

Disease spread: The system of vegetative propagation of sweet potatoes provides a highly efficient mechanism for the perpetuation and dissemination of sweet potato virus diseases.

Sheffield (1953) reported that spread of the disease by the vector in the field was normally slight and suggested that the more important damage may arise from propagation of infected vines.

In Nigeria, although large populations of whiteflies and aphids have been reared in captivity on sweet potatoes, field infestation levels are rather low and it appears that field transmission efficiencies of SPVD by these vectors is also quite low (Hahn *et al* 1981). Under Ibadan (Nigeria) conditions it normally takes one to three years before SPVD-free sweet potato seedlings develop severe SPVD under field conditions. Hahn (1979) reported that most of the symptomless plants used as disease-free controls in trials for yield comparison between SPVD-infected and disease-free plants remained symptomless until harvested four months after planting.

Aphids are fairly efficient vectors of internal cork when feeding from plant to plant within a given field (Martin and Elmer 1961). However, they apparently lose their infectivity rapidly, resulting in very little spread from one infected field to other virus-free fields 100 yards away (Martin and Kantack 1960).

The evidence therefore suggests that at least with some sweet potato virus diseases, man, by propagating vine cuttings from virus-infected sweet potato plants, may be the principle vector of these diseases.

Elimination of sweet potato viruses - meristem-tip culture: A method for eliminating viruses from sweet potato cultivars is based on the discovery that virus concentrations are lower in plant stem apices, and that virus symptoms are sometimes eliminated by growing new plants from shoot and or meristem-tips from diseased plants (Hollings 1965). By combining aseptic procedures for dissecting the meristem tips and a sterile nutrient medium to grow plants from these tips, virus-free plants are often obtained. Reports indicate that virus-free sweet potatoes have been grown from meristem tips of virus-infected plants in the United States of America (Nielsen 1960), Japan (Mori 1971), New Zealand (Over de Linden and Elliot 1971) Puerto Rico (Alconero *et al* 1975) and Nigeria (Frison 1979).

Meristem tips of sweet potato cultivars do not grow with equal facility on nutrient medium, and the proportion of virus-free plants may be small. An alternative is the use of thermotherapy. By growing infected sweet potatoes at 38°C for four to 12 weeks, it is possible to obtain virus-free plants from some cultivars (Elliott 1969). Heat treatment has been used to eliminate successfully internal cork, yellow dwarf, and chlorotic spots but not russet crack (Anon 1978).

To confirm the virus-free status of the plants produced from meristem tips and or by heat therapy, all plants are indexed using the wild *I. setosa* as a test plant. This is done by grafting a two-leaf shoot of the sweet potato onto *I. setosa* and checking for the development of virus symptoms. *Ipomoea setosa* is a sensitive indicator host and expresses virus symptoms

much more readily than sweet potato. Indexing has to be negative three times over a year's growth before a sweet potato plant is chosen as a mother plant (Anon 1978).

Integrated control

It is proposed that a high degree of control of sweet potato virus diseases can be achieved by combining the use of host plant resistance with virus-free planting material. The success of such a control practice depends to a large extent on the incidence and magnitude of subsequent field re-infection. Subsequent field re-infection is influenced in turn by the varietal susceptibility of the planting material to the prevailing viruses and the existence of favorable environmental conditions for disease development after re-infection.

Hahn *et al* (1981) reported that the IITA improved sweet potato varieties which are resistant to SPVD can also yield an average of 20-30 t/ha of fresh roots in four months without fertilizers.

In field tests the resistant variety TIS 2498 had a low SPVD severity rating and only a small increase in prevalence.

The low rate of disease spread in virus-free plants of a resistant variety offers therefore possibilities for maintaining a virus-free crop yielding an average of 20-30 t/ha, and roguing out the small number of plants which are subsequently re-infected.

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Sweet Potato Virus Diseases and Meristem Culture as A Means of Disease Control in Taiwan

R. J. CHU[a], C. H. LIAO and M. L. CHUNG[b]

[a]Council for Agricultural Planning and Development, 37 Nan Hai Rd. Taipei, Taiwan.
[b]Chiayi Agricultural Experiment Station, 2 Min Cheng Rd. Chiayi, Taiwan

INTRODUCTION

Virus diseases of sweet potato have not attracted much attention in Taiwan until recently. At the Chiayi Agricultural Experiment Station (CAES) where varietal collections of sweet potato have been maintained for breeding purposes, Yang (1972) surveyed the collections and obtained evidence of virus infection. A more thorough survey was made later by Liao (1978) involving field observations for virus symptoms and some indexing attempts made over two growth seasons. This survey revealed virus infection in 285 varieties out of 320 surveyed. An ensuing research program on sweet potato virus diseases placed emphasis on identifying the viruses and establishing virus-free clones for multiplication. This paper reviews the work along these lines and provides a sketch of research findings.

TYPES OF VIRUS SYMPTOMS IN THE FIELD

In a general survey, Liao (1978) observed suspected virus symptoms in most of the 320 sweet potato varieties maintained at the Chiayi Agricultural Experiment Station. These symptoms were categorized as yellow spots, purple spots and purple rings, mottle and feathery mottle, mosaic, ruffle, and leaf rolling. Yellow spots and purple rings were seen in 190 and 183 varieties, respectively; however, there was some overlapping of symptoms and most varieties exhibited both types in different leaf positions and different seasons. Of the 116 varieties which showed feathery mottle, 108 also produced yellow spots, purple rings or both. Leaf rolling was found to be another predominant type of symptom which occurred alone or in combination with other symptoms in 185 varieties. Mosaic was observed in 20 varieties and ruffle in 18 accompanying other symptoms. Liao also attempted to transmit virus from varieties either with or without symptoms to indicator plants *Ipomoea setosa* or *I. kidaiana* by mechanical inoculation or by grafting. Transmission was successful with 68 varieties showing symptoms out of 130 tested. One out of 12 symptomless plants also showed a positive reaction when indexed on these indicator plants.

TWO SAP-TRANSMISSIBLE SWEET POTATO VIRUSES

Two sap-transmissible viruses, designated SPV-A and SPV-N, have been isolated from Tainung 63 plants showing interveinal chlorotic spotting symptoms (Liao *et al* 1979a, 1979b). Both viruses were readily transferred by leaf rubbing to *Chenopodium quinoa* and to some species of *Ipomoea*. They can be differentiated by symptoms and aphid transmissibility. The following descriptions of these two sweet potato viruses are mainly based on Chien (1979) and Liao *et al* (1979a).

SPV-A

This virus has a narrow host range which is consistent with other aphid-borne sweet potato viruses described by various investigators (Nome 1973; Campbell *et al* 1974; Moyer and Kennedy 1978). By mechanical inoculation, young Tainung 63 plants developed systemic interveinal chlorotic spots in 8-10 days. These spots were indistinct and had ill-defined borders. They usually faded in 1-2 weeks after first appearance. On a purple-pigmented cultivar Hung-hsin-wei, chlorotic spots were also produced under nethouse conditions but in the field the main symptoms consisted of purple ringspots. Vein clearing or yellowing was not observed on these and other cultivars tested.

On *I. nil*, systemic vein yellowing was first noticed in larger veins about 6-8 days after inoculation; veinlets were affected later, thus bringing about a typical feathery mottle appearance. Systemic yellow spots of varying size developed in about four weeks after inoculation on the 6th-8th leaves counting from the primary leaf pair which received inoculation. These lesions faded and became invisible later. Young leaves coming out later showed no lesions. Infected plants were slightly stunted. Similar symptoms were observed on *I. setosa* and *I. hederacea*.

The inoculated leaves of *C. quinoa* and *C. amaranticolor* produced chlorotic spots, diameter 2-5 mm, in about 6-8 days. Older lesions on the latter species often turned red, but necrosis did not occur in either host.

Reactions of other test plants to SPV-A are given in Table 1.

Table 1. Reactions of various plant species inoculated with SPV-N and SPV-A under greenhouse conditions

Test plant	Reaction[a]	
	SPV-N	SPV-A
Amaranthaceae		
Amaranthus spinosus	-	-
Celosia cristata	-	-
Gomphrena globosa	-	-
Balsaminaceae		
Impatiens balsamina	-	-
Caryophyllaceae		
Dianthus chinensis	-	-
Chenopodiaceae	-	-
Chenopodium amaranticolor	L,Ns	L,Cs
Chenopodium quinoa	L,Ns	L,Cs
Chenopodium murale	L,Ns	L,Cs
Spinacia oleracea	-	-
Compositae		
Cosmos bipinnatus	-	-
Calendula officinalis	-	-
Tagetes erecta	-	-
Cruciferae		
Brassica chinensis	-	-
Brassica rapa var *perriridis*	-	-
Raphanus sativus	-	-
Cucurbitaceae		
Cucumis metuliferus	-	-
Momordica balsamina	-	-

Convolvulaceae		
Ipomoea bona-nox	-	-
Ipomoea hederacea	-	S,Vd
Ipomoea obscura	-	S,Vd
Ipomoea ramouri	-	S,Vd
Ipomoea nil	S,Vs,Vn,R	S,Vd,Vn,Cs
Ipomoea setosa	S,Vc,Vn	S,Vd,Cn,Cs
Ipomoea reptans	-	-
Quamoclit vulgaris	-	-
Gramineae		
Avena byzantina 'Coast Black'	-	-
Avena sativa 'Clintland'	-	-
Hordeum vulgare 'Moreval'	-	-
Sorghum bicolor 'Rio'	-	-
Sorghum halepense	-	-
Triticum aestivum	-	-
Labiatae		
Saliva splendens	-	-
Leguminosae		
Glycine max 'Bragg'	-	-
Phaseolus vulgaris 'Bountiful'	-	-
Pisum sativum 'Perfected Wales'	-	-
Trifolium repens 'New Zealand'	-	-
Trifolium pratense 'Kenlend'	-	-
Mirabilis jalapa	-	-
Solanaceae		
Capsicum annuum	-	-
Lycopersicum esculentum 'Marglobe'	-	-
Lycium chinense	-	-
Nicotiana alata	-	-
Nicotiana benthamiana	S,Mt,Mo,N	-
Nicotiana debneyi	L,Cs	-
Nicotiana gluca	-	-
Nicotiana glutinosa	-	-
Nicotiana megalosiphon	S,Mt	-
Nicotiana rependa	L,Cs	-
Nicotiana rustica	-	-
Nicotiana sylvestris	-	-
Nicotiana tabacum 'Judy's Pride'	L,Cs	-
Nicotiana tabacum 'Turkish'	-	-
Nicotiana tabacum 'Sam sun 15A'	Sc	-
Nicotiana tabacum 'Xanthi NC'	Sc	-
Nicotiana tabacum 'Hicks'	L,Cs	-
Nicotiana tabacum 'Havana'	L,Cs	-
Nicotiana tabacum 'V 20'	-	-
Nicotiana tabacum 'Van Hicks'	-	-
Peteunia hybrida	-	-
Physalis floridana	-	-

[a]Reaction legend: - = negative reaction; L = local; S = systemic; R = recovery of symptoms; N = necrosis; Cs = chlorotic spot; Mo = mosaic; Mt = mottle; Ns = necrotic spot; Sc = symptomless carrier; Vd = diffused vein yellowing; Vc = vein clearing; Vn = vein netting; Vs = chlorotic vein-spotting

Green peach aphid (*Myzus persicae*) transmitted SPV-A in a non-persistent manner. An acquisition time of 0.5-2 minutes resulted in a higher transmission rate (60-80%) than that was obtained when the aphid was allowed an acquisition period of five minutes or longer (0-30%) (Liao *et al* 1979a). In later experiments, transmission was also obtained with cotton aphid (*Aphis gossypii*) as vector but not with *Rhopalosiphum maidis* (Liao unpublished data). Seeds collected from infected *I. nil* and sweet potato plants did not transmit the virus (Liao *et al* 1979a).

SPV-N

This virus appeared to be latent or nearly so in most sweet potato varieties. Cultivar Hong-Hsin Wei did not show symptoms upon infection with the virus. Mild mottling and vein yellowing were observed on Tainung 63 plants about four weeks after inoculation. On *I. nil*, SPV-N induced pale green dots along the veins and some vein yellowing in expanded leaves. The dotted areas were irregular, sometimes discontinuous, and one-sided along the veins. They had well-defined borders. Upper leaves were usually without symptoms. Reactions of *I. setosa* and *I. hederacea* were similar to *I. nil*. However, under identical conditions for inoculation, a lower infection rate was usually obtained with the former two.

C. quinoa produced chlorotic local lesions, diameter 3-5 mm, in 4-6 days after inoculation with SPV-N. The lesions were also produced on *C. amaranticolor* which, however, was less susceptible as an assay plant than *C. quinoa* and usually gave fewer lesion counts with the same inocula. Aged lesions became necrotic in both hosts.

SPV-N appeared distinctive in that it infected some *Nicotiana* plants which are not hosts of other known sweet potato viruses. On *N. benthamiana*, systemic symptoms developed in 4-6 days after inoculation. Infected leaves showed mottle, interveinal chlorosis, leaf puckering, and some degree of leaf distortion. A severe strain of the virus also caused necrosis in random areas along the veins. No necrosis was observed with a mild strain (Chien 1979). Working with a severe strain, Chien determined the virus increment in *N. benthamiana* and found virus concentration to peak at seven days following inoculation. *N. megalosiphon* also showed systemic mottling when infected, but it was found to be less susceptible than *N. benthamiana*. Several plants of the genus *Nicotiana*, including *N. debneyi* and *N. tabacum*, reacted with SPV-N by producing vague, chlorotic lesions on inoculated leaves (Table 1).

Transmission of SPV-N was not obtained with *M. persicae* as vector or using seeds collected from infected *I. nil* plants (Chien 1979; Liao *et al* 1979a).

COMPARISON OF SPV-A AND SPV-N WITH OTHER KNOWN SWEET POTATO VIRUSES

Both SPV-A and SPV-N have thread-like virus particles with a diameter of about 12 nm. Previous measurements of particle length indicate a range of 850-900 nm for SPV-A and of 800-870 nm for SPV-N in dip preparations. Modal length occurred at 830-880 nm for both viruses. Partially purified samples of SPV-N yielded a length range of 750-800 nm (Chien 1979). However, these values are based presumably on a rather limited number of observations and thus need confirmation. Particle morphology together with transmissibility by aphids in a non-persistent manner (Liao and Chung 1979) seems to be a justifiable basis for placing SPV-A in the potato virus-y group.

Table 2. Comparison of some properties of SPV-A and SPV-N with other known viruses on sweet potato

Properties	SPV-A	SPV-N*	FMV[z]	RC-FMV[y]	VMV[x]	Sheffield (1958) A	Sheffield (1958) B	MMV[w]	Lobenstein[v] VCV	Lobenstein[v] RSV
Transmission by										
mechanical means	+	+	+	+	+	-	+	+	-	-
Myzus persicae	+	-	+	+	+	+	-	-	-	+
Aphis gossypii	+	-	+	+				-		
Rhopalosiphum maidis	-	-	-			-	-	-		
Bemisia tabaci	-	-	-		-	-	+	+	+	-
Host range										
Amaranthaceae	-	-	-	-		-	+	+		
Chenopodiaceae	+	+	-	+	-	-	-	+		
Compositae	-	-	-	-	-	-	-	+		
Convolvulaceae	+	+	+	+	+	+	+	+	+	+
Solanaceae	-	+	-	-	-	-	+	+	-	
Local lesion host										
Chenopodium amaranticolor	+	+	-	+	-	-	+	+		
Gomphrena globosa	-	-	-			-	+	+		
Nicotiana glutinosa	-	-	-		-	-	-	-		
Properties *in vitro*										
Dilution end point	10^{-3} -10^{-4}	10^{-2} -10^{-3}	10^{-3} -10^{-4}	10^{-3} -10^{-4}	10^{-4} -10^{-5}			10^{-2} -10^{-3}		
Thermal inactive point (°C)	55-60	60-65	60-65	60-65	62-65			55-60		
Ageing (days)	1	1	1	1	10-20			3-7		
Particle morphology	thread	thread	thread	thread	thread			thread		
Particle length	830-880	830-880	800-850	810-860	760-770			950		

[z]FMV = Feathery mottle virus (Moyer and Kennedy 1978)
[y]RC-FMV = Russet crack strain of feathery mottle virus (Campbell *et al* 1974; Moyer *et al* 1980).
[x]VMV = Vein mosaic virus (Nome 1973)
[w]MMV = Mild mottle virus (Hollings and Bock 1976)
[v]VCV = Vein clearing virus; RSV = Ring spot virus (Loebenstein and Harpaz 1960)
*SPV-N = More recent measurement by the present authors of SPV-N particles in dip preparation revealed a modal length of 700-750 nm.

Some of the *in vitro* properties of both SPV-A and SPV-N have been determined (Chien 1979; Liao *et al* 1979). SPV-A exhibited a dilution end point of 10^{-3} - 10^{-4} and a thermal inactivation point of 50-60°C; it lost infectivity in 1:100 diluted crude sap after 24 hr at 25°C. SPV-N exhibited a dilution end point of 10^{-2} - 10^{-3} and a thermal inactivation point of 55-60°C; it also lost its infectivity in 24 hr at 25°C.

WHITEFLY-TRANSMISSIBLE AGENT CAUSING LEAFROLL SYMPTOMS

Using the whitefly (*Bemisia tabaci*) as vector, a disease agent responsible for leaf crinkling and rolling was successfully transferred from diseased Tainung 63 plants to *I. nil* and *I. setosa* and to healthy Tainung 63 plants derived from meristem-tip culture. Slight swelling of veins was observed at the lower side of affected leaves. Infected plants had leaves severely rolled upward (in sweet potato) or downward (in *I. nil* and *I. setosa*) and were markedly stunted (Liao *et al* 1979). These symptoms were prominent only on young plants in summer, from May to September, and transmission experiments carried out in other months often gave negative results (Liao and Chung unpublished)

The whiteflies appeared to be inefficient vectors for the leafroll agent. Successful transmission was obtained only when a large number of insects, 100 individuals or more, were used per test plant after having access to source plants for 24 hr. Attempts to transmit the whitefly-borne disease agent by mechanical means failed (Liao and Chung, unpublished data).

Yang (1972) reported the transmission by *B. tabaci* of a disease from sweet potato plants showing vein clearing and feathery mottle symptoms to young plants grown from the seed. No detailed description was given of the disease which resulted from the transmission test.

MERISTEM CULTURE TO FREE SWEET POTATO CULTIVARS FROM VIRUS INFECTION

Aware of a high virus disease incidence in its varietal collections (Liao 1978), CAES initiated a meristem culture program in 1978 in an attempt to eliminate viruses from some valuable cultivars. Meristem cultures were obtained from cultivars Tainung 63, Tainung 57, Tainung 64, Okinawa 100 and Hong-Hsin Wei by explanting shoot tip tissues, 0.3-0.6 mm in length, from plants previously exposed to 38-40°C for about one month. A high percentage of the young plants derived therefrom were indexed virus-free (Liao and Chung 1979). For instance, 16 out of 24 Tainung 63 plants from shoot-tip cultures were found free from both SPV-A and SPV-N when indexed on *I. nil* and *C. quinoa*, while the original source plants carried both viruses, possibly complexing with others.

Plants derived from meristem cultures and indexed virus-free grew more vigorously than the source plants. In a nethouse trial, virus-free plants of cultivar Tainung 63 yielded 19.6 t/ha of fleshy roots and 9.2 t/ha of tops as compared to 12.9 and 7.5 t/ha for the respective portions from plants that were virus-infected. Healthy Okinawa 100 plants yielded 14.5 t/ha of fleshy roots and 7.9 t/ha of tops, while virus-infected plants yielded 6.4 and 6.4 t/ha, respectively. In a field test, the fleshy root yields of virus-free plants were 28.1; 25.3; 20.2 and 49.3 t/ha for Tainung 57, Tainung 63, Okinawa 100 and Hong-Hsin Wei, respectively. Plants of these cultivars infected with a virus complex yielded 24.5, 35.6, 30.5 and

31.7% less, respectively. The reduction in the stem and leaf yield was less marked (Liao and Chung 1981).

A further yield trial was conducted by Liao (unpublished data) to compare virus-free plants of different cultivars with plants infected either by a known virus or a virus complex. Results showed no significant difference in yield between the healthy plants and the plants infected with SPV-A or SPV-N or both. A significantly lower yield of fleshy roots came from plants which were used to start meristem culture and which presumably carried a virus complex.

Liao and Chung (1981) also determined the effect of virus infection on dry matter content, crude protein content and sugar refractometer reading of sweet potato plants. Plants infected with a virus complex were found to score higher in all these determinations than healthy ones.

DISCUSSION

The production of sweet potatoes in Taiwan is characterized by small, scattered farms all over the island. No systematic survey has been made as to virus incidence in the growers' fields. Although a high virus disease incidence in varietal collections of CAES (Liao 1978) may not be indicative of the magnitude of the disease problem in commercial planting, virus infection is believed to be widespread because sweet potato is an asexually propagated crop and some major cultivars have been used by farmers for many years without frequent renewal. No governmental certification system exists to keep sweet potatoes free from agents causing systemic diseases, including viruses.

Apparently, some cultivars of sweet potato grown on this island have probably harbored a complex of viruses. One line of evidence has come from the field trial conducted by Liao (unpublished data) who observed a fleshy root yield not significantly different between healthy plants and plants infected with SPV-A, SPV-N, or both. Their yield, however, was significantly higher than that of infected plants showing more severe symptoms and probably carrying additional viruses from natural infection in previous growth seasons. Obviously, the presence of other viruses could have affected plant yield to a greater extent than did SPV-A and SPV-N. Another piece of evidence is that inoculation of some cultivars, notably Okinawa 100, with either SPV-A or SPV-N or both did not result in symptoms resembling those of naturally diseased plants. In these cases, the elements responsible for yield reduction still await identification and isolation.

Of the two sap-transmissible sweet potato viruses mentioned above, SPV-A is probably closely related to sweet potato feathery mottle virus or its strains (Campbell *et al* 1974; Moyer and Kennedy 1978; Moyer *et al* 1980) on the basis of particle morphology, transmissibility by aphids in a non-persistent manner, host range and some *in vitro* properties. That SPV-A induced only chlorotic spots on test cultivars, such as Tainung 63 and Okinawa 100, does not exclude it from being classified with the feathery mottle virus group if the consensus of Campbell *et al* (1974) is to be accepted.

SPV-N appears to be distinct from all sweet potato viruses so far reported. Although it resembles the whitefly-borne sweet potato mild mottle virus (Hollings *et al* 1976; Hollings and Bock 1976) in that it infects *C.*

amaranticolor, *C. quinoa* and several species of *Nicotiana*, there are, however, some major differences. Hollings' mild mottle virus induced necrotic spots as well as systemic vein clearing, leaf mottling, crinkling, and plant stunting in *N. glutinosa* and *N. tabacum*. In contrast, the former species was not infected with SPV-N and the latter reacted to it by producing localized chlorosis on inoculated leaves only. Work on serological aspects and on possible vector transmission of SPV-N is in progress.

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Postharvest Disease Management for Sweet Potatoes

JAMES W. MOYER

Department of Plant Pathology, North Carolina State University, Raleigh, NC 27650, USA

INTRODUCTION

Sweet potatoes, *Ipomoea batatas* (L) Lam, are grown for many uses. Primarily they are used for human consumption in the United States and elsewhere because of their high nutritive value. In addition to carbohydrates they are high in vitamins; orange-flecked cultivars are particularly high in vitamin A. Roots and foliage are used for animal feed in many countries. Interest has been recently renewed in industrial uses for starch and ethanol production. The extent to which growers are concerned with postharvest care depends a great deal on the intended use. However, nearly everyone who produces sweet potatoes must store the harvested root for a period of time following harvest. Disease-related losses may occur no matter how short the storage period. Some of the most devastating diseases strike within a few hours after digging. For example, bacterial softrot, caused by *Erwinia chrysanthemi*, can destroy an entire root in 48 hr following infection under ideal conditions.

Disease problems may arise which are unique to each of the intended uses. Each use requires the roots to be stored for varying periods of time. The impact of storage diseases can be minimized when sweet potatoes are grown by subsistence farmers in a tropical climate. Under these conditions, continuous cropping may allow the use of freshly harvested roots. Conversely, where sweet potatoes are grown as an annual crop in a temperate region, it may be important to maintain the roots for many months, especially since growers naturally try to capitalize on peak marketing periods, such as holidays, for extra profits. As marketing becomes more sophisticated and intercommodity competition increases it is also becoming necessary to retain harvest-time quality for many months. Furthermore, consumers demand a constant supply and are reluctant to accept seasonal fluctuations. Similar factors apply to production for canneries, which must have a supply over a sufficiently long period of time to justify the effort in terms of profit. Industrial users also need an assured supply of reasonable quality.

Growers who rely on roots as their source of 'seed' are also influenced by postharvest diseases of sweet potato. Roots used to produce sprouts, which are then transplanted to the field for production of more roots, will henceforth be referred to as 'seed' in this paper. The importance of using good quality seed cannot be overstated. Some diseases which become apparent during storage are actually present - though undetectable - in or on the seed. The classic disease of this type is blackrot, caused by *Ceratocystis fimbriata* Ellis and Halsted. However, other diseases caused by fungi, bacteria and viruses may also originate from seed roots used for propagation. It is clear that everyone who produces sweet potatoes, for whatever purpose, should be cognizant of the potential losses due to disease which occur following harvest.

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DISEASES

Effective disease management should be integrated with cultural practices. The impact of postharvest sweet potato diseases can frequently be reduced by improving production practices. Prevention is better - and cheaper - than cure. To support this hypothesis and to be consistent with an integrated approach to postharvest disease control, diseases have been classified here in a system based on the relationship of the most probable time of infection to critical events during production. The rationale is that by the time most postharvest diseases become apparent, implementation of control measures is wasted effort. The focus in this paper is on those diseases which are problems following harvest during storage. Thus, considered here are examples of diseases in three categories based on time of initial infection in relation to harvest (that is when infection first occurs during production, providing inoculum for epidemics that may occur during storage). These categories are: 1) diseases contracted prior to harvest, 2) disease contracted during the harvest process, and 3) diseases contracted during storage and shipping. These divisions should not imply etiological or other biological affinities within each group. Nor is it intended that the categories be mutually exclusive (Table 1).

Before engaging in detailed control recommendations applicable to each disease type, we should examine disease cycles from each class. This is not an exhaustive list but instead will deal with a limited number of examples. Sweet potato diseases have been reviewed many times (Halsted 1890; Harter and Weimer 1929; Chupp and Sherf 1969; Steinbauer and Kushman 1971) and some of the more notorious ones are listed in Table 1.

Table 1. List of storage diseases with pathogen and common name. Time of infection in relation to harvest is given to aid in implementation of controls

Disease		Infection[a]		
Pathogen	Common name	Pre-harvest	Harvest	Post-harvest
FUNGI				
Ceratocystis fimbriata	Blackrot	**	*	*
Lasiodiplodia theobromae	Java blackrot	*	**	*
Monilochaetes infuscans	Scurf	**	*	*
Macrophomina phaseolina	Charcoal rot		**	
Rhizopus stolonifer	Softrot		**	**
Diaporthe batatatis	Dryrot		*	
Fusarium oxysporum	Surface rot		**	
Fusarium solani	Rootrot		**	
BACTERIA				
Erwinia chrysanthemi	Bacterial softrot	**	**	**
NEMATODE				
Meloidogyne spp	Rootknot	**		
VIRUS				
Unknown	Internal cork	**		

[a]** - indicates when primary time of infection is most probable and when controls should be introduced into the production cycle
* - indicates other times when new infections or spread from previously infected roots may occur

Figure 1. Symptoms of the scurf disease caused by *Monilochaetes infuscans* on storage roots

Figure 2. Colonization of sweet potato plants by *Monilochaetes infuscans*. A. Colonization of sprouts from infected roots; arrows indicate lesions. B. Symptoms (arrows) at harvest on underground stems and roots grown from infected cuttings

Preharvest infection

Several postharvest sweet potato disease epidemics are contracted prior to harvest. The pathogens which incite these diseases are frequently introduced when infected seed roots are used for propagation. These diseases may be present at a relatively low level at harvest, but provide an excellent source of inoculum. The inoculum can then be spread to healthy roots by contact during handling. Wash tanks provide another reservoir of inoculum. When roots are stored in boxes or bins, air currents and insects can spread the inoculum. Once the pathogens are introduced into the production chain they are difficult to remove.

Blackrot, caused by *Ceratocystis fimbriata*, has been a problem wherever sweet potatoes are intensively grown. Symptoms, consisting of dark lesions, occur on underground stems and roots. Root lesions are circular and may penetrate inwards to the vascular ring. Secondary invasion may result in decay of the entire root. The pathogen is spread on seed roots and young sprouts where symptoms go undetected, and it may survive on debris left in the field. The pathogen sporulates on roots during storage; mites can spread the inoculum resulting in significant disease increase (Halsted 1890; Steinbauer and Kushman 1971).

Scurf, caused by *Monilochaetes infuscans* Ell and Halst ex Harter, is primarily a cosmetic disease (Halsted 1890) (Figure 1). Like blackrot, it affects all underground portions of the plant. However, it has little influence on yield (Figure 2 A,B). Colonization is confined to the periderm, not affecting the edible portion of the root, but the superficial, dark brown to black spots on the root surface are objectionable to consumers. Also, increased shrinkage does occur during storage due to excessive moisture loss from ruptured areas of the root periderm. Lesions continue to enlarge during storage. Conidia are produced in long chains on the root surface and may be spread to other roots, inciting new infections. Unlike many root pathogens of sweet potato, *M. infuscans* does not require a wound for infection. Appressoria are formed on the root suface from germ tubes and the periderm is then colonized intracellularly (Lawrence and Moyer 1981).

Viruses can also cause storage diseases of sweet potato. Internal cork disease, although the pathogen has not yet been identified, is thought to be of viral origin. The disease agent has been transmitted by grafting and spread has been observed under field conditions. This disease can be particularly serious because affected roots cannot be detected without slicing into into the root itself (Nusbaum 1946). Thus, standard grading procedures do not cull diseased roots. Lesions occur on the interior of the root as dark brown, corky areas. Lesion size and number increase at storage temperatures greater than 20°C. This disease becomes of greater importance when roots are stored for several months (Aycock and Hughes 1952; Aycock *et al* 1953; Nielsen 1951).

Nematodes, particularly rootknot, have not been considered responsible for storage problems. However, the rootknot group, *Meloidogyne* spp, may cause cracking or other injury which could open the root to other pathogens. In addition, egg masses can be found in the periderm or cortex of roots grown in heavily infested fields (Steinbauer and Kushman 1971).

Harvest infection

Diseases in this category are usually caused by soil organisms which require fresh wounds to infect sweet potato roots successfully. Even the smallest abrasion which removes the outer 'skin' will provide the necessary opening for infection.

Fusarium spp frequently cause diseases which become apparent during storage. A disease commonly called surface rot is caused by *Fusarium oxysporum* Schlert, (Figure 3A,B) (Harter and Wiemer 1919). Lesions are circular, spreading out from the inoculation site, and become conspicuous after 3-4 weeks in storage. The lesions, dark brown in color, may be several centimeters in diameter, but seldom extend below the periderm. Excessive wounding caused by rough handling at harvest, and improper storage resulting in slow healing, increase the incidence of this disease. Roots harvested from wet soils are particularly favored by the disease. The disease does not generally spread in storage except when additional wounding occurs, providing new infection sites (Lauritzen 1935; Nielsen 1965). *Fusarium solani* (Sacc) Mart emend Snyd and Hans infection superficially resembles infection by *F. oxysporum*. However, the lesion may extend well into the root (Figure C) (Nielson and Moyer 1979). The advancing margin of the lesion is dark brown with freshly decayed tissue brown to orange and sharply delimited from healthy tissue. The lesion may extend beyond the vascular ring eventually

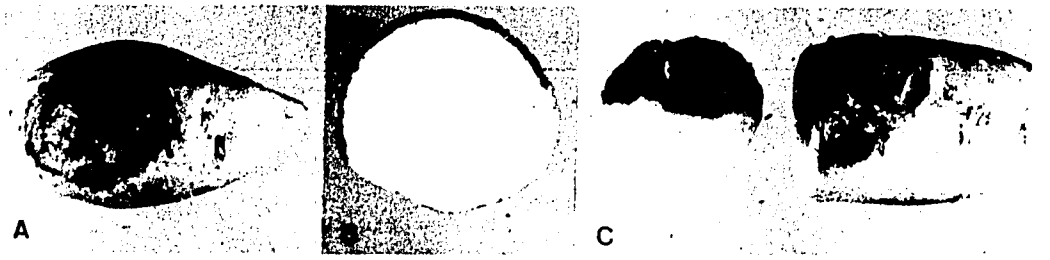

Figure 3. Symptoms of surface rot and rootrot caused by *Fusarium oxysporum* and *Fusarium solani*, respectively. A. A surface lesion caused by *F. oxysporum*. B. A side view of surface rot lesion. C. Lesions on storage root caused by *F. solani*

destroying the entire root (Figure 3C). The pathogen grows most rapidly at 28°C in pure culture, though the rate of disease development in roots has been observed to be greatest at 24°C. There are several reports (McClure 1951; Clark 1980) of stem infections by *F. solani*, suggesting this pathogen may also be seedborne. Preliminary studies conducted by the author support this hypothesis. Artificially inoculated stem cuttings and sprouts produced from diseased roots were shown to be infected (Moyer and Campbell, unpublished data). However, the epidemiological significance has not yet been demonstrated. Both of these *Fusarium* spp are nonspecialized forms frequently found in agricultural soils. The host range of a sweet potato isolate of *F. solani* includes the fruits of apple, cucumber, eggplant, squash, tomato and potato tubers in addition to sweet potato (Nielson and Moyer 1979; Clark 1980).

Java blackrot, caused by *Diplodia tubericola* (Ell and Ev) Taub, and charcoal rot, caused by *Macrophomina phaseoli* (Tossi) Goid are also important wound pathogens which can cause severe losses in storage. They have a wide host range and frequently present problems in tropical regions. They are included here because of their soilborne nature. They may cause serious losses if infection of injured roots occurs during harvest (Harter and Weimer 1929). Like the *Fusaria* discussed above *D. tubericola* may also infect stem tissue (Daines 1959).

Postharvest infection

The diseases classified here have one characteristic in common: roots decay in a few hours or days following infection rendering them unfit for sale or consumption. These diseases are frequently observed immediately after harvest, or after removal from storage and subsequent packaging for the market place. They are classified here because preventative measures must be incorporated into final preparation for marketing. The small wounds inflicted by the cleaning process, contaminated wash water, and the packaging of wet roots, provide near optimum conditions for infection. The production of pectolytic enzymes by the organism following infection causes a rapid dissolution of the cell walls resulting in a softrot type of disease.

One softrot is caused by *Rhizopus stolonifer* (Ehr ex Fr) Lind. This organism is a wound pathogen found nearly everywhere. Infected tissue is soft, moist and stringy. It also gives off a characteristic sweet smell. The presence of dense, aerial mycelia with dark brown spores, often called 'whiskers', is a diagnostic sign of the disease. If a suspect root is observed, the formation of whiskers can be induced by puncturing the root

surface in several places with a knife. Later, infected roots become shriveled and brittle due to moisture loss. The organism sporulates profusely under favorable conditions providing inoculum which can be spread by flies, rodents and air currents (Halsted 1890). An abundance of fruit flies (*Drosophila* spp) in a storage house usually signals the presence of this disease. New infections can then occur in freshly wounded areas. A single infected root introduced into a tank of water used to clean the roots can contaminate subsequent roots washed in that water. Roots may then be destroyed during the few days between packaging and delivery to the consumer.

A more recently recognized softrot disease of sweet potato is cause by *Erwinia chrysanthemi*. This disease has only been reported as a severe problem in the state of Georgia, USA (Martin and Dukes 1977). However, it has also been observed to a lesser extent in North Carolina. The root phase of this disease can be confused with *Rhizopus* softrot. *E. chrysanthemi* is a common pathogen with a wide host range and is included because the potential hazard is great (Schaad and Brenner 1977). The disease is classified a postharvest disease here because of its devastating effect on roots. However, it could also be classified under the other two categories, because plants are also infected in the field.

Bacterial softrot thrives at relatively high temperatures (32-34°C) compared to *Rhizopus* softrot. Fresh wounds and free moisture are required for infection, making the environment created by washing and packaging favorable for the disease. When infected roots are used for propagation, sprouts may harbor symptomless infections. A rapid, moist decay of stem and petioles may result later in the growing season during periods of high temperature and free moisture. The bacteria will survive in this debris providing an excellent source of inoculum when the roots are harvested. Plant symptoms include yellow leaves with water-soaked, dark brown to black lesions on the stems and petioles. Black streaks may occur in the vascular tissue of stems and roots. The symptoms are similar to those cause by *Fusarium oxysporum* f sp *batatas* (Wr) Snyd and Hans (Martin and Dukes 1977; Schaad and Brenner 1976). Both the stem and root phase of the disease poses a potential threat in tropical regions where warm rains occur. In more temperate regions, epidemics may only occur in storage. Observations by the author suggest the epidemic is incited by a few infected roots being introduced into the wash water during grading and packaging. As many as 30 of the roots passing through the same wash process have been observed to be inoculated in this manner.

Eight pathogens were selected as examples of the three classes which incite postharvest diseases, though many more have been reported (Chupp and Sherf 1960; Steinbauer and Fushman 1971). From these examples we can see that many of the postharvest maladies begin at or before the crop is harvested.

CONTROL

Control of postharvest diseases should be seen from the point of view of prevention. Little can be done once the root is infected. Many published recommendations for control of postharvest diseases begin with harvest. However, a sound strategy for postharvest disease control should begin with 'seed' selection. Only healthy roots should be used for propagation. Resistant cultivars are available for some diseases such as internal cork and bacterial softrot, though sources of acceptable levels of resistance have

not been identified for all of the diseases. Cold frames or land used for propagation should be fumigated and rotated for each crop. Preferably a 2-4 year rotation should be adopted. A similar rotation should be followed for land used to produce the crop. Many of the pathogens such as *M. incognita*, *C. fimbriata* and *E. chrysanthemi* can survive in plant debris remaining from the previous crop. Vine cuttings should be made above the soil line rather than pulled to avoid contamination by soilborne organisms. Under less than ideal conditions it may be necessary to treat roots and/or cuttings with a fungicide.

At harvest, efforts to control these diseases should be intensified. Machinery should be properly adjusted. Workers should be instructed to handle roots carefully to minimize scrapes and bruises which invite infection by the soilborne wound pathogens. Whenever possible, wet soils should be allowed to dry before harvest. Diseased roots should be discarded and healthy roots placed in containers which have recently been sanitized. Several materials can be used for this purpose: methyl bromide, various fungicides or calcium hypochlorite for bacteria.

Roots should be taken to storage facilities to begin curing immediately following removal from the soil. Curing initiates a rapid healing of wounds which prevents infection by several organisms. Freshly-harvested roots can be cured by maintaining them at 28-30°C and 85-90% relative humidity for approximately seven days. These conditions favor healing and minimize development of rots such as *F. solani*. Roots should then be stored at 15°C until used. It is also important to minimize moving stored roots following curing. New wounds will occur providing another opportunity for pathogens such as *R. stolonifer* or *Fusarium* spp.

Roots are frequently washed, sorted and graded in preparation for marketing, and this provides another opportunity for wounding. *R. stolonifer* and *E. chrysanthemi* can become serious problems during this process. Wash water should be frequently changed to prevent accumulation of inoculum. Calcium hypochlorite is an effective sanitizer and is effective against *E. chrysanthemi*. In addition, roots can be treated with a fungicide which inhibits *R. stolonifer*. All pesticides and materials should be used in accordance with local laws and manufacturer's recommendations.

A preventative strategy for control of sweet potato storage diseases is essential to achieve a high level of success. Planning controls which begin at the earliest stages of production can have additional benefits. For example, selecting high quality roots for propagation is effective not only against storage diseases, but also against field diseases and helps the maintenance of horticultural characteristics.

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General Discussion

(Session III)

ANONYMOUS: Which season of the year is the best for screening sweet potato for weevil resistance? Did you take averages ratings over seasons, locations and years?

TALEKAR: At AVRDC the fall season, planting in September, is a better season for screening. Our results are based on screenings done at two locations over eight seasons during the past four years.

ANONYMOUS: What is the effect of crop rotation on sweet potato weevil appearance and attack incidence? If any, which crops reduce incidence?

TALEKAR: Crop rotation with rice definitely reduces weevil infestation of a subsequent sweet potato crop. However, if a weevil source exists in neighbouring fields or if you use planting materials from weevil infested plants, rotation is of not much use. Simple sanitation procedures such as using planting material free of weevil, and cleaning the field free of weevil sources such as perennial *Ipomoea* weeds, and of the buds and debris from the previous sweet potato crop, will considerably reduce weevil infestation without rotation.

WARGIONO: Do you think that there is a correction between tuberous root position, latex content, skin thickness and weevil damage? Could you tell us whether I 152, which you showed to be moderately resistant, is deep rooted or has high latex content?

TALEKAR: Deeper tuberous roots are definitely less infested than the roots close to the surface. We have not done any study on the effect of latex content or skin thickness on weevil infestation. I 152 is not a deep rooted cultivar. We have not yet studied other characteristics.

MEYNHARDT: Does bearing habit influence percentage weevil infestation? Are there indications that cultivars which bear their roots deeper in the soil are less susceptible to weevil infestation?

TALEKAR: Yes, the deeper the roots the lower is the weevil infestation. This has been shown by several workers. I have reviewed the information in my paper. Deep rooted cultivars are not necessarily less susceptible to weevil, it is just that deeper roots are not easily accessible to weevil.

TANABE: You mentioned weevils do not affect the yield. Do you mean biological yield or marketable yield of sweet potato? Your slides indicate weevils infested vines which very likely will interfere with the translocation of dry matter into the storage root. Could you comment on this?

TALEKAR: Our results show that weevil infestation does not reduce total root yield. I realize that theoretically infestation should reduce translocation of photosynthate or mineral nutrients but in practice we do not get any yield reduction, possibly due to the excessive vegetative growth that sweet potato puts up. As a result, an adequate quantity of photosynthate

is still translocated and an adequate yield results. Excessive vegetative growth probably uses quite a lot of photosynthate in control plants.

URITANI: Have you ever investigated whether some specific attractants are present in some species of *Ipomoea*?

TALEKAR: We have not done any research on this aspect. However, the fact that weevil infests almost exclusively *Ipomoea* species suggest the possible existence of an attractant, or of some other factor in *Ipomoea* essential for growth and development of weevil.

URITANI: Have you ever investigated some relationship between resistance to weevil and some secondary metabolites produced in sweet potato in response to infestation?

TALEKAR: No, we have not done any research into this aspect. I am aware of the work done in Japan. The secondary metabolites seem to be nonspecific as they are produced as a result of infestation by weevil as well as infestation by blackrot fungus. The possibility of such chemicals being involved in resistance to weevil, therefore, seems to be rather remote.

WILSON: Has any effort been made to identify sources of weevil resistance in *Ipomoea* species other than sweet potato?

TALEKAR: We have not made any systematic efforts directly but we have observed that certain *Ipomoea* species are not at all attacked by this insect. However, no other *Ipomoea* species besides sweet potato that we observed, resistant or susceptible, forms tuberous roots. This could pose a serious problem in utilizing such sources for resistance breeding in sweet potato.

WADDILL: Were the plants which showed no relationship between yield and number of weevils emerging attacked by the weevil soon after planting or only late in crop development?

TALEKAR: In two seasons the plants were infested six weeks after planting and in one season they were exposed to natural weevil infestation which was almost from planting time, because the crop was planted soon after harvesting a heavily infested sweet potato crop. In all three cases there was considerable weevil infestation when we observed the roots at harvest time.

VILLAREAL: Can you feed weevil-infested sweet potatoes to animals? The weevil can be an additional source of protein.

WADDILL: Yes.

ANONYMOUS: Is it correct to state that feathery mottle (FM) is a complex of two viruses a) one transmitted by *Myzus persicae* b) the other transmitted by whiteflies, and that both virus components have to be present for symptoms to develop? If this is so, the sweet potato virus A which has been identified in Taiwan might not be identical with FM, since sweet potato virus A can by itself produce mottle symptoms on sweet potato. Can you please comment on this?

HAHN: Feathery mottle virus is aphid transmitted with particles of about

85 nm length. Several strains have been described which include the common strain, russet crack and yellow vein. The complex you are referring to is sweet potato virus disease found in Africa. Both components transmitted by aphid and whitefly must be present for symptom expression. Sweet potato virus A is most likely a russet crack strain of FM.

ANONYMOUS: Is IITA going to ship its breeding lines as meristem tip culture in the future or is this already being done.

HAHN: It is already being done. In fact, I just delivered to Dr Villareal several meristem cultures of some promising IITA lines.

ANONYMOUS: Can FM be transmitted to *Chenopodium quinoa* or is it confined to *Ipomoea* sp?

CHIU: The russet crack and yellow virus strain of FM infest *C. quinoa*; however, the common strain does not.

URITANI: Did you find any pathogenic fungi which can penetrate into the tissue through the epidermal cell layer without mechanical injury?

MOYER: Yes: *M. Sphaerosporum*, causal agent of scurf. An appressorium is produced by the germ tube which penetrates the cell wall. Interestingly, as hyphae grow intracellularly, a new appressorium is produced each time the fungus passes through the cell wall.

WINARNO: Curing of sweet potatoes is usually conducted at relatively high temperatures (30°C, RH 85-90%) to avoid blackrot damage, but further problems arise like the development of internal cork due to virus. Could you recommend the best conditions (temperature) so we can avoid both problems?

MOYER: Roots are only cured at these high temperatures for five to seven days. It requires several months for internal cork virus to develop. Curing followed by storage at 15°C will solve these problems.

WAN: Virus-free seedlings of sweet potato can be obtained by thermotherapy and tip culture; what are the temperatures needed and what duration of heat treatment? Does tip culture completely eliminate or inactivate the virus based on your experience?

CHIU: We obtained meristem tip culture by a procedure which involved exposing the source plants to 38°C for four weeks and excising the shoot tips 0.3-0.6 mm in length. In this case a temperature of 38°C did not seem to inactivate the virus (or viruses) completely but it slowed down virus movement to the shoot tip. In one experiment, we obtained 16 plants which were virus-free out of 24 which were indexed.

WUSTMAN: Is the application of systemic insecticides to be recommended in reducing the spread of sweet potato viruses in the field?

CHIU: Application of systemic insecticides may be effective in reducing the spread of the whitefly-transmitted sweet potato viruses which are semi-persistent or persistent in their vector, but may not be effective against the aphid-transmitted non-persistent viruses such as sweet potato feathery mottle virus and its strains, especially when the virus spread is in large

part due to incoming migrants. However, to suppress within-the-field virus spread, systemic insecticides could be of some value.

WUSTMAN: Is monitoring of aphids and whitefly flights a useful technique for seed vine production?

CHIU: It would be a useful technique in areas intended for seed vine production. The monitoring results will serve as a basis for adjusting the planting date of the crop and for scheduling insecticide applications to prevent the spread of persistent viruses due to incoming vector insects mentioned above.

SESSION IV

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Research on Production of Sweet Potatoes from Cut Root Pieces

J. C. BOUWKAMP

Department of Horticulture, University of Maryland, College Park, MD 20742, USA.

INTRODUCTION

Sweet potato planting materials usually consist of sprouts or vine cuttings. Sprouts are produced by placing 'seed roots' in beds (often later covered with sash or polyethylene film), covering the roots with 5-8 cm of sand, then pulling the sprouts when they reach a height of 20-25 cm. Vine cuttings, obtained from established plantings, are used primarily for production of disease-free 'seed' or for main crop production in areas with long growing seasons.

Both systems require extensive labor. One alternative is a simplified system of production consisting of direct planting of small whole roots or root pieces (similar to the practice with white potato (*Solanum tuberosum* L) tubers). Early attempts (Lutz *et al* 1946) to produce sweet potatoes from root pieces were unsuccessful, resulting in poorly shaped roots, low yields and poor stands. In most cases the root piece enlarged, producing a badly misshappen root. Later work by several Japanese scientists (Kobayashi 1968; Kobayashi and Akita 1966; Kodama and Kobayashi 1952, 1954; Kodama and Nomoto 1954, 1955; and Kodama *et al* 1958) was more encouraging and rekindled interest in the United States. Our efforts began in 1970.

MATERIALS AND METHODS

All experiments were done at the University of Maryland Vegetable Research Farm located near Salisbury, Maryland, USA (38° 22' N latitude) on Norfolk sandy loam soil (fine-loamy, siliceous, thermic typic paleudults soil). Spacing was 0.9 m between rows and 0.3 m between plants in rows, resulting in a population density of approximately 35,800 hills/ha. All plots received 1680 kg/ha of 5-10-20 (NPK) with 2% MgO fertilizer, one-third applied before planting and plowed down, one-third one month after planting or transplanting, and the remaining one-third two months later. Root pieces were 20-25 g each in weight, and were treated with a DCNA dip (75 w, 12 g/liter) immediately after cutting unless otherwise stated. Decayed root pieces were discarded before planting and only sound root pieces were planted. Root pieces were hand-planted in furrows approximately 3 cm deep and covered to a depth of 5-6 cm by making a small ridge on the row. Additional cultivations increased the height of the ridge to 7-9 cm.

CLASSIFICATION OF RESPONSE TYPES

Success when using root pieces as planting material depends on new fleshy roots growing from the sprouts arising from the root piece (known as indirect daughter roots) and on the root piece not becoming a metabolic sink and thus enlarging. We classify a response type depending on where the new fleshy roots grow and on what becomes of the root piece (Figure 1): 1) indirect daughter root piece enlarging (IDRE); 2) indirect daughter root piece

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Figure 1. Root piece response types. (A) indirect daughter, root piece enlarging (B) indirect daughter, root piece remaining (C) indirect daughter, root piece disappearing, (D) direct daughter, root piece enlarging, (E) mother root piece enlarging; arrows indicate original root piece

remaining but not enlarging (IDRR); 3) indirect daughter root piece disappearing (IDRD); 4) direct daughter (new fleshy root grows from root piece) root piece enlarging (DDRE); 5) direct daughter root piece remaining (DDRR); and 6) mother root piece enlarging with no or very few daughters (MRE). In fact these are not distinct classes but there are intermediate types tending to a continuous graduation especially in the degree of root piece enlargement. For classification purposes we rate a line according to the modal response class. For example a line with all seed pieces remaining and a few enlarging slightly would be classified as RR; a line with both direct and indirect daughters would be classified according to whether the majority of the stored reserves was in direct or indirect daughters and MRE are classified as having less than 20% of the stored reserves in daughter roots.

PREPLANTING TREATMENTS

Using lines from groups 2 and 3, we found that we could produce a crop of sweet potatoes comparable to that produced from sprouts (Table 1, from Bouwkamp and Scott 1972). Other experiments and other experimenters convinced us that the difficulty of obtaining a satisfactory and uniform stand was a serious problem and would have to be resolved before production from root pieces could become feasible. Thus we decided to investigate cutting the roots and placing the root pieces in presprouting conditions (90% RH and at about 30°C). We expected that this treatment would serve to break proximal dominance (Thompson and Beattie 1931), heal the cut surfaces and induce early sprouting (Deonier and Kushman 1960). We found (Bouwkamp *et al* 1971)

Table 1. Yields of several clones of sweet potatoes grown from root pieces and sprouts

Propagation method and cultivar	Yield (t/ha)				
	Grade[a]				Total
	jumbo	no. 1	no. 2	culls	marketable
Root pieces[b]					
Redmar	3.4	29.5	11.9	0.2	44.7
MD 18	2.6	20.3	11.8	2.5	34.6
MD 112	3.0	6.8	2.5	0.1	12.3
MD 115	6.8	20.2	6.5	0.3	33.4
MD 116	15.1	21.8	10.5	0.7	47.4
LSD 5	8.9	6.0	3.0	1.1	13.4
Sprouts[c]					
Redmar	1.6	33.1	11.0	0.0	45.8
MD 18	0.0	15.5	17.0	0.0	32.5
MD 112	3.0	20.7	14.0	0.0	37.7
MD 115	7.8	27.6	8.5	0.0	43.9
MD 116	18.1	22.9	6.8	0.0	47.8
LSD 5	4.8	4.1	1.7	-	5.0

[a]Jumbos 8.75 cm diameter, 22.9 cm length, or 5675 g
No. 1 5-8.75 cm diameter, 7.2-22.9 cm length, 567.5 g
No. 2 2.5-5 cm diameter, 5-17.5 cm length
[b]Root pieces planted 18 May 1971; harvested 13 Oct; 21,510 hills/ha
[c]Sprouts planted 24 May 1971; harvested 5; 33,850 hills/ha

Table 2. Effectiveness of DCNA dip in controlling softrot of sweet potato root pieces

Treatment	Percentage (by wt) sound at time of evaluation		
	Redmar	Julian	Mean[a]
Control	45.5	87.5	66.5 a
DCNA 75W (12 g/liter)	96.3	98.0	97.2 b
DCNA 75W (24 g/liter)	97.6	97.9	97.8 b
Mean[a]	83.1 a	94.5 b	

[a]Mean separation by Duncan's Multiple Range Test at the .05 level of probability

that losses of root pieces due to rotting caused by *Rhizopus* species were controlled by DCNA (2-6-dichloro-4-nitroaniline) and there were significant differences between cultivars with regard to susceptibility (Table 2).

We also studied the effects of the length of time the root pieces were exposed to presprouting conditions or early emergence, final stand and yield. The cultivar Redmar was used and all root pieces were treated with fungicide before treatment. We made two separate plantings, the first on 20 May, the second on 2 June. Stand counts were made several times during the growing season. All plots were harvested on 10 October giving growing seasons of 142 and 129 days respectively. The results are presented in Table 3 and 4. In both experiments significantly poorer early and final

Table 3. Effects of length of presprouting treatment of emergence and yield of sweet potatoes grown from root pieces (experiment 1)[a]

Weeks of treatment	% emergence after:				Total marketable yield (t/ha)
	27 days	37 days	41 days	48 days	
0	1 b	7 b	22 c	38 c	21.7 a
1	20 a	37 a	43 b	63 ab	23.5 a
2	14 a	33 a	41 b	47 bc	25.5 a
3	34 a	48 a	50 b	62 ab	25.8 a
5	30 a	47 a	63 a	72 a	29.3 a

[a]Mean separation within columns by Duncan's New Multiple Range Test at the .05 level of probability

stands were obtained from the plots which had not received the presprouting treatment and in experiment 1 the one-week treatment was also poorer than longer treatments. Yields were not significantly affected although in both experiments the control (0 treatment) resulted in the lowest yields.

As a result of these experiments, we generally employ a two to three-week presprouting treatment before planting in the field. There may be some advantage to a longer period of presprouting in locations where the length of the growing season is limited since sprouts which emerge more quickly would give the effect of a longer growing season. It should be noted that the five-week treatment gave the highest yields, equivalent to between one and two more weeks of growing season than in the two-week and three-week treatments, since we know that Redmar yields increase at approximately 0.45 t/ha/day during the last half of the growing season (Scott and Bouwkamp 1975).

QUALITY OF SWEET POTATOES GROWN FROM ROOT PIECES

Since quality, especially processing quality, is important in the USA, we decided to investigate the effects of propagation methods on the various attributes normally associated with quality. Crops were produced in 1978 and 1979 from both sprouts and root pieces. In 1978 we grew one cultivar and three breeding lines (Redmar, MD 302, MD 628 and MD 714) and in 1979, three breeding lines (MD 628, NC 718 and NC 719). In both years we used a split plot design with four replications. Plots consisted of a single row 10 m long.

Table 4. Effects of length of presprouting treatment of emergence and yield of sweet potatoes grown from root pieces (experiment 2)[a]

Weeks of treatment	% emergence after:				Total marketable yield (t/ha)
	14 days	24 days	28 days	35 days	
0	0 d	22 b	31 d	38 c	23.4 a
1	2 cd	49 a	63 c	72 b	27.1 a
2	8 bc	58 a	78 a	83 a	32.1 a
3	12 ab	60 a	78 a	81 ab	31.1 a
4	21 a	60 a	64 bc	70 b	28.4 a
5	23 a	62 a	74 ab	80 ab	32.6 a

[a]Mean separation within columns by Duncan's New Multiple Range Test at the .05 level of probability

At harvest, we determined the total marketable yield and yield in the various size classes. The roots were processed the day after harvest (according to standard techniques and procedures) and various tests were undertaken on the raw product. We determined specific gravity by weight and water displacement, percentage N by total Kjeldahl, percentage dry matter from oven-dried samples. Phenolase activity (darkening) was established by blending roots with equal weights of distilled water and various solutions (1 g thiourea per liter of dH_2O, 10 g catechol per liter of dH_2O, and 1 g thiourea + 1 g $FeCl_3$ per liter of dH_2O). Color values (L, reflectance; a, redness; and b, yellowness) were determined on a Hunter Color Difference meter against a sweet potato standard plate (L = 58.6, a = +29.4, b = +32.0).

Canned samples were analyzed for color approximately six months after canning by a Hunter Color Difference meter, percentage fiber was determined by AOAC procedures and firmness measured as resistance to shearing on an Allo-Kramer shear press. The results are presented in Table 5.

The results are similar for the two years although the effects may not be significant in both years. It would seem that reduced yields may be expected from root piece grown crops, at least with present cultivars and techniques. The reduced yields may be partially attributed to a shorter

Table 5. Significance of effects on yields and various raw product and canned product quality attributes in each of two years

Variable	Treatment effects[*] (sprouts vs root pieces)		cultivar effects		Interaction effects[†] (treatment x cultivar)	
	1978	1979	1978	1979	1978	1979
Yield No. 1	37**	81	**	**	**(M)	*(R)
Yield No. 2	105	103	**	ns	*(R)	ns
Yield Jumbo	10**	88	**	**	**(M)	ns
Total marketable	53**	86	**	**	*(M)	*(R)
% dry matter (roots)	97	94**	**	ns	ns	ns
% N dwb roots	88**	85 *	**	*	ns	ns
Specific gravity	100	100	**	**	ns	ns
Δ L (Thio - H_2O)	114		**		ns	
Δ L (Thio - Cat.)	116		**		ns	
Δ L (Thio - $FeCl_3$)	108		**		ns	
Hunter "a" (Thio)	99		**		ns	
% dry matter (leaves)	104**		**		ns	
% N dwb leaves	107**		**		ns	
Hunter "a"	91**	92	**	ns	ns	ns
Hunter "b"	96**	98	**	ns	**(M)	ns
Hunter "L"	96**	97	**	ns	**(R)	ns
% fiber	84	91	ns	**	ns	ns
Firmness-shear	85**	98	**	**	ns	ns

[*]Root piece grown means expressed as a percentage of sprout grown means followed by significance level

[†]** = highly significant; * = significant, ns = not significant. Significance of interaction effect followed by nature of interaction (R) = Reversal effect, (M) = Magnitude effect

effective growing season. Several quality attributes may be lower for root piece grown sweet potatoes and warrant further investigation. The lower N concentration, especially if reflected in lower protein values, is probably the most serious concern. With regard to processing quality the lower firmness and the higher discoloration (as measured by lower L values and higher ΔL values) are the most serious concern.

There is, however, some reason for optimism in that some cultivar X treatment interactions are of a reversal type, indicating that certain cultivars may perform better when grown from root pieces than from sprouts. Thus we may be able to select lines which perform well and also have good quality when grown from root pieces.

SELECTION FOR ROOT PIECE PRODUCTION

Our selection scheme proceeds as follows (Table 6). Seedlings are screened for root color in the greenhouse during the late winter or early spring, then vine cuttings of the selected seedlings are grown in the field during the summer and selected for horticultural characters in the fall. They are placed in storage, and selected for storage quality in the late winter, with particular regard to their resistance to storage rots.

Table 6. The selection system used at the University of Maryland for selecting sweet potato lines adapted for root piece production

Time	Year	Location	Select for:	Selections remaining per 10,000 original seedlings
E. Spring	1	Greenhouse	Root flesh color	3,000
Fall	1	Field	Horticultural characters	400
E. Spring	2	Storage	Storage quality	350
L. Spring	2	Propagation beds	Survival and rate sprouting	300
Fall	2	Field (preliminary trial)	ID, survival, horticultural characters	30
E. Spring	3	Storage	Storage quality	25
L. Spring	3	Pre-sprouting	Rot resistance	15
Fall	3	Field (observational trial)	ID, survival, horticultural characters	10
E. Spring	4	Storage	Storage quality	8
L. Spring	4	Presprouting	Rot resistance	5
Fall	4	Field (advanced trials)	Horticultural characters, yield, quality	2-3

Roots are bedded in the spring, evaluated for sprouting ability, then removed from the beds. The sprouts are removed and the roots cut into 20-25 g pieces and ten pieces of each line are planted. We refer to this as preliminary testing. In the fall, the plots are dug and selections are made on the basis of horticultural characteristics, yield potential, stand survival and so on. Selected lines are harvested, cured and stored. In the following spring roots are cut, treated with fungicide and placed in presprouting conditions for two to three weeks. After presprouting data are obtained on the percentage of rotting and poor lines discarded, sound root pieces are planted into what we call observational trials, usually non-replicated. In the fall the lines are once again selected for horticultural characters, stand survival, and degree of root piece enlargement. Selected lines are placed in advanced trials or returned to observational trials the following spring. Advanced trials are usually replicated and we obtain yield and quality data in the fall.

Table 7. Frequency distribution of observational lines for the percentage of rotted root pieces two weeks after cutting

% rotted root pieces	Frequency
<0.5	29.8
0.5-2.4	13.8
2.5-4.99	22.3
5.0-9.99	11.7
10.0-19.99	10.6
>20	11.7

ROTTING

Data obtained from three years observational trials (Table 7) indicate a fairly high level of rot resistance in the population but it should be noted that the root pieces had been treated with Botran dip at the rate of 12 g/liter prior to presprouting. We attribute this level of resistance to two factors. Firstly, the lines have been subjected to two separate evaluations for freedom from storage rots, and secondly the root pieces in the preliminary trial were not treated with fungicides and only those lines with good survival were selected for the observational trial. Thus most of the highly susceptible lines were discarded prior to the observational trials from which these data were obtained.

Freedom from rotting is an important trait for two reasons. First, loss of cut root pieces results in a waste of propagation material thus necessitating more planting material than would normally be needed. Second, the more susceptible lines produce a poorer stand even when only sound root pieces are planted. In 1976 we planted all 16 lines in the observational trial even though some had poor resistance. We found a highly significant linear correlation of -0.642 between percentage rots and percentage stand survival.

We believe that as our level of rot resistance increases it may be possible to eliminate the use of fungicides before presprouting.

RESPONSE TYPES AND ASSOCIATED CHARACTERISTICS

As mentioned previously we recognize six response types and in 1980 we made a careful study of the 220 lines in our preliminary trial. In addition to classifying the lines as to response types, we also recorded the survival and the number of sprouts per surviving hill. The results are presented in Figure 2. It may be noted that the predominant types are root piece enlarging (RE types) and indirect daughter (ID) types. With regard to sprouts/hill the lower values predominate and with regard to survival/hill the higher rates of survival predominate.

Survival, sprouts/hill, and sprouting rating (obtained in propagation beds) in each of the response types are presented in Figure 3. Note that all direct daughter DD types have been combined since the DDRR class included only two individuals. It can be seen that the IDRD and MRE classes are quite different from the other response classes for both variables. This was verified by tests for non-homogeneity.

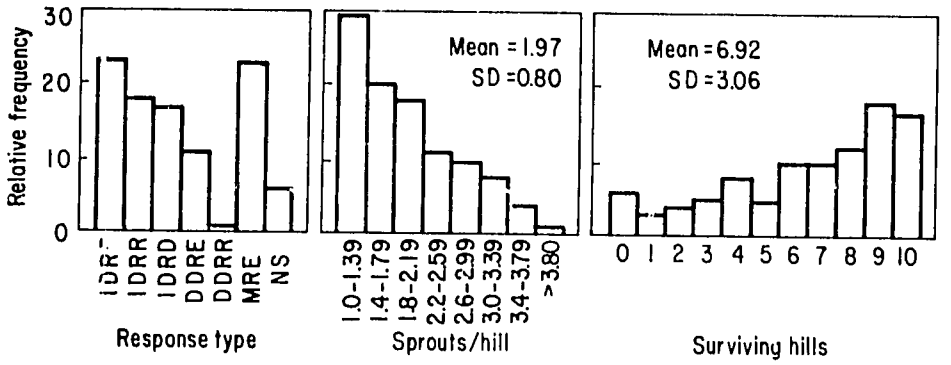

Figure 2. Relative frequency of response types, sprouts per hill and survival in a population of sweet potato lines planted as root pieces

The relationship between survival and sprouts/hill was investigated through polynomial regression. The regression line was calculated and found to be $\hat{y} = 0.05 + 4.26\,x - 0.77\,X^2$ ($R^2 = .323$) where $\hat{y}$ is the predicted survival and X is the number of sprouts/hill. This relationship can be explained by assuming that poor sprouting or slow sprouting lines are more likely to succumb to rotting or insect predation before the root pieces can be established. The more vigorous sprouting types are more likely to sprout quickly and profusely, thus decreasing the vulnerability of such root pieces to attack.

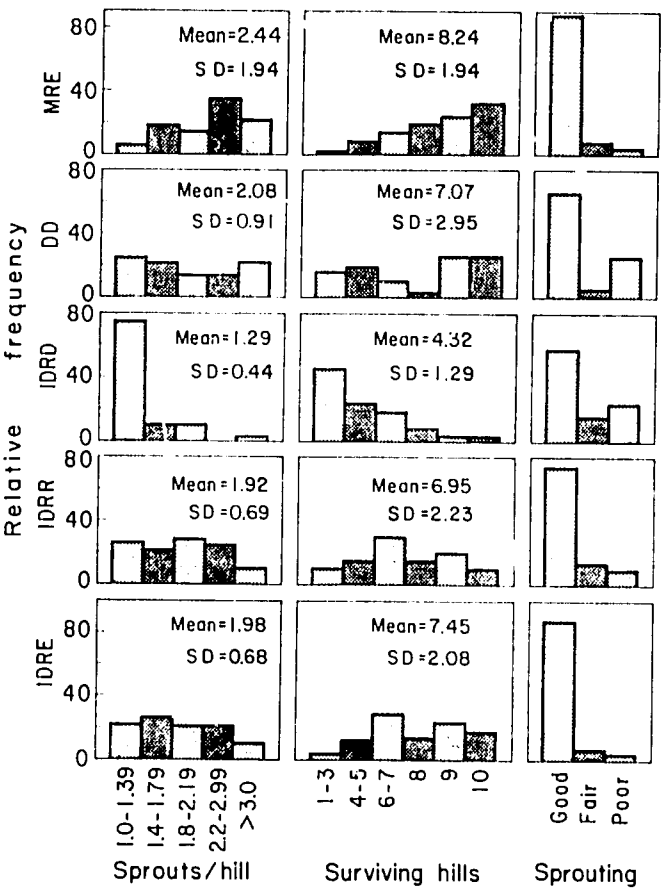

Figure 3. Relative frequencies of sprouts per hill, survival and sprouting evaluation among the various response types

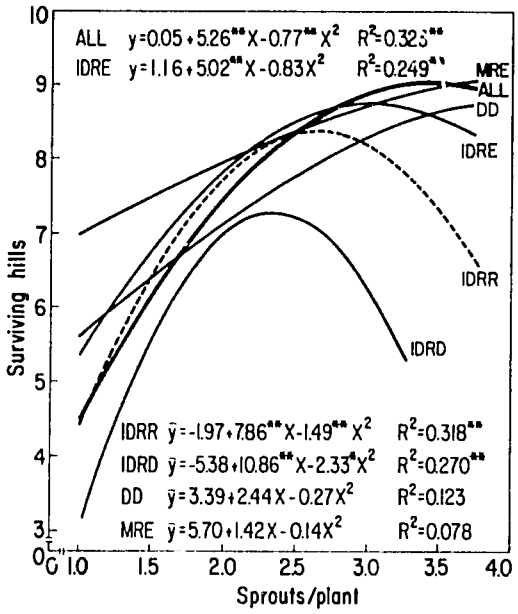

Figure 4. Polynomial regression lines indicating the relationship of survival rate and sprouts per hill for the various response types

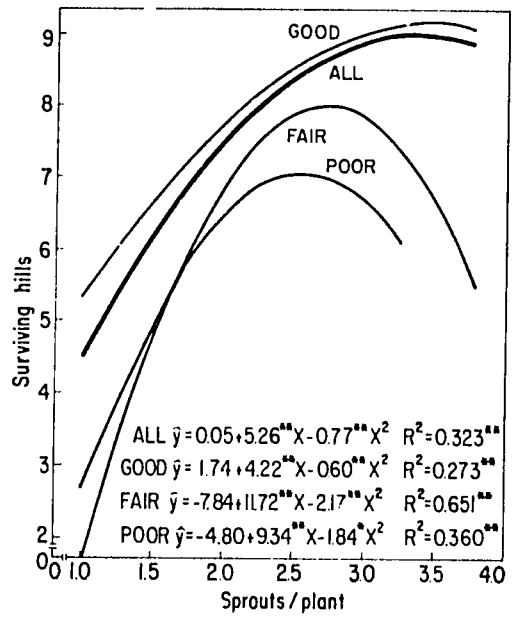

Figure 5. Polynomial regression lines indicating the relationship between survival rate and sprouts per hill for the various sprouting classes (evaluated before planting)

The relationship between sprouts surviving/hill and survival among the various response types is somewhat confusing (Figure 4). A test for coincidence of regression equations indicates that the equations are significantly different but none of the response class equations are as good as the overall equation in terms of R^2 value.

The relationship of sprouting (rated in propagation beds as good, fair and poor) with the various response types was investigated. We found that in general, good sprouting lines were randomly distributed among the response types but fair and poor sprouting lines were represented in greater than expected numbers in the IDRD, DD, and none surviving (NS) classes. We interpret these results to mean that poor sprouting will result in fewer surviving plants and in those that do survive, the root piece is more likely to disappear. Thus the IDRD class is made up of lines which are generally poorer sprouters, resulting in fewer sprouts surviving/hill and fewer surviving hills.

The relationship between sprouts surviving/hill and survival among the various sprouting classes is more revealing (Figure 5). It may be seen that the fair and poor sprouting types represent a different relationship between sprouts surviving/hills and survival than the good sprouting lines. The quadratic nature of the response may be explained by assuming that the proximal root pieces survived at a higher rate than the more distal pieces in fair and poor sprouting lines (which would be expected to show a higher rate of strong proximal dominance).

Thus the breeding lines represented by the right side of the regression lines are made up of poor and fair sprouting types with strong proximal dominance. The result is a survival of more proximal pieces than distal ones,

Table 8. Frequency distributions of response types and sprouting classes for the years 1971 and 1980

	1971	1980
IDRE	22.2	23.2
IDRR	21.8	18.2
IDRD	19.4	17.3
DDRE	19.4	11.4
DDRR	10.1	0.9
MRE	3.9	22.7
NS	3.1	6.4
Good sprouting	23.2	74.6
Fair sprouting	37.2	11.3
Poor sprouting	39.6	14.1

which is evidenced by more sprouts surviving/hill and a lower survival rate. We can also explain the quadratic nature of the IDRR and IDRD response types by noting that these classes are composed of 25% and 40%, respectively, of fair and poor sprouting lines.

Further evidence for the importance of the relationship between sprouting and response type can be obtained by comparing response types in the 1971 preliminary trial with the 1980 preliminary trial (Table 8). It may be noted that frequency of the DD and IDRD response group has decreased and the frequency of the IDRE and MRE response types has increased.

We may conclude that by increasing the sprouting ability of the population as a whole we have also increased the frequency of root piece enlargement and decreased the frequency of direct daughters in the population. Since we had no data from 1971 on survival or number of sprouts surviving/hill, we can only speculate that both have increased due to increasing sprouting ability of the population.

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Seed bed preparation at AVRDC for seedling screening.

Physical Factors Affecting Root Yield of Sweet Potato (*Ipomoea batatas* (L) Lam)

A. SAJJAPONGSE and Y.C. ROAN

Asian Vegetable Research and Development Center, Shanhua, Tainan 741, Taiwan

INTRODUCTION

In the case of sweet potato, as with most root crops, it is only the roots themselves which are normally harvested and considered as the source of food. The extent of root development, and hence tuberous yield, is to a large extent influenced by the vegetative part or top growth, though favorable environmental conditions for top growth are not always suitable for root formation. A leafy plant with vigorous vine growth is quite often found to have a low root yield. It is believed that the first stage of root formation is the accumulation of photosynthate, predominantly of carbohydrates, from the top (Austin *et al* 1970). The timing of N application, irrigation or soil moisture, and soil physical properties, are some of the factors believed to play important roles in root yield. Too much N could cause excessive top growth but a reduction in root yield (Johnson and Ware 1948; Lana and Peterson 1956; De Geus 1967). Jones (1961) suggested that approximately 3810 mm of water for the season were required to produce a crop of sweet potato. Pearson (1961) found that irrigation application of 254 mm at weekly intervals was sufficient to produce high sweet potato yield while with the application of 127 mm at weekly intervals the yield was significantly reduced. The imposition of temporary drought stress at a certain time may trigger more root formation; however, soil compaction may also have a significant influence on yield.

The objective of this study is to evaluate the effect of irrigation and soil compaction on root yields of sweet potato.

MATERIALS AND METHODS

Three experiments were carried out during 1979-80. Two field experiments were designed to investigate the effect of time of irrigation; and the third, a pot experiment, was conducted to study the effect of soil compaction on root yield.

Field experiments

The two field experiments, one in the fall (12 October 1979-31 March 1980), and the other in spring (19 March - 31 July 1980), were identical, except that ten irrigation treatments were employed in the fall and 12 treatments were used in the spring.

A randomized complete block design with various times of irrigation as treatments ranging from 20 days after planting (DAP) to 120 DAP, and replicated four times, was used. The land was first rototilled and beds of 3 x 12 m in size, consisting of three ridges, were afterwards constructed. The replications were separated by 1 m walkways and the beds by 0.5 m walkways.

Prior to planting, the bed was fertilized with 40, 60, and 100 kg/ha of N, P_2O_5, and K_2O as urea, superphosphate and potassium chloride, respectively. One month later, all treatments received an additional fertilization of 40 and 100 kg/ha of N, and K_2O as a side-dressed application. Hilling was also performed at this time. AVRDC's sweet potato breeding line AIS 35-2 was used for planting. Cuttings about 30 cm long were planted on the beds at a spacing of 0.3 x 1 m (3 rows/bed).

The first differential irrigation treatment started at 20 DAP and the last one at 120 DAP. During each irrigation, the soil moisture was brought up to about field capacity. Throughout the development of the plant, weed was removed by hoeing. At harvest, only the center row was taken for data collection.

Pot experiment

This pot experiment consisted of eight different bulk densities of soil as treatments. It was arranged in a randomized complete block design and replicated three times. The experiment was conducted outside the greenhouse.

Soil taken from the field was air-dried and passed through a 2 mm sieve. It was then placed in a 14 liter bucket to a depth of about 4 cm and pounded with a wood pestle to a uniform compaction, as checked by the penetrometer. This was repeated layer after layer until the bucket was almost full. Eight bulk densities were obtained in this manner. Details of the treatments are presented in Table 1. Prior to pounding, each batch of 18 kg soil received 10.3, 9 and 4.5 g respectively of ammonium sulfate, superphosphate, and potassium chloride. After pounding, the soil moisture content was brought up to field capacity and incubated for three days before planting. One 30 cm cutting of sweet potato selection AIS 35-2 was planted in each pot on 1 August 1980. A soil moisture content of about field capacity was maintained throughout the growing period of the plant. At harvest, 23 December 1980, the above ground portion was cut and weighed separately from the root. Root yield, number of roots per plant, and average root weight were also recorded.

Table 1. Details of the treatments used in the spring experiment

Treatment	Total dry soil	Vol of soil	Bulk density	Penetrometer reading
	kg/pot	liter	g/cc	kg/sq cm
1	17.0	14.2	1.19	soft
2	17.5	14.2	1.23	soft
3	18.5	14.2	1.30	2
4	19.9	14.2	1.40	3
5	21.3	14.2	1.50	5
6	22.7	14.2	1.60	11
7	24.1	14.2	1.70	13
8	25.6	14.2	1.80	15

RESULTS AND DISCUSSION

Effect of time of irrigation

The effects of time of irrigation on root yield, vine weight, root number, and root size are presented in Table 2 for the fall planting. Top growth or vine fresh weight was significantly affected by time of irrigation. The lowest top growth of 3.8 t/ha was from the check (no irrigation). Among the irrigated treatments, applying water at 30 DAP gave the lowest top growth of 4.3 t/ha whereas the highest growth of 6.9 t/ha was from the treatment which received irrigation at 60 and 120 DAP. The data indicated that irrigation at the later growth stage gave better top growth. The trend was also very similar for root yield. The lowest yield of 13.4 t/ha was from the check which received no irrigation. Yield of the treatment receiving irrigation once at 30 DAP, 14.4 t/ha, was much lower than those of other treatments which received irrigation at the later growth stages, 60, 90, and 120 DAP. The difference in root yield was accounted for by differences in root size as shown by correlation coefficient analysis (Table 3). The results of the second experiment, in the spring of 1980, are shown in Table 4. They were essentially in agreement with the fall 1979 results. Again, applying irrigation at 30 DAP drastically reduced root yield even lower than the check (5.6 vs 6.6 t/ha). Irrigation at 40 or 50 DAP also gave low yields. The best single water application was 60 DAP with the yield of 8.3 t/ha. Applying irrigation two times at 40 and 90 DAP gave the highest yield. Yield difference was attributed to difference in root size (Table 3).

Economic yield of the crop is not always closely related with total growth. For sweet potato, excessive top growth may result in low root yield. The relationship between vine weight and root yield of the fall experiment was highly significant ($r = 0.88^{**}$) whereas that of the spring trial was not

Table 2. Effect of time of irrigation on yield and top growth of sweet potato (AIS 35-2), fall 1979, AVRDC

Time of irrigation	Vine wt	Root yield	Root no.	Root size
DAP	------- t/ha	--------	no/plant	g/root
30	4.4	14.2	4.13	122.90
60	5.2	18.8	4.27	152.30
90	5.8	18.6	4.23	152.09
120	6.8	19.9	4.32	148.69
30, 60	5.3	18.1	3.87	164.67
30, 90	5.6	17.0	4.84	120.35
60, 120	6.9	19.6	4.36	147.21
90, 120	6.5	17.6	3.92	154.43
30,60,90,120	6.5	19.2	4.34	143.21
no irrigation	3.8	13.4	3.83	116.76
LSD .05	1.68	ns	ns	ns

ns = not significant

Table 3. The correlation coefficient of root yield versus root number and root weight per plant as affected by time of irrigation, AVRDC, 1979-1980

	Correlation coefficient			
	Fall		Spring	
	Root no.	Root wt	Root no.	Root size
Total yield	0.36	0.75*	0.44	0.95**

*significant at 5% probability level; **highly significant at 1% probability level

significant (r = 0.55). Suppression of leaf growth selectively by moisture stress may favor the formation of flower buds (William and Joseph 1976) and time of irrigation could have a pronounced effect on root yield of sweet potato (Tanaka and Sekioka 1976). The formation of sweet potato roots may be stimulated when drought stress is imposed some time during the plant growing period. Jones (1961) showed that irrigating sweet potato when 40% of total available water was depleted gave the highest root yield. This study indicates that the first irrigation ought to be withheld until 60 DAP. If this is done, more photosynthate may be translocated to enhance the formation of and/or the enlargement of roots.

Effect of soil compaction

Table 5 shows the effect of soil compaction on growth and root development of sweet potato. As soil compaction increased, plant growth, as shown by number of leaves per plant and plant height measured at 30 DAP, was

Table 4. Effect of time of irrigation on root yield of sweet potato (AIS 35-2), spring 1980, AVRDC

Time of irrigation	Vine wt	Total yield	Root no.	Root wt
DAP	------- t/ha	---------	no/plant	g/root
20	15.0	7.7	3.9	68.5
30	14.8	5.6	3.1	63.8
40	12.1	5.7	3.4	60.3
50	17.0	6.9	3.4	71.0
60	15.5	8.3	3.1	87.5
90	21.9	7.4	3.4	74.5
20,90	18.8	9.1	3.6	80.8
30,90	17.5	9.0	3.6	81.3
40,90	20.3	11.9	3.5	102.1
50,90	20.5	10.4	3.5	94.8
20,30,40,50,60,90	14.6	10.0	3.9	84.8
no irrigation	17.3	6.6	3.3	67.5

Table 5. Effect of soil compaction on sweet potato (AIS 35-2), 1980, AVRDC

Bulk density	Growth at 30 DAP leaf no.	Growth at 30 DAP height	Vine wt	Root yield weight	Root yield no.	Root yield size
g/cc	no./plant	cm	---g/plant----		no./plant	g/root
1.19	71.3	58.7	308.7	294.3	6.3	46.7
1.23	51.7	35.3	248.3	324.3	3.3	98.3
1.30	50.3	29.0	255.0	410.7	4.0	102.7
1.40	61.0	39.0	245.0	367.7	4.7	78.2
1.50	59.3	38.0	286.7	406.7	6.7	60.7
1.60	42.7	37.7	261.7	282.7	5.7	49.6
1.70	38.7	33.0	353.3	160.0	7.7	20.8
1.80	47.7	36.0	271.7	323.0	4.0	80.7

Table 6. The correlation coefficient of root yield versus root number and root size per plant as affected by soil compaction, AVRDC, 1980

	Correlation coefficient	
	Root no.	Root size
Total yield	-0.53	0.76*

*significant at 5% probability level

drastically reduced. The best growth was obtained from the lowest soil bulk density (1.19 g/cc). On the other hand, the effect of soil compaction on root yield was somewhat different. Low yields resulted from either too high or too low soil compactions. The best yields of 367.7 to 410.7 g/plant were obtained when soil had a bulk density of between 1.3 and 1.5 g/cc. Yield differences were due more to difference in root size than to root number (Table 6).

To obtain better yield, the density of soil should be considered. The results show that loose soil or soil with low bulk density enhances more vegetative growth at the expense of root formation. On the other hand, high bulk density reduces both root yield and top growth of sweet potato and root enlargement is resisted. The best bulk density of the soil is about 1.3 to 1.5 g/cc.

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Timing and Frequency of Topping Sweet Potato at Varying Levels of Nitrogen

P. U. BARTOLINI

Philippine Root Crop Research and Training Center, VISCA, Leyte 7127, the Philippines

INTRODUCTION

In the Philippines, consumers eat not only the roots but also the tender tops of sweet potato (*Ipomoea batatas* (L) Poir). Sweet potato tops provide a good source of vitamins A and B_1, iron and protein. They are a potential source of food and feed to supplement the usual diet of people and animals.

Sweet potato tops contain as much protein as 2.8 g per 100 g of edible portion (FNCR 1968). Li (1974) has also mentioned that roots of various cultivars contain between 1.3% and 25.8% protein. When tops are harvested it is important therefore to time the harvesting so that the production of roots is not affected. Sweet potato tops are also valuable as planting materials for propagation. Shortage of planting materials often limits the expansion of production areas.

The objectives of this experiment were to determine the best age of plant for topping, to measure the effects of frequency of topping on root formation and on the chemical components of roots, and to determine the effects of various fertility levels and topping treatments on the yield and on other agronomic characters of sweet potato.

MATERIALS AND METHODS

Three experiments were conducted over two years, and designated as Experiment A (comprising two experiments in the first year) and Experiment B (one experiment in the second year).

Experiment A

This experiment examined the interaction of plant age and frequency of topping and was conducted for two croppings - one dry and one wet season - in the first year. The treatments included in Experiment A are shown below:

Treatment code	Dry season cropping age of plant at topping[a] (wks after planting)	Wet season cropping age of plant at topping[b] (wks after planting)
T_0	Zero topping	Zero topping
T_1	4-6	4-8
T_2	6-8	6-10
T_3	8-10	8-12
T_4	10-12	10-14

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T_5	12-14	12-16
T_6	14-16	Continuous topping (4-16)
T_7	10-16	-
T_8	12-16	-

[z]Two toppings at biweekly intervals were done except for T_0, T_7 and T_8 which were topped 0, 4, and 3 times, respectively
[y]Three toppings at biweekly intervals were done except for T_0 and T_6 which were topped 0 and 7 times, respectively

The same procedure and cultural management were used for both croppings. A uniform rate of fertilizer of 60-62.4-49.8 kg NPK/ha was applied at planting. Thirty-centimeter apical cuttings of variety BNAS 51 were planted singly and spaced 25 cm apart in rows 100 cm apart. Weeding was done as often as necessary. Cultivation and hilling up was done after one month from planting. Tips were cut in 35 cm lengths by cutting at the seventh node counting from the whorl of unopened leaves. Data on number and weight of tops, marketable roots and nonmarketable roots at harvest were gathered. The randomized complete block design with three replications was used for both experiments.

Experiment B

This was conducted in the second year and tested combinations of plants topped at four different ages and treated with five different fertilizer levels. They consisted of a zero topping control (T_0), topping thrice at biweekly intervals at 6-10 (T_2) and 12-16 (T_5) wks after planting, and topping seven times starting at the 4th and ending at the 16th week after planting (T_6). The fertilizer levels were 0-0-0, 0-60-60, 30-30-30, 60-60-60 and 90-60-60 NPK kg/ha. All fertilizer treatments were applied at planting except 90-60-60; in this case one-third of the N was applied one month after planting. The rest of it was applied at planting.

The experiment was conducted in split plot design with three replications each with N levels as the main plot and the age of plant at topping as sub-plot. Data gathered followed the pattern of that in Experiment A and analysis of the root for starch and sugar content was included.

RESULTS AND DISCUSSION

Marketable root yield

The results from the dry season cropping (Figure 1) show the effects of topping on yield of marketable roots. Although not statistically significant, numerical differences in root yield seem to follow a certain trend. Compared with T_0 (zero topping control) the highest yield was obtained in T_1 or topping twice about one month from planting, which gave a yield of 21 t/ha. This was followed by T_2, topping about 1½ months from planting, which gave a yield of 20 t/ha of marketable fresh roots. The results seem to suggest that topping twice increased yield when done when the plant was between one and two months old. However, it appears that topping is detrimental to root production when done beyond two months from planting. Rapid root formation and development takes place at this time. Increasing the frequency of topping to four times as shown by T_7 reduced yield even more drastically.

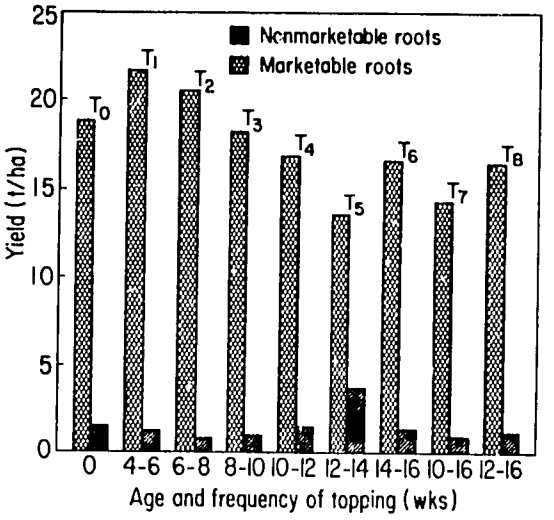

Figure 1. Mean yield of marketable and nonmarketable roots of sweet potato as affected by topping treatments, dry season cropping, 1979

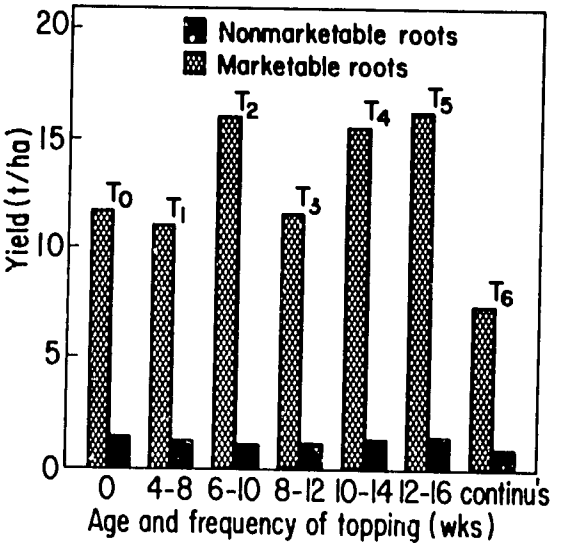

Figure 2. Mean yield of marketable and nonmarketable roots of sweet potato as affected by topping treatments, wet season cropping, 1979

The wet season cropping shows significant differences among topping treatments (Figure 2). Compared with T_0 (control), T_2 gave the highest yield of 17.1 t/ha followed by T_5 with 16.8 t/ha of fresh marketable roots. T_6 (continuous topping) resulted in drastic reduction in yield with only 7.1 t/ha. Topping thrice during the crop's growth cycle showed significant effects on the yield of sweet potato. Proper timing of topping increased yield but more frequent and continuous topping reduced yield considerably.

During the second year, in Experiment B, the weight of marketable roots was affected significantly by topping and not by fertilizer treatments (Figure 3). Fertilization did not overcome the marketable root yield reduc-

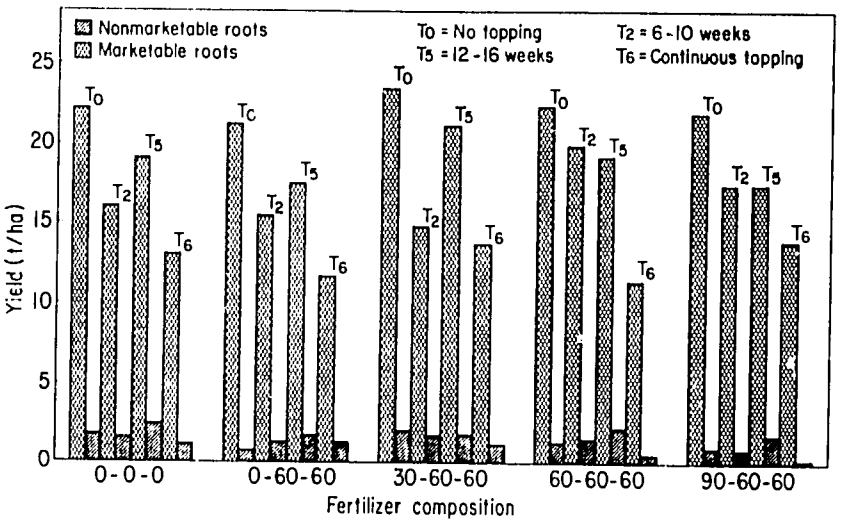

Figure 3. Yield of marketable and nonmarketable roots of sweet potato (BNAS 51) as affected by fertilizer and topping treatments, dry season cropping, 1980

tion caused by topping, and this also confirmed the studies made by Gonzales *et al* (1977). T_0 (zero topping) gave the highest yield of marketable roots, followed by T_5 with 22.0 and 18.5 t/ha respectively. T_6 (continuous topping) resulted in the lowest yield with only 12.8 t/ha marketable roots.

Number of marketable roots

High yield is associated both with bigger marketable roots and with a higher number of them. Topping only thrice favorably induced the production of more marketable roots (Table 1, wet season cropping). T_6 (continuous topping) reduced the number of marketable roots considerably in all croppings.

Both fertilization and topping treatments affected the number of marketable roots (Table 1, dry season). Increasing levels of fertilizer reduced the number of marketable roots. This may be due to the vigorous growth of the plant which produced more vegetative parts and lower yield. Zero fertilization and zero topping resulted favorably in a greater number of marketable roots.

Top yield

More frequent or continuous topping increased the number successively, in all croppings, so that the higher the number of toppings, the higher the number of tops harvested, although it reduced root yield (Table 1).

Percentage starch content (dry weight basis)

The level of fertilizer and frequency of topping treatments affected the starch content of the roots (Table 2). Increasing levels of nitrogen fertilizer seemed to result in an increase in the percentage starch content of roots. F_3 (60-60-60) and F_4 (90-60-60) gave the highest starch percentage, both 67.1%. They were followed by F_2 (30-60-60) and F_1 (0-60-60), which gave percentage starch contents of 66.5% and 66.0% respectively.

Topping seemed to affect the percentage starch content in the roots as shown by its decreasing order from continuous topping (T_6) with 66.8% to zero topping with only 66.0% starch.

Percentage total sugars

Percentage of total sugars was not affected either by fertilization or by topping treatments. Neither did percentage sugars significantly vary among fertilizer or among topping treatments.

CONCLUSION

Topping increased root yield significantly when done between about 1½ to two months after planting. Topping beyond two months was detrimental to root production. More frequent or continuous topping reduced root production drastically but higher top yield was obtained.

Nitrogen fertilization and topping seemed to affect the percentage starch content of the roots. Percentage of total sugars was not affected either by fertilization or by topping.

Table 1. Mean numbers of marketable and nonmarketable roots and number of tops harvested of sweet potato (BNAS 51) as affected by age of plant at topping and frequency of topping and fertilizer treatment

Treatment	Number of roots ($\times 10^3$)*		No. of tops harvested/ha ($\times 10^4$)
	marketable	nonmarketable	
Experiment A			
Dry season cropping			
T_0 (zero topping)	76.8	42.7	-
T_1 (4-6 wks)	82.9	34.5	21.7 d
T_2 (6-8 wks)	72.3	30.3	36.7 d
T_3 (8-10 wks)	73.5	25.8	53.4 d
T_4 (10-12 wks)	82.7	41.8	65.4 bc
T_5 (12-14 wks)	72.7	41.6	67.0 bc
T_6 (14-16 wks)	70.8	43.3	52.0 c
T_7 (10-16 wks)	72.0	37.3	111.0 a
T_8 (12-16 wks)	64.6	40.8	79.1 b
CV ( )	16.3	22.1	3.6
Wet season cropping			
T_0 (zero topping)	34.8 c	13.0	-
T_1 (4-8 wks)	33.7 c	19.5	71.5 c
T_2 (6-10 wks)	50.8 a	14.8	110.1 bc
T_3 (8-12 wks)	36.5 c	19.0	117.0 b
T_4 (10-14 wks)	49.3 a	16.2	109.2 bc
T_5 (12-16 wks)	43.3 b	18.8	114.8 b
T_6 (continuous topping)	27.5 d	11.2	178.2 a
CV ( )	21.8	30.4	18.4
Experiment B			
Dry season cropping			
Fertilizer level			
F_0 (0-0-0)	104.8 a	46.9 a	50.1
F_1 (0-60-60)	89.0 b	39.7 ab	48.9
F_2 (30-60-60)	87.2 bc	37.0 abc	52.0
F_3 (60-60-60)	86.8 bcd	28.4 bcd	54.7
F_4 (90-60-60)	80.4 e	20.6 d	55.2
Age of plants at topping			
T_0 (no topping)	105.6 a	37.2 ab	-
T_2 (6-10 wks)	83.7 bc	31.5 bc	30.7 c
T_5 (12-16 wks)	97.4 ab	46.4 a	45.9 b
T_6 (continuous topping)	71.7 c	23.1 c	81.1 a
CV ( )			
Mainplot	24.4	45.4	25.1
Sub-plot	7.2	38.9	15.6

*Means followed by the same letter do not differ significantly at 5% level using Duncan's Multiple Range Test

Table 2. Percentage starch content and percentage total sugars as affected by fertilizer levels and topping (dry weight basis)[a]

Treatments	% starch content	% total sugars
Fertilizer levels		
F_0 0-0-0	65.4	12.6
F_1 0-60-60	66.0	12.5
F_2 30-60-60	66.5	12.3
F_3 60-60-60	67.1	12.4
F_4 90-60-60	67.1	12.6
Topping ages		
T_0 zero topping	66.0	12.5
T_2 6-10 wks after planting	66.3	12.5
T_5 12-16 wks after planting	66.7	12.4
T_6 continuous	66.8	12.6

[a]Three samples taken from each replication were combined for the analysis to produce 100 g dry weight sample

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Mechanization of Sweet Potato Production

L.G. WILSON[a] and C.F. ABRAMS, JR.[b]

[a]Horticultural Science, North Carolina State University, Raleigh, NC 27650, USA
[b]Biological and Agricultural Engineering, North Carolina State University, USA

INTRODUCTION

Approximately 700,000 tons of sweet potatoes are produced on approximately 48,500 ha annually in the United States. Over one third of this production is in North Carolina. Some farmers grow just a few hectares while others grow several hundred hectares to this crop. In North Carolina there are approximately 1500 farmers who grow sweet potatoes, but about 90% of the crop is produced by about 10% of the growers. The latter generally grow sweet potatoes as their principal crop and utilize more mechanization than most smaller growers.

Sweet potato production operations are labor intensive. As labor costs increase and/or labor becomes unavailable, the need for mechanization increases. Developments in mechanization result in large measure from public supported research efforts at US land grant institutions. Mechanization on the farm is often based on research findings. Such implementation plus many other innovations have resulted in labor saving equipment and methods for nearly every phase of production.

Mechanization of sweet potato production must be considered systematically with attention given to the interactions among the various processes and operations which comprise the growth, harvest, and disposition of this product.

The sweet potato production system is comprised of five identifiable stages: plant production, plant growth, harvest and handling, on-farm processing, and disposition. Figure 1 presents this view schematically and attempts to show the myriad interdependencies which exist. There is room for improvement at every stage and significant progress has already been made.

Operations described herein are elaborated on more fully in a North Carolina sweet potato production bulletin (Wilson *et al* 1980).

TRANSPLANT PRODUCTION

Sweet potatoes are vegetatively propagated. Commercial sweet potato production practices include the production of transplants from 'mother roots'. Sweet potato seedstock (storage roots) is bedded early in the spring for the production of transplants. Presprouting seedstock at 24-30°C and 90-95% relative humidity for two to four weeks will significantly increase transplant production.

The sweet potato plant bed site should be on well drained sandy loam soil which has not been used to produce sweet potatoes for at least three years (to avoid seedborne disease problems). This soil should be well-

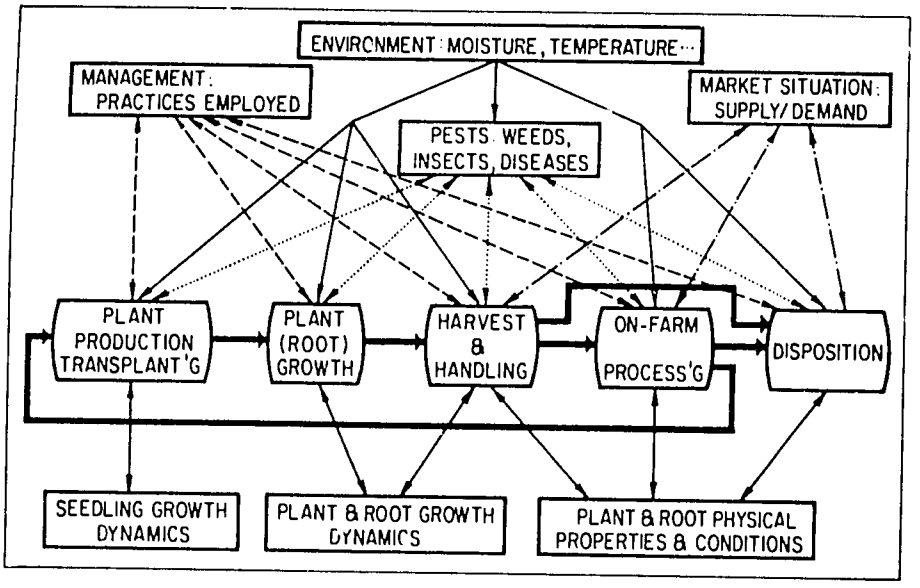

Figure 1. Schematic of sweet potato production system simulation

tilled. Most sweet potato varieties are susceptible to flooding damage which dictates that beds be elevated. Generally the seedstock is distributed uniformly over the prepared soil surface and then covered with soil to a uniform depth of about 5 cm.

Seedstock distribution can be done by hand by individually placing the roots on the soil. Usually seed is carefully poured from 23 kg (1 US bu) boxes. This can be done by hand carrying the box to the bed. Most often, however, a trailer carrying several boxes of seedstock will move over the bed area while workers distribute the roots box by box. Dumping devices developed for this purpose can be mounted on the rear of the trailer.

Bins which will hold approximately 450 kg of sweet potato roots are replacing the single bushel units for seedstock storage and handling. Emptying these boxes onto the bed is accomplished using mechanical or hydraulic dumping devices mounted on the rear of a trailer. Transfer of bins along the trailer into the dumping position is usually facilitated by roller conveyors.

Bulk sweet potato seedstock bedding equipment (Edwards Manufacturing Co, Bunn, NC) has been developed which will continuously and uniformly distribute roots on the bed surface. The hopper is approximately the shape of an inverted pyramid and holds 5675 kg of seedstock. The opening at the base of the hopper is 30.5 cm x 76.2 cm. The seedstock drops through this opening onto a hydraulically driven conveyor. Uniform distribution is accomplished by varying the speed of the conveyor and the speed of the tractor. Seedstock damage appears to be equivalent to that observed using other distribution systems. This is the most rapid, least labor intensive system currently in use.

Rotting of sweet potato seedstock in beds can be minimized by not bedding diseased roots. The application of approved fungicides directly to bedded seedstock further reduces the potential for development of rots.

Low volume tractor mounted sprayers are used for this operation.

To restrain the mother roots during transplant pulling or cutting operations some growers use plastic netting. This netting consists of filaments which are heat-bonded together on approximately 5 cm centers. Netting is supplied as a roll which is mounted on the rear of a tractor. As the tractor advances over the bed the netting is unrolled onto the bedded seedstock, prior to covering with soil. The width of the netting typically extends several cm beyond the width of the bedded seedstock. It is temporarily held in place by shovelling soil onto the outer edges.

Covering bedded sweet potato seedstock with soil can be undertaken using several types of three-point hitch toolbar-mounted equipment. Well tilled loose soil can be thrown over the bed in a single operation. Generally soil is dug from between the beds for this purpose resulting in between bed drains. Most bed covering equipment requires a baffle or dray to level the soil uniformly over the seedstock. Uniform soil depth is important for uniform transplant production. Bedding too deeply may result in O_2 starvation, CO_2 accumulation and subsequent breakdown and rotting.

Fertilization of sweet potato seed beds is important for maximum production of strong, vigorous transplants. Generally, about 36 kg of 8-8-8 NPK or its 1-1-1 equivalent grade are recommended per 100 sq m of bed area. Fertilizer may be applied after the seedstock is covered with soil using a spreader. It should then be lightly raked to incorporate it into the top 0.5 cm of soil. Another method is to incorporate the fertilizer by broadcasting into the top 2.5 cm of soil prior to making the beds. Additional fertilizer should be broadcast later as a topdressing (at 10 kg of $NaNO_3$/100 sq m) following each pulling of transplants.

Weed competition must be minimized in sweet potato beds for optimum transplant production. The application of approved and recommended herbicides (such as diphenamid) is made by low volume sprayer after the seedstock is covered with soil.

Sweet potato seedstock is vulnerable to freezing temperatures, and thus, clear plastic bed covering (1-2 mm thickness) is commonly used for early bedded roots. Plastic film is provided in rolls of desired widths (approximately one-third wider than bed width) and unrolled onto the soil surface from the rear of a tractor in the same way as described for netting. Single discs mounted behind and on each side of the unrolling film are used to deposit soil onto the edge of the film to hold it in place. Use of plastic film bed covers is also a form of moisture control.

If plastic film bed coverings are used this material should be moderately ventilated within 24 to 48 hours to prevent overheating, O_2 depletion and CO_2 accumulation. This can be accomplished by perforating the plastic film (approximately one 1 cm hole per 25 sq cm) with short spikes mounted on a drum and pulled over the beds behind the tractor. When transplants begin to emerge throughout the bed and/or when daily ambient temperatures are generally about 20°C or higher, plastic bed covers may be removed.

TRANSPLANTING AND CROP PRODUCTION

Field preparation for sweet potato production is similar to that for

other row crops. Fields are plowed and tilled with appropriate equipment as early as soil conditions permit. Typical row width is 107 cm and ridges 20-30 cm high are prepared.

Field fertilization practices vary, but some fertilizer is usually applied prior to planting. This is either broadcast and incorporated, or drilled into the row as part of the land forming operations. In the latter case liquid nematicide fumigants may be applied simultaneously; transplanting must then be delayed two weeks to avoid injury. Whatever the sequence of operations it is important to prepare and maintain high beds to minimize the effects of flood damage due to potential extended periods of rain in late season.

Transplanting sweet potatoes from the beds to the field (20-30 cm within-row spacing) is done with equipment similar to that used for most other transplanted vegetable crops. Commercial transplants can be pulled from the beds but should be cut if diseases are suspected in the beds. Transplants used for seed production should be cut from the beds to prevent the possible transfer of seedborne or soilborne diseases to the field. Cutting transplants from beds is still a manual operation.

Herbicides are widely used to minimize weed competition in sweet potato fields. Preplant incorporated herbicides, vernolate for example, can be applied prior to planting or preemergence herbicides such as diphenamid, chloramben, or DCPA can be applied to the soil directly over the tops of the plants by low volume sprayers within a day of transplanting.

HARVEST AND HANDLING MECHANIZATION RESEARCH

O'Brien and Scheuerman (1969) describe the general harvesting aid approach as now applied to sweet potatoes. They describe a machine consisting of a digging elevator and inspection belt interposed between platforms on which workers stand to retrieve roots from the belt. The machine is preceded in the field by a deviner for removing the mass of vines from the row. Workers on the machine generally perform the same operations as they would on the ground: they separate roots from remaining vines and debris, classify roots by size and condition, and place them into containers which may be either bushel boxes or 450 kg bins.

Hammerle (1971) reviews a possible system for fully mechanized sweet potato harvesting. He also discusses an early attempt at combine harvesting which included all operations in one machine: digging, soil-root-vine separation, size grading, cleaning and packing.

Burkhardt [illegible] (1971) present the first demonstrably workable approach to combine type harvesting of sweet potatoes The machine which they developed embodied the concept of an overhead vine conveyor, vine separation and soil removal. The roots were deposited into large field bins and the functions of grading and further cleaning were relegated to a central facility. This basic harvesting approach was developed into a commercial machine (Johnson Manufacturing Co, Pendleton, NC) and has seen some limited use in the southeastern USA.

Humphries and Abrams (1975) describe a machine for removing the vines and main stem from the roots prior to digging and discuss its possible use

both with harvesting aids and combine type harvesters.

Mechanized field grading of sweet potatoes has received some attention. Goodman and Hamann (1971) and Carr *et al* (1970) describe the development of a sizer which could be incorporated into a harvester. This sizer utilized the principle of an expanding opening between belts moving in the same general direction to provide size discrimination and a V formed by belts operating on different-sized sheaves for pre-sizing orientation. The concept was ultimately employed in the development of a stationary unit for use in a central grading facility as described by Brantley *et al* (1975).

Curing and storage of sweet potatoes is recognized as an important part of an efficient system. The ability to store the roots provides for orderly marketing of the product and year-round availability of it in its fresh form. Curing coupled with well managed storage tends to maintain a high quality product. Kushman and Wright (1965 and 1968) describe means for environmental control of storage facilities by means of overhead ventilation and a system for proper curing and storing of the crop with proper attention to temperature and humidity.

The harvest and handling and the on-farm processing stages of the production system consume the largest share of the human effort and capital costs, exclusive of land. The success of the producer is very much dependent upon the effective management of these operations. Furthermore, the nature of these operations are such as to lend themselves to improvement through mechanization.

As with many crops, mechanization of harvest has progressed along two pathways: harvesting aids and combine type harvesters. Harvesting aids are machines which, when introduced into the system, result in possible improvements in the existing traditional harvesting approaches but which do not fundamentally change the sequence or types of operations performed. Machines which allow workers to ride through the field while performing crop retrieval, as opposed to walking and stooping, are typical of this class of mechanization. Combine type mechanization alternatives generally embody some fundamental change in the sequence and types of operations performed and generally reduce the direct human effort drastically.

CURRENT HARVESTING AND HANDLING OPERATIONS

Mechanization of sweet potato harvesting and handling operations is increasing. In the United States most sweet potatoes are still dug out of the ground and picked up by hand. Digging equipment basically inverts sweet potato hills to expose the storage roots for easy collection and field grading. The effectiveness of this operation depends on proper equipment adjustment and careful ground speed control. Some harvesting systems require that vines be removed by rotary mower. Others also require that lateral vines be cut by vertically mounted flat discs (this is known as barring off).

Containers for sweet potatoes vary from 23 kg units to 450 kg bulk bins. One large North Carolina grower uses several 2200 kg bulk bins. Hand manageable units include wirebound boxes, wooden boxes and bushel baskets. These are handled individually from the field to the shipper and/or into curing and storage. Palletization of these containers is common, and this minimizes

handling and reduces damage. Plastic buckets are commonly used for picking up sweet potatoes and transferring them into bins.

Moldboard plows dig sweet potatoes with a minimum of skinning damage, but do not expose the roots very well. Moldboard plow modifications can improve digging effectiveness with only moderate skinning. A popular modification includes cutting off the end of the turning blade and attaching a rotating spiral to facilitate loosening the soil around the roots.

Irish potato diggers are popular in some areas. Their rod conveyor chain effectively separates storage roots from the soil under proper moisture conditions. But light, dry soil sifts through the conveyor chain readily and allows too much contact with the tender storage roots causing excessive skinning.

Large discs mounted on three-point hitch tractor toolbars have been widely adopted in recent years. The discs are adjusted at approximately a 45° angle to the row and about 10° off vertical. Vines are cut at the same time as the hills are inverted. This sytem works well in light soils exposing the roots with little skinning, but does not work in heavy soils.

Harvesting aids are those machines which, after preparatory mowing and barring off operations, dig, elevate and convey sweet potatoes to a sorting crew riding on board the harvester. Generally, labor requirements are similar to those needed for hand harvesting, but advantages are that all labor is kept together and the men's work can be undertaken standing or sitting rather than stooping or crawling.

Soil carried along with the sweet potatoes provides some cushioning and is gradually sifted out by the conveyor chain. Shaking devices on the elevator chain help to remove soil. For use in light, sandy soils the chain is usually continuous for elevation and sorting. In heavier soils one length of chain elevates the sweet potatoes to the sorting area where they are dropped a few cm onto a horizontal chain. This slight drop helps to break up the soil and expose the sweet potatoes. Sweet potatoes are detached by and from the vine-root mass where necessary, and separated or graded by size or quality (or both) into containers for delivery to the warehouse. Some harvesting aids have mechanical devices (in the form of parallel spring-loaded rollers) which detach all sweet potatoes remaining on the vine-root system after it passes the last person on the line. These roots usually go into a canner bin.

Systems of grading and handling sweet potatoes from the harvesting aids vary with individual growers and with the particular machine being used. Marketable sweet potatoes may be picked off the conveyor and placed by grade into either 23 kg containers or 450 kg bins. Culls and other sweet potatoes may go back on the ground or into a 450 kg bin at the end of the conveyor. Alternatively, the vines, soil clods, trash and culls may be taken off the conveyor by hand allowing all the marketable sweet potatoes to be collected in containers at the end of the conveyor. Bin tilting and/or bin rotating devices are built into some harvesting aids to minimize handling damage.

Fork lifts are utilized in the field to transfer palletized boxes or bins to trucks for transport to the warehouse. Fork lifts are utilized at the warehouse area for unloading trucks and for moving sweet potatoes into

and out of curing and storage areas. Fork lifts with rotating heads are also widely used to dump sweet potatoes on packing lines.

Combines are equipment which will dig, detach and place sweet potatoes into boxes or bins mechanically. Preparatory operations such as vine cutting and/or barring off may not be required. Proper adjustment of the various components of a combine is critical to minimize handling damage. Combines are expensive, sophisticated machines which require good operators and a minimum of downtime for greatest efficiency. Digging and elevating sweet potatoes is similar to that of harvesting aids.

Tractor-drawn combines require a tractor driver and a combine operator. The tractor driver controls such functions as the forward speed, depth of digging blade and elevator chain speed. The combine is equipped with hydraulic motors to drive chains and hydraulic cylinders for steering and bin movement. This hydraulic system is powered by a pump driven by a power takeoff. A double chain is used. The top chain carries the intact vines with the sweet potatoes still attached and suspended below the chain. The lower chain is similar to that used on harvesting aids. Sweet potatoes which become detached during elevation are caught on the flights and continued on to the top. At the top of the upper conveyor is a pair of spring-loaded roller snappers which detach those sweet potatoes still on the vines.

Sweet potatoes are transferred onto a reversible, movable cross conveyor which transports them into a 450 kg bin. Bins located on both sides of the combine can be moved forward or backward to attain the proper position for filling. In the filling position a bin can be tilted to minimize the distance from the end of the cross conveyor to the bottom of the bin. The bin is gradually lowered to a horizontal position as it is filled. The cross conveyor is extended into the base of the tilted bin initially then moved forward and backward to uniformly fill the bin.

Vines are transported on the continuous upper conveyor chain to the rear of the combine where they are returned to the ground.

Self-propelled sweet potato combines have been built which have been used on a limited basis. They dig one or two rows simultaneously and can segregate small roots intended for canning from other marketable sweet potatoes. Automatic box filling is similar to that described for the trailer combine. One model uses between 12 and 24 450 kg bins, while another combine uses 2200 kg bins. Two operators are required for these sophisticated machines.

Irish potato combines have been used for collecting sweet potatoes intended for processing. Modifications of such combines have made it possible to dig sweet potatoes for the fresh market. Generally, sweet potatoes are collected in 23 kg boxes bacause of handling and logistics problems with bins in the field. Damage to sweet potatoes is generally considered to be no worse than that experienced with hand harvesting systems.

CURING

The ideal environment for curing sweet potatoes involves a temperature of 30°C with 90-95% relative humidity and adequate aeration. Curing promotes rapid healing of cuts, bruises and skinned areas, thereby preventing

decay. Curing lessens shrinkage and weight loss and improves sweet potato cooking quality by converting starches to sugars. Sweet potatoes should be cured within two hours of harvest.

Modern, insulated facilities are constructed to provide optimum curing conditions uniformly throughout each room. Heating and humidification are provided by furnaces and humidifiers. Warm moist air is distributed by floor trenches.

STORAGE

The ideal storage enviroment for sweet potatoes should be kept at 13°C with 85-90% relative humidity and adequate aeration. Modern storage buildings are designed to maintain these conditions for several months by appropriate insulation, proper heat distribution and adequate ventilation.

GRADING AND PACKING

Fork lifts with rotating heads are used to invert bins to dump sweet potatoes gently into water handling systems in which chlorination is recommended. Tank dimensions vary, but most maintain 60-90 cm water depth. Longitudinal movement of sweet potatoes in water is promoted by numerous jets of water (from 1 cm holes in 5 cm pipes strategically located beneath the surface of the water in the tank). Sweet potatoes are transferred out of the receiving tank either by flighted elevators or by a paddle wheel system (Edwards Manufacturing Co, Bunn, NC). Additional transfers require additional elevators or paddle wheels.

Sweet potatoes are treated by spraying, dipping or drenching with a recommended fungicide 2, 6-dichloro-4-nitroaniline, for example to prevent in-transit decay. Workers located on either side of the grading line remove sweet potatoes which are not up to standard. Fresh market quality sweet potatoes are then mechanically size-sorted and packaged for shipment to market. Most shippers pack in fiberboard cartons which contain 18 or 23 kg of sweet potatoes.

CURRENT RESEARCH IN MECHANICAL HARVEST AND HANDLING

Simulation of the harvest and handling system both gives guidance in the conduct of research and can be useful in ultimate implementation of research. A simulation model for the in-field harvest and handling operations has been developed (Abrams *et al* 1980) and it is now in use in studying various alternatives.

As alternative system which is being studied involves harvesting the roots in bulk with no field grading or sorting and transporting to a central facility where they are cleaned, sorted and placed into curing (Abrams *et al* 1978). For this purpose, an experimental harvester using the same harvesting concept as described by Burkhardt *et al* (1971) was designed and built (Figure 2). It differs in that an articulated side delivery conveyor was provided to allow conveyance of the roots into any container or transporter positioned alongside the harvester. It is thus generally similar to conventional Irish potato harvesters.

Various bulk transporters for the roots were studied. The V-bottom

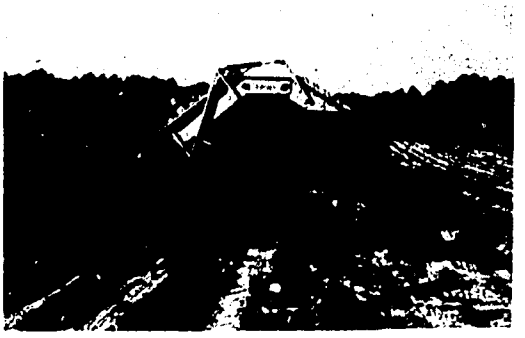

Figure 2. Sweet potato combine digs and detaches sweet potatoes from the vine and deposits them in a container

Irish potato hopper was found to be difficult to unload due to the bridging and interlocking of the sweet potatoes. A modified gravity flow grain box (approximately 2300 kg capacity) was found to be workable; however, the required modifications, which included increasing the slope of the floor, were too extensive to warrant its use. Using what was learned from studies with these two types of transporters, a bottom-emptying hopper of similar size was designed. This transporter was found to perform well. In an effort to discover a simpler means of handling the roots, however, a tilling-bed dump box was studied. Damage levels were not found to be significantly different from those observed with the other units tested. It is important to note, however, that the damage levels observed in all of these tests were tolerable only if the roots were placed immediately into curing.

The weak link in the whole process is curing. Curing is important whether the roots are mechanically harvested or not. With mechanical harvesting, the likelihood of increased skinning damage exists (Figure 3); curing allows this damage to heal properly. However, it is not convenient to cure all the harvest under the present system. We are studying alternative configurations for curing and storage which might improve this situation. Curing and storing in place in large, continuous volume piles with no containers offers an advantage in terms of space utilization. Depth of piling is an important parameter of such a system. The allowable depth has been estimated to be about 3.6 m (Abrams 1979). The air flow properties of large piles have also been estimated and sweet potatoes have been found to behave in a way similar to Irish potatoes (Abrams and Fish 1978). Work on fluming (Trykowski and Abrams 1979) indicates a possible advantage by allowing more automation in handling sweet potatoes between curing and storage. Challenges to be overcome include disease control, environmental control, forming the piles and removing roots from the piles.

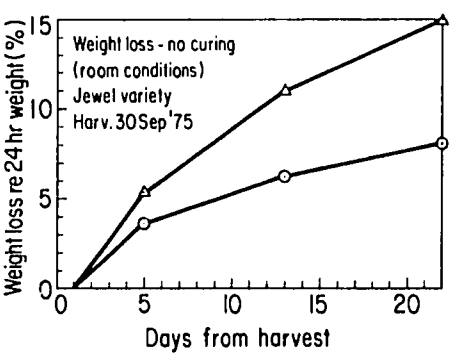

Figure 3. Weight loss comparison of uncured sweet potatoes (variety Jewel) harvested conventionally by hand and harvested mechanically in bulk

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Cropping Systems Involving Sweet Potato in Taiwan

H. WAN

Taiwan Agricultural Research Institute, 189 Chung-Cheng Rd. Wufeng, Taichung, Taiwan

INTRODUCTION

Sweet potato used to be the most important feed crop with the second largest production hectareage next only to rice in Taiwan. Annual hectareage was around 230,000 ha over a period of 25 years beginning 1948 (PDAF 1980). Production varied year by year from 2.0 to 3.7 million tons during the same period. Since 1971, however, sweet potato hectareage has declined. The lowest hectareage was 74,336 ha in 1979 and production was 1.22 million tons in 1979 (PDAF 1980). The decline of sweet potato production results from the increasing use of corn for feeds and the development of water resources which has expanded rice cultivation. The trend is still continuing but at a relatively slower rate. The sweet potato hectareage distribution over the island is 48.8%, 23.5%, 18.5% and 9.2% in the southern, central, northern and eastern parts respectively. It is obvious that sweet potato is a major crop in the south where irrigation water is limited.

Taiwan is partly in the tropical and partly in the subtropical region, with abundant rainfall and solar radiation so that multiple cropping systems are generally practiced. A number of cropping patterns were reported by Ho and Young (1966). Sweet potato under multiple cropping systems can be grown all the year round. There are four cropping seasons, fall (August to September), spring (February to March), summer (June to July) and winter (September to October). Because planting season is not a limiting factor for growing sweet potato, its position in cropping systems can become quite complicated. Sweet potato can either be a major crop in a rotational system or a minor one in an interplanting pattern. However, in recent years, multiple cropping systems have become less diversified as a result of labor shortage and higher cost of production (Wan 1971).

This paper presents some major cropping systems involving sweet potato in rotational or interplanting patterns in Taiwan.

CROPPING SYSTEMS ON PADDY FIELDS

Sweet potato is grown on paddy fields (55.3% of production) and on uplands (44.7%) as well. In terms of hectareage, the spring and summer crop crops are mostly grown on uplands with little irrigation while the fall and winter crops are grown on irrigated paddy fields. Five major cropping systems on paddy fields are described below.

Rice-rice-sweet potato

In this cropping pattern, sweet potato is grown as a relay inter-planting crop which requires a growing period of 5-6 months. The rice crop preceding the sweet potato is transplanted at 25 cm x 25 cm with a 50 cm space left between every four blocks of rows of rice. A small ridge, 6-10 cm high and 10-15 cm wide is then built in each of these 50 cm spaces after the last

weeding and after the rice field has been drained. Sweet potatoes are planted on the ridge 5-6 weeks prior to the harvesting of second rice crop. Sweet potato is harvested after about 1-1½ months. The planting density is about 50,000 cuttings/ha. The fertilizers, 40-80 kg N, 54 kg P, and 70 kg K per hectare are applied immediately after the rice harvest to both sides of the rows of sweet potato. It is then ridged (FFTC 1974).

During the early growth stage of sweet potato, care should be taken not to flood the field. At the ripening stage of rice, the rice plants adjacent to the sweet potato should be slightly spread so that sweet potato plants can receive sunlight. The sweet potato can be harvested in February and the field is then ready for transplanting the first crop of rice (Figure 1A).

Rice-sweet potato-rice

Sweet potato may also be grown as a summer crop and may be grown between two rice crops. It is relay-interplanted with the first rice crop for a period of about 40-50 days. The total growing period including the interplanting is less than three months. Sweet potato in this cropping pattern is not only grown for its roots but also for its vines as green feed for livestock. Taichung DAIS (1965) reported that 13,000 kg of roots and and 30,000 kg of vines per hectare could be harvested, and Lin *et al* (1968) also reported that there was only a 2.8% yield reduction for the first rice crop and no appreciable effect was observed on the second rice crop. This pattern is extensively used in central Taiwan (Figure 1B).

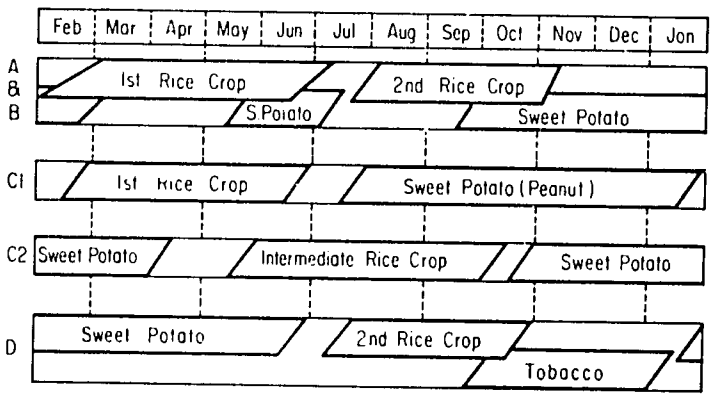

Figure 1. Cropping patterns on paddy field

Rice-sweet potato

This pattern is more common in the south. Rice is grown either as the first crop (Figure 1, C_1) or as an intermediate crop (Figure 1, C_2). The first rice crop is planted in mid-February and harvested in June. Then sweet potato is planted in July and harvested in January the next year (Figure 1, C_2).

Sweet potato-rice-tobacco

Sweet potato may take the place of the first rice crop in areas where the irrigation water is not sufficient for growing two crops of rice. In this pattern, sweet potato is planted in January and harvested in late June. The second rice crop is then transplanted and will be harvested in late October or early November. Before rice harvest, a winter tobacco crop is

relay-interplanted. The relay-interplanting of tobacco on paddy is particularly interesting. The method has been fully described (FFTC 1974).

Two weeks before the rice harvest, the farmer uses a bamboo stick to part the rice plants gently outwards to open the rows sufficiently to allow room for planting the tobacco plants. Not all rice rows are treated in this way. Three rows are left undisturbed, then the fourth and fifth are parted for tobacco planting as described. This pattern is repeated across the field. In the spaces in which tobacco is planted, 50% of the required compost and 20% of the total chemical fertilizers must be applied evenly before planting. The remaining fertilizers and compost are sidedressed along the row after the rice harvest. Then the soil is loosened with a small harrow and the fertilizers are mixed with the soil in one operation. At 50 cm intervals between the two parted rows of rice, a small hill is built for the planting of the tobacco seedlings. Building hills in this way results in the formation of shallow ditches which facilitate drainage.

Immediately after the rice harvest, the remaining fertilizers and compost are sidedressed along the row and a ridge 3-6 cm high is then made using a garden tractor. The final ridging is done two weeks later. The first priming of tobacco begins 70 days after trarsplanting and continues until January.

Rice-sugarcane-sweet potato

In Chiayi-Tainan area, the supply for irrigation water is not sufficient for the whole area to grow rice. Thus, a rotational irrigation scheme is practiced by dividing the whole area into three irrigation zones to which the amount and time of irrigation water supply are tightly controlled by a special committee in a three-year rotational system. The scheme allows farmers in each zone to grow two rice crops in three years. In the other years, sugarcane and sweet potato are planted as rotational crops with less water supplied.

As shown in Figure 2, the crop sequence in each zone for the three-year period is essentially the same, rice-sugarcane-cashcrop-rice-sweet potato. However, it differs in that the crop sequence is rotated by year for each zone. For instance, the order of crops grown in the first year in Zone I, in the third year in Zone II and in the second year in Zone III are exactly the same. This rotational irrigation scheme has resulted in more economic use of water, intensive land utilization, and increased crop production.

CROPPING SYSTEMS ON UPLANDS

Cropping systems in the uplands are even more complicated. In most

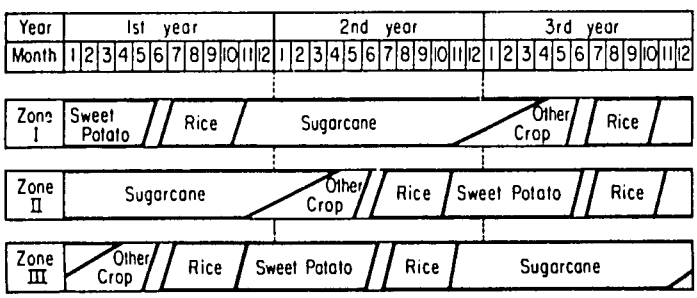

Figure 2. Three-year rotation cropping systems in Chiayi - Tainan Area

cases, sweet potato is the major crop while peanut, soybean, and other vegetables are the rotational crops. In addition, different interplanting systems are also practiced. Although sweet potato is usually the major crop, occasionally it is the secondary one. Several cropping patterns are described here.

Two-crop pattern

Sweet potato-peanut: Sweet potato is the major crop, and is planted in July and harvested in January. Then peanut is planted in February and harvested in June.

Three-crop pattern

Sweet potato-peanut(soybean)-vegetables: The three-crop pattern is similar to the two-crop pattern except that an additional short season vegetable is grown during the winter, generally from December to February (Figure 3). The vegetables involved may be Chinese cabbage, cabbage, radish or other crops.

Peanut can be either a spring or fall crop. Thus, in a three-crop pattern, sweet potato may be planted in the spring and peanut in the fall, or vice versa. If sweet potato is planted as a spring crop, peanut is the major crop. Otherwise, sweet potato is considered the major crop. In some cases, soybean may take the place of peanut.

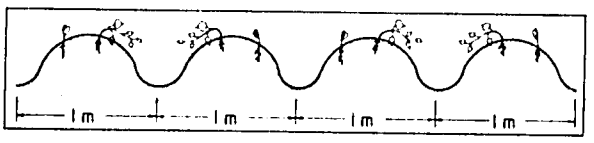

Figure 3. Cropping patterns on upland

Sorghum (peanut)-soybean-sweet potato: Although sorghum hectareage is not very large in Taiwan, yet it is an important rotational summer crop in the Tainan area. It is planted in late February or early March and harvested 120 days later. A crop of soybean is then planted and harvested within 90 days. In early October, a winter sweet potato crop is grown. This pattern differs from that in the paddy areas in that no interplanting is practiced.

In eastern Taiwan, the growing season is shorter and the temperature is lower in spring than in the south. Under these circumstances peanut is often planted instead of sorghum and the winter sweet potato must then be interplanted 20-30 days before the harvest of the preceding soybean crop in order to lengthen the growing period for sweet potato. This improved cropping pattern can increase profit by up to 69.2% as compared with the peanut-sweet potato pattern (Chung and Su 1967).

Interplanting pattern

Sweet potato and sugarcane interplanting: The slow growth of sugarcane at the early growing stage allows farmers to interplant an additional crop of sweet potato between rows without too much detrimental effect on the sugarcane. The land preparation is mainly for the benefit of the sugarcane, with the rows spaced 1.25 meters apart. Traditionally, sugarcane seedlings are planted in the furrow while sweet potato is planted on the ridge.

Before sweet potato planting, all fertilizers are applied as basic fertilizer. The cuttings are planted 30 cm apart within the row making a plant density of around 30,000 plants/ha. No cultivation or ridging is done for sweet potato in order to avoid any harmful effect on the sugarcane. Immediately after the sweet potato harvest, 150-180 days after planting, the sugarcane is ridged.

In this cropping system, an additional sweet potato can be harvested so that the profit per hectare is increased. However, the effect of interplanting sweet potato on the yield of sugarcane varies from 7.0% to 17.6% depending on planting season and varieties of sweet potato used (Tang 1960). It is preferable to use early maturing varieties with short vine growth, such as Tainung 57, as these have higher yield potential and cause fewer ill effects to the sugarcane (Table 1). The yield of sweet potato under these conditions is always lower than that from a normal crop, which naturally receives more care than an interplanted crop. Late planting will affect the yields of both sugarcane and sweet potato (Table 1). The residual effect of fertilizers used for sweet potato is another advantage in the interplanting system.

Sweet potato and soybean interplanting: In this interplanting pattern, sweet potato is the major crop. The interplanted soybean is harvested within three months of planting. The vines of the sweet potato by this

Table 1. Yields of sugarcane and sweet potato in single and interplanting cropping systems (Tang 1960)

Time of planting	Cropping system	Sweet potato		Sugarcane	
		vine	root	yield	index
		-------- t/ha -------			
	Sugarcane single cropping	-	-	96.0	100
August	Tainung 53 interplanted	14.2	20.5	83.1	86.6
	Tainung 57 interplanted	13.6	18.6	89.2	93.0
	Red Flesh interplanted	24.2	11.5	79.1	82.4
October	Sugarcane single planted	-	-	70.6	100
	Tainung 53 interplanted	9.5	12.2	61.5	87.1
	Red Flesh interplanted	10.4	21.0	58.6	83.1

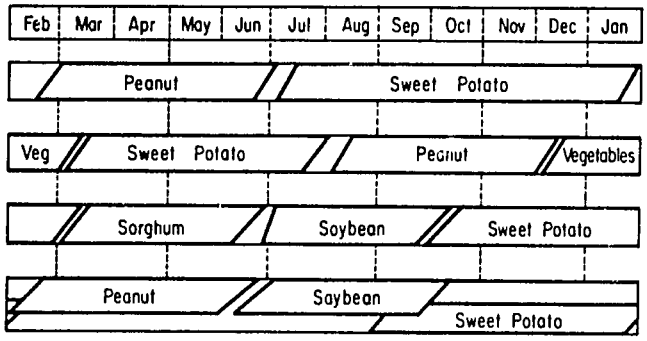

Figure 4. Schematic diagram showing the method used in sweet potato and soybean interplanting

stage have not yet entirely covered the whole field. In general, sweet potato and soybeans are planted at the same time.

The land is prepared for sweet potato with ridges 1 m apart. After basal fertilizer application, planting is carried out so that there is a row of soybeans on one side of each ridge, and a row of sweet potatoes on the other. However, their relative positions are reversed from one ridge to the next, in such a way as to create a planting pattern of two rows of soybeans alternating with two rows of sweet potato (Figure 4).

Before soybean planting, basic fertilizers are applied in shallow furrows and then covered by soil. Soybeans are planted in hills spaced 15-20 cm apart with two or three seeds per hill.

Cultivation, ridging, and sidedressing of remaining fertilizers are done for sweet potato only on one side of each row, and the vines are also trained to grow in the common furrow in order to avoid shading the soybean plants.

Sweet potato can be grown all the year round, while soybeans are rather sensitive to temperature and daylength. Therefore, the proper soybean variety and planting time must be carefully selected. In southern Taiwan, it is advisable for the winter crop of soybean to be planted no later than October.

The yield of sweet potato when intercropped with soybean, as compared with sweet potato monoculture, drops by 13-24% (depending on the soybean plant type) when the two crops are planted at the same time. Yield losses reach 17-19% if soybeans are planted ten days later (Kaohsiung DAIS 1961). However, farmers generally plant sweet potato and soybeans at the same time, which minimizes loss of sweet potato yield and saves time. Soybean yield per hectare is also low under this system because of the wider between-row spacing needed for sweet potato (Table 2). Although this interplanting system does affect the yield of sweet potato, the total value of crops per hectare is still increased (Kaohsiung DAIS 1961).

Sweet potato and corn interplanting: The sweet potato and corn intercropping system differs from the sweet potato-soybean pattern only in that the corn is interplanted 30 days after the planting of sweet potato when the cultivation, ridging and side-dressing of fertilizers for sweet potato have been completed. This is because corn overshadows sweet potato to a much greater extent than soybean.

Table 2. Yields of sweet potato and soybean in single and interplanting cropping systems (Kaohsiung DAIS 1961)

Cropping system	Sweet potato yield	Sweet potato index	Soybean
	t/ha		t/ha
Single cropping			
Tainung 53 planted on Sept 30	31.5	100	-
Soybean interplanted on Sept 30			
Palmetto	24.1	76.4	1.0
Shih-shih	27.5	87.2	0.6
Soybean interplanted on October 10			
Palmetto	25.5	81.0	0.6
Shih-shih	26.2	83.3	0.5

Chang *et al* (1963) reported that the yield of sweet potato was seriously affected if corn was interplanted 30 days after sweet potato planting. A 20-30% yield reduction, varying with the sensitivity to shading of different sweet potato varieties, was observed. Yield reduction would be as high as 60% if corn and sweet potato were interplanted at the same time (Table 3). The yield of corn itself also drops as compared with the yield from single cropping (Table 3).

Table 3. Yields of sweet potato and corn in single and intercropping systems (Chang *et al* 1963)

Cropping system	Sweet potato yield	Sweet potato index	Corn yield	Corn index
	t/ha		t/ha	
Tainung 57				
Single cropping				
Sept 8	49.8	100	7.4	100
Corn interplanted				
Sept 8	19.8	39.7	6.7	90.0
Oct 9	35.0	70.3	6.2	84.2
Red Flesh				
Single cropping				
Sept 8	35.8	100	7.4	100
Corn interplanted				
Sept 8	19.1	53.2	6.6	89.6
Oct 9	28.8	80.3	5.2	70.8

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Performance of Sweet Potato Varieties Grown Under Coconuts

D. L. ZARA S. E. CUEVAS and J. T. CARLOS, JR.

Department of Horticulture, University of the Philippines at Los Banos, College, Laguna, the Philippines

INTRODUCTION

Coconut is one of the most important perennial crops in the humid tropics of Asia. In the Philippines, 3.42 million hectares of land or 25% of the total cropland is devoted to coconut (Coconut Statistics 1980). Close to one-third of the population is directly or indirectly dependent upon this industry for its livelihood. It is estimated that within 20-30 years, between 20% and 25% of the country's economic growth will have to be fuelled by the coconut industry (Creencia 1979; Igual 1978).

Despite the fact that the Philippines is the world's largest producer of coconut (Igual 1978) the net income from coconut farming is still quite low (Medina *et al* 1976; Valiente *et al* 1977). This suggests that technology and production practices are inadequate.

In a pure stand of coconut planted at spacings ranging from 7 x 7 m to 10 x 10 m and an effective root zone of 2 m radius, it is estimated that only 12.6% to 25.7% of the total available area is effectively utilized (Neliat *et al* 1974). Likewise, the structure and orientation of coconut leaves allow part of the solar radiation incident on the foliage to percolate down the lower profiles to the ground surface. Thus, pure coconut plantations have annual biological production of only 17.1 t/ha which is far below theoretical values (Neliat *et al* 1974).

Coconut farms may be more fully utilized by planting compatible companion crops between trees. In the Philippines, many crops have been successfuly grown under coconut trees. Good returns have been obtained from the intercrops, and the coconuts too have benefited (Bartolome and Tolentino 1952; Leach *et al* 1971; Cuevas *et al* 1974; Ramadasan *et al* 1976; Brant 1978; Creencia 1978).

In a survey conducted by Cuevas *et al* (1974), sweet potato was found to be one of the most common crops to be grown under coconuts in the provinces of Albay and Leyte, but not in other provinces.

Sweet potato thrives under a wide range of environments and is easy to establish. It can keep down weeds under the grove even as its shoots provide a rich source of vegetables for the farmer. The tillage operations necessary before planting and at harvesting provide aeration beneficial to the root system of the coconut palm. The roots are a great potential source of food, feed, and even industrial energy.

Because shading affects plant processes, the performance of sweet potato under coconuts varies widely from one variety to another. Yield differences between crops grown in open and shaded conditions are unpredict-

able. Tsuno and Fujise (1965) as cited by Austin and Aung (1973a) reported that the rate at which the photosynthates are removed from the leaves to the roots more affects the yield than does the rate of photosynthate production in the leaves *per se*. Thus, varieties with higher photosynthetic rates or with greater leaf area index do not necessarily give the highest yield.

This study was conducted through five alternating wet and dry seasons from February 1976 to April 1978. A total of 26 sweet potato varieties were tested at UPLBCA Experiment Station at Bitukang Manok in Barangay Mainit, Bay, Laguna.

MATERIALS AND METHODS

Most of the varieties used were selected from the collections of the Department of Agronomy, UPLBCA. Because of a lack of cuttings, four of the 26 varieties were not grown in the open field during the dry season of 1976. Also, Misamis Oriental and Georgia Red were not grown during the succeeding seasons because of a lack of planting materials (Table 1).

Plowing and harrowing of the area was undertaken twice. Plots measuring 2 x 7 m were used for each variety both in the open field and under coconuts. These were replicated three times. Hills were spaced at 50 cm between and within furrows and planted with one cutting per hill. Thus, four plants were accommodated per square meter.

Fertilizer (40 kg NPK/ha) was applied twice; half of the amount was applied at two weeks and the remaining half at six weeks after planting. Dry season crops were irrigated. Weeding and cultivation were undertaken twice prior to each application of fertilizer. Pest and disease controls were applied at the recommended rates for the crops.

Harvesting started 15 weeks after planting. Since it was done manually by means of spading forks, it took about one week to finish all the samples.

Ten sample plants per plot were taken at random. Vine length and fresh weights of vines and roots were recorded at harvest.

RESULTS

The trials conducted in the wet and dry seasons of 1976 were not successful and no useful data were gathered. The vine weights of the varieties tested in 1977 dry season are shown in Table 2. Karja produced the heaviest vines under both conditions. The lowest producer of vegetable top was Kinaransi Puti in shaded conditions, while BNAS 51 gave the lowest vine yield in the open field.

The varieties tested during the wet season of 1977 gave varied results in vine weight. Eight of 12 varieties produced heavier vines in shaded conditions than in the open field. Thus, the average production of vine in shaded conditions was higher. However, vine production under shade even with a regular supply of irrigation water during the dry season of 1978 was lower. This held true for all varieties. The highest yielders were Quezon 7 and (Jap x US) 23 for the shaded and open conditions, respectively. The lowest yielder was North Carolina under both conditions (Table 3).

Vine length varied significantly among varieties grown under both conditions. Kaalsa and Ilocos Norte produced the longest vines under shade and in the open field, respectively, while Seedling 47 gave the shortest under both conditions (Table 4).

In Table 5, vine length of the varieties tried in the wet season of 1977 and dry season of 1978 are shown. Quezon 7 consistently produced the longest during the two seasons under both conditions. C 36 and North Carolina produced the shortest vines under shade and in the open field, respectively.

Table 1. Sweet potato varieties grown under coconuts and in the open field, February 1977 to April 1978

Varieties	1977		1978
	Dry season	Wet season	Dry season
Kaalsa	✓		
Karja	✓		
Kinaransi Puti	✓		
Misamis Oriental			
(Japan X US) 23	✓	✓	✓
(Japan X US) 17	✓	✓	✓
Bangued	✓		
UPCA 47	✓		
Seedling 45	✓		
Seedling 47	✓		
BNAS 51	✓	✓	✓
Georgia Red			
Kaogbon	✓		
Katalo	✓		
Ilocos Norte	✓		
Ilocos Sur	✓		
Quezon 7	✓		
C 200-1		✓	✓
Minuras		✓	✓
North Carolina		✓	✓
San Roque		✓	✓
C 7		✓	✓
C 36		✓	✓
Albay 2		✓	✓
Quezon 13		✓	✓
C 106			✓

Table 2. Vine weight (g/plant) of 14 sweet potato cultivars in open field and under coconut palms, 1977 dry season[a]

Variety	Open field (B)	Under coconut (A)	A/B (%)
UPCA 47	380	570	66.67
Kinaransi Puti	249	450	55.33
Karja	832	1048	79.39
Kaogbon	399	427	93.42
Kaalsa	361	463	77.97
(Jap X US) 23	487	643	75.74
(Jap X US) 17	372	371	100.03
BNAS 51	387	349	110.89
Katalo	322	715	45.03
Ilocos Norte	532	444	119.82
Ilocos Sur	494	828	59.66
Seedling #47	563	612	91.99
Seedling #45	544	385	141.30
Bangued	433	579	74.78
GRAND MEAN	454	563	84.61
HSD .05	267.7	329.0	
.01	282.1	346.7	
CV (%)	14.4	22.0	

[a]Population density is 4 plants/sq m

Table 3. Vine weight (g/plant) of 14 sweet potato varieties in open field and under coconut palms, wet season 1977 and dry season 1978[a]

Variety	Wet season 1977			Dry season 1978		
	open field (B)	under coco-nut (A)	A/B (%)	open field (B)	under coco-nut (A)	A/B (%)
Quezon 7	549	475	115.60	363	366	99.18
C 200-1	475	553	85.90	281	434	64.75
(Jap X US) 17	678	458	148.03	204	287	71.08
(Jap X US) 23	729	565	129.02	210	577	36.39
Minuras	599	481	124.53	177	313	56.55
North Carolina	317	314	100.95	188	192	97.91
San Roque	314	452	69.50	251	327	76.75
C 7	699	867	80.62	127	325	39.08
C 36	515	469	109.80	232	353	65.72
Albay 2	669	720	77.16	151	338	44.47
Quezon 13	418	401	104.23	248	320	77.50
BNAS 51	603	532	113.34	192	331	58.00
C 106	-	-	-	254	354	71.75
GRAND MEAN	547	524	104.89	216	347	66.08
HSD .05	378.6	245.3		167.1	286.1	
.01	395.5	256.3		173.2	NS	
CV (%)	24.1	15.0		24.3	26.2	

[a]Population density is 4 plants/sq m

Table 4. Vine length (cm/plant) of 14 sweet potato cultivars in open field and under coconut palms 1977 dry season[a]

Variety	Open field (B)	Under coconut (A)	A/B (%)
UPCA 47	332	257	129.18
Kinaransi Puti	314	286	109.79
Karja	229	210	109.05
Kaogbon	274	236	116.10
Kaalsa	411	314	130.89
(Jap X US) 23	232	211	109.95
(Jap X US) 17	246	210	117.14
BNAS 51	259	200	129.50
Katalo	258	205	125.85
Ilocos Norte	310	359	86.35
Ilocos Sur	333	357	93.28
Seedling #47	169	140	120.71
Seedling #45	241	174	138.50
Bangued	179	147	121.77
GRAND MEAN	271	236	117.00
HSD .05	108.4	114.2	
.01	114.3	120.3	
CV (%)	13.8	12.7	

[a]Population density is 4 plants/sq m

Table 5. Vine length (cm/plant) of 13 sweet potato cultivars in open field and under coconut palms, wet season 1977 and dry season 1978[a]

Variety	Wet season 1977			Dry season 1978		
	open field (B)	under coco-nut (A)	A/B (%)	open field (B)	under coco-nut (A)	A/B (%)
Quezon 7	642	354	181.35	358	329	108.81
C 200-1	428	299	143.14	269	260	103.43
(Jap X US) 17	508	238	213.44	251	197	127.41
(Jap X US) 23	459	231	198.70	249	217	114.75
Minuras	477	312	152.90	233	223	104.48
North Carolina	266	171	155.55	233	101	230.67
San Roque	554	385	143.90	237	242	97.93
C 7	340	302	112.60	240	149	161.67
C 36	489	336	145.53	207	287	72.12
Albay 2	422	301	140.20	278	173	160.69
Quezon 13	550	331	116.16	329	220	149.54
BNAS 51	584	316	184.81	232	208	111.54
C 106	-	-	-	302	282	107.09
GRAND MEAN	477	298	160.07	263	222	126.89
HSD .05	134.8	321.5		114.4	NS	
.01	140.9	335.9		120.0		
CV (%)	15.1	22.5		16.3	31.5	

[a]Population density is 4 plants/sq m

Shading seemed to promote vine elongation. All the varieties produced longer vines when grown under coconuts than when in the open field, except for Ilocos Norte, Ilocos Sur and C 36.

All the varieties grown during the dry season (February-May) of 1977 produced roots. Significant differences were observed between varieties. The four top performing varieties under shade were (Jap X US) 17, BNAS 51, Ilocos Norte, and (Jap X US) 23. It is surprising to note that the yield of Ilocos Norte and Seedling 45 were even better when under shade than when in the open field (Table 6). With a regular supply of irrigation water, these varieties grew vigorous and bushy under shade. This is also evidenced in their vine weight and vine length.

Three varieties that performed well under both conditions were selected from among the varieties grown in 1977-78. These were again tested in the succeeding two seasons to verify their performance under coconut palms.

Table 7 presents the root yield per plant of the varieties grown in the wet season of 1977 and dry season of 1978. The wet season cropping resulted in very low yields of the intercropped plants to the extent that no useable data were gathered for four varieties. The yield of the single crops during the season is also low. Albay 2, Quezon 7 and C 36 under shade did not produce marketable storage roots. These low yields are attributable to the damage caused by heavy rains and floods which occurred during the season (Figure 1). Of the three varieties retested only BNAS 51 performed well under coconut palms.

With a regular supply of water, good performances were observed in all the varieties grown during the 1978 dry season (Table 7). No significant differences were obtained among the root yields of the crops under both conditions. Minuras produced noticeably more storage roots when shaded and had the highest root yield among the 13 varieties. Again BNAS 51 produced good yields under coconuts and in the open field.

DISCUSSION

The production of sweet potato tops and roots are considered separate in the Philippines. The production of the roots is given the first priority while that of the vegetative tops (for utilization in the animal feed industry) can be considered of lesser importance.

During the three seasons when the root and vine yields were gathered, it was observed that both yields were generally suppressed by shading. Except during the 1977 wet season, the average weights of vines were generally lower for the crops grown under coconuts than those grown in the open fields. Likewise, root yield was lower for the intercropped varieties.

However, in seasons when average vine weight of the intercropped plants was low in percentage terms, a corresponding increase in percentage root yield was observed (Figure 2). This was observed during 1978 dry season. It is interesting to note that when the average weight of the tops under shade exceeds that in the open field, root yield is very much depressed. During the wet season of 1977, less than one-third of the roots obtainable

Table 6. Root weight (g/plant) of 14 sweet potato cultivars in open field and under coconut palms, 1977 dry season[a]

Variety	Open field (B)	Under coconut (A)	A/B (%)
UPCA 47	63	63	100.00
Kinaransi Puti	340	28	8.24
Karja	106	4	3.77
Kaogbon	244	111	45.49
Kaalsa	386	108	27.98
(Jap X US) 23	392	151	38.52
(Jap X US) 17	282	207	73.40
BNAS 51	414	171	41.30
Katalo	210	26	12.38
Ilocos Norte	168	155	227.94
Ilocos Sur	280	77	27.50
Seedling #47	336	105	31.25
Seedling #45	73	148	202.74
Bangued	239	130	54.39
GRAND MEAN	242	106	43.8
HSD .05	279.7	176.9	
.01	294.7	186.4	
CV (%)	35.1	50.8	

[a]Population density is 4 plants/sq m

Table 7. Tuber weight (g/plant) of 12 sweet potato cultivars in open field and under coconut palms, wet season 1977 and dry season 1978[a]

Variety	Wet season 1977			Dry season 1978		
	open field (B)	under coconut (A)	A/B (%)	open field (B)	under coconut (A)	A/B (%)
C 200-1	48	12	25.00	256	130	50.08
(Jap X US) 17	35	24	68.57	216	108	50.00
(Jap X US) 23	68	22	32.35	279	112	40.14
Minuras	146	18	12.32	177	198	111.86
North Carolina	86	35	40.70	188	154	81.91
San Roque	54	23	42.49	263	109	41.44
C 7	253	21	8.30	169	56	33.14
Quezon 13	27	0	-	298	133	44.63
BNAS 51	116	78	67.24	195	153	78.46
Albay 2	0	0	-	259	117	45.17
Quezon 7	0	0	-	216	61	28.24
C 36	0	0	-	230	101	43.91
GRAND MEAN	93	29	31.18	229	119	51.96
HSD .05	NS	NS		NS	NS	
.01						

[a]Population density is 4 plants/sq m

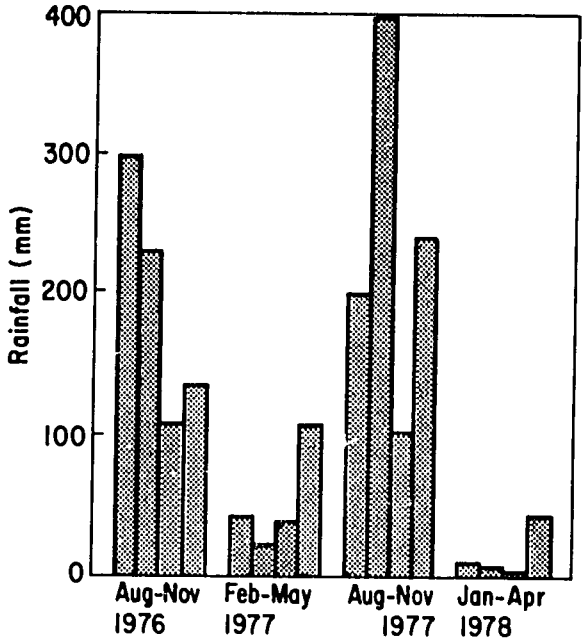

Figure 1. (Above) Monthly rainfall at Los Baños, Laguna from August 1976 to April 1978

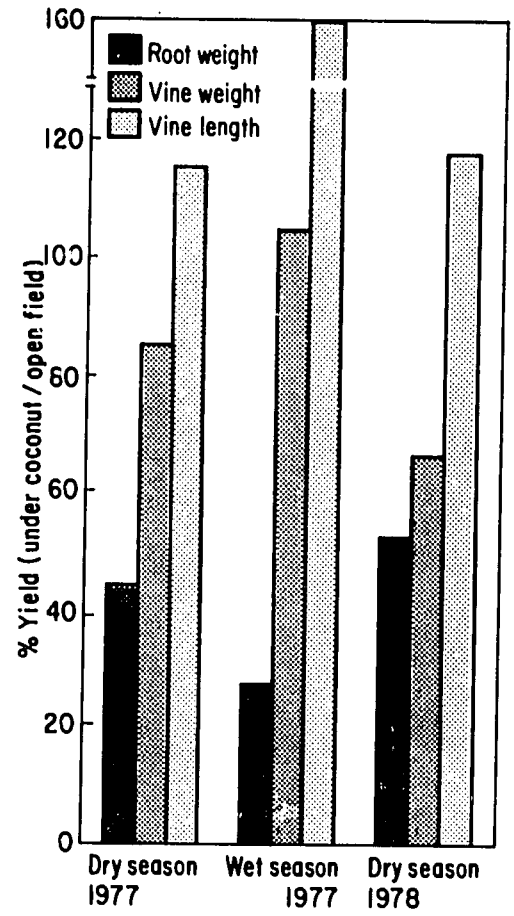

Figure 2. (Right) Percent yields of root weight, vine weight and vine length of sweet potatoes

in the open field were harvested from the intercropped plants (Table 4). In this case it can be suggested that excessive growth of vines took place at the expense of the storage roots.

Although Austin *et al* (1970) found that storage root weight increases occurred concurrently with growth of vegetative tops with a high degree of correlation, the rate at which assimilates are transferred would appear to be more important for storage root development than are increases in leaf area (Austin and Aung 1973a). It is not surprising that higher root yields were obtained during 1978 than during the previous trials even though vine yields were lower.

The length of vines is immaterial to the production of storage roots. Plants grown under coconuts produced lanky vines with long internodes and fewer leaves. The average root yield under these conditions was very much lower than in the open field. To explain this, Austin and Aung (1973a) and Incoll and Neales (1970) suggested that the stems acted as intermediate sinks which compete successfully with the storage roots (the terminal sink) for photosynthate originating from the leaves. Thus, in their other experiment (Austin and Aung 1973b), in which stem growth was restricted, chemicals which failed to suppress the growth of cultivar Centennial significantly decreased storage root dry weight. However, precautions should be taken in vine growth restriction. With severe reduction of vines by cutting them to either 30 cm and 45 cm, tuber yields were gravely reduced (Ching 1923).

Storage root yields were also partly affected by the season during which the crop was grown. Dry season crops produced higher yields than the wet season crops (Table 7). This could be attributed to the differences under both conditions in the amount of light available for the crops, since available light was influenced by overcast weather. Figure 2 shows the amount of rainfall during the growing period of the crops. Kennard (1944) thought that rainfall and photoperiod exerted some effect on yield. This was also reported by Kim (1961) who observed that a 16-hour photoperiod promoted storage root formation, while an 8-hour photoperiod obstructed the process.

Though root yields are affected by vine yield, the latter should not be used as a measure of the performance of sweet potato varieties. In this study, significant differences were observed on vine yields during the three seasons while significant differences in root yield were observed in the 1977 dry season only. The additional ten varieties tested during the 1977 wet season and 1978 dry season were the varieties which performed equally well in the trial conducted by the Department of Agronomy, UPLBCA.

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Intercropping With Sweet Potato (*Ipomoea batatas*) in Central America

R. A. MORENO

Centro Agronomic Tropical de Investigacion y Ensenanza (CATIE), Turrialba, Costa Rica

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L) Lamb) was probably first domesticated in the lowlands of northern South America and the Antilles. Its early introduction into Middle America made it known to the Mayans who named it 'camotli', from which the Spanish name 'camote' is derived (Leon 1977; Bronson 1966). In spite of its early domestication in the area, sweet potato is not an important crop in any of the six countries of the Central American Isthmus (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama). Marketing problems are probably the main constraint to the widespread cultivation of this crop in the area. However, it is frequently cultivated for home consumption in the gardens of small farmers and less frequently cultivated as a cash crop in small areas near large cities.

Though scarce, such information as is available from different ecological areas, mainly in El Salvador and Costa Rica, reveals the potential of sweet potato for inclusion in cropping systems suited to the agronomic and socio-economic conditions of Central American small farmers (Bieber 1978; Moreno 1979). Multiple cropping, including the simultaneous cultivation of two or more crops in the same piece of land, is important in the region.

Since 1973, the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) located in Turrialba, Costa Rica, has been conducting research to develop appropriate technology for small farmers in Central America. Problem-oriented on-farm experimentation conducted by local scientists in collaboration with CATIE's resident agronomists in each country receives most emphasis in the outreach phase of this program. More basic types of research aimed to find medium and long term solutions to small farmers' production problems are conducted at the headquarters to support the outreach activities (Moreno and Saunders 1978).

The description of existing cropping systems and environments, the design of technological alternatives, field experimentation, and monitoring of useful innovations are the basic stages of the research methodology.

The design of new cropping systems for small farmers necessarily involves a knowledge of the physiological response of the crops to the environment. Included in the concept of environment is the presence of other crops, since growing plants in association is one of the mechanisms by which Central American small farmers cope with the agronomic and economic risks involved in production.

Turrialba (9° 53' N, 83° 39' W) is 600 m above sea level and has a mean annual precipitation of 2700 mm. Evapotranspiration exceeds precipitation only between January and March. The mean annual temperature is 22° C and mean annual solar radiation input is 154 kcal cm^{-2}. The soils of the field

plot area are in the Rocky phase of the Instituto soil series and in the Inceptisol order and Tropepts suborder of the Seventh Approximation Classification system (Hardy 1961). Since 1973, several cropping patterns including sweet potato have been field tested in Turrialba. The component crops used in the design were maize (*Zea mays* L) cassava (*Manihot esculenta* Crantz) common bean (*Phaseolus vulgaris* L) and sweet potato. Sweet potato was included as a component because of its high vitamins and protein content, the possibility of using it as animal feed, its ability to grow in poor soils, and its drought tolerance.

In Turrialba, the main constraint to dry grain production is the short harvesting period (February-March) when average monthly precipitation is less than 100 mm. Lack of water and low temperatures during the dry period are the main constraints to cassava production. Excessive water in the soil profile during the rest of the year is probably the main constraint to sweet potato production.

This paper reviews and attempts to combine the results obtained at CATIE in intercrops of sweet potato with maize, common beans and cassava. The research results reported here have been obtained with the species, cultivars, planting distances and densities summarized in Table 1.

Table 1. Species, varieties, planting distances and density of planting of different cropping patterns based on sweet potatoes

Species	Varieties	Planting distance (m) within row	between rows	Density plants sq m
Common beans				
Phaseolus vulgaris	CATIE-1	0.2	0.5	10
Maize				
Zea mays	Tuxpeño Planta Baja C-7	0.5	1.0	4
Sweet Potato				
Ipomoea batatas	C-15	0.4	0.5	5
Cassava				
Manihot esculenta	Valenca	0.5	1.0	2

INTERCROPPING SWEET POTATO WITH MAIZE

The first field trials during the process of designing cropping systems with these two crops grown in association were carried out with the cropping patterns represented in Figure 1B. This pattern was tested in two planting seasons: November-March and May-October. These trials were conducted between 1973 and 1975. Two rows of sweet potato (0.5 m apart) were interplanted between rows of 30-day-old maize 1 m apart. Maize was bent over after 4 months and harvested at 4.5-5 m months. Bending the cover plant is a practice that protects the cob from attack by pathogens in case of rainfall before harvesting. Sweet potato was also harvested at 4.5-5 months. NPK was applied at 175-33-42 kg/ha during the first planting season and at 150-40-63 kg/ha during the second planting season.

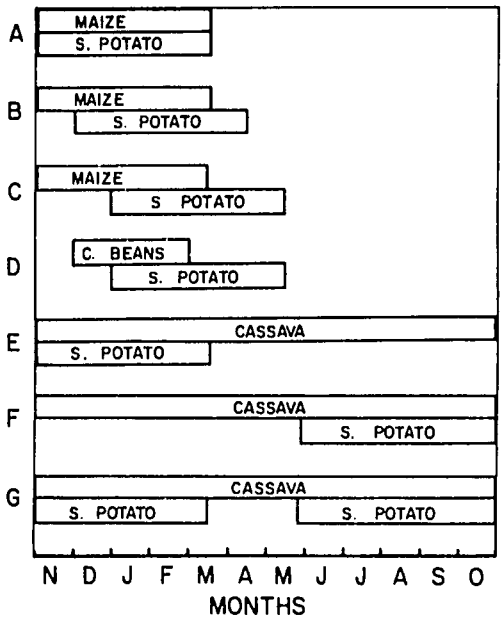


Figure 1. Cropping patterns with sweet potato, maize, common bean and cassava tested in Turrialba, Costa Rica 1974-1978

After these first trials further experimentation was carried out during 1975 to determine the influence of cropping pattern and levels of applied K on yields of this intercrop. Cropping pattern 1B was compared with sweet potato planted simultaneously with maize (Figure 1A), and with sweet potato planted 60 days after maize (Figure 1C) during the first planting season. Light available to sweet potato was modified by planting it in different cropping patterns. The same basic fertilization of 150-40 kg/ha for N and P was applied, but K was applied at three different levels, 63,125 and 187 kg/ha. Both maize and sweet potato were cultivated as monocrop checks during these trials. The maize monocrop received 110-52-35 and the sweet potato crop 65-10-30 N, P and K kg/ha.

For the first planting season, between 1973 and 1975, the average root yield of intercropped sweet potato in cropping pattern 1B was extremely low (1.1 t/ha) compared with its yield in monoculture (10.7 t/ha). Maize yielded 2.5 t/ha in association with sweet potato but only 2.1 t/ha as a monocrop. In the second planting season, yields were 3.5 and 2.0 t/ha for intercropped sweet potatoes and maize, while in monoculture these crops yielded 4.7 and 2.2 t/ha. Competition with sweet potato planted 30 days after maize did not significantly affect the yield of maize. No significant difference in yield was obtained with this crop association whether it was cultivated once a year followed by fallow in the same plot or whether it was rotated with either maize, sweet potato or maize associated with sweet potato.

It was assumed that the yield of maize associated with sweet potatoes was higher in association than monocrop during the first planting season probably because of excessive N. During the second planting season the higher levels of P and K applied probably increased sweet potato yield which competed with maize to reduce its yield.

The comparison of cropping patterns 1A, B and C showed a decrease in sweet potato yield as its planting date was delayed with respect to the maize. A 72% yield reduction (Table 2) was caused by delaying planting 30

Table 2. Yield of sweet potato fresh roots and maize grain (14% HOH), in different cropping patterns, total accumulated radiation intercepted by sweet potato from 0-90 days and accumulated rainfall during sweet potato life cycle. Turrialba, Costa Rica, 1976

Cropping pattern	Maize (t/ha)	Sweet potato (t/ha)	Accumulated radiation (0-90 days) intercepted by sweet potato (kcl/sq cm)	Accumulated rainfall during sweet potato cropping cycle (mm)
Maize / S. potato	2.21	9.61	22.9	659
Maize / S. potato	3.47	2.66	14.8	338
Maize / S. potato	3.45	2.16	12.1	699

days, which could in part be attributed to water stress, since rainfall was approximately 50% lower than normal during this cropping cycle. The best treatment yielded 2.5 t/ha of maize and 11.4 t/ha of sweet potato when both crops were planted simultaneously and fertilized with 187 kg K/ha. No significant differences in radiation or temperature in the open field between sweet potato planting dates were recorded, but differences in radiation intercepted by sweet potatoes interplanted with maize at different dates were significant (Table 2) and probably accounted for most of the difference in yield.

Radiation, nutrients, temperature and soil moisture are known to determine sweet potato yield (Hahn 1977). In Turrialba, light and nutrients are the most probable factors modified in associations with maize. Maize, being a C-4 crop, develops its canopy before sweet potato, intercepting most of the available light. According to Arze (1975), an average of 243 cal/sq m/day of solar radiation was available for sweet potato in the interspaces of Tuxpeño Planta Baja C-7 maize. An average of 437 cal/sq m/day was available for a sweet potato monocrop. This reduction of approximately 50% in light intensity is enough to reduce dry matter production and probably both lignification of stele cells and cambial activity as well.

A reduction in sweet potato yield when it was cultivated in association with maize has been reported, but no further information is available (Tang Dept of Agric 1960). In several trials carried out in Turrialba a significant and positive correlation was found between radiation intercepted by sweet potato and both leaf area and total biomass (Escobar 1975; Lizarraga 1976).

As previously stated, differences in soil moisture available for each planting date of sweet potato probably affected the performance of cropping pattern 1B when tested against cropping patterns 1A and 1C. In all these trials no correlation was found between root yield and K and P content in the aerial biomass or the roots. A high N content in the sweet potato foliage negatively affected yield as previously reported elsewhere (Hahn 1977). In maize tissue the percentage of Ca and Mg increased as competition with sweet potato decreased. Whenever the planting date, sweet potato extracted relatively large amounts of Mg from the soil. Simultaneous planting

of sweet potato and maize resulted in the strongest competition for available Mg between these two crops. Also Ca and Mg content of maize tissue decreased as the applied K increased. Adequate amounts of Mg are thought necessary to prevent imbalance of this element in the soil and plant tissue when K fertilization is used to obtain an adequate balance with applied N (Zuniga 1976). In the three cropping patterns K, Ca and Mg average levels in the soil decreased from 1.05 to 0.72, 4.70 to 3.71 and 2.14 to 1.62 me/100 ml of soil between planting and harvesting time.

The optimum N/K ratio used to fertilize sweet potato and maize has been studied for these crops in monoculture (Fujise and Tsuno 1967; Bishop, Smeltzer and Maceacaern 1972) but the simultaneous cultivation of these species presents some specific problems since an adequate level of N fertilization for maize is relatively high to attain good sweet potato root yield. Further experimentation was carried out during 1977 to find an appropriate fertilizer management for this two crop combination. Several treatments in which different levels of N and K were applied under a constant level of applied P (40 kg/ha) were tested with cropping pattern 1A.

In Table 3 these treatments are presented with data for dry matter yield of maize and sweet potato both in total biomass and edible fraction. Treatments 5, 6, 7 and 8 resulted in more total biomass, but treatments 5 and 6 produced the largest amount of edible biomass, suggesting an N:K relation of the order of 1:2 to attain the best performance by this crop combination under conditions similar to Turrialba. Above-ground dry matter of maize increased with applied N up to 120 kg N/ha and 187 kg K/ha which also yielded the largest grain dry matter production and grain yield (14 H_2O). Maize did not respond to increased levels of applied K in terms of grain dry matter or grain yield (14 H_2O) probably because of low values of the relation Mg:K and (Ca + Mg):K in the soil which decreased even further with high levels of applied K.

Maximum above-ground dry matter production by sweet potato was reached at 90 days; it increased proportionally from 5.6 to 8.1 t/ha from treatments 1 to 8 as applied N increased. At 150 days (Table 3) all treatments decreased to values in the range of 1.9 to 2.7 t/ha with no significant differences among them. Dry matter began to accumulate in the tubers immediately after above-ground biomass reached its maximum dry weight. It tended to decrease as applied N increased. The same was true for root fresh weight.

Based on data provided by McDowell [illegible] (1974) and Merrit and Watt (1955), dry matter weight of the edible fraction of these two crops was transformed into energy (g calories) as a common unit to express yield. Sweet potato energy yields decreased as N applied increased; the opposite was true for maize yield. Again no full response to N was obtained in terms of g calories produced by maize or maize associated with sweet potato due to a low base ratio in the soil. Fertilization with 110 and 183 kg/ha of N and K produced the largest amount of energy when these two crops were grown in association. In Table 4 the amount of nutrients taken up by maize and sweet potato growing in association is presented. For maize, the order of importance of nutrients was K, N, Mg, Ca, P while for sweet potato it was K, N, Ca, Mg, S. Maize absorbed most of the P, Mg, Cu, Mn and Zn available while sweet potato absorbed most of the S, Fe and Al.

Table 3. Average dry matter production by 120-day-old maize and 150-day-old sweet potato grown associated under different levels on N and K applied. Turrialba, Costa Rica, 1977

Treatment	Applied element N	Applied element K	Maize shoots	Maize grain	Harvest index	Sweet potato shoots	Sweet potato roots	Harvest index	Total dry matter Whole plant*	Total dry matter edible fraction	Combined harvest index
	kg/ha		t/ha			t/ha			t/ha		
1	25	189	4.8	1.9 (2.3)[a]	28.2	2.0	2.7 (9.0)[a]	57.5	11.4	4.6	40.3
2	60	95	5.3	2.5 (3.0)	32.2	2.3	2.2 (7.4)	49.1	12.3	4.7	38.2
3	60	284	5.8	1.9 (2.3)	25.1	1.9	2.5 (8.4)	56.4	12.1	4.4	36.3
4	120	34	5.6	2.8 (3.3)	33.1	2.4	1.7 (5.5)	40.5	11.9	4.5	37.8
5	120	189	6.8	3.4 (4.1)	33.4	2.4	1.9 (6.3)	44.6	14.5	5.3	36.5
6	120	323	6.7	2.9 (3.5)	30.3	2.1	2.2 (7.4)	47.0	13.9	5.1	36.6
7	180	95	6.7	3.2 (3.9)	32.4	2.6	1.5 (5.0)	35.7	14.0	4.7	33.5
8	180	284	6.5	2.9 (3.5)	30.8	2.7	1.6 (5.5)	37.7	13.7	4.5	32.8
9	240	189	6.8	2.6 (3.1)	27.7	2.1	1.4 (4.7)	40.2	12.9	4.0	31.0

[a]Figures in parenthesis are maize grain yield (14 H_2O) and sweet potato fresh root weight, both in t/ha
*Maize root system not considered

Table 4. Nutrient uptake by maize and sweet potato grown in association. Turrialba, Costa Rica, 1977

Nutrients	Time of maximum uptake (days after planting)	Uptake maize (kg/ha)	Uptake s. potato (kg/ha)	Percentage in each crop maize	Percentage in each crop s. potato	Percentage of total taken up
N	120	76.6	55.4	58.0	42.0	27.5
K	90	113.0	96.6	54.0	46.0	43.7
P	120	13.7	5.0	73.5	26.5	3.9
S	120	3.0	5.6	29.5	70.5	1.7
Ca	120	22.0	32.6	40.0	60.0	11.4
Mg	120	26.0	16.0	62.0	38.0	8.9
Na	120	4.0	4.7	46.5	53.5	1.8
Cu	45	0.04	0.01	82.0	18.0	0.01
Mn	120	0.06	0.01	80.7	19.3	0.02
Zn	120	0.07	0.04	65.0	35.0	0.02
Fe	45	0.03	1.45	2.0	98.0	0.31
Al	45	0.08	4.00	2.0	98.0	0.83

INTERCROPPING SWEET POTATOES WITH COMMON BEANS

In Turrialba common beans are cultivated once a year to be harvested as dry grain during the short dry season (February-March). From 1974 to 1978 14 field trials were carried out under similar management conditions in which sweet potato was interplanted in alternate rows 30 days after beans (Figure 1D). This crop combination received a total of 145-61-45 kg/ha of NPK. Most of the N and P was applied at planting of the beans; the rest was applied immediately prior to sweet potato planting. Manual weeding took place two weeks after planting beans and immediately before sweet potato interplanting.

On the average common beans yielded 1.4 t/ha and sweet potato 7.9 g/ha. Yields in monoculture for these crops were 1.3 and 10.7 t/ha respectively. The crop association was cultivated only once and the soil was left fallow during the rest of the year. At 60 and 90 days the foliage biomass of sweet potato intercropped with common beans was not significantly different from the foliar biomass of sweet potato in monoculture. However, a delay in the rate of biomass accumulation in the root systems was recorded in intercropped sweet potato as compared to its monocrop. Number of roots/plant was 2.2-2.5 in sweet potato associated with common beans and 3.6-3.7 in sweet potato monoculture. This reduction in root number accounted for most of the yield reduction in intercropped sweet potato. Competition for nutrients during early stages in the development of intercropped sweet potato resulted in fewer roots/plant while lack of sufficient water for translocation of photosynthates probably accounted for the delay in the rate of biomass accumulation in the root system. No differences in intercepted radiation was registered between sweet potato monocrop and when intercropped with beans.

Land equivalent ratio values between 1.6 and 1.8 have been obtained with this crop combination. These high values are comparable with those obtained in combinations of long life-cycle crops such as cassava with short life-cycle crop such as common beans (Moreno and Hart 1979).

Maize and common beans is the most widely cultivated crop combination among small farmers of Central America. Maize is planted at the onset of the rainy season and beans are relay intercropped between maize stalks at the end of the rainy period. In most cases common beans reach higher market prices than maize and consequently the level of input used in their production is higher too. The intercrop of sweet potato in 30-40-day-old beans represents a valuable production alternative to make better use of fertilizer and other inputs that are normally applied to common beans. Early maturing and drought resistant sweet potato cultivars should be tested on-farm in intercrop with common beans to further validate this production innovation which could also represent an important source of animal feed.

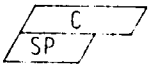
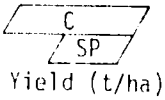
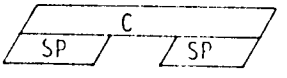
INTERCROPPING SWEET POTATO WITH CASSAVA

Cassava has slow initial growth and does not usually cover the ground completely until 90 to 120 days after planting. During this initial stage, intercropping with a short cycle crop such as sweet potato improves utilization of light and soil. Some cassava genotypes have their leaf area reduced by leaf loss 200-240 days after planting, making it possible for another crop to be planted in the interspaces of cassava stalks 120-160 days before its harvest (Moreno 1980).

Three cropping patterns with cassava and sweet potato (Figure 1E, F and G) have been tested in Turrialba since 1974. Two rows (0.5 m apart) of sweet potato were intercropped in cassava rows (1 m apart). In cropping pattern 1E sweet potato was planted simultaneously with cassava and harvested manually after 140 days. Sweet potato was harvested before cassava roots had fully developed. No significant damage to the cassava root system was caused when digging for sweet potato roots. Loosening the soil at this stage seems to favor the development of the cassava roots. In cropping pattern 1F, sweet potato was interplanted towards the end of the cassava life cycle to make full full use of available radiation in the cassava interspaces immediately after it began to lose its foliage. At harvest cassava plants are first hand-pulled which loosens soils enough to facilitate sweet potato digging. These two cropping patterns received an average yearly total of 150-48-75 kg/ha of N, P and K. While N and P remained constant, K application was increased from 45 to 63 and 125 kg/ha during 1975-76, 1976-77 and 1977-78. In cropping pattern 1G, two crops of sweet potatoes were interplanted with cassava. A total of 185-49-75 kg/ha of N, P and K were applied every planting season. Potassium was also increased to 125 kg/ha during 1976-77 and 1977-78.

Table 5 summarizes yields of these crops in different cropping patterns during four planting seasons. Intercropping cassava and sweet potatoes simultaneously reduces cassava yield by 37% as compared with its yield when sweet potatoes were intercropped at the end of its life cycle. Monocrop cassava yields averaged 17 t/ha over the four planting seasons. The cultivation of sweet potatoes at the end of cassava life cycle does not reduce cassava yield significantly as previously reported for other crops (Moreno 1980).

Table 5. Yields of cassava (C) and sweet potato (SP) intercropped in three different patterns during four planting seasons. Turrialba, Costa Rica, 1974-1978

	CROPPING PATTERN*						
							
	Yield (t/ha)						
Year	C	SP	C	SP	SP	C	SP
1974-75	10.7	9.0	14.8	5.9	7.8	10.4	7.9
1975-76	4.3	9.8	12.2	6.2	10.7	6.4	7.1
1976-77	9.6	3.5	16.6	0.6	6.0	10.1	0.3
1977-78	13.5	1.6	16.7	0.0	1.0	15.9	0.0

*Cassava harvested 12 months old; sweet potato harvested at 4.5-5 months

Sweet potato yields were fairly constant from 1974 to 1976 but they were significantly reduced in the three cropping patterns from 1976 to 1978. This yield reduction affected mainly the sweet potatoes planted at the end of cassava life cycle. No significant increase in pests or pathogens was registered during this period of lower yields. However, as shown in Figure 2A and B a reduction in extractable Mg affected the three cropping patterns, especially cropping pattern 1G, during the four planting seasons. Extractable K was also reduced although this reduction did not affect cropping pattern 1F with the same intensity. Apparently increased K applied during

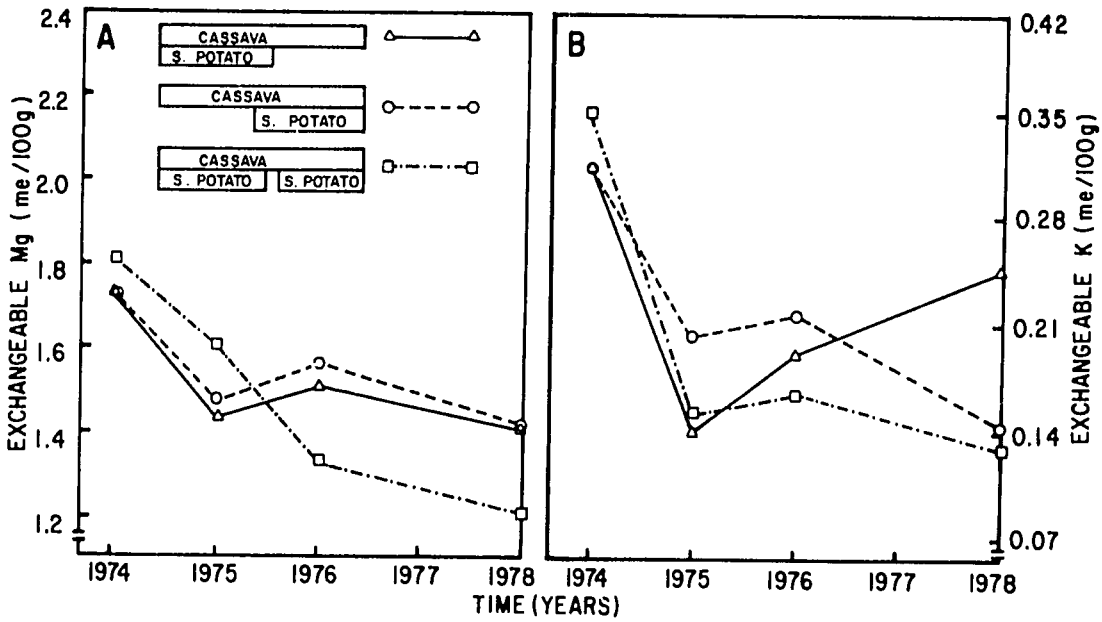


Figure 2. Effect of time and cropping systems on the soil exchangeable nutritients of an Inceptisol at Turrialba, Costa Rica. A) exchangeable Mg and B) exchangeable K (Burgos 1980)

the last years of the field experiments was not enough to cover the crops' uptake.

The production of roots and leaf dry matter for cropping pattern 1G during 1974 to 1976 is shown in Figure 3. Sweet potato (5 plants/sq m) reached a peak of approximately 1 t/ha about 90 days after planting, accounting for most of the leaf biomass during the initial stages of this crop association. Dry matter accumulation in the root system increased after 90 days. Cassava (2 plants/sq m) reached its maximum weight in dry matter in the leaves between 210-270 days after planting. The dry weight of its root system increased markedly after 180 days. Growth of the second sweet potato was delayed and reached its maximum weight in leaf dry matter 120 days after planting. Its lower level of intercepted light during early stages of its life cycle probably accounted for this delay. This second crop of sweet potatoes was harvested at 160 days when its root system was still accumulating dry weight and no signs of root quality deterioration were observed. Probably a 30-40 days delay in harvesting could have significantly increased root yield. Radiation available for sweet potatoes interplanted simultaneously with cassava was reduced to 75-80% of the open field radiation 100 days after planting. Most of the above ground biomass of the sweet potato was formed during this period. Translocation of photosynthates and accumulation of biomass in roots occurred when radiation in the interrows of cassava was decreasing from 75 to 30% of the open field radiation. The second sweet potato crop was established when approximately 50% of the open field radiation was available. Approximately 80% of the solar radiation was available when it reached its maximum leaf dry matter weight (120 days). This available radiation increased to 88% at harvesting time. More light available for the first sweet potato crop was probably the cause of its better yield in terms of root dry weight.

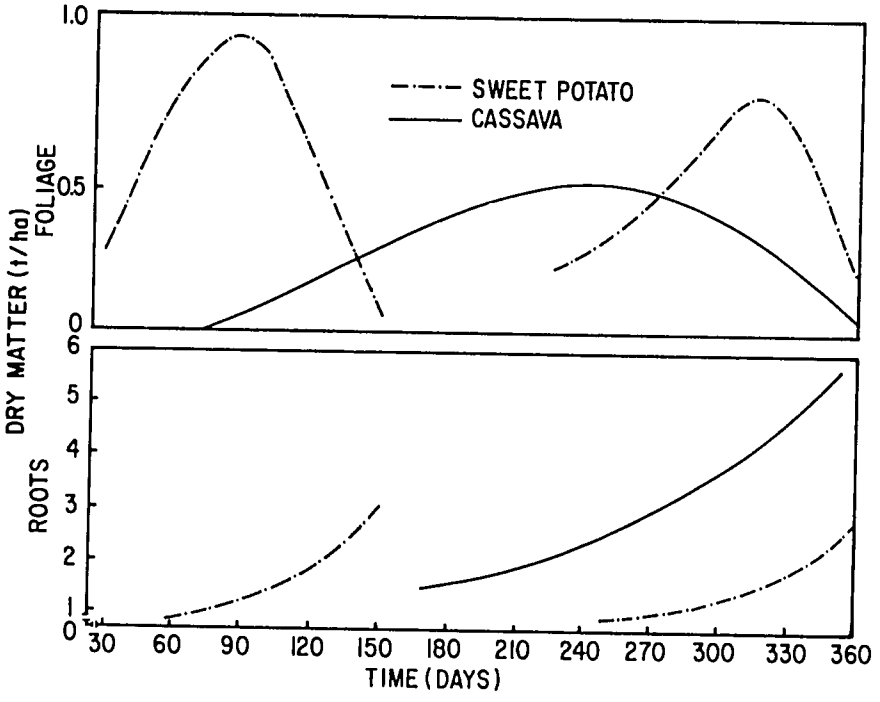


Figure 3. Yields of leaves and tuber dry matter on time for two crops of sweet potatoes and cassava intercropped in Turrialba, Costa Rica (Gallegos 1975)

THE POTENTIAL OF SWEET POTATOES IN INTERCROPPING SYSTEMS

Sweet potato is usually planted as a monocrop in different cropping patterns, particularly in regions with a well defined dry season where it is included as a cash crop to make use of residual water and fertilizer. In Turrialba, sweet potato yielded a fresh root weight of approximately 18 t/ha with one application of 133 kg/ha K, following an association of maize and common beans (Brioso de Leon 1979). However, when land is scarce and labor is abundant, there are also the possibilities for intercropping sweet potatoes with several other species. Sweet potato is intercropped in certain areas of the Antilles, particularly during the establishment phase of perennials such as plantain and bananas.

Competition for light and nutrients is probably the main factor that modifies the performance of sweet potato when intercropped as compared to its performance in monocrop. Research should be intensified to find both cropping patterns that allow adequate amount of radiation to be intercepted by intercropped sweet potato and to ensure fertilizer practices that ensure an appropriate level of nutrients for the intercrops.

In the case of sweet potatoes and maize, light seems to be more important than nutrients in its effect on root fresh weight yield. Preliminary results from Turrialba indicate that cropping patterns with double rows of maize and four rows of sweet potatoes result in good yields of both crops. This cropping pattern permits enough light to be intercepted by sweet potatoes and allows for N fertilization to be individually applied to the maize (unpublished results, CATIE, Turrialba, Costa Rica). In spite of the competitive nature of the relationship between these two crops (Figure 4), this

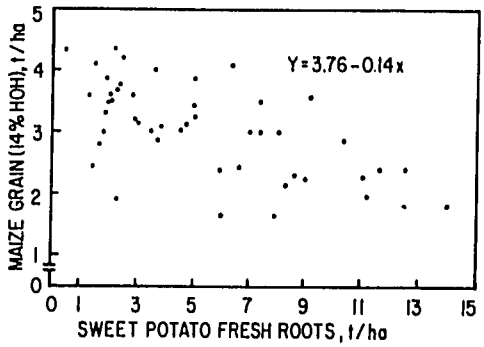


Figure 4. Yields of maize grain (14% HOH) and fresh tuber sweet potato from several trials (1975-76) with these crops in association. Turrialba, Costa Rica (Mateo 1976; Jaramillo, 1977)

crop combination produces a considerable amount of total biomass a year since it can be cultivated twice in certain regions with bimodal rainfall distribution, such as Turrialba. The relationship described in Figure 4 was obtained after pooling results from several field trials (Mateo 1976; Jaramillo 1977).

Nutrients rather than light seem to be the main limiting factor for intercropping cassava and sweet potatoes. Erect types of cassava provide sufficient light for a sweet potato crop planted simultaneously with them, and cassava cultivars that have their leaf area reduced at the end of their life cycle allow for another sweet potato intercrop to be harvested simultaneously. Management of Mg and K in the fertilization seems to be critical for the sustained production of this crop combination under soil conditions similar to Turrialba. This is probably true for intercrops of sweet potato with other root crops.

Intercrops with sweet potatoes represent also a valuable production alternative for mixed animal and crop farm systems where the animal component depends on farm crops. Several research results shows promising perspectives both for meat and milk production (Baker 1976; Ruiz *et al* 1977).

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General Discussion

(Session IV)

HO: What are the major advantages of using cut root pieces over using cuttings: which mature first?

BOUWKAMP: The major advantage is that the procedure is less labor intensive and adapts to mechanization. Root pieces require a slightly longer growing season than production from sprouts.

CHEN: What is the parameter for screening sweet potato for storage stability? How about the range of storage period of sweet potato among the varieties tested?

BOUWKAMP: For a given year, all varieties are stored the same length of time. Among years the length of storage was very similar - there was only approximately two weeks difference.

ANONYMOUS: I notice that you used the term 'root piece' for your propagation material. In the literature, however, the terms 'seed piece' and 'tuber piece' are also used. Which is correct? Would it not be to our advantage to adopt a consistent terminology?

BOUWKAMP: The term root piece is correct since the planting material is a piece of a root not a seed or a tuber. It would be helpful to adopt a consistent terminology and I would suggest root piece since the storage organ of the sweet potato is a root not a seed or a tuber.

URITANI: Please explain the difference in the effect on growth and yield between cut pieces from the proximal end and those from the distal end?

BOUWKAMP: If there is strong proximal dominance, the proximal ends survive better and produce more sprouts per hill than the distal ends. I know of no data which suggest a yield difference.

RASHID: Have you taken into account the effect of temperature in interpreting your results?

SAJJAPONGSE: Yes.

KAO: About your irrigation experiments, how do you explain the different results obtained in your fall crop and spring trial? When did you harvest to measure root yield?

SAJJAPONGSE: The difference in root yields between the fall and the spring trial was due to difference in temperature and number of days to harvest. In fall, the temperature was low and sweet potato was harvested at 170 days whereas the temperature in spring was very high and sweet potato was harvested at 140 days. Long term projects will include a wide range of temperature and sweet potato growth.

URITANI: Your sweet potatoes could have suffered from physiological deterioration when submerged in water. This may mean that sweet potato is rather susceptible to high soil moisture. Is this right?

SAJJAPONGSE: I don't think sweet potato is very sensitive to flooding. During irrigation, the plots were not submerged. They were moist. Under this situation then, I don't believe that sweet potatoes in our trials suffered from any physiological deterioration.

MEYNHARDT: Variations between replicates were large in your experiments. Did you use disease-free material, especially virus-free material, as your experimental material?

SAJJAPONGSE: We did not have virus problems in our trials. We believed that we used clean materials in our experiments.

WARGIONO: Did you observe any correlation of yield with weevil damage?

SAJJAPONGSE: We did not do this in our studies.

ANONYMOUS: Was irrigation practiced in your compaction experiment? Do you think the poor yield in the case of low bulk density is related to moisture stress or not?

SAJJAPONGSE: The soil compaction experiment was conducted in pots and we kept the soil moisture content to about field capacity throughout. It was easy to control soil moisture. I don't think the poor yield was affected by soil moisture.

HAHN: There were no differences in yield among treatments when irrigated and when high soil compaction was applied. Why is that so? What does it mean?

SAJJAPONGSE: Although there was no statistical difference in yield among treatments, at least a trend was established which indicated the effect of irrigation and soil compaction on yield. The non-significance was probably due to the great variation between replicates.

HAHN: What is the significance of irrigation and soil compaction studies for small sweet potato growers in Asia?

SAJJAPONGSE: At the time of root formation (30-40 DAP), irrigation should be withheld. The best bulk density of soil was 1.3 to 1.5 g/cc. These principles could be practiced by farmers in general if high yield is expected.

LEE: At the time of irrigation, did you apply irrigation water up to a certain soil moisture content or did you apply a fixed amount of water?

SAJJAPONGSE: It was more or less a fixed amount of water. We filled up the furrow on each side of the bed and then let the water penetrate through the bed. Since our soil has a light texture, the excess water would leach away rather easily and moisture at field capacity would be obtained.

AGATA: What do you think is the mechanism of high production under 30-40 DAP conditions?

SAJJAPONGSE: Irrigation should be nheld at 30-40 DAP, so that more photosynthate from the leaves can be translocated to form tuberous roots.

WARGIONO: As you showed in your slides, topping increases yield and starch content. Could you explain why? Which topping treatment will you recommend?

BARTOLINI: Topping increased yield and starch content of the roots because it minimizes the competition between the shoots and the roots in drawing photosynthates. The roots acted as a magnetic sink to draw the photosynthate instead of it going to the shoots and buds. Limiting vegetative growth enhances starch concentration in the roots. I recommend late topping since roots are already initiated and developed at this stage.

URITANI: Which is more suitable to get high yield, topping at the initial stage or at a later stage?

BARTOLINI: Our results showed that high yields could be obtained by topping both at the early and later stage compared to no topping. Topping early at about 1½ to 2 months and late at 3 to 4 months appeared suitable to obtain high yield.

ANONYMOUS: How were the sweet potatoes topped? For example, what was the length of shoots cut? One could possibly explain your increased yields with the 6-8 week topping due to a change in dry matter allocation. However, your yield increase late in the season when vine growth has decreased substantially would be difficult to explain.

BARTOLINI: Topping is cutting off a 35 cm apical portion of the sweet potato with about seven leaves. Topping was done twice, thrice, four times, and continuously at biweekly intervals. BNAS 51 is a heavy foliage sweet potato variety. Topping late in the season limits its vegetative growth. Thus, most of the photosynthates are channelled to the roots instead of the leaves.

VON UEXKULL: Your data showed that incorporation of 3 tons straw increased K intake to 119 kg K_2O/ha. Assuming the rice straw had 1% K_2O, it would have added 30 kg K_2O to the soil. How do you explain such a big increase in K intake?

WARGIONO: With the positive effect of rice straw in increasing soil texture and CEC, sweet potato growth was good and good yield resulted. Consequently the total nutrient uptake increased.

CHEN: As we saw yesterday in Tong-Shun, when the soil condition is wet, the sweet potato harvester cannot remove soil from the root. Is there any other type of harvester that can function well under wet soil conditions?

WILSON: Harvesting sweet potatoes is facilitated by relatively dry soil conditions. Too dry soil results in increased root damage. Vibrating or shaking devices on the elevator chain aid the separation of soil from roots.

VILLORENTE: With the extent of farm mechanization of sweet potato you have discussed, what is the minimum area being cultivated to sweet potato in the US? How much is the investment involved in acquiring, operating and maintaining the machine?

WILSON: Many fields of less than half a hectare which are grown in the US are probably harvested by hand or simple plow. Usually 8-20 hectares are required to justify some degree of mechanization. Simple equipment can be purchased for several hundred to a few thousand dollars. For example, harvesting aids (riding harvesters) sell for $500-$1,000 each. More sophisticated equipment will cost several thousand dollars. Maintenance costs correspond to sophistication of equipment.

WINARNO: What pesticides are generally used for sweet potatoes before sorting and what dose did you use?

WILSON: They are all spelled out in the NC Sweet Potato Production Bulletin, 'Growing and Marketing of Quality Sweet Potatoes'.

URITANI: Do you have a problem of wounding damage to sweet potatoes with mechanization?

WILSON: Yes, proper equipment adjustment and operation are critical to minimize damage. Curing sweet potatoes is important for disease control and enhanced storability and quality maintenance. It is critically important for mechanically harvested sweet potatoes and should be done as soon as possible after harvest.

SELLECK: Would the white potato digger used for sweet potato be more effective if sweet potato tops were dessicated with herbicides prior to harvest? What herbicides are used commercially for weed control? What are the promising new herbicide candidates?

WILSON: Probably not. Vine removal by cutting eliminates or minimizes interference with digging. Eride, Amiben, Dacthal and Vernam are used commercially. A promising herbicide is Surflan.

TICKOO: What are the net economic returns per hectare for some of the most important cropping sequences? Is sugarcane an economical component of cropping systems in Taiwan owing to its long growing period?

WAN: If labor is inexpensive and abundant as in the 1960s, the additional crop in multiple cropping means extra profit to the farmers. The sugarcane as a component of a cropping system is largely used in Tainan where water is limited so that growing more than one rice crop is impossible. Therefore sugarcane has been used as a rotational crop. However, it is only economical if the world market price for sugar is reasonable, regardless of its long growing period.

ANONYMOUS: You have mentioned that the acreage of sweet potato in Taiwan is decreasing in favor of rice. How do these two crops compare in economic returns to the producers?

WAN: The gross profits from rice and sweet potato per hectare are approximately NT$80,000 and NT$70,000, respectively. However, there are less inputs for sweet potato so that the net return for the two crops is not much different. The problem is that the government has a price support system for rice but not for sweet potato.

WUSTMAN: Do you find any significant difference in sweet potato weevil incidence when growing sweet potatoes under various cropping patterns?

WAN: We did not find weevil a problem in cropping systems involving sweet potato on paddy fields. There is weevil on uplands, but it is not serious even there.

ANONYMOUS: From your slides, it seems the yield data for intercropping were made 20 years ago. Do you have any recent data from modern farmers in Taiwan now? Would you tell us what kind of major problems are involved in the intercropping system?

WAN: Intercropping is a labor intensive system. In the early 1960s labor was abundant and inexpensive so that our main concern was production increment per hectare. However, in recent years, there has been shortage of labor. Therefore, it is not possible for farmers to continue such intensive farming, and we are trying to study labor-saving farming methods.

ANONYMOUS: Where do farmers in Taiwan get their planting materials?

WAN: Sweet potato can be grown in Taiwan all year round, so that farmers can get cuttings from field plantings. For the fall plantings, roots are bedded in spring to obtain new planting materials.

WARGIONO: Which cropping system will you recommend and which one will give the highest income?

WAN: This depends partly on the location within Taiwan where different cropping systems are adapted. For example, a three-year rotational irrigation scheme has been practiced in Tainan area so that the rice-sugarcane-sweet potato scheme is the most profitable.

ANONYMOUS: What percent of total cultivated land is under respectively two, three and four crops a year in Taiwan?

WAN: We do not have this kind of data. However, we have the general multiple cropping index in Taiwan, which was around 163 in 1979.

ANONYMOUS: Mr Zara of the University of the Philippines at Los Baños showed a marked difference in the response of sweet potato to shading by coconut. You showed that in Costa Rica sweet potato was strongly suppressed by intercropped maize. Did you test this with different varieties?

MORENO: No, we don't have available data from different varieties but the search for shade tolerance among sweet potato varieties is very important in the development of multiple cropping systems, There is negative correlation between root yield of sweet potato and maize grain when these crops are grown together. With good management, particularly N/K ration, adequate for both crops, and better spacing arrangements between these two crops, a land equivalent ratio value above one can be obtained.

SESSION V

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Autohexaploid Evolution of the Sweet Potato

I. NISHIYAMA

18 Hazamacho, Shugakuin, Sakyoku, Kyoto 606, Japan

INTRODUCTION

It is said that some hundred species of *Ipomoea* are found in tropical and warm temperate regions. However, the taxonomy of *Ipomoea* is still insufficiently studied. The large genus is usually sub-divided into several sub-genera and sections. Sweet potato, *I. batatas* (L) Lam and its relatives are included in the section *batatas*. Recently Austin (1978) made an extensive classification of this section, including 13 species (Table 1).

In order to study the origin of crop plants it is generally necessary to obtain information on how, when and where prehistoric crop plants first occurred. Our knowledge so far suggests that the cultivated plant and its ancestor usually must have the same or nearly the same genome constitution. In the case of polyploids, it is further useful to synthesize artificial polyploids with the same genome formula as that of the cultivated plant by employing its basic species. It is also important that the ancestor resembles the cultivated plant in many aspects of morphology, physiology, cross-compatibility, geographical distribution, plant remains, and others. Of course they are different in certain wild and cultivated type characteristics.

Based on cytogenetic studies Nishiyama and coworkers (1962, 1963, 1971, 1975) have found a wild ancestor, *Ipomoea trifida* (HBK) Don (6x), and its basic species (2x, 4x) of the sweet potato, and have discussed their evolutionary relationships. The principle of the hypothesis has been supported by many Japanese workers who recently found 2x- and 4x- forms of *I. trifida* (6x) (Muramatsu and Shiotani 1974; Teramura 1979; Kobayashi 1980; Kobayashi *et al* 1980; Muramatsu 1980; Shiotani and Kawase 1980). However, Jones (1967), Martin and Jones (1972), Martin *et al* (1974), and Austin (1977, 1978) disagree with Nishiyama and coworkers' opinion but do not propose any alternative hypothesis.

This paper presents a review, and gives new data on the evolutionary development of the sweet potato, and suggests a new breeding method by using its progenitors.

ANCESTORS POSTULATED BY EARLY WORKERS UNTIL 1957

After Columbus's discovery of America in 1492, sweet potato was distributed over the Old World. It was usually assumed that the sweet potato might have its origin in tropical America, though there were different opinions which suggested African or Asian origin (de Candolle 1884). At the beginning of the 20th century some workers proposed that *I. fastigiata*, *I. pandurata* (Waite 1907), *I. tiliacea* (House 1908), *I. triloba* (Watanabe 1939, 1940) might be ancestral forms of the sweet potato, because of resemblance in their plant morphology. The *I. tiliacea* hypothesis was especially popular among many botanists. Chromosome number (2n=90) of the sweet potato was first counted by King and Bamford (1937) and Watanabe

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Table 1. Taxonomy of *Ipomoea* section *batatas* (after Austin 1978)

Species	Ploidy[a]
1. *Ipomoea batatas* (L) Lam	6x
2. *I. cynanchifolia* Meisn	2x
3. *I. gracilis* R BK	4x
4. *I.* X *grandifolia* (Dammer) O'Donell	2x
5. *I. lacunosa* L.	2x
6. *I.* X *leucantha* Jacq	2x
7. *I. littoralis* Blume	4x
8. *I. ramosissima* (Poir) Choisy	2x
9. *I. tenuissima* Choisy	2x
10. *I. tiliacea* (Willd) Choisy	4x
11. *I. trichocarpa* Ell	2x
12. *I. trifida* (HBK) G Don	2x, 4x, 6x
13. *I. triloba* L	2x

[a]Ploidy, especially 4x and 6x of *I. trifida* is appended by the present author, x = 15

(1939). Cytological investigations of numerous *Ipomoea* species were further reported by many workers. Most of the species showed 2n=30, and only two species, *I. gracilis (I. fastigiata)* and *I. tiliacea*, had 2n=60 (King and Bamford 1937; Wolcott 1937, Watanabe 1939; Ting *et al* 1957; Jones 1964). Different chromosome numbers, 2n=30 and 60, in both *I. ramoni* and *I. tiliacea* were reported in the literature (Jones 1964). This was probably due to taxonomic confusion. Because of the difference of chromosome numbers and interspecific cross-incompatibility Ting *et al* (1957) concluded that no phylogenic relationship existed between *I. batatas* and the other species mentioned above. The identity of its ancestor remains to be established.

WORKING HYPOTHESIS ON THE EVOLUTION OF SWEET POTATO

It has become clear that only *I. batatas* (L) Lam (2n=90) is distinct from the other species (2n=30,60) in chromosome number, cross-compatibility, and domesticated characters, such as production of edible roots. Before exploring its ancestral plants we wish to discuss hypothetically all possible evolutionary courses from ancestral diploids to hexaploid sweet potato. The courses are diagramatically indicated as follows:

Course	Wild type	Cultivated type	Remark
I	2x → 4x → 6x	→ 6x	Supported by Nishiyama (1962, 1971)
II	2x → 4x	→ 6x	
III		2x → 4x → 6x	Suggested by Jones (1967)
IV	2x ----- 4x	6x	Situation until 1957

Course I. All ancestors (2x, 4x, 6x) are wild plants, producing no edible roots. The sweet potato is derived from hexaploid wild plants by gene mutation and increase of gene dosage. This is supported by cytogenetic investigations of the sweet potato and its relatives. Details are given later.

Course II. All diploid and tetraploid ancestors are wild, while hexaploids induced by doubling chromosomes of their triploid hydrids are of cultivated type like sweet potato.

Course III. All ancestors (2x 4x) are of cultivated type. Accordingly the only hexaploids derived by doubling chromosomes of their triploid hybrids are sweet potato varieties.

Course IV. No phylogenic relationship was found between the sweet potato and the other *Ipomoea* species until 1953.

TAXONOMY OF *I. batatas* AND ITS ALLIED SPECIES

A new hexaploid form, *I. trifida* (HBK) Don (strain K 123, K 177), was found in Mexico for the first time in 1955). It was proven to be a probable ancestor of the sweet potato (Nishiyama 1963, Nishiyama and Teramura 1962). The finding suggested that its diploid and tetraploid progenitors might be found in tropical America. Since then, *I. leucantha* Jacq (2x, K 221) and *I. littoralis* Blume (4x, K 233) were collected by Japanese botanists in Mexico. By genome analysis, they were confirmed to be basic forms of *I. trifida* (6x) (Nishiyama 1971). Besides, new diploid and tetraploid forms of *I. trifida* (6x) were recently found by Muramatsu and Shiotani (1974) and Kobayashi (1980) in Mexico, Venezuela and Colombia. In his taxonomy, Austin (1978) also stated that *I. trifida* (2x) was widely distributed in tropical America. Thus it becomes clear that *I. trifida* is a species complex involving 2x, 4x and 6x forms.

Austin (1977) further proposed that *I. gracilis*, *I. littoralis* and new tetraploids found by Martin *et al* (1974) might originate from hybrids between *I. batatas* and probably *I. trifida* (2x), because the morphology of the tetraploid species was intermediate between them. This is questionable because most of hybrid offsprings from *I. batatas* crossed with *I. trifida* (2x) or *I. leucantha* (2x) produce tuberous roots, and their natural hybridizations are very difficult (Nishiyama *et al* 1975; Shiotani *et al* 1980). However, the cross is possibly successful when the young embryos are artificially cultured. Austin (1977) furthermore suggested that *I. leucantha* Jacq might arise through hybridization between *I. lacunosa* and *I. trichocarpa* for a couple of hundred years. This is hard to justify from a standpoint of their cytogenetic relationships. Both *I. lacunosa* and *I. trichocarpa* have the same genome formula AA, and are cross-compatible with each other, while *I. leucantha* has BB genomes, and is cross-incompatible with the former two (Jones and Deonier 1965; Nishiyama 1971; Nishiyama *et al* 1975).

Out of the 13 species of *Ipomoea* section *batatas*, *I. trifida* (2x, 4x, 6x), *I. leucantha* (2x) and *I. littoralis* (4x) were found to be closely related to the phylogeny of *I. batatas*, and evidence of this is given in the following paragraphs. Table 2 gives a list of their phylogenic taxonomy. It is partly revised from Nishiyama's (1971), because of the recent discovery of diploid and tetraploid forms of *I. trifida* (6x).

Table 2. Phylogenic taxonomy of *Ipomoea batatas* group

Ipomoea batatas (L) Lam

var *diploid-trifida* (HBK) Nishiyama (Nish)

f *diploid-trifida* (HBK) Muram et Shiot ex Nish (Figure 4, f *trifida* 2x)

f *leucantha* Nish Syn: *I. batatas* (L) Lam var *leucantha* Nish in B.M. T. 84, 385, 1971 (Figure 4, f *leucantha* 2x)

var *tetraploid-trifida* (HBK) Nish

f *tetraploid-trifida* (HBK) Muram et Shot ex Nish

f *littoralis* (Blume) Nish Syn: *I. batatas* (L) Lam var *littoralis* (Blume) Nish l.c. (Figure 4, f *littoralis* 4x)

var *hexaploid-trifida* (HBK) Nish Syn: *I. batatas* (L) Lam var *batatas* f *trifida* Nish l.c. (Figure 4, var *trifida* 6x)

f *hexaploid-trifida* (HBK) Nish Syn: *I. batatas* (L) Lam var *batatas* f *trifida* (HBK) Nish l.c. (Figure 4, f *trifida* 6x)

f *batatas* (L) Nish Syn: *I. batatas* (L) Lam var *batatas* Nish l.c. (Figure 4, f *batatas* 6x) (Sweet potato)

GENOME ANALYSIS IN THE *I. batatas* GROUP

In order to understand a genome relationship between *I. batatas* and its closely related plants, meiotic pairing of chromosomes in pollen mother cells of their hybrids should be observed. A variable number of univalents, bivalents and multivalents is usually observed in most of the hybrids. However, Figure 1 indicates only an averaged number of bivalents at first metaphase in each hybrid where a trivalent, quadrivalent including pentavalent, and hexavalent are treated as one, two and three bivalents, respectively.

All hexaploid hybrids among sweet potato (6x), *trifida* (6x) and *trifida* (3x)-6x showed 45II or about 45II; of course complex pairings often occurred. The *trifida* (3x)-6x was obtained in the progeny of triploid *trifida*, proba-

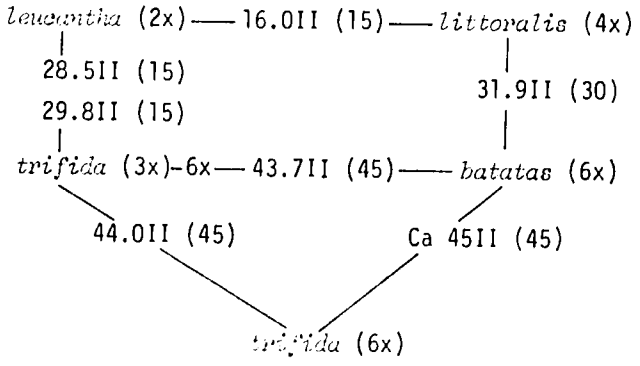

Figure 1. Average number of bivalents in hybrids among *I. batatas* and its closely related plants. Figures in parentheses show expected numbers of bivalents formed by allosyndesis (after Nishiyama 1971)

bly a natural hybrid between *trifida* (2x) and *trifida* (4x), collected in Mexico. It is certain that these hexaploids have the same genome formula.

In a pentaploid hybrid, *I. batatas* (6x) X *littoralis* (4x) about 3GII were usually found. Accordingly both parents may have two genomes in common.

In a triploid hybrid the formation of 16II suggests that both parents *leucantha* and *littoralis* have one common genome.

It is very interesting that a tetraploid hybrid, *trifida* (3x)-6x crossed with *leucantha* (2x), showed about 30II, instead of the expected 15II. This suggests that 15 chromosomes of *trifida* (3x)-6x pair with those of *leucantha* and the remaining 30 chromosomes of the former from 15II. Carefully examining the chromosome behavior shown in Figure 1, it is concluded that the *I. batatas* group is autoploid derived from duplication of *trifida* (2x) or *leucantha* genomes BB. Alloploid origin of the sweet potato, previously postulated by some authors (Ting and Kehr 1955; Sharm and Datta 1958; Yen 1974) should be rejected.

COMMON CHARACTERISTICS OF *I. batatas* AND ITS ALLIED SPECIES

In morphological observations it is often difficult to distinguish members of the *I. batatas* group from the other species in *Ipomoea* section *batatas* (Martin and Jones 1972; Martin *et al* 1974). However, distinction can be successfully made from a standpoint of the genome analysis and sexual compatibility. Figure 2 indicates comparative characteristics of the *I. batatas* group and the others which were formerly assumed to be progenitors or close relatives of the sweet potato. These plants were divided for convenience into A-, B-, and X-group. In the A-group are included *I. triloba* and closely related *lacunosa*, *trichocarpa* and *ramoni*. Jones and Deonier (1965) reported that they were self-compatible and cross-compatible with each other, all of them had the same genome formula AA. The B-group is the *I. batatas* group, containing autoploids (2x, 4x, 6x) with doubling of the genome B. All of them are self-incompatible but cross-compatible with each other. Two well known tetraploids, *I. tiliacea* and *I. gracilis*, in the X-group are self-incompatible but crossed with one another. Their genome constitution has not yet been studied. The B-group does not cross with the A- and X-groups, while the A-group crosses with the X-group when the latter is pollen parent.

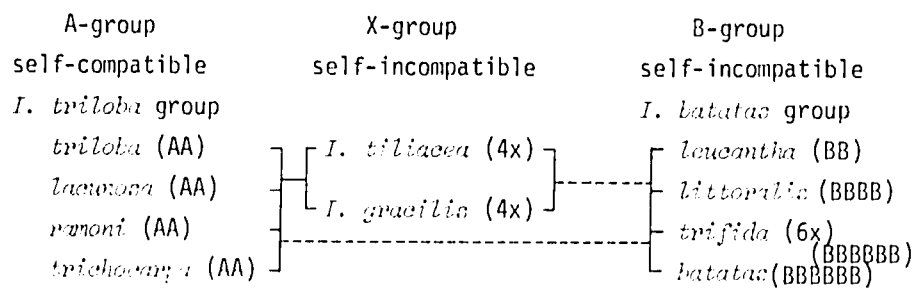

Figure 2. Sexual compatibility relationships in *Ipomoea batatas* section *batatas*. Legend: __compatible; --- incompatible.

ARTIFICIAL POLYPLOIDS

Many tetra- and hexaploids were artificially produced from basic forms in the A- and B-group. They were fertile although usually less so than the original forms (Sakamoto 1970). Meiotic behavior of chromosomes was almost normal, except for occasional multivalents and univalents (Shiotani *et al* 1970). Artificial polyploids in the B-group were easily crossed with each other, and also with sweet potato and *trifida* (6x), whereas similar artificial ones in the A-group were still incompatible with those of the B-group (Figure 3).

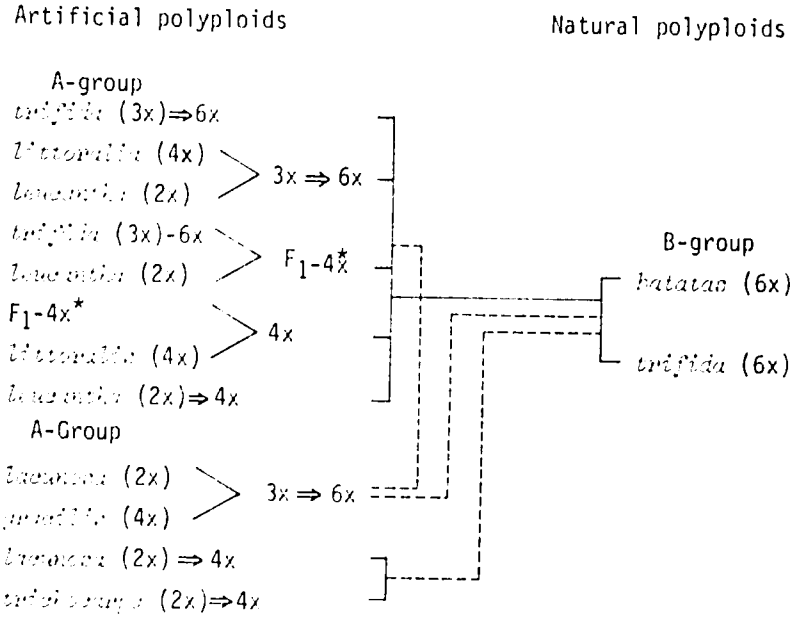

Figure 3. Artificial polyploids in the A- and B-group. and their cross-compatibility relationships. Legend:— compatible; --- incompatible (after Nishiyama *et al* 1975)

Artificial hexaploids from *littoralis* (4x) X *leucantha* (2x), or *trifida* (3x) were quite similar to natural *trifida* (6x) in almost all characteristics. However, it is noteworthy that autohexaploid *leucantha* showed remarkably decreased vigor, and was sometimes deformed and highly sterile. It was hard to cross it with sweet potato. Since autotetraploid *leucantha* was of gigas type and moderately fertile the growth inhibition might be due to a deleterious effect of high autoploidy, induced by doubling of a *leucantha*-isogenome. The facts strongly suggest that the genomes of *leucantha* and *littoralis* have differentiated to some extent from each other. However, they must have been highly homologous as they do not disturb seed fertility or regular meiotic pairing of chromosomes in certain hybrid situations.

PHYLOGENY OF SWEET POTATO

The research data mentioned above strongly suggest that sweet potato has arisen through course I in the working hypothesis. Figure 4 further shows a diagrammatic illustration on the mode of origin of the sweet potato. The sweet potato might have originated through two evolutionary events; (1)

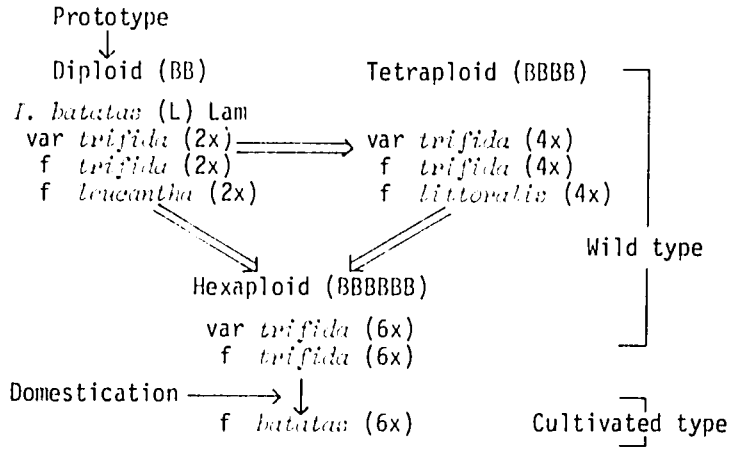

Figure 4. Diagrammatic illustration of a series of evolutionary events of sweet potato. Double lines indicate doubling of the chromosome number (x = 15)

the occurrence of *trifida* (6x) by duplication of a single chromosome set B from *trifida* (2x) or its close relative *leucantha* and (2) domestication of wild type characteristics of *trifida* (6x) into cultivated types. It is interesting that natural autohexaploids usually have been free from any deleterious effect of high autoploidy. It seems likely that harmony has been acquired by genetic differentiation or heterozygosity in hexaploids or in its diploid and tetraploid progenitors. Outcrossing can accelerate it.

Tuberous root-forming diploid and tetraploid relatives have still not been found. In hexaploids, however, there are two types with and without tuberous roots. The formation of edible roots is one of the most important characters of the sweet potato. But it is well known that sweet potato varieties occasionally produce a few seedlings which never form tuberous root roots (Tioutine 1935; Miyake and Matsunaga 1939; Jones 1967). This is probably because the sweet potato is still heterozygous for the formation of tuberous roots. If ancestral diploid and tetraploid texa were tuberous the sweet potato should be homozygous. Tuberous roots appear to have arisen in *trifida* (6x) by successive mutations of a number of genes.

Inheritance of autohexaploids is generally controlled by random assortment of six homologous chromosomes or their chromatids accompanied by crossing over between kinetochores and gene loci. In the sweet potato or *trifida* (6x), however, certain chromosomes may not permit free mixing, because they seem to have to some extent differentiated. They may still be in favor of accumulating genes, six doses being expected at the maximum, instead of two doses in the corresponding diploids. The phenotypic expression may be changed owing to different dose rates. The frequency of six dose recessives or dominants is extremely low in autohexaploids (Table 3). Accordingly certain sweet potato clones or a number of seedlings have been found to exhibit a variation of the root formation character, or to exhibit some of such primitive characteristics as twining stems and pubescence on some plant organs. Occasional wild type segregates from the sweet potato can be practically distinguished from the typical *trifida* (6x), though hardly in the extreme case. The wild type segregates are pseudo-*trifida* (6x) and may be called 'trifidoid'.

Table 3. Segregation ratios of recessive homozygotes in autopolyploids, calculated from the random chromosome assortment

Auto-ploidy	Genotype	Rece. homo. : others	Genotype	Rece. homo. : others
2x	R^1r^1	1 : 3	$R^1r^1T^1t^1Y^1y^1$	1 : 63
4x	R^3r^1	0 : 4	$R^3r^1T^3t^1Y^3y^1$	0 : 64
	R^2r^2	1 : 35	$R^2r^2T^2t^2Y^2y^2$	1 : 46, 656
	R^1r^3	1 : 3	$R^1r^3T^1t^3Y^1y^3$	1 : 63
6x	R^5r^1	0 : 4	$R^5r^1T^5t^1Y^5y^1$	0 : 64
	R^4r^2	0 : 25	$R^4r^2T^4t^2Y^4y^2$	0 : 15, 625
	R^3r^3	1 : 399	$R^3r^3T^3t^3Y^3y^3$	1 : 63, 999, 999
	R^2r^4	1 : 24	$R^2r^4T^2t^4Y^2y^4$	1 : 15, 624
	R^1r^5	1 : 3	$R^1r^5T^1t^5Y^1y^5$	1 : 63

ORIGIN OF SWEET POTATO AND ITS NATIVE REGIONS

As stated above, sweet potato plants seem to orginate from *trifida* (6x) through genic differentiation, especially for formation of tuberous roots. Before consideration of the genetic mechanism of thickening of roots, I will briefly refer to histological differences between tuberous and non-tuberous roots. Nishimura *et al* (1980) reported their histological differences as follows:

I. Tuberous roots of sweet potato: (1) Non-lignification of parenchymatous cells and vessels in the primary xylem, (2) formation of the primary vascular cambium which vigorously produces the secondary xylem, (3) Initiation of the secondary and tertiary development of both xylems.

II. Non-tuberous or somewhat thickened roots of *trifida* (6x): (1) Lignification of a large part of parenchyma, and vessels in the primary xylem, (2) The primary vascular cambium and secondary xylem were very poorly formed, (3x) Both xylems showed little or no secondary or tertiary development. Thus, the anatomical structure rather resembles that of ordinary roots. In short, peculiar differentiations of the tissue structure of tuberous roots seem to be controlled by certain alleles.

We have little or no knowledge of the mode of inheritance of edible roots. I tentatively assign three different pairs of alleles, R-r, T-t and Y-y, to designate rooting. In terms of interaction of R, T and Y they finally effect non-tuberous roots, and similarly, r, t, and y govern edible roots. Originally R, T and Y might mutate to r, t and y, respectively in different individuals of *trifida* (6x) with a genotype $R^6T^6Y^6$. Its outcrossing habit might be of great advantage that all of the mutant genes are brought in together in one individual, for example with a genotype $R^5r^1T^5t^1Y^5y^1$. The genotype situation of its offspring is extremely complicated as can be seen in Table 3 in which the calculation is simply made only by the random chromosome assortment in autoploids. Now we arbitrarily assume that dose rates

f each dominant gene 2-0: recessive gene 4-6, such as genotypes $R^2r^4T^2t^4Y^2y^4$-$^6t^6y^6$, produce edible roots. Accordingly *trifida* (6x) with non-tuberous oots may consist of a great variation of genotypes from $R^6T^6Y^6$ to $R^3r^3T^3t^3$-$^3y^3$. They may show various degrees of thickness of non-tuberous roots. At ny rate some of them are able to segregate an edible root-forming offspring ut the others do not.

Based on a linguistic theory it has been proposed that the sweet potato as transferred from the New World to the Old World, especially into the acific, through three dispersion lines (Barrau 1957). Yen (1974) revised arrau's hypothesis with his data on sweet potato variability.

1. 'Kamote' line: Mexico -- Micronesia---Philippine Islands---China---- apan.

2. 'Batata' line: Caribbean Islands -Europe--Africa--India--- ndonesia (Timor) New Guinea --Melanesia (New Britain, Solomon Islands, ew Hebrides, New Caledonia, Fiji Islands).

3. 'Kumara' line: Peru, Ecuador, Colombia-- Polynesia (Marquesas--- aster Islands, Society Islands, Hawaii, Cook Islands--- Tonga, Western amoa) --New Zealand.

Recently Kobayashi (1974) found that the sweet potato and *trifida* 6x) had seven cross-incompatibility groups, A, B, C, E, F, G, H, in common. n the other hand, Nakanishi and Kobayashi (1978) preliminarily identified 5 cross-incompatibility groups, A-L and N-P, in about 700 sweet potato cul- ivars, including Yen's (1974) collection from America, Asia, and pan- acific islands. The incompatibility group B showed the widest distribution n almost all regions in the three dispersion routes, followed by the order f A, C, E, H and D. It is noted that group A was usually found everywhere n the Kamote line (Mexico, Philippine Islands, China, Japan), and the line (America, Timor, New Guinea, Solomon Islands, New Hebrides, ew Caledonia). However, on the Kumara line, of 66 cultivars from Peru, olombia and Ecuador, and of 55 cultivars from Polynesia, none was found to xhibit group A. Only two cultivars from Easter Island and Western Samoa xhibited group A. The origin of these two cultivars is unknown. The estern Samoa cultivar is rather indicative of a mixed derivation from elanesia and Polynesian varieties, and Yen (1974) postulated probable con- act between them. The geographical evidence suggests that the sweet potato ith group A arose in Mexico and that with group B occurred in both Mexico nd Peru or its vicinity. The cultivars showing J, K, O and P seem to be ndigenous to Peru, Colombia or Ecuador though some of them were found on aster Island.

In short, it may be generally concluded from the several pieces of vidence discussed above that sweet potato is of polyphyletic origin in ropical America, Mexico and from Colombia to Peru.

A NEW BREEDING METHOD FOR SWEET POTATO, UTILIZING ITS ANCESTORS

Some relatives can be used for improvement of sweet potato by means of he usual cross-breeding methods. Because of the tremendous complexities of exasomic inheritance, however, it is obvious that we must either grow very arge populations of autohexaploids or devise some step by step scheme for btaining plants with the desired characters (see Table 3). I wish to pro-

pose a new breeding method for sweet potato. The procedure is briefly given here:

(1) Resolution of sweet potato (6x) into 2x- or 4x-forms.

(2) Breeding 2x- or 4x-sweet potato as genetic stocks with recombinations of major genes for desired traits which are found in sweet potato (6x) or its ancestors.

(3) Artificial synthesis of sweet potato (6x) from desirable 2x- and 4x-sweet potato, resulting in raw sweet potato (6x) with expected genotypes.

(4) Synthesized raw sweet potato clones (6x) may possess certain minor defects which must be corrected by further breeding aimed at recombining useful genes or increasing vigor.

As an example, a procedure for obtaining 2x- and 4x-sweet potato is outlined in the following:

I. Induction of 2x- or 4x-forms from sweet potato (6x)

A. Diploid relative (*trifida*, 2x) BtBt X Sweet potato (6x) BBBBBB

F_1 hybrid BBBBt (artificial culture of hybrid embryos)

F_2

$\widehat{Bt}BBB\widehat{BB}t$ ($\widehat{BB}t$ is a genome mixing chromosomes of B and Bt)

F_x

BBBB (sweet potato, 4x)

B. Sweet potato (4x) BBBB X Diploid relatives (*trifida*, 2x) BtBt

F_1 hybrid BBBt

F_2

BB + Bt (extra chromosomes)

F_x

BB (sweet potato, 2x)

C. Sweet potato (2x) BB X Sweet potato (6x) BBBBBB

F_1 hybrid BBBB (artificial culture of hybrid embryos)

(sweet potato, 4x)

II. The anther culture method seems to be an important technique for obtaining 2x- and 3x-forms from pollen grains of 4x- and 6x-sweet potato, respectively.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to Dr M. Hiroe for his kind help on the taxonomy of *I. batatas* group.

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Analysis of the Incompatibility and Sterility of Sweet Potato

F. W. MARTIN

Mayaguez Institute of Tropical Agriculture, Mayaguez, Puerto Rico 00708

INTRODUCTION

The details of the reproductive behavior of a given species are of basic importance to the plant scientist, especially to the plant breeder who must take such details into account in improving the plant or developing better varieties. In this respect the sweet potato is an unusual species, distributed throughout the tropics and part of the temperate zone, and under development in several important locations, yet still little understood with respect to some of its problems of reproduction. I believe, however, that the bulk of the investigation necessary to understand the reproductive nature of the sweet potato has been done.

Certain facts about the breeding system of the sweet potato are clear. The sweet potato is a hexaploid, and is highly probable that it is an autohexaploid. In common with many primitive species of the genus *Ipomoea* and the family Convolvulaceae, it is self-incompatible. This physiological system enforces outcrossing. Cross-pollination is done by insects, mainly by bees.

In addition to these simple facts is the common observation that even in cross-pollinations very few seeds are produced. Plant breeders have had to undertake tedious hand pollinations in order to make the specific crosses necessary for the advanced varieties now available. But why is it so difficult to obtain seed?

If one examines the capsules set or the seeds set after pollination in a large number of crossing combinations, the following kinds of data are obtained (Table 1). Curves for the two kinds of data are similar in appearance. The mode is zero in both cases, and in the majority of the crossing combinations very few capsules and very few seeds are produced (Martin 1965). Rarely can a pair of sweet potatoes be found that can be said to be fully cross-fertile.

This can now be clearly stated to be caused by two phenomena, self-incompatibility and sterility. These are entirely distinct processes, and they must be studied separately.

SELF-INCOMPATIBILITY IN SWEET POTATO

Analysis in a diploid species

Analysis of the incompatibility in *Ipomoea* requires the use of a diploid species free from the sterilities of the sweet potato. In a survey of incompatibility in the family Convolvulaceae, eight such species were found (Martin 1970). One of these species, *I. setifera* Poir, was selected for detailed analysis (Martin 1968).

Ipomoea setifera is a wild perennial climbing or trailing species that

Table 1. Distribution of podset and seedset data in a large number of sweet potato cross pollinations

Precent success	Number of cross pollinations	
	Of pods	Of seed
0	38	40
1-6	20	35
7-12	19	11
13-18	13	10
19-24	5	7
25-30	6	6
31-36	5	10
37-42	6	3
43-48	5	4
49-54	5	3
55-60	5	4
61-66	5	2
67-72	1	1
73-100	7	3

flowers only during short days at Mayaguez, Puerto Rico. Seeds were collected from five widely separated localities in western Puerto Rico, and grown outdoors. In preliminary studies, we observed the mode of behavior of pollen in compatible and incompatible matings, tested bud pollination as a means to avoid self-incompatibility, and examined the results of several hundred reciprocal pairs of pollinations. Compatibility was determined by two criteria: success or failure of pollen germination on the style, and success or failure of podset after controlled pollination.

The number of incompatibility groups and their crossing relationships were determined by two screenings. In the first, 21 plants from the Mayaguez area were crossed in most of the possible combinations, and observed for fruitset. In the second screening, five groups of plants from distinct geographic areas were sampled for incompatibility groups. First we determined the crossing relationships of a small number of plants; then we reciprocally crossed one or two plants of each incompatibility group to unclassified plants to determine their relationships. New testers were added as new groups were delineated.

Inspections of pollinated stigmas revealed three kinds of behavior. In incompatible crosses all pollen grains failed to germinate. In compatible crosses all (or almost all) of the pollen grains germinated. In some crosses, part of the pollen germinated and part did not. This partial incompatibility was difficult to distinguish from full compatibility because the harsh treatment given to stigmas to prepare them for inspection often removed many of the non-germinated pollen grains. The number of germinated pollen grains in fertile or partially incompatible matings was usually

between ten and 25, sufficient to have fertilized all of the four ovules of the normal flower. In both species, seedsetting failure was associated with complete pollen germination failure in the hundreds of cases studied. The inhibition of pollen germination is thus the physiological basis of incompatibility in this species.

Self- and cross-incompatibility were not avoided by bud pollination in over 150 combinations tested and observed for pollen germination or seedset.

When the results of about 300 cross-pollinations were graphed for seeds produced per pollination, we found a bimodal curve corresponding to incompatibility, and to full or partial compatibility.

Reciprocal crosses between two individuals were both fertile or both incompatible, or one was compatible and one incompatible.

The survey of crossability among plants taken from five distinct geographical populations revealed ten incompatibility groups. In each group the members were intra-incompatible. Some of the inter-group crossing combinations were fertile, and some were not.

The analysis of the self-incompatibility system was then made. Floriferous plants of the three most prevalent incompatibility groups (A, B, and C) were chosen and hybridized under isolated conditions. The progenies were classified for incompatibility by crosses among sibs, and with parents. On the basis of these results, new parents were chosen, and another generation of progenies was screened.

The offspring of the crosses among groups A, B, and C were of four kinds. These four kinds corresponded to groups A, B, C, and H of the original population. Each family consisted of two or four groups. Two groups in each family were always of the parental types, and each crossed reciprocally with one parent but not with the other. On the other hand, crosses between groups A and B also produced individuals reciprocally fertile with both parents (group C), and reciprocally incompatible with both (group H). Some families also contained a few female-sterile plants, easily classified on the basis of their behavior as males.

The new type of plant produced by families A and B was reciprocally crossed to a plant of group C, the only one of the four groups with which it was fertile. In each of the two reciprocal families produced, two groups of progeny were produced. These groups were not like the parents but were identical in behavior with groups A and B.

A suitable model (Figure 1) can be constructed to explain the results of the crosses among groups A, B, C, and H. That model depends on the assumption that a series of multiple alleles controls the incompatibility groups of *Ipomoea setifera*. These alleles act sporophytically to determine the phenotype of the pollen. Thus, all pollen grains react alike. The alleles can have independent effects on the incompatibility phenotype, or one can dominate over the other in stigma and pollen. Following conventional treatment, the alleles have been numbered R_1, R_2, and R_3. Both R_1 and R_2 act independently, and are dominant in stigma and style to R_3. This model conforms to the type of incompatibility described previously in *Cosmos bipinnatus* Cav and *Raphanus* (Sampson 1964).

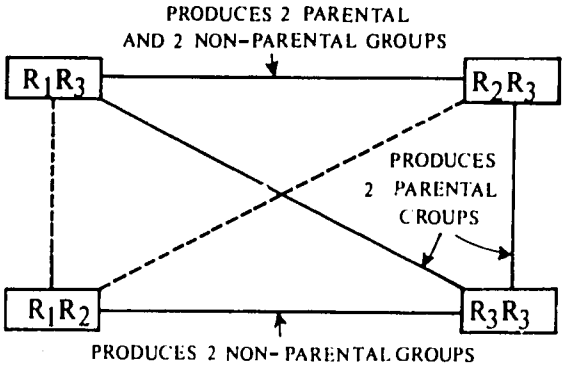

Figure 1. Pattern of crosses among 4 groups of *Ipomoea setifera*, and proposed genotypes

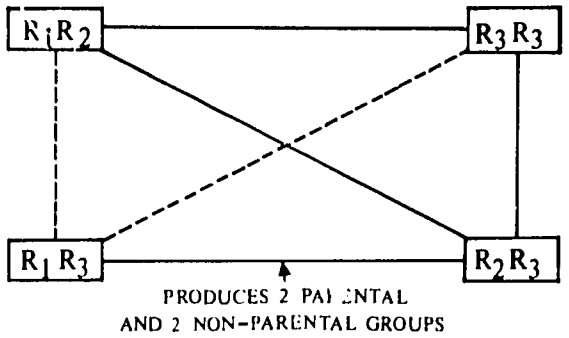

Figure 2. Pattern of crosses found by Van Schreven (1953) in sweet potato

Thus, the system of self-incompatibility in the family Convolvulaceae now appears to be of the multi-allelic, sporophytic type found in the families Compositae and Cruciferae. This is the only system extant capable of explaining the particular results of this study. The characteristics common to this system, and the system found in *I. setifera* include:

More than two incompatibility groups

Unilateral incompatibility between some groups

Incompatibility between some parents and their progeny

Two or four incompatibility groups in a family

The occurrence of parental groups in some families

INTERPRETATION OF THE SELF-INCOMPATIBILITY OF THE SWEET POTATO

Since the sweet potato is a hexaploid, the incompatibility locus must have been duplicated or even triplicated during its evolution. The question is whether the model of self-incompatibility found in *Ipomoea setifera*, duplicated or triplicated in a hexaploid that shows bivalent pairing, can explain the complex crossing behavior previously described in sweet potato.

The pattern of crosses among four groups of *Ipomoea setifera* analyzed in detail in this study conforms exactly to the pattern of crosses among incompatibility groups found by Van Schreven (1953) among her crosses of the sweet potato. The similarity of the patterns must be regarded as a coincidence, however, for the model of relationships among the *I. setifera* classes does not explain the Van Schreven case. By making a different set of assumptions about the genotypes and dominance relationships of incompatibility alleles, however, the Van Schreven data can be reconciled to the multi-allelic, sporophytic control hypothesis (Figure 2).

It is assumed that R_1 is dominant to R_2; R_2 is assumed to be dominant to R_3; but R_1 and R_3 are assumed to act independently. Dominance relations are assumed to be the same in stigma and pollen.

In contrast with the Van Schreven data, the crossing relationships that Fujise (1964) found in the sweet potato cannot be reconciled to the one-

locus, multi-allelic sporophytic hypothesis. His three intra-incompatible, inter-compatible groups (A, B, and C) produced progeny as follows when crossed: A x B or B x A produced A,B, and C types; A x C or C x A also produced A,B, and C types; B x C or C x B produced only B and C types. Furthermore, after self-pollination, pseudo-compatible A varieties produced A and B types, and B varieties produced B and C types. More than two loci (or genes) would be necessary to produce three such incompatibility groups, no matter what scheme is followed.

A simple two-loci model explaining the results of Fujise is presented in Table 2. Because bivalent pairing is the rule in sweet potato the two loci receive separate letter designations. But the interrelationships between loci (epistatic relationships) are assumed to be comparable to the interrelationships among alleles at one locus (dominance relationships). The model assumes that R_1 is dominant over R_2, and epistatic to S_1 and S_2; and that S_1 is dominant over S_2. Both S_1 and S_2 are epistatic to R_2.

Thus, the two-loci, multi-allelic sporophytic model can explain Fujise's results. Furthermore, it can be extended to include new groups when they are identified and adequately delineated. The model does not contradict the one proposed for the Van Schreven data, inasmuch as in particular crosses, either one or both loci may be operating.

Table 2. A two-loci, multi-allelic, sporophytic model to explain crossing patterns of sweet potato obtained by Fujise (1964)

Variety	Genotype	Phenotype	Phenotypes of progeny after selfing
A	$R_1R_2S_1S_2$	R_1	R_1,S_1,S_2
B	$R_2R_2S_1S_2$	S_1	S_1,S_2
C	$R_2R_2S_2S_2$	S_2	S_2

Because the similarities between varieties, as measured by correlation coefficients, are almost normally distributed, classifications for incompatibility in the sweet potato must be made and interpreted with cautio Nevertheless, there is little doubt that the genetic basis and control of self-incompatibility in sweet potato conforms to the multi-allelic sporophytic type.

ANALYSIS OF THE STERILITY OF THE SWEET POTATO

The sterility of the sweet potato results from a series of phenomena that reduce fertility even in fully compatible crosses. Analysis of the sterility consists in identifying the reproductive processes that are affected, the degree to which these processes are damaged, and of explaining the causes of the damage.

Reproductive processes damaged by sterility

Failures in reproductive processes that have been detected in sweet potato are described in Table 3. Some of these failures are very common and

Table 3. Detectable failures in sweet potato reproductive processes

Failure	Method of detection	Estimated magnitude of damage
Pre-pollination events		
Male gametes are abnormal	Pollen production failure	Rare
Female gametes are abnormal	Microscope examination	Very rare
Pollination events		
Some pollen does not germinate	Counts of pollen on stigma on any stigma	Very common
Stigma does not stimulate germination	All pollen fails to germinate on stigmas of one female	Rare, but known
Post-pollination events		
Pollen tubes do not pass from stigma to style	Microscopic observation	Common, 30-95%
Pollen tubes do not pass through entire style	Microscopic observation	Common, 10-20%
Pollen tubes do not result in fertilization	Microscopic observation and seed and scale counts	Common, 10-60%
Ovules develop as scales	Observations and counts	Very common, 75%
Seeds do not develop normal endosperms	Observations and counts	Very common, 25-50%
Seeds do not germinate	Observations and counts	Common, 10-25%
Seedlings are weak and die	Observations and counts	Uncommon, 2-3
Seedlings do not grow into mature plants	Observations and counts	Uncommon, 1%
Mature plants do not flower	Observations	Rare

are easy to detect. Others are less common or rare, and ability to detect them and to judge their frequency varies. The post-pollination barriers to seedset in sweet potato have been carefully described by Martin and Cabanillas (1966) and two types of barriers can be described. The first of these are those barriers in which the pollen germinates but fails to result in fertilization.

In two selected crosses, large numbers of pollen grains, between 15 and 20, germinated on the stigma (Table 4). Yet only a fraction of the tubes passed from stigma into style.

In the second cross for which pollen tubes were counted in cross section, about 5% of the tubes passed from stigma to style. The numbers of tubes seen in the various parts of the styles did not change appreciably (Table 4). In the first cross, about 33% of tubes passed from stigma to style. Again, numbers of tubes in various regions of the style did not

Table 4. Pollen tube growth and podset in two crosses of sweet potato

Clones	Pollinations made	Mean number of pollen tubes				Percent podset	Seeds per pollination
		stigma	upper style	mid style	lower style		
89 x 94	42	19.6	6.1	5.7	5.0	42.8	0.86
101 x 85	94	16.1	0.9	0.7	0.6	6.4	0.10

change. In both crosses the mean number of pollen tubes penetrating the lower style was about six times the mean number of seeds per pollination. Thus, many pollen grains that germinate do not fertilize ovules.

The second type of barrier is that in which weakness or death of the embryo occurs after fertilization (Table 5). This may occur at any step of the process of development of embryo or endosperm, resulting in aborted scales, small and malformed seeds, empty seeds, seeds that do not germinate, seedlings that die young, and so on.

In unpollinated or incompatibly pollinated flowers of sweet potato the ovules increase slightly in size during the three- to four-day period that the flower remains on the plant. However, several days after anthesis, the ovaries of compatibly pollinated flowers begin to swell. The majority of such young fruit then develops to maturity. During the process of development all ovules grow in size together up to about the third day. Then one or two presumably fertilized ovules increase rapidly in size, whereas growth of those that remain is arrested. Dissection of these soon-to-be aborted ovules reveals apparently normal morphology and some differentiation with respect to shape, but no multicellular development. As the good seeds continue to expand, the aborted ovules tend to be compressed to one side of the fruit, and may shrivel. When the seed pod dries, the mature seed shrinks to a diameter of 3-5 mm, half its mature-green size. The aborted ovules dry to insignificant scales 0.5-1.5 mm in length. In 130 capsules, 329 dried scales and 191 recognizable seeds were found. Although seeds differ in size (Table 5), the two categories, scales (presumably representing unfertilized ovules) and seeds, do not overlap in weight or size distribution. Scales, of course, do not germinate, whereas seeds of large size germinate more readily than smaller seeds (Table 5). The smaller and weaker seeds represented 50% of the total number tested.

Table 5. Distribution of sizes of mature seed and aborted ovules of sweet potato, with respect to germination

Weight of seed or ovule (mg)	Number of examples	Percentage germinated
0.0 - 0.5	329	0.0
1.1 - 1.5	15	0.0
1.6 - 3.0	17	0.0
3.1 - 7.0	12	0.0
7.1-11.0	17	11.7
11.1-15.0	34	29.6
15.1-19.0	35	68.6
19.1-23.0	40	97.5
23.1-27.0	16	100.0
27.1-31.0	5	100.0

Thus, sterility can occur at many stages of the development process, both before and after pollination.

The causes of sterility

At the present time it is impossible to establish the causes of sterility in the sweet potato. Because sterility occurs at so many stages and is expressed in so many ways, it is most likely that a single process is responsible: polyploidy. Sterility is common enough in polyploids, and is caused by two phenomena, errors in meiosis resulting in gross defects in the genetic complement, and segregation and recombination that lead to so-called unbalanced gene distribution. This means that a certain proportion of gametes and of embryos receive an unfavorable combination of genes that fails to function adequately in certain circumstances.

It is highly probable that selection among seedlings of carefully controlled crosses for desirable new recombinants to be used as varieties often preserves unbalanced gene combinations. On the other hand, open-pollination among varieties practiced for several generations should favor fertile over sterile plants, as well as those that tend to flower freely. Martin and Jones (1971) showed that flowering increased about 300% in six generations of open-pollinated crosses and resulted in extremes of prematurely flowering seedlings, those that flower at the first node (Martin 1973). However, open-pollination did not result in increase of either self-fertility or cross-compatibility in spite of the strong natural selection that open-pollination imposes. Thus, it seems unlikely that either sterility or self-incompatibility are influenced by selection pressures.

CONCLUSIONS

Most of the research reported here is ten or more years old. Scattered in various journals, it is often unknown to plant breeders. The conclusions of this research, as yet not modified by subsequent studies, are that poor reproduction in the sweet potato is due to a duplicated or triplicated self-incompatibility system of the multiple-allelic sporophytic type, and to sterility expressed at many stages, due to genetic unbalance accompanying hexaploidy. While flowering can be increased by open-pollinated mass selection, incompatibility and sterility are not affected. Thus, sweet potato breeding is likely to contine to be a painstaking process. Open-pollinated populations, and mass recurrent selection, followed by careful screening for new varieties, are probably the best techniques the plant breeder can employ.

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Side dressing sweet potato breeding lines with N fertilizer.

The Development of Sweet Potato in South Africa

J. T. MEYNHARDT and T. G. JOUBERT

Horticultural Research Institute, Private Bag X293, Pretoria 0001, Republic of South Africa

INTRODUCTION

The sweet potato (*Ipomoea batatas*) was introduced into South Africa shortly after the Dutch colonized the Cape in 1652. According to available evidence in the archives these introductions were made from Brazil.

From these introductions through selection of local types a few traditional varieties originated. Amongst these are Borrie, which has a white skin color and a white to slightly yellow flesh color. It has a somewhat dry but sweet taste when baked. Another old variety worth mentioning is the so-called 'Six Months White'. This variety has a long growing season and has a white skin and flesh color. It has an extremely dry taste when baked, giving rise to the common name amongst certain sections of the population of 'choack' sweet potato.

During 1951 T.G. Joubert (Anon 1954), a plant breeder at this Institute, introduced some varieties from the United States of America and also certain breeding lines from the Louisiana Agricultural Experiment Station in the USA. These included the variety Porto Rico and breeding line L-240 (also known as Early Port). Seeds of L-240 were planted and produced to promising breeding lines, 4-95 and 4-126. Further seed introductions were made from the Edisto Experiment Station in South Carolina, USA. From these four promising breeding lines were selected. These were lines 6-27, 7-3, 7-42 and 7-59.

The varieties and breeding lines mentioned above were used in a breeding program in an effort to obtain better adapted varieties for South Africa. The aims of this program were to obtain higher yielding, smooth and uniform varieties with resistance to diseases and nematodes (especially *Meloidogyne* spp). It was also hoped to improve eating and nutritional quality, as well as to improve postharvest storage quality. Efforts are being made lately to improve starch contents for industrial purposes.

PROCEDURE

In South Africa the usual procedure for the propagation of sweet potato is to store the cured roots through winter and to plant them out in a nursery early in spring. Cuttings of the shoots of these roots are used as planting material in early summer. These 15-20 cm cuttings are planted in rows on ridges to the extent of 25-30,000 cuttings/ha. Irrigation is usually applied to start the cuttings growing. Additional irrigation is applied in many areas when necessary, although in certain areas of the subtropical region this crop is grown without supplementary irrigation. Fertilizer is usually applied according to soil analysis requirements. In some areas boron is also applied just after planting time. The use of disease-free planting material from special nurserymen forms part of the production phase of this crop in South Africa. Disease-free material is usually phased out of the production cycle the third year after obtaining it from the Department of Agriculture nuclear stock.

In the breeding program of sweet potato at the Horticultural Research Institute the conventional methods of intercrossing sometimes followed by backcrossing and interbreeding were used, followed by selection of the best breeding lines.

RESULTS

Development of new varieties

According to the Progress Report of Sweet Potato Breeding of the Horticultural Research Institute (Anon 1979) the breeding histories of current varieties are as follows:

1. Mafutha: A selection (number 4-95) obtained from seed of L-240 introduced from Louisiana Agricultural and Experimental Station. Released as a new variety in 1959.

2. Impala (57-2): Obtained from the cross $\frac{7\text{-}3 \times 7\text{-}42}{4\text{-}126}$ and released in 1962.

3. Wildebeest (55-17-1): Obtained from the cross 7-42 x 4-126 and released in 1962.

4. Griqua (6-27): Selection from a seed introduction made from Edisto Experimental Station in the USA.

5. Eland (56-27-1): From the cross 7-59 x 4-126 and released in 1965.

6. Hartebeest (61-7-1): From the cross $\frac{7\text{-}42 \times (\text{L-}240 \times \text{Six Months White})}{7\text{-}59 \times 4\text{-}126}$ and released in 1965.

7. Kudu (61-8-4): Obtained from the cross 6-27 x 55-17-1 and released in 1965.

8. Brondal (58-1-3): From the cross $\frac{7\text{-}42 \times (\text{L-}240 \times \text{Six Months White})}{7\text{-}59 \times 4\text{-}126}$ and released in 1970.

9. Ribbok (73-1-75): Obtained from open-pollinated seed from the variety Impala (57-2) and released in 1978.

Description of the varieties

Table 1 presents some comparative data of eight well known and popular varieties in South Africa, grown in an experimental trial near Pretoria. According to these figures it is clear that Mafutha, Eland, Griqua, Brondal and Ribbok produce the largest roots. However Impala with smaller, but more uniform roots, is usually more in demand on the market and realizes very good prices. The 72.8 t/ha yield of Impala makes it sought after by producers in this area. This yield is approached by the 67.7 t/ha of Ribbok. The yields of Brondal and Kudu also make them attractive to growers. This is especially true for Brondal because of its excellent dehydrated product which makes it a popular variety with processors. Kudu on the other hand has very good eating quality when baked.

Table 1. Comparative data for the certain sweet potato varieties when grown at the Horticultural Research Institute near Pretoria

Variety	Skin color	Mean weight per root (g)	Average yield (t/ha)	Resistance to[z]		Carbohydrate g/100 fresh weight	Carotene mg/100 g fresh weight	Protein g/100 g fresh weight	Flesh color
				Meloidogyne spp	Soil rot				
Mafutha	pink	480	35.7	VS	MS	28.2	0.65	1.6	white to light yellow
Impala	red	282	72.8	R	VS	21.3	0.67	1.2	orange
Eland	grey-yellow	424	45.4	R	MS	23.1	0.15	1.1	orange
Griqua	light pink	460	35.2	MS	MS	-	-	-	light yellow
Six Months white	white	325	20.2	R	R	36.3	0.01	3.3	white
Kudu	grey-yellow	307	55.3	MS	R	20.9	0.18	1.1	light yellow
Brondal	light red	482	56.9	MS	MS	20.8	Traces	1.0	light yellow
Ribbok	pale pink	510	67.7	R	VS	24.8	0.05	0.9	light yellow

[z]R = Resistant
MS = Moderately susceptible
VS = Very susceptible

The rather high carbohydrate content of Six Months White makes it an attractive breeding line to combine high carbohydrate content with a good yield. This variety also has potential as a breeding line for increased protein content.

Comparative yield of some varieties at different localities in South Africa

The results in Table 2 give the comparative yields of the varieties Impala, Brondal, Kudu and Ribbok at different localities in South Africa. These localities include the Horticultural Research Institute at Pretoria which is located at an altitude of about 1175 m above sea level. The average monthly temperature during the growing season is 19.6°C and rainfall is about 93 mm. Additional irrigation during dry spells is necessary. The Addo site is situated in the Eastern Cape at an altitude of about 50 m above sea level. The average monthly temperature during the growing season is 21.2°C and rainfall 38.8 mm. Irrigation is an absolute necessity in this area. The third site is at Nelspruit in the Transvaal subtropical area at an altitude of 369 m above sea level. The average monthly temperature during the growing season is 22.7°C and rainfall is about 108 mm. Irrigation is only necessary during dry spells.

From the results in Table 2 it is clear that Impala is the best yielding variety at Pretoria and Nelspruit, but the poorest yielder at Addo in the Eastern Cape. On the other hand Brondal and Kudu yields excellent crops at Addo, with Brondal topping the list with a yield of 93 t/ha. Ribbok and Brondal both also gave very good yields at Pretoria and Nelspruit respectively.

Table 2. Comparative yield of four sweet potato varieties in experimental trials at three places in South Africa

Variety	Pretoria (t/ha)	Nelspruit (t/ha)	Addo (t/ha)
Impala	73	72	25
Brondal	57	70	93
Kudu	55	55	75
Ribbok	68	40	50

Comparative highest experimental and farm yields

The results in Table 3 gives an indication of maximum experimental yields obtained at the Horticultural Research Institute Experimental Farm at Nelspruit for the varieties Impala, Brondal and Ribbok. It also gives the average farm yield of these varieties in the subtropical area and the maximum farm yields obtained in the same area. It should also be stated that the area of some of the farm lands for which these yields are applicable were in the region of 25 hectares per variety.

From these results it is clear that the average yields for both the experimental trials and farmers in the subtropical area differ greatly from the high yields obtained some years. These differences can only be attri-

buted to climatological conditions of which the lack of rain during some years, and also sometimes a too high precipitation especially just before harvesting time, are the main factors. It is however also clear that some of the better farmers in the drier areas, where irrigation must be carried out regularly, usually attain the higher yields. Some of these farmers regularly attain yields of 70-80 t/ha.

Table 3. Comparative highest experimental and farm yields at Nelspruit

Variety	Subtropical area, Experimental Farm, Nelspruit		Subtropical area, farmers' fields	
	average yield[x] (t/ha)	highest yield (t/ha)	average yield[y] (t/ha)	highest yield[y] (t/ha)
Impala	48	72	35	70
Brondal	45	70	34	75
Ribbok	35	50	32	80

[x]5 year period
[y]Figures supplied by farmers

Effect of the use of disease-free planting material

According to the results in Table 4 it is clear that the use of disease-free planting material had a drastic influence on the yield of the sweet potato varieties. For instance the yield of Impala decreased by 25 t/ha when three-year-old planting material was used, compared to planting material which remained negative to virus infection when tested. For Brondal the equivalent decrease in yield over the same period was 11 t/ha. These results indicate that the utilization of a scheme through which farmers are regularly supplied with disease-free planting material is essential for maintaining high production in South Africa.

Table 4. The effect of disease-free planting materials on yield of sweet potato

Variety	Disease-free planting material (t/ha)	Three-year-old planting material (t/ha)
Impala	80	55
Brondal	51	40

DISCUSSION

From the results presented above it is clear that plant breeders in South Africa have succeeded in developing sweet potato varieties adapted to local conditions and with very good yields in certain areas. Those varieties also selected on the basis of eating quality also satisfy the demand at the moment. However, disease resistance, especially tolerance or resistance to virus diseases, still remains an unattained objective. The development of varieties with better dehydration qualities and of those for indus-

trial use is still in the initial stages. Improvement of keeping quality is also to receive further attention.

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Performance of Exotic Germplasm of Sweet Potato in Bangladesh

M. M. RASHID, A. A. MAZUMDAR and S. MOLLA

Bangladesh Agricultural Research Institute, Joydebpur, Dacca, Bangladesh

INTRODUCTION

Among the food crops of Bangladesh, sweet potato is ninth in hectareage and fourth in production. In 1979-80, it covered 72,356 hectares and production was 0.77 million tons. However the real significance of the crop lies in the fact that it ideally suits the small and marginal farmers, as it can be produced with very few inputs. Sweet potato is primarily used as a supplementary item of food but owing to its favorable prices as compared with cereals, in some places people consume the roots as a staple during the peak harvesting season.

Sweet potato was introduced into the area now constituting Bangladesh during the second half of the 19th century, but its production system long remained out of touch with modern technology. The average yield of the crop is still only 10.4 t/ha. Primitive production methods and low yield potential of the indigenous cultivars have been identified as the two major reasons for this low yield. All cultivars so far known in Bangladesh are white-fleshed. Farmers store the roots in their dwelling houses for periods of two to four months and the spoilage in this process is very high. Against this background, a research program for the overall improvement of the crop has been started. Development of high yielding, insect resistant and carotene-rich cultivars with a good taste and good storage quality is the major aim of the program. The progress made in this direction is reported in part in this paper.

MATERIALS AND METHODS

Research on sweet potato in Bangladesh was started in 1976. Improvement of cultivars was a priority of the program. In view of the long time it was expected it would take to collect and evaluate indigenous germplasm, it was decided to procure standard cultivars and breeding lines from abroad and test their adaptibility and yields. By 1979 46 genotypes had been collected. Of these, 12 were from the IITA, six from AVRDC, nine from the Philippines, five from Japan, four from the USA, one from Sri Lanka and 19 from other unknown on unrecorded sources. The names, origins and important characters of the cultivars are given in Table 1. Three of the US cultivars, namely USA-1, USA-2 and BAU-2 are selections from open-pollinated seed-propagated lines. With the exception of the IITA cultivars, vines were collected for the other genotypes. Two local cultivars were included as checks. Six cultivars including five from the AVRDC were lost and hence not reported here.

The cultivars were subjected to a replicated trial during the winter season of 1979-80 at two locations, Joydebpur and Mymensingh. The former is located near the capital city of Dacca and the latter is 120 km to the northeast. The soils of the two places are laterite clay (pH 5.5) and

Table 1. Particulars about the origin and major characteristics of the sweet potato cultivars

Name of cultivars	Origin[a]	No. of roots/hill	Avg root wt (g)	Flesh color
AIS 209-3	AVRDC	4.8	133.5	orange
TIS 2328	IITA	5.7	138.6	cream
TIS 2330	IITA	4.1	121.6	white
TIS 2498	IITA	4.0	100.0	white
TIS 2532	IITA	5.1	129.7	cream
TIS 3017	IITA	5.2	91.6	cream
TIS 3030	IITA	4.0	169.5	cream
TIS 3032	IITA	5.9	125.1	white
TIS 3055	IITA	3.8	151.8	white
TIS 3247	IITA	6.0	146.4	yellow
TIS 5016	IITA	4.4	141.0	cream
TIS 5081	IITA	6.0	116.7	cream
TIB 8	IITA	4.3	144.6	cream
Gokomachari	Japan	4.4	75.9	white
Okinawa	Japan	4.3	93.4	white
Kokeia	Japan	5.5	191.3	cream
Norin	Japan	4.4	171.6	cream
Norin S	Japan	3.3	157.3	white
DAJA	Philippines	5.1	138.8	cream
Gyy	Philippines	5.3	120.2	white
HDK 12	Philippines	5.3	105.4	cream
Old Yellow	Philippines	3.4	186.0	white
Red Tuber Tail	Philippines	4.9	182.8	cream
Tainan 15	Taiwan	6.1	143.2	cream
Tainung New 10	Taiwan	6.0	129.4	white
Tinirining	Philippines	5.9	188.6	cream
BNAS 51	Philippines	3.5	159.5	cream
Wariyapola	Sri Lanka	4.6	137.7	white
Pelican Processor	USA	4.7	80.3	white
USA 1	USA	5.5	174.4	cream
USA 2	USA	4.6	84.7	white
BAU 2	USA	4.4	156.1	orange
RS No 1	Unknown	5.1	163.0	cream
RS No 4	Unknown	6.3	153.5	cream
Mount Diamond 1	Unknown	5.5	126.0	white
Mount Diamond 3	Unknown	3.8	202.2	white
Mount Diamond 4	Unknown	4.3	168.0	white
Julian	USA	4.9	202.2	white
Jewel	USA	7.2	89.3	cream
Local White	Bangladesh	3.7	166.4	white
Local Red	Bangladesh	5.7	130.6	white

[a]Those from the Philippines were obtained from the AVRDC-Philippine Outreach Program at Los Baños, Laguna

alluvial sandy loam (pH 6.6) respectively. The temperature and rainfall data of the growing season are given below.

	Joydebpur			Mymensingh		
	Air temperature (°C) Maximum	Minimum	Rainfall (cm)	Air temperature (°C) Maximum	Minimum	Rainfall (cm)
November	30.1	20.1	8.3	30.4	20.3	0.7
December	26.1	13.7	0.0	26.2	14.5	4.5
January	25.1	11.6	0.8	24.9	10.7	0.2
February	26.9	13.7	0.4	27.0	13.7	2.6
March	31.7	19.6	2.9	32.8	18.6	3.3
April	35.0	24.3	11.0	35.9	21.6	18.4

Stem cuttings were planted on 19 November at Joydebpur and 6 November at Mymensingh at a spacing of 60 cm between rows and 30 cm between hills. The crop was fertilized with 5000 kg cowdung, 50 kg urea,100 kg triple super phosphate and 100 kg muriate of potash per hectare. At Joydebpur the crop was irrigated three times but at Mymensingh irrigation was undertaken only twice. Harvesting was done after 150-160 days.

The main criteria for evaluating the cultivars were yield, weevil infestation, carotene content and storage behavior. The evaluation is not yet complete. In this paper, only the yield data are given. Different botanical characters of the cultivars have been recorded and some of these are presented in Table 1.

RESULTS AND DISCUSSION

The yields given by the cultivars at the two centers are presented in Table 1. From the table it is evident that the cultivars differed widely among themselves in yield at both centers. At Joydebpur, the yield range was 8.8 to 47.0 and at Mymensingh it was 4.8 to 38.5 t/ha. Based on the average of the two locations, the cultivar BNAS-51 from the Philippines gave the highest yield of 41.3 t/ha closely followed by Kokeia (40.0 t/ha), a Japanese cultivar. The next highest yielder, Tinirining, was far behind with 31.2 t/ha. The only AVRDC cultivar AIS 209-3 was very close to it with 30.3 t/ha. All other cultivars were behind these by a big margin. The distribution of the cultivars among the different yield classes is shown in Table 2.

The yields given by the cultivars at the two centers are presented in Table 3. The crop in this experiment was irrigated and fertilizer was applied. Cultivation techniques were otherwise as employed by small farmers in Bangladesh.

Table 2. Distribution of the cultivars among different yield classes

Locations	Yield classes (t/ha)				
	<10	>10 - <20	>20 - <30	>30 - <40	>40
Joydebpur	3	11	18	5	5
Mymensingh	7	29	4	2	0
Average of two locations	2	25	11	2	2

A noticeable feature of the results is the unexpectedly wide difference in yield between the two locations. On the average, the cultivars gave nearly twice as much yield at Joydebpur as they gave at Mymensingh. The average yields were 25.9 and 14.8 t/ha respectively, indicating a highly

Table 3. Comparative yields (t/ha) of exotic sweet potato cultivars at two locations in Bangladesh during the year 1979-80

Name of cultivars	Joydebpur	Mymensingh	Mean
AIS 209-3	40.4	20.1	30.3
TIS 2328	15.7	15.5	15.6
TIS 2330	20.6	8.4	14.5
TIS 2498	15.9	15.1	15.5
TIS 2532	24.2	13.0	18.6
TIS 3017	24.5	13.8	19.2
TIS 3030	21.9	11.3	16.6
TIS 3032	33.3	18.2	25.8
TIS 3055	16.6	14.6	15.6
TIS 3247	28.6	20.1	14.4
TIS 5016	40.0	11.9	26.0
TIS 5081	24.2	10.9	17.6
TIB 8	18.0	9.6	13.8
Gokomachari	13.2	13.4	13.3
Okinawa	9.2	7.7	8.4
Kokeia	41.4	38.5	40.0
Norin	9.8	7.5	8.7
Norin S	27.8	22.6	25.2
DAJA	25.5	12.4	19.0
GYY	17.8	15.9	16.8
HDK 12	15.8	10.0	12.9
Old Yellow	16.4	6.3	11.3
Red Tuber Tail	24.3	18.8	21.6
Tainung 15	37.8	12.6	25.2
Tainung New 10	20.3	10.0	15.2
Tinirining	43.4	19.0	31.2
BNAS 51	47.0	35.6	41.3
Wariyapola	26.6	23.0	24.8
Pelican Processor	8.8	12.6	10.7
USA 1	21.2	14.2	17.7
USA 2	22.2	10.0	16.1
BAU 2	12.4	16.6	13.5
RS No 1	22.5	18.0	20.3
RS No 4	28.6	18.0	23.3
Mount Diamond 1	30.6	13.4	22.0
Mount Diamond 3	15.1	13.6	14.4
Mound Diamond 4	31.6	19.0	25.3
Julian	19.3	4.8	12.0
Cinjhi	34.5	18.8	26.6
Jewel	21.4	13.0	17.2
Local white	21.9	7.1	14.5
Local Red	20.4	11.3	15.8
Mean	25.9	14.8	19.2

significant influence of environmental factors, in this case soil, on the yield of sweet potato, since the climatic conditions (temperature and rainfall) of the two locations did not differ greatly. We previously felt that loamy soil was more suitable for sweet potato than clay, but the present experiment proved just the reverse. In Bangladesh sweet potato is grown mostly in the alluvial soils of the river banks, like the soil at Mymensingh. This experiment showed that laterite clay can be a better soil for this crop, though Joydebpur is traditionally not a sweet potato growing area.

Results of these experiments showed that it is possible to bring about tremendous improvement in the sweet potato crop in Bangladesh both in yield and quality through the introduction of exotic germplasm. The two local cultivars included in the trial gave yields around 15 t/ha. Out of the 40 exotic cultivars as many as 27 gave yields higher than the average of the two locals and in many cases the differences were quite large. Although the two locals cannot be regarded as representative of all sweet potatoes in Bangladesh, since the indigenous germplasm still remains unexplored, it can be safely said that the exotic materials so far collected possess genotypes of very high yield potential and if found otherwise satisfactory, these genotypes hold the prospect of boosting total production of the crop in the country during the coming years. Luckily, all four of the top yielders have creamy to yellow flesh and this quality alone is of considerable significance as far as the preference of the consumers is concerned.

However, the final adoption of the exotic cultivars by the farmers depends on their performance in terms of weevil resistance, storage quality and taste. Some of the top yielders have already been sent out for farmers' field trials. Simultaneously the collection and evaluation of the local germplasm have been taken up.

Some of the AVRDC lines not reported here have given good yields in the farmers' field trials conducted by the Mennonite Central Committee in the Noakhali district, about 200 km southeast of Dacca. In one place the cultivar AIS 243-2 gave a yield of 35.5 t/ha. The highest yield recorded for AIS 0122-2 was 18.9 t/ha. The yields of AIS 35-1, AIS 35-2 and AIS 272-9, were at the same level as the local checks and even lower in some instances.

ACKNOWLEDGEMENT

This experiment was conducted under a research project entitled Bangladesh Vegetable Research and Development Centre, financed by the Bangladesh Agricultural Research Council. The cooperation of the Ford Foundation, IITA and AVRDC in procuring the germplasm of sweet potato is gratefully acknowledged.

Sweet potato tips prepared for vegetable consumption are rich in Vitamin A.

The Breeding of Sweet Potatoes for Human Consumption

H. WANG

Chiayi Agricultural Experiment Station, Taiwan Agricultural Research Institute, Chiayi, Taiwan

INTRODUCTION

The sweet potato is rich not only in carbohydrates, but also in vitamins and minerals (Villareal 1977). It is regarded as a high-energy, low-protein food, though usually considered to be inferior to rice and wheat in protein content. Sweet potato is deficient in sulfur-containing amino acids and tryptophan, but this is partially compensated for by high levels of vitamins A and C and of some minerals. Purcell (1972) reported that most cultivars contain between 4.5%-7% protein. However, the protein content of sweet potatoes from a North Carolina root collection was found to range from 1.73% to 9.14% on a dry weight basis. These data confirm the results of many other workers (AVRDC 1974; Li 1974). AVRDC (1974) has reported that the protein content of the plant parts above the ground range from 21.7% to 31.3% on a dry weight basis. The results indicate that the leaves and stem tips of the vine have a higher nutritional value than the roots.

Sweet potato for use as food is usually prepared fresh after harvest, particularly in tropical and subtropical regions. In the temperate zone, sweet potato is normally kept after harvest until the winter season. In the United States, large quantities are canned and also prepared in dehydrated form (Demaree *et al* 1960; Edmund 1971). Sweet potato starch is probably used more for textile sizing and in laundering than for food. Sammy (1970) reported that sweet potato flour can be utilized as a substitute for wheat flour at a rate of up to 15% in bread and 20% to 30% in pastries. Other uses of sweet potato flour have been investigated and suggested (Poole *et al* 1955) and they include the possible use of it as an ingredient in cakes, doughnuts, cookies, gingerbread, pies and pastry, puddings and vegetable dishes.

In Taiwan, sweet potatoes are readily available in local markets. Baked sweet potato roots are very often served as a dessert or snack in city streets. Sweet potatoes can be kept well for at least two months in winter (Wang 1974).

VARIETIES AND IMPROVEMENT

Improvement work before 1946

Sweet potato improvement work was initiated in Taiwan in 1911 and may be divided into two stages.

Firstly, from 1911 to 1921, about 164 varieties were introduced from Japan, Java, the United States, Borneo, the Celebes and mainland China.

Then, from 1922 to 1945, a cross-breeding program was carried out at the Chiayi Agricultural Experiment Station by Hirama (1929-37 and 1935) aimed at improving quality, and in particular at raising the starch content of sweet potato with a view to its use for food, animal feed and for in-

dustrial purposes. Forty-seven new varieties (Tainung 1 to 47) were named and recommended to farmers for cultivation.

Improvement work since 1946

Since 1946, sweet potato breeding has been conducted by Chiayi Agricultural Experiment Station (CAES), and various District Agricultural Improvement Stations. AVRDC (1974) started its own breeding program for sweet potatoes of high nutritional value in 1972-73.

Further introductions have been made from Japan, the Philippines, the United States and mainland China since 1946, as most sweet potato collections were lost during World War II. Up to 1970, more than one hundred varieties and/or clones had been introduced by CAES (Wang 1976) and a cross-breeding program carried out with the following objectives:

1. To develop varieties which mature early enough to replace native varieties in northern and north central Taiwan. For this purpose, crosses were made between native varieties and American, Japanese and old Tainung varieties.

2. To develop varieties which excel the old Tainung varieties in both quality and yield. To this end, crosses were made between Tainung varieties and varieties introduced from foreign countries.

3. To develop carotene-rich varieties, which possess higher nutritional value for table use of processing. For this purpose, the introduced carotene-rich varieties Nancy Hall, Porto Rico, Centennial, seedling No. 779 from California and other orange-fleshed American varieties or clones were used in crosses mostly with Tainung and Nunglin varieties. The yield and other major characters of the parents most usually used are listed in Table 1.

Since 1946, sixteen new improved varieties (designated Tainung 48 to 57 and Tainung 59 to 64) have been developed for release to farmers by CAES. One other, Tainung 58 (P30), was released by TARI (Mou *et al* 1957). Of these 17 new Tainung varieties, eight are for table use, and two of these eight varieties, (Tainung 63 and 64) were released from the first year seedlings of polycross (Li 1980). The carotene content of these eight new varieties has increased from 0 to 22.5 mg/100 g.

White-fleshed sweet potato varieties were released by three District Agricultural Improvement Stations (Chen and Hsu 1974; Li 1980). In addition, a new clone, C 53-83 was selected by CAES from hybrid seeds obtained by crossing Tainung 54 with No. 779 in 1964. Selection by elimination was carried out in 1965. Comparative trials among clones were completed from 1966-1968 period, and the agronomical properties studies were carried out from 1968 to 1970. Yield observation trials at three locations in Yunlin District were made again from 1977 to 1979. Results are shown in Table 2.

Dense planting (20 cm between hills) increased not only the yield but the number of roots, as shown in Table 3. Clone C 53-83 was superior to the other clone, L 21-33, in these respects. The size of the root was also reduced to fit the processing requirement of about 2.5 to 4.4 cm in diameter.

Table 1. Origin, date of introduction, percentage of chips and carotene content of parental varieties (Wang 1974)

Variety	Percentage of dry chips (%)	Carotene content (mg/100 g)
Native varieties:		
Today Early	25.5	0.4
Chi-Ting-Chun	24.1	0.4
Red Tuber-Tail	18.0	1.2
Varieties introduced:		
Nancy Hall	37.0	3.6
Porto Rico	31.0	5.5
Kandee	30.5	9.2
Goldrush	24.4	16.0
Heartogold	24.8	11.0
Virginian	22.4	18.2
Allgold	27.7	19.8
No. 779	26.4	14.9
Centennial	28.9	18.0
Rose Centennial	25.8	19.0
Julian	28.8	24.8
L 2-116	33.2	16.5
L 3-64	32.8	13.1
L 4-89	32.6	12.4
Okinawa 100	37.0	-
Nunglin 18	39.8	-
Nunglin 19	36.0	-
Nunglin 21	39.2	-
Nunglin 26	40.0	-

No distinct variation of the carotene content was observed to result from variations of locations of cultivation or soil type. Light soil texture usually gives more uniform roots, a quality required for canning.

Experience in Taiwan show that August-September is the appropriate time for planting, and harvest is expected in the following January-February. Roots harvested approximately four to five months after planting are suitable for canning. As far as the carotene content is concerned, sweet potatoes planted in August-September have a higher content than those planted in other months and sweet potatoes harvested at four months after planting have a higher content than those harvested at three or five months after planting.

FACTS RELATED TO BREEDING

Flowering

Although sweet potato blooms easily under natural conditions in the southern United States, scientists in Taiwan have met with difficulty in inducing it to flower (AVRDC 1974; Wang 1951).

Table 2. Average data from observation trials of six seedlings of sweet potato at three locations in Yunlin District in 1977-79

Variety or Seedling	Parentage	Yield (t/ha)[y] Yuanchang	Taihsi	Shuilin	Carotene content (mg/100 g)	Taste index
C 70-101	Tainung 62 x C 64-11	37.0 (28.7)	20.6 (30.0)	27.6 (32.1)	4.6	4
C 70-54	C 64-88 x L 2-116	35.3 (27.5)	27.9 (27.7)	26.0 (27.4)	12.4	4
C 70-66	Centennial x Tainung 55	39.8 (26.0)	23.2 (27.8)	32.5 (27.7)	14.5	4
C 70-79	C 64-11 x C 64-33	30.0 (27.0)	15.2 (27.6)	23.5 (27.1)	6.8	5
C 64-83 (C 53-83)	Tainung 54 x No. 779	30.7 (25.4)	27.4 (26.3)	20.7 (26.0)	13.0	5
C 69-19[z]	Tainung 62 x No. 779	30.8 (34.3)	22.0 (34.2)	25.6 (33.1)	4.0	6
Tainung 57	(ck 1)	34.8 (30.0)	29.8 (30.6)	18.9 (30.3)	2.0	6
Tainung 62[z]	(ck 2)	34.2 (29.9)	27.0 (28.9)	24.9 (29.6)	8.0	5

[z]Variety and seedling included in trial starting the second year, August 1978
[y]Figure in parenthesis refers to dry chips percentage. One year data of 1978-1979

Table 3. Effect of dense planting on root yields and numbers of sweet potato clones, C 53-83 and L 21-33[x]

Space	C 53-83 Root yield (t/ha)	C 53-83 Root number (1000/ha)	L 21-33 Root yield (t/ha)	L 21-33 Root number (1000/ha)	Average root yield (t/ha)	Average root number (1000/ha)
20 cm	41.4 (112)	541.4 (132)	23.5 (109)	396.7 (130)	32.5 (111)	468.9 (131)
30 cm	37.0 (100)	410.2 (100)	21.5 (100)	303.7 (100)	29.3 (100)	356.8 (100)
LSD 1%					2.0	49.9

[x]Figure in parenthesis indicates the percentage of increase compared with 30 cm spacing

Wang (1964b) reported that the best season for sweet potato pollination in Chiayi, Taiwan, is from the beginning of November to the middle of December, when the average daily temperature is between 20°C to 25°C. Beyond this range, flowering, seedsetting and the number of seeds per capsule are all restricted. Flower buds of several varieties suffer injury when the temperature drops below 12°C. These results confirm the findings made by Montelaro and Miller (1951) who reported a decline in seedset during very hot or cold periods, with maximum seedset occurring when the mean daily temperature was about 23.9°C. Warmke and Cruzado (1949) reported that the percentage of seedset at the beginning and end of the season was low, compared with that in the middle of the season, from 1-15 February in Puerto Rico, located at 18° north.

Fruiting and seedsetting ability

Poor fruiting and seedsetting are the greatest obstacles in sweet potato improvement breeding programs. Environmental factors along with genetic, morphological, physiological, cytological and pathological factors must be considered as influencing the fertilization process.

Stout (1924) suggested that the type of sterility operating in the sweet potato was that of incompatibility in the fertilization process; in other words, that self-incompatibility might be present. Wang (1964a) reported that 45 of 76 sweet potato varieties and seedlings studied were completely self-incompatible. Hernandez and Miller (1962 and 1964) stated that the presence of self- and cross-incompatibility made it difficult to obtain seed from crosses between certain parents and suggested that incompatibility in the sweet potato is determined by genes that form a multiple allelomorphic series. Their statement agrees with Wang (1964a) when he classified 76 varieties and seedlings collected from Japan, mainland China, Taiwan, the Philippines and the United States into five intra-incompatible inter-compatible groups and one intra-inter-compatible group. The five intra-incompatible groups were assigned genes S_1 through S_5 of a multiple allelomorphic series representing incompatibility groups I, II, III, IV and V. The varieties in group VI were postulated to posses a fertility restoring factor (S_f)

Since Terao (1934) classified 51 varieties of sweet potato into three incompatibility groups designated A, B and C in 1934, the incompatibility groups that have been identified have already increased from three to fourteen (Sakamoto 1973; Yomo 1977).

Pollen has been studied by Wang (1964b) as a cause of low seed and fruitset, particularly for four varieties, Hawaiian, 60-Day, Hochwan Big Vine and Cliett Bunch Porto Rico. All had 50% or more sterile pollen. Cytological observations made for those four varieties showed that lagging chromosomes were found at metaphase on the pollen mother cell and indicated that those could be partially associated with their high percentage of sterile pollen. Wang's results obtained confirm the statement made by Ting and Kehr (1953) and Ting [illegible] (1957) but were not supported by Jones's results (1965).

Research on the sweet potato megagametophyte has not been extensive. Martin (1965) stated that although most sweet potato varieties have four ovules per ovary, it is very seldom that four seeds mature. Those with less than four regular ovules in the ovary as reported by Burnham (1967) and Wang and Burnham (1968) exhibit lower seedset. The situation is further aggravated if a female-sterile variety is used as a parent in making crosses.

BREEDING BEHAVIOR

Germplasm introduction

Introduction is the first step for sweet potato improvement. Nancy Hall was introduced from the United States to Szechuan province, China in 1940 during World War II, and it was widely grown as an important food crop (Shen 1951). In Taiwan, the first introductions were made between 1911 and 1921. The variety White Holland, which was originally introduced from Japan, was one of the major varieties grown on the island in the early improvement

stage (Cheng 1956). Although the second introduction (including more than 30 American carotene-rich varieties and 31 high starch Japanese varieties) was made in the period between 1945 to 1970, none of those varieties has proved successful enough to be selected directly for commercial growing except the variety Okinawa 100 (Chien 1964) which has been grown in some areas of Taiwan for a considerable period.

Mutation and selection

Since sweet potato is a root crop and is propagated asexually, mutations usually arise either from roots or from vines. In Taiwan, mutations in the sweet potato roots are very often observed (Wang 1964c). In the early 20th century before flower induction techniques were perfected, the selection of mutant types of sweet potatoes was the only method which could be used for changing their genetic makeup (Miller 1939). However, most mutations in sweet potatoes were reported to be retrogressive (Hernandez *et al* 1964). Gamma irradiation treatment was applied to three varieties, but the mutations of all three proved inferior in overall performance.

Hybridization and selection of self-fertile clones

Hybridization: Up to the present, a large number of cultivars have been released in Japan, Taiwan, the United States and other places after hybridization for different purposes. In Taiwan, breeding programs have two objects: to develop varieties for animal feed and industrial purposes, and to develop varieties for table use.

Selfing: In general, sweet potatoes are self-sterile plants, and only a small number of varieties and clones have been found to be self-fertile (Hernandez and Miller 1962; Wang 1964). Hernandez and Miller (1962) reported that of the 18 sweet potato breeding parents that were selfed, only three were were self-compatible. Wang (1964a) agreed with them and reported that Kandee is highly self-fertile, and Nancy Hall, Tainung 31 and Tainung 36 are self-fertile too. Wang (1969) reported again that an incompatibility grouping of the first generation of self-pollinated varieties Nancy Hall and Kandee had been made and indicated that most S_1 clones were not restricted by genetical cross-incompatibility factors. Poole (1955) reported that vigor is not depressed upon inbreeding. Sakai (1964) indicated that degeneration by inbreeding is weak in respect to starch content.

Since sweet potatoes are heterozygous, the characteristics of all varieties and/or seedlings developed from hybridization differ from each other. There are marked variations in leaf shape, skin, and flesh color, root form and other characters. However, a range of protein content from 11.9% to 17.0 was reported by Kehr *et al* (1953) when the top of Jersey sweet potato was grown on four different root stocks. Although the sweet potato root yield was reported to be non-additive (Sakai 1964) certain genotypes which appeared to possess both drought tolerance and good yielding ability were found by Villareal (1979b) on the evaluation of AVRDC collections. Varietal differences in chemical traits - starch, beta-carotene, protein, sugar - of sweet potatoes have been reported (AVRDC 1974; Li 1974a; Wang 1974). Plant breeders intend to combine these desirable characters with high yields and disease and insect resistance. Recently, the nutritional value of sweet potato tops has gradually been attracting the attention of breeders. Villareal (1979) observed that sweet potatoes exhibit a wide variety of morpho-

logical traits in the tips. Thus, selection can be made for yield, palatability, tenderness, flavor and nutritional quality from a large number of cultivars and breeding lines.

Hernandez *et al* (1965) indicated that white flesh color is incompletely dominant over orange. The total carotenoid pigments appeared to be controlled by several genes, possibly six that are additive, and crosses between parents medium to high in total carotenoids produced seedlings with a mean total pigment content of 12.8 to 15.8 mg/100 gms fresh weight. Transgressive segregation was indicated in crosses between certain parents.

Sakai (1964) reported that, since the starch content of sweet potatoes is determined mainly by the additive effect of polygenes, the accumulation of genes controlling high starch content in domestic varieties is recommended. To accumulate these genes, selfing or sib-crossing is effective, since degeneration by inbreeding is weak in this character. In some cases, good results are obtained from line-crosses. Consequently, the high starch content varieties thus selected and cultured may be used as parents for breeding varieties with high starch content and high yield.

Hammett *et al* (1966) reported the occurrence of variations in the fiber content of fleshy roots of sweet potato seedlings, with two sets of genes appearing to be involved. One of these controls the presence of fiber while the other controls fiber size. His data indicated that a few genes with simple dominance controlled fiber size while the total fiber content was controlled by several genes, geometric in effect and linked with genes for fiber size. Consequently, breeding for low fiber content is feasible.

Constantin *et al* (1966) reported that the baked roots of sweet potato seedlings from the progeny of several parental combinations were evaluated for flesh color, flavor, texture, fiber content, sweetness, moisture content and general acceptability, and that all of these ratings were averaged to obtain a baking index for each seedling. Crosses between parents with a low baking index produced seedlings most of which had low indexes. In crosses between parents with average or superior baking quality, 74% to 94% of the seedlings had average or superior baking quality. Villareal *et al* (1979a) reported that the steamed roots of promising breeding lines of sweet potato and cultivars were evaluated by a panel for flavor, dryness, stickiness, color and general acceptability to determine selection criteria that influence general acceptability. The acceptability ranking of roots varied according to the nationality of panel member. Based on the results of stepwise multiple regression analysis, it appeared that flavor and color would be useful characteristics for predicting general acceptability of steamed sweet potato roots.

A far as the nutritional value is concerned, carotene content is recognized as a very important constituent which is of interest to plant breeders. AVRDC (1975) reported that orange-fleshed selections were high in beta-carotene. Fortunately, they also ranked high in protein. Jones *et al* (1969) and Jones (1977) reported however a negative association of flesh color and dry matter. Thus, concurrent selection for high dry matter may be difficult but not impossible.

Dry matter has been used as an indicator of starch content according to Purcell *et al* (1976 after Juritz 1921). Dry matter is positively correlated

with starch content. According to Sistrunk *et al* (1954 after Core 1920) sweet potatoes are rich in diastase which when present in very small quantities may convert practically all of the starch to reducing sugar during the cooking process. Dawson (1950-51) reported that when sweet potatoes are cooked the total sugar content is increased by the action of beta-amylase, an enzyme which, when activated by the rising temperature of cooking, converts the starch to maltose and dextrins before it is inactivated by the higher final temperature of the cooking. Sweet potatoes of Porto Rico variety are particularly high in beta-amylase and after curing and storage nearly all of the starch can be converted by slow baking. Hasselbring and Hawkins (1915) reported that sweet potatoes remain low in sugar content during the growing season, but after harvest, the conversion of starch to sugar is rapid, particularly at low temperatures. Sistrunk (1977) reported that baking converted more starch to sugar than boiling did.

Starch, along with carotene and protein, are recognized as three essential characters in sweet potato breeding programs for human consumption. Carotene content is negatively correlated with dry matter content, dry matter is positively correlated with starch content, and starch content is associated with eating quality. Thus, during selection, in addition to yield, starch content of about 20% and dry matter above 30% should be considered as criteria more important than either carotene or protein content. A sweet potato variety which simply has a high carotene content would probably be low in dry matter and high in moisture. This could prove unpalatable, at least to to people in Taiwan.

Table 2 shows that seedling C 69-19 and variety Tainung 57 both rate highly in chips percentage and tasting grade, but are low in carotene. However, the ratings of the other two seedlings, C 70-54 and C 70-66, was just the reverse.

The average dry chips percentage of all clones and varieties tested had declined 2 or 3 compared with their former levels recorded at CAES. This decline in dry chips percentage was followed by the decreasing of taste indexes from 5 to 4 due to the increase of soil moisture resulting in dry matter reduction. Low dry matter is associated with low taste index. This confirms the findings of Constantin *et al* (1974) which indicated that high moisture levels cause a decrease in both dry matter and protein. Therefore, the selection criterion for dry chips percentage should be raised 2 or 3% above the usual level of 30 in areas of high soil moisture in order to meet the requirement.

To breed a variety with dry matter content of more than 35% and carotene content ranging from 12 to 15 mg/100 g (like the new variety Carver) is not difficult.

Open-pollination: Polycross, one of the pollinating processes in use now, was probably first suggested as a means of induction of fruitset and seedset in the breeding of sweet potatoes by Miller, Hernandez and their collaborators (1964). They said: 'Since the sweet potato is very heterozygous, selected parents with good horticultural characters from different incompatibility groups are introduced into the field breeding nursery and seeds are obtained from each female parent.' Wang and Burnham (1968) reported that triple pollination (placing pollen from three pollen parent clones on the same stigmatic surface) resulted in an increase in average number of

seeds per fruit but not an increase in fruitset. The constructive idea of using polycross made by Hernandez and Miller (1964) has attracted much attention from plant breeders. A new breeding procedure for sweet potato was proposed by Jones (1965). Jones *et al* (1976) reported that maintaining a large population size could eliminate the handicap of sterilities and incompatibilities. Jones' proposed breeding procedure is being adopted by Yomo (1977) and Li (1974b). Yomo (1977) suggested that the intermating population should include at least eight incompatibility groups. As is known up to the present, northern American varieties and/or clones belong to five or six incompatibility groups (Hernandez *et al* 1964). Furthermore, most American varieties tested by Wang (1964a) and classified by Hernandez and Miller (1964) belong to one group only. Therefore, it is essential that a large number of incompatibility groups should be included in the intermating population for mass selection.

Hybrid vigor

Sweet potato is generally recognized as a self-incompatible plant. Martin (1965) reported that self-incompatibility is but one of the outcrossing mechanisms extant in flowering plants that lead to a high level of heterozygosity in a population and to a genetical architecture based on homeostasis and hybrid vigor. Edmond (1971) reported that an unusual degree of hybrid vigor may be present in the sweet potato. Hanna (1960) reported that one desirable strain, No. 779, bloomed poorly even after grafting treatment, but I found it bloomed freely in Taiwan. So he asked me to make some crosses for him between No. 779 and some Taiwan varieties on 26 November 1957. Not only were greater yields obtained, but the progeny of these crosses proved to be quite vigorous, resistant to sunscorching, bruising and decay organisms (Hanna 1960). In a high percentage of these seedlings, weight loss in storage was greatly reduced.

BREEDING PROCEDURE

Flowering induction

According to local environmental conditions, girdling, grafting, short daylength control, or even any two of these combined together as a special treatment, may give good results for flower-induction. If a grafting treatment is selected, plants of either other *Ipomoea* species or free-flowering sweet potato varieties are prepared as stock plants by planting them in the greenhouse or in the nursery. Grafting is usually made at one-and-a-half months before pollination.

Incompatibility grouping

Prior to making crosses, it has to be determined to which incompatibility group(s) belong the varieties and/or seedlings to be used as parental stocks. To establish this, flowers of each parental variety or seedling intended for use as a female parent are pollinated in turn by a member of each incompatibility group. Stigmas and styles of pollinated flowers are collected two or three hours after pollination, and pollen germination and pollen tube growth are examined by staining with lactol phenol cotton blue solution as a criterion for classification. Failure of pollen to germinate means that the two crossed varieties or clones belong to the same incompatibility group. So far, a total of 184 varieties and/or clones which origi-

Table 4. Incompatibility grouping on the varieties and/or clones of sweet potato at CAES, Taiwan

Origin	Number of varieties or clones surveyed	Incompatibility groups[a]					
		I	II	III	IV	V	Others
Taiwan							
Native	37	10	6	1	16	4	
Tainung	33	2	1	2	24	4	
Improved	47	12	12	4	9	8	2
Mainland China	10	5	3	1	1		
The Philippines	6	4					2
The United States	16	1	13		2		
Japan							
Native variety	4	2(A)	1(B)	1(C)			
Nunglin (Improved)	31	8	17	5	1		
TOTAL	184	44	53	14	53	16	4

[a]Letter in parenthesis shows the designation of incompatibility groups of Japanese system

nated from Japan, the Philippines, the United States, mainland China and Taiwan have been classified into five incompatibility groups as shown in Table 4.

Pollination

Cross-pollination at CAES is made every year from the middle of October until January of the next year. The average percentage fruitset and average number of seeds per fruit during the years from 1973 to 1980 were 50.0% and 1.54 respectively.

Seed scarification and storage

Since the seed coat is impermeable to water, germination of untreated seeds could take as long as two or three months. Scarification has been reported to be very successful in promoting rapid seedling emergence (Steinbauer 1938; Martin 1946). If the seeds are immersed in concentrated sulfuric acid for one hour and stirred twice or three times, then water-soaked for two or three hours prior to sowing, over 95% germination is easily obtained. Sweet potato seeds may keep their germination ability for several years, if the seeds are kept well.

Evaluation of breeding lines

In general, from the first sowing of seeds to the release of promising clones of sweet potato to growers takes eight or more years and consists of many steps.

Seedling screening: In Taiwan, seeds are usually sown either in the greenhouse or in the seed bed in the field in April. As soon as the seedlings reach 30 cm, they are transplanted to the field and multiplied to 3 or 4 plants each. These plants are then planted in the field, spaced at

one meter intervals, in the middle of August. After about four months growth, harvesting and first screening are undertaken in the middle of December. Screening is based upon the essential traits of yield, skin and flesh color, root form, number of edible roots, veining and growth cracks as well as disease and insect resistance. A second screening is made based on dry chips percentage and on taste. Those selections with a dry chips percentage less than 30% and an eating quality grade less than 5 (eating quality consists of 9 grades reported by Hirama (1935)) will be discarded regardless of any superior characters that appeared in the first screenings. After the first year's two screenings, the selection rate is less than 2%, calculating from the original populations involved. At Louisiana Agricultural Experiment Station less than 1% selection rate was obtained (Miller and Hernandez 1959). Scientists at AVRDC (1975) reported that a selection rate of between 1.5% and 7.3% was probably disadvantageous in that some desirable genotypes were lost.

Comparative trials: The clones selected from the second year observations are entered in comparative trials with a control variety for at least two years. A randomized complete block design is usually adopted with four or six replications. Plot size is 8 sq m in single row planting. Each plot consists of 32 plants. For each clone, records are kept of essential characters and factors related to yields.

Advanced trials: Advanced trials may be started from the fifth or sixth year and continued at least for another two or three years. No more than 15 clones (including the check) are usually selected from the comparative trial. The layout is usually the same as in the comparative trial. Plot size may be enlarged from single to double rows. At the end of this trial, two or three clones which appear quite stable in yields and other quantitative characters are selected for regional trials.

Table 5. Analysis of the carotene contents of sweet potato clone C 53-83 grown at different locations in Taiwan, 1969-70

Location	Soil type	Carotene content (mg/100 g)					
		replication					
		1	2	3	4	Total	Average
Touliu	sandstone, shale alluvial	13.1	9.2	8.6	12.4	43.3	10.8
Huwei	slate, sandstone shale alluvial	12.4	13.1	9.8	12.4	47.7	11.9
Peichiang	sandstone, shale alluvial	10.4	9.8	8.0	8.6	36.8	9.2
Wushulin	sandstone, shale alluvial	12.4	12.4	11.7	11.7	48.2	12.1
Chiaotou	sandstone, shale alluvial	13.8	10.4	14.9	10.4	49.5	12.4
Fentien	schist and limestone alluvial	13.1	13.1	10.4	11.7	48.3	12.1
Fanlu	red yellow podzolic	11.7	11.0	9.2	14.5	46.4	11.6
Mailiao	slate alluvial	8.6	9.2	11.7	9.8	39.3	9.8
Chiayi A.E.S.	red yellow podzolic	9.8	8.0	11.0	11.0	39.8	10.0
L.S.D. 5%							2.4
1%							3.3

Regional or observation trials: The clones used in these trials are generally from different breeding organizations, and local or traditional varieties should be included as controls. A randomized complete block design with four replications is usually adopted. These trials should be continued for three years, and an attempt made to examine how the clone(s) respond(s) under the local climate and soil conditions (Table 5).

Registration and release: After regional trials, when a clone or clones have been found to be definitely superior to local or traditional varieties in one or more respects and to be stable, the breeder may be ready to initiate release proceedings. Using appropriate code and number for the new clone(s), a list should be requested covering their origin, description, and performance.

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More than 60 percent of the sweet potatoes grown on Taiwan are used for industrial purposes or animal feed.

Sweet Potato Tips as Vegetables

R. L. VILLAREAL, S. C. TSOU, H. F. LO and S. C. CHIU

Asian Vegetable Research and Development Center, Shanhua, Tainan 741, Taiwan

INTRODUCTION

When the Philippines suffered serious flooding in 1972, only two green leafy vegetables could be regularly found in both urban and rural markets - sweet potato tips and water convolvulus or 'kangkong' (*Ipomoea aquatica*). All other vegetables were destroyed by about a month's continuous rain. Tips in this context refer to that portion of the top used for human consumption. The term top is used to denote the entire above ground part of the plant.

During the Second World War, many American and Filipino soldiers in the prison camps in the Philippines subsisted on rice and sweet potato tips (Miller 1967). Those fed with tips retained fairly good vision, whereas those who were fed a rice diet alone developed skin diseases and poor eyesight, due to lack of vitamin A. Many Filipinos for that matter survived famine and malnutrition during the war because of sweet potatoes. During those days, virtually every Filipino family had a vegetable garden and sweet potato was always a crop included in every garden. We know now that if even a very active man eats about 100 grams of tips a day he gets his supply of vitamin A for about two days, one-quarter of his vitamin B_2 requirement, and more than half of his vitamin C and Fe needs in addition to some quantities of Ca, ash and fiber.

Weather in the Asian tropics is hot and humid in summer, and thus vegetable production is low and prices are high. Sweet potato tips, able to survive adverse conditions, could serve as an additional leafy green vegetable during this time of the year if not the whole year round. The tips' high amounts of vitamins A, B_2, C and of some minerals could also help alleviate nutritional problems such as night blindness, scurvy and anemia among the inhabitants of the poorer areas of the tropics.

The purpose of this paper is to summarize the approaches which we follow at AVRDC in developing sweet potato varieties for tips.

PROBLEMS

Although sweet potato tips have been used as vegetables in the Philippines, Indonesia, Thailand, Malaysia (Villareal *et al* 1979a), many rural areas of Kwangtung and Fukien Provinces in southern China (personal communication with C. L. Luh, senior consultant, Taiwan Sugar Corporation), Guinea, Korea (Dahniya 1979), Zaire (Ifefo 1979), Sierra Leone (Kamara *et al* 1979), Tanzania (Msabaha 1979) and Liberia (Saqui 1979), their usefulness as human food has been neglected in sweet potato research. Consequently, there were many questions that needed answers when AVRDC started its pioneering work on this sadly underrated vegetable. For example, which leaf shapes, and color of stems, veins or leaves are preferred? Are non-hairy preferred to hairy leaves? How can one evaluate for tenderness, since this trait is always sought after in a leafy vegetable? Which of these quality character-

istics contribute to acceptability? Which parts are eaten - the stems, the leaves or both? Information was also needed on nutritional quality, productivity and how productivity could be improved. In short, sweet potato had to be evaluated in the several ways in which conventional leafy vegetables have normally been evaluated.

PROGRESS SO FAR

As a starting point the senior author conducted a limited consumer survey in the Philippines in 1974. He observed that acceptable sweet potato tips should be tender, glabrous (non-hairy) and purplish, the preference for purple being to add color to the table (Villareal *et al* 1979a). The parts eaten consisted of the top 10 cm tips including both stem and leaves. These are the parts generally eaten in many other countries, too. In Korea the petioles are eaten instead of tips whereas among Haka people living in Taiwan, the mature leaves and petioles are eaten.

Survey of morphological traits

Based on the aforementioned survey, four separate screenings were conducted between August and September in 1974, 1976 and 1977 evaluating 177, 136 and 56 accessions, respectively. The aim was to identify accessions with acceptable morphological traits for human consumption. The results of these screenings are summarized in Table 1 and Figure 1.

A wide variety of color and shape is available with or without glabrous leaves (Table 1). Some cultivars with only slightly hairy leaves could be selected if glabrous cultivars would not combine with other desirable traits.

Table 1. Morphological traits of tips of 369 sweet potato cultivars

	Stems	Veins	Leaves
	---- (number of cultivars) -----		
Color			
Purple	61	229	43
Green-purple	135	13	169[a]
Green	173	127	152
Others	0	0	5
Hairiness			
Glabrous			139
With light hairs			153
With medium hairs			56
With heavy hairs			21
			230
Leaf shape			
Entire (one point)			183
Trifoliate (3 points/leaf)			54
Palmate (5 points/leaf)			107
Others			25

[a]Green with purple edge
(Source: Villareal *et al* 1979a)

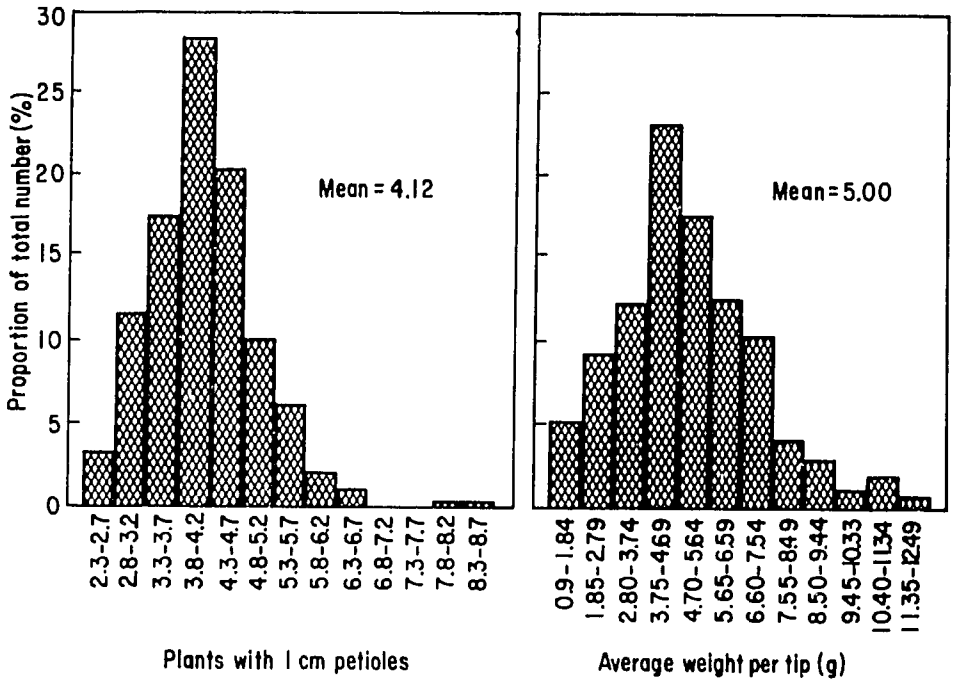

Figure 1. Distributions of tips with 1 cm petioles and various weights among 369 sweet potato cultivars (Villareal *et al* 1979a)

The general preference for 10 cm tips as greens in many countries where tips are eaten as vegetables is logical, since a large proportion of the leaves in the top 10 cm are new and thus tender. It was noted from the study that leaves with more than 1 cm petioles are older and generally tougher than those with less than 1 cm petioles. We therefore assessed desirability by counting the number of leaves with and without 1 cm petioles on each 10 cm tip on ten random samples per entry. Tips with the largest number of leaves with petioles less than 1 cm long were considered desirable, since they are more tender and good for the table. Results of the study (Figure 1) showed that there were from 2.3 to 8.7 such leaves per tip, and it was possible to select from about 3% of the accessions evaluated so far as this trait was concerned.

Tips are marketed in the Philippines either by weight or by number (AVRDC 1975, 1976), but only by weight in Malaysia and Taiwan. Therefore the researchers were interested in tips which weighed more, but were tender. Evaluation showed that a 10 cm tip could vary between 0.9 g and 12.5 g (Figure 1).

Evaluation for yield and nutritional and eating qualities

Promising cultivars which combine appropriate color, hairiness and tenderness were then evaluated for yield, and for nutritional and eating qualities. We included BNAS White, a popular Philippine cultivar grown for roots and tips, and Kinangkong for tips. Dilaw is also a popular Philippine cultivar for tips because of its attractive yellow leaves.

The results of the yield trial are presented in Table 2. Four entries (Dilaw, Kinangkong, PI 344138 and PI 344120) outyielded BNAS White, the check cultivar in terms of weight/ha; the other entries were comparable with the check. With the exception of Dilaw the same entries outperformed the check in

Table 2. Tip and root yield of ten sweet potato cultivars[a]

Cultivar name	Tip yield[a] weight (t/ha)	% over control	number (1000/ha)	T[x]	Root yield[w] (t/ha)
Dilaw	16	46	1420	38	2
Kinangkong	14	27	3520	59	1
PI 344138	14	27	1860	43	15
PI 344120	14	27	2080	46	15
Daja 380	13	18	746	27	10
PI 318856	12	9	1250	35	16
Earlyport	11	0	970	31	9
HM 16	11	0	1310	37	6
Rose Centennial	10	-10	610	25	3
BNAS-White (control)	11	-	1230	36	12
Avg	13		1500	38	9
LSD .05	3			5	3

[a]Planted 28 July 1976. [y]Harvested six times at 14-day intervals from 6 Sept to 28 Nov. [x]Transformation using square roots of tips/ha. [w]Marketable yield; harvested 6 Dec after 130 days
(Source: Villareal *et al* 1979b)

number of tips/hectare. If a grower needs a dual cultivar (which yields equally well for roots and tips), the choice would be PI 344128, PI 344120 or PI 318856. As evidenced in Table 2, the root yields of other entries were drastically affected by frequent harvesting of tips whereas these three entries gave at least 15 t/ha of marketable roots although they were subjected to the same frequency of harvesting as the others. It is clear from other studies (Dahniya 1979; Gonzales *et al* 1977; Yen 1974) that loss of sweet potato leaves in general results in reduced root yields.

Another experiment was held to determine whether frequency of harvesting, and nitrogen fertilization, would influence tip yield and other traits of three cultivars with different leaf types. It was found that frequency of harvesting did not influence yield or other traits, but the effects of nitrogen application and choice of cultivars were significant for some traits (Table 3). The 120 kg N/ha treatment outyielded the control due to production of more and heavier tips. This treatment also produced higher protein contents but lower oxalate levels in the leaves than the control, suggesting that levels of both compounds can be manipulated though nitrogen fertilization. Dry matter and vitamin B_2 were not influenced by additional nitrogen fertilizer. Kinangkong, the fine-leaf type gave the highest number of tips/ha, had the highest protein content, lowest oxalate, and fairly high dry matter, which makes it a very desirable green vegetable. Its vitamin B_2 content is comparable with that of the two other cultivars.

Nutritional evaluation showed variations in dry matter, fiber content, ash, vitamins B_2 and C and oxalate content (Villareal *et al* 1979b). No significant differences were detected among cultivars in Ca, Fe, and vitamin A contents. Sweet potato tips are superior to other leafy vegetables in

Table 3. Comparison of tip yield and other traits of three varieties of sweet potato[a]

Factors	Number (1000/ha)	Number T[b]	Weight (t/ha)	Avg wt/tip (g)	Protein (%)	Dry matter (%)	Oxalate %	Vit B_2[c] (mg/100 g)
Nitrogen level (kg/ha)	Effects of three levels of nitrogen							
0	3198	56.6	24	4.35	2.79	10.0	0.46	0.22
60	3039	55.1	22	4.55	2.97	10.0	0.43	0.22
120	3575	59.8	26	4.62	2.98	10.0	0.42	0.23
LSD .05		2.4	2	0.14	0.04	NS	0.02	NS
Variety	Three cultivars with different leaf types							
Dilaw (broad)	1826	42.7	18	6.72	2.93	9.0	0.49	0.21
AIS 016-1 (medium)	3287	57.3	26	4.10	2.77	10.7	0.48	0.22
Kinangkong (fine)	5100	71.4	25	2.67	3.05	10.3	0.34	0.24
LSD .05		5.7	5	0.33	0.08	0.3	0.04	NS

[a]Planted 15 June 1977; means of weekly and twice-monthly harvestings (means of two replications)
[b]Transformation using square roots of the number of tips/ha
[c]Data from weekly harvestings only

nutrient contents (Table 4). Potentially their most important contribution to nutrition may be in their high level of vitamin B_2, which is generally deficient in most Asian diets. Their lower amounts of oxalate than amaranth and spinach make them appear better in terms of lower oxalate than these two vegetables.

One of the most difficult tasks in encouraging greater use of sweet potato tips is to determine the different selection criteria to be used in predicting their general acceptability. The researchers approached this by evaluating the crop's eating qualities such as tenderness, flavor, stem and leaf color and hairiness (Villareal *et al* 1979c). It was found that all these quality attributes are important in predicting general acceptability of blanched tips (Table 5). However, an initial selection could be conducted in terms of stem color and hairiness. In stepwise multiple regression analysis to determine the relative contribution of each of the quality traits to acceptability of sweet potato tips, the coefficient of determination (R^2) indicated that stem color (X_3) accounted for 64% of the variation in acceptability (Table 5). Adding hairiness (X_5) into the equation showed an increase of 22% of accuracy in predicting acceptability.

Table 4. Nutritional constituents of sweet potato tips and of five common leafy vegetables

Vegetable	Moisture	Protein	Fiber	Minerals: Ash	Minerals: Ca	Minerals: Fe	Vitamins: A	Vitamins: B_2	Vitamins: C	Oxalic[e] acid
	%				(mg/100 g)		(IU/100 g)	(mg/100 g)		(% DW)
Sweet potato tips[a]	86.1	2.7	2.0	1.7	74	4	5580	0.35	41	5.1
Water convolvulus[b]	91.8	2.3	0.9	1.0	94	1	4200	0.20	43	4.5
Spinach[c]	92.3	2.3	0.8	1.7	70	2	10500	0.18	60	9.6[d]
Amaranth[c]	87.8	1.8	1.3	2.1	300	6	1800	0.23	17	10.3
Head lettuce[c]	96.3	0.9	0.3	0.2	14	0.2	4300	0.03	6	1.3
Cabbage[c]	92.1	1.7	0.9	0.7	64	0.7	75	0.05	62	0.3

[a]Average of ten sweet potato cultivars (Luh and Moomaw 1979)
[b]Source: T. C. Tung, P. C. Huang, H. C. Li and H. L. Chen. 1975. Composition of foods used in Taiwan
[c]Source: Food and Nutrition Research Center. 1968. Food composition table. Handbook 1 (4th revision), Manila, Philippines
[d]Source: Eheart, J. F. and P. H. Massey, Jr. 1962. Factors affecting the oxalate content of spinach, Agric. Food Chem. 10:325-327

Table 5. Summary of stepwise multiple regression analysis of acceptability and eating quality characteristic of sweet potato tips (Villareal *et al* 1979c)

Variable[z]	Accumulative (R^2)
1. Stem color (X_3)	0.64**
2. Hairiness (X_5)	0.86**
3. Tenderness (X_1)	0.90**
4. Leaf color (X_4)	0.92**
5. Flavor (X_2)	0.95**

[z]Order of variables entered in addition to previous variables; **Highly significant at 1% probability level using F-test

RESEARCH PRIORITIES

After conducting a series of pioneering studies on tips for human consumption, AVRDC scientists feel that there is still much work to be done to enhance their utilization. Investigations should be undertaken in the following areas:

1. Development of an attractive variety for sweet potato tips

Acceptance of tips is still influenced by psychological factors because they are considered 'poor man's salad'. Tips with new attractive appearance would help dispel this stigma. Some genotypes with better market appeal are deep purple or deep yellow with fine to medium leaves. So far AVRDC breeders have not succeeded in combining the attractive yellow color of Dilaw with fine or medium leaves. Dilaw is difficult to cross and the gene that controls this leaf color seems to be a deleterious recessive. Of the thousands of seeds sown at AVRDC only one seedling appeared yellow, but it was weak and eventually died. Last year, Dilaw produced a lot of open-pollinated seeds. We sowed about 500 seeds in May 1981. Four yellow seedlings emerged but the yellow color disappeared in about 15 days from germination. Thus, a month-old seedling of Dilaw which was yellow at germination appeared lighter green on the tips and normal green on the older leaves. There has been little progress at AVRDC on developing a deep purple variety.

2. Development of a variety with mild flavor

The strong flavor of tips make them less easy to cook with other vegetables. There seems to be a limited number of dishes which can be prepared out of tips. For instance, cabbage, cauliflower, broccoli, Chinese cabbage and even water convolvulus when cooked with sweet potato tips tend to lose their natural flavor. One alternative approach might be for home economists to develop tip dishes which exploit this strong flavor.

3. Evaluation of toughness in tips

Tips are considered tough compared to other leafy vegetables. The

level of concentration of fiber which contributes to the toughness of tips should be determined. Does fiber tend to be concentrated in the petiole, stem or leaves? Are there distinct varietal differences in terms of fiber content of tips? Would heavy nitrogen application and frequent irrigation make tips more tender?

4. Determination of chemical constituents

A complete bioassay to determine chemical and other constituents which might be either harmful or beneficial to human health should be carried out. Bitterness in tips for example might be due to phenolic compounds. Is excess intake of these compounds poisonous? What screening technique could be used to determine their presence in tips? On the other hand, sweet potato tips are also known to have saluretic properties (increasing the elimination of sodium salt) and diuretic properties (increasing amount of urine) which make them good vegetables for individuals suffering from high blood pressure (Villareal *et al* 1979a). Could tips, then, be recommended by doctors as a regular diet for people with high blood pressure? Why is this not done? Are there side effects associated with eating tips?

5. Development of ways of maintaining postharvest quality

The postharvest appearance of tips deteriorates rapidly. There is a need to identify and develop simple, inexpensive and effective means of maintaining the quality of tips from producer to consumer and to investigate the postharvest characteristics of different varieties. Do varieties with smaller leaves have longer shelf-life than those with bigger leaves? Do yellow leaves maintain attractiveness longer than either purple or green leaves?

6. Development of varieties with erect plant habit

The creeping growth habit of sweet potato makes harvesting of tips difficult. This difficulty would be alleviated if the tips were in a standing rather than in a drooping position at time of harvest. Such tips would be easier to harvest and may be amenable to mechanization in the future. This growth habit needs to be transferred to acceptable varieties. Another possibility which should be explored is the raising of tips with the use of bedded roots which normally produce standing sprouts or slips.

Please note that the problems we have identified relate mostly to the needs of the consumers (items 1 to 5). Only item 6 deals with the problems of the farmer-producer. Production problems of tip growers should also be given more attention.

CONCLUSION

Undoubtedly the sweet potato tips, like the roots, are under-exploited. But they could have a significant role to play in feeding large numbers of people in the Third World because tips and roots are inexpensive, easy to grow and nutritious. Scientists should help make this vegetable's tips and roots more appealing and acceptable. Plant breeders should develop a desirable sweet potato variety for tips and the food scientists and home economists should prepare more appetizing and appealing dishes out of tips. We hope that other scientists will share their expertise in this worthwhile undertaking.

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Breeding Sweet Potato for Disease Resistance

H. L. HAMMETT[a], T. P. HERNANDEZ[b], W. J. MARTIN and C. A. CLARK[c]

[a]LSU Sweet Potato Research Center, Box 120, Chase, LA71324, USA
[b]Department of Horticulture, Louisiana State University, Baton Rouge, LA70803, USA
[c]Department of Plant Pathology and Crop Physiology, Louisana State University, USA

INTRODUCTION

The sweet potato is one of the major food crops of the world with more than 15 million hectares grown in 1975 (Cummings 1976). According to Edmond and Ammerman (1971) the sweet potato is one of the most efficient plants in food production per unit area per manhour and is a rich source of carbohydrates, vitamins and certain minerals. The croo is also used for animal feed and in some areas, notably the USA, there is considerable interest in the crop as an alcohol source for fuel.

Twenty-eight vegetable crops are listed in Agricultural Statistics (Anon 1978). Sweet potatoes rank ninth in hectareage (58,000 ha) and sixth in value (US$120 million) in the United States. Estimated crop losses due to diseases amount to 10% of the production (Wood 1953). The sweet potato. is certainly not below average in this respect and if storage losses are considered too, total losses would be well above the 10% level. Commings (1976) stated sweet potato yields were less than half of the potential. This paper will concentrate on those diseases generally considered to be production problems.

The major diseases of sweet potatoes in the United States were listed by Martin (1976) and Martin, Nielsen and Morrison (1979) and Edmond and Ammerman (1971) as those caused by viruses, fungi and nematodes. They are:

Viruses
1. Internal cork
2. Feathery mottle
3. Russet crack

Fungi
1. *Fusarium* wilt or stem rot (*Fusarium oxysporium* f *batatas*)
2. Blackrot (*Ceratocystis fimbriata*)
3. Soilrot (*Streptomyces ipomoea*)
4. Scurf (*Monilochaetes infuscans*)
5. Circular spot and sclerotial blight (*Sclerotium rolfsii*)

Nematodes
1. Rootknot nematodes (*Meloidogyne incognita, M. hapla* and *M. javanica*)
2. Reniform nematode (*Rotylenchulus reniformus*)

VIRUS DISEASES

Internal cork

Internal cork virus (ICV) of sweet potatoes was a major disease of the

crop during the late 1940s and 1950s. Martin (1960) stated that considerable resistance to the development of root symptoms existed among cultivars but resistance to the virus itself was limited. He described the cultivar Allgood as a 'Typhoid Mary' in that it was a highly susceptible active carrier of the virus but did not develop symptoms of the disease. Martin (1970) reviewed virus disease work in sweet potatoes and reported resistance to ICV was available and was readily transmitted to sweet potato progenies.

Harmon (1960) studied the inheritance of resistance to ICV. He screened a large number of cultivars and breeding lines between 1946 and 1960 and found six that had no ICV symptoms and a similar number with over 50% of the roots showing pronounced symptoms. He selected six of these lines as parents in studies of the inheritance of ICV resistance in a controlled crossing program. The results of his efforts are summarized in Table 1. When both parents were classified as resistant, no ICV symptoms were observed in the progeny. If both parents were susceptible, all of the progeny had symptoms of ICV. The resistant x susceptible or susceptible x resistant crosses produced progenies in which approximately 25% of the individuals had symptoms of ICV. Harmon suggested resistance was controlled by dominant genes.

Several cultivars have been classified as symptomless carriers of the virus (Martin 1960, 1970). Some pathologists today are suggesting that 'resistance' is merely resistance to the development of the symptoms of ICV with few of the 'resistant' selections truly resistant to replication of the virus. Most of the 'resistant' cultivars and selections are probably symptomless carriers of the virus.

Table 1. Cork index and percentage of roots and clones showing cork symptoms for selected parental lines and their progenies

Parent or Progeny	Cork index	Roots			Clones		
		total number	with symptoms number	%	total number	with symptoms number	%
Whitestar (WS)[z]	1.74	43	2	4.6	1	1	100.0
Whitestar (selfed)	0.82	122	3	2.4	6	2	33.3
HM-15[z]	0.00	38	0	0.0	1	0	0.0
HM-15 (selfed)	0.35	649	3	0.5	58	1	1.7
HM-36[z]	0.00	59	0	0.0	1	0	0.0
L-130[z]	14.28	7	4	57.1	1	1	100.0
L-130 (selfed)	17.86	29	12	41.4	3	3	100.0
L-21[z]	5.00	10	2	20.0	1	1	100.0
Porto Rico[z]	22.39	96	48	50.0	1	1	100.0
R x R	0.00	977	0	0.0	81	0	0.0
R x S	3.25	376	24	6.4	33	7	21.2
S x R	2.18	964	53	5.5	91	24	26.4
S x S	19.29	127	68	53.5	9	8	100.0

[z]Parental lines used in crosses
(Source: Harmon 1960)

All of the parental lines in the LSU breeding nursery are 'resistant' to ICV or at least to the development of symptoms of the disease. Symptoms of ICV have not been observed in Louisiana State University (LSU) selections grown under field conditions in more than 20 years. The LSU screening program for ICV resistance involves core grafting diseased tissue into roots of the selections and holding them under conditions favorable for disease development. Sprouts from the inoculated roots are grown and roots they produce are examined for ICV symptoms. The susceptible check cultivars have been the only ones showing root symptoms of the disease for the past four years of testing.

Other viruses

Feathery mottle (FMV) and russet crack have not been problems of economic importance in Louisiana fields. The Jersey types, grown in the northeastern part of the US production area, appear to be more susceptible to the russet crack symptom.

THE FUNGUS DISEASES

Fusarium wilt

Fusarium wilt or stemrot caused by *Fusarium oxysporum* f sp *batatas* is found throughout the sweet potato production area of the United States and across mucn of the world (Nielsen 1970). It was a major fungus disease of economic importance in sweet potatoes throughout the southern United States prior to the 1950s and according to Edmond (1971) it was responsible for loss of as much as 50% of the plants in some plantings. Tinian, Goldrush and Carogold have a relatively high degree of resistance.

Kakar (1965) and Hernandez *et al* (1967) studied the inheritance of *Fusarium* wilt resistance in sweet potatoes. The progenies of 29 crosses were evaluated for resistance to *Fusarium* wilt.

Fusarium wilt index was computed for each seedling. Twelve terminal cuttings of each seedling were inoculated by dipping the basal cut in a spore suspension of *Fusarium* inoculum and then transplanting the seedling into clean sand. The highly susceptible cultivar Heartogold and the resistant one Goldrush were used as checks and were inoculated in the same manner. When cuttings of the susceptible check began to die, all cuttings were evaluated and placed in one of five categories: 0 - no vascular discoloration, I - trace of vascular discoloration, II - moderate vascular discoloration, III - severe vascular discoloration and IV - severe wilting/dead plants. The wilt index of each seedling was computed using the following formula:

$$\text{Wilt index} = \frac{\text{Summation of category numbers x no. plants in each category}}{\text{Number of plants tested x 4 (no. classes - 1)}}$$

The wilt index was then used to classify the seedlings as: highly resistant (HR) = wilt index of 0-20; resistant (R) = wilt index of 21-40; moderately resistant (MR) = wilt index 41-60; moderately susceptible (MS) = wilt index of 61-80 and susceptible (S) = wilt index of 81-100.

The data are summarized in Table 2. The results in general indicated

Table 2. Percentage distribution of sweet potato progenies into *Fusarium* wilt classes

Cross	Number seedlings	Percentage distribution of seedlings in each wilt class[a]				
		HR	R	MR	MS	S
MR (selfed)	142	8.5	28.8	42.3	15.5	4.9
MR (selfed)	78	0.0	3.8	37.8	42.3	16.7
MS (selfed)	132	0.0	15.1	59.1	23.5	2.3
MS (selfed)	27	0.0	0.0	29.6	59.3	11.1
HR x R	43	0.0	3.3	41.9	39.5	9.3
R x HR	41	0.0	31.7	42.8	12.5	0.0
R x HR	226	22.1	51.3	25.6	0.0	0.0
MR x HR	521	0.2	7.8	47.2	33.6	10.9
MR x R	283	0.7	11.0	30.4	37.1	20.8
MR x MR	905	2.3	8.4	42.5	31.6	15.1
MS x R	384	2.6	1.8	22.9	43.4	31.6
MR x MS	110	3.3	7.2	41.2	43.5	5.7
MR x S	199	0.0	1.2	23.2	53.5	22.1

[a]HR = highly resistant = wilt index of 0-20
R = resistant = wilt index of 21-40
MR = moderately resistant = wilt index of 41-60
MS = moderately susceptible = wilt index of 61-80
S = susceptible = wilt index of 81-100
(Source: Kakar 1965)

that crosses involving parents of moderate (or higher) resistance produced progenies with a large percentage of individuals in the resistant category. Some of the parents transmitted a high degree of resistance and Julian was outstanding in this respect. When the parents were moderately susceptible, or susceptible, a low percentage of seedlings in the progeny had resistance to *Fusarium* wilt. However these parents did carry genes for resistance to the disease.

With resistance is a quantitative character controlled by six genes that are additive. Transgressive inheritance was indicated in some crosses. A heritability estimate of 33% was reported and selection based on phenotype suggested. Jones (1969) reported a heritability estimate of 86% and he stated the additive component accounted for virtually all of the genetic variance.

Selections from the LSU breeding program are routinely screened for resistance to wilt. Approximately 80% of the seedlings tested over the last four years have possessed a level of resistance ranging from 'intermediate' (a relatively good level of field resistance) to 'highly resistant'.

Various degrees of *Fusarium* wilt resistance occur in different selections and are useful under field conditions. For example, Centennial is classed as intermediate but under field conditions the resistance is sufficient to ensure that the disease is not a problem in most cases. Resistance to *Fusarium* wilt is readily available, easily incorporated and very effective under field conditions so there is no reason why such resistance should not

be incorporated into all new cultivars. Although resistance has been very stable to date, we are aware of the fact that there might be differences in the severity of the pathogen. Current screening is done using only one isolate of the pathogen. We must constantly seek to maintain and incorporate diverse sources of resistance.

Blackrot

Blackrot, *Ceratocystis fimbriata* has been an occasional disease of importance in production areas of Louisiana. Nielsen (1970) reported control by chemical and sanitation practices. Some attention has been paid towards developing resistant varieties. Nielsen and Yen (1966) studied over 600 cultivars from worldwide sources. All developed symptoms of the disease but some were much more severe than others. The six most resistant were from South America, five from Peru and one from Ecuador. However, Martin (1960) reported differences among cultivars in the degree of severity. There is no known source of resistance to the disease which approaches immunity.

Soilrot or pox

Soilrot, caused by *Streptomyces ipomoea*, is widely distributed in the United States. It has been reported from Iowa to Louisiana and from New Jersey to California (Nielsen 1970; Hernandez 1979). Technically, *Streptomyces* belongs to the Actinomycetes which is taxonomically closer to bacteria than fungi. It is often placed with fungi, probably for convenience. The pathogen is soilborne and may destroy the crop under soil and weather conditions favorable for development of the disease. The disease is often severe in soil having a pH of 5.8 or above, while generally at pH of 5.2 or lower there is little damage.

Breeding for soilrot resistance began in Louisana about 1946 and the cultivar Acadian was released as moderately resistant in 1957. Jasper, released in 1974, has a high level of resistance to soilrot (Hernandez *et al* 1974). In 1980, Travis, a cultivar with good resistance to soilrot, stemrot, internal cork and rootknot nematodes, was released (Hernandez *et al* 1980).

The greatest extremes in susceptibility and resistance may occur with soilrot. Resistance alone appears adequate to control the disease but there is some question whether different races of the pathogen may occur. There are two phases of the disease, the rootlet phase which affects vine growth and total yield, and the pox phase which is characterized by lesions on the storage roots. Resistance to the two phases may well be inherited independently.

All selections from the LSU breeding program are screened for soilrot resistance. Progress in the development of parental lines with disease resistance is shown in Table 3. The breeding program includes a soilrot nursery in which only soilrot resistant parents with good horticultural qualities are grown. Of the seedlings selected in 1980, almost 60% proved intermediate to resistant to soilrot in tests. Those selections that do not have at least an intermediate level of resistance are generally not considered for further testing. Each year new soilrot resistant parents are entered into this nursery and less productive parents are removed. Soilrot resistance will continue to be a major selection criterion in the Louisiana breeding program because of the importance of the disease in our production areas.

Table 3. Progress in the development of disease resistant parental lines in the LSU sweet potato breeding nursery

Year	Percent of parents with resistance to			
	Fusarium wilt	Internal cork	Root knot	Soil rot
1940	15	0	0	5
1950	50	15	8	10
1960	56	28	17	28
1970	80	85	23	72
1980	100	100	37	98[z]

[z]56% of the 1979 seedling selections tested intermediate to resistant to soilrot

Scurf

Scurf, caused by *Monilochaetes infuscans*, occurs in sweet potato producing areas virtually worldwide (Edmond and Ammerman 1971). Struble and Morrison (1963) and Nielsen and Yen (1966) screened more than 600 lines for reaction to scurf and found only minor differences in susceptibility. All lines developed disease symptoms but some appeared less severe than others. Martin (1960) reported there appeared to be little worthwile resistance to scurf. Martin *et al* (1970) pointed out that no sweet potatoes have been found to be immune to scurf. They suggested the 'resistant cultivars' (those with small lesions) may be of little value in a breeding program.

Scurf is relatively easy to control by crop rotation, sanitation and use of clean planting material. Because of slow growth of the pathogen, the length of the slender attachment root may play a role in the incidence of the disease, according to Martin and Hernandez (1966), but its significance is minor. Due to the absence of a useful source of resistance, there is no breeding directed toward scurf resistant cultivars.

NEMATODES

Rootknot nematodes, *Meloidogyne* species, are a serious problem in sweet potato production areas throughout the United States and especially in sandy soils (Morrison 1970; Hernandez 1979). Species of *Meloidogyne* involved include *M. incognita*, *M. hapla* and *M. javanica*. According to Martin *et al* (1966) and Brathwaite (1977), the reniform nematode, *Rotylenchulus reniformis* as well as certain other nematodes may cause problems in some areas.

Giamalva *et al* (1963) studied the response of eight cultivars to *M. incognita*, *M. hapla*, *M. javanica* and *M. arenaria* and found two cultivars, Heartogold and Nemagold, resistant to all four species. They varied in the degree of resistance to various species. Jatala and Russell (1972) studied the nature of resistance to *M. incognita* in the sweet potato. They reported the rate of larval penetration was significantly greater in the susceptible cultivar than in the resistant cultivars and increased as the temperature increased from 24 to 32°C. They suggested a root exudate by the resistant cultivar as the basis for resistance.

Davide and Struble (1966) and Martin and Birchfield (1973) reported different physiological races of *M. incognita* could be isolated on sweet potatoes. The presence of multiple races of *M. incognita* will make selection for resistance more complicated. Brathwaite (1977), in discussing breeding for resistance to *M. incognita*, stated that some crosses between resistant parents resulted in hypersensitivity. Jones *et al* (1967) reported a good level of success in the development of lines with a high degree of resistance to nematodes. Dukes *et al* (1978) announced the release of a breeding line designated W-51 for use as a rootknot resistant parent in sweet potato breeding programs. W-51 was described as highly resistant to two races of *M. incognita*, including a race which develops on other resistant cultivars, and to *M. javanica* and *M. hapla*.

Jones and Dukes (1980) studied the inheritance of rootknot resistance in sweet potatoes caused by *M. incognita* and *M. javanica*. They used three measures of resistance: number of egg masses, gall index and necrosis index and reported heritability estimates of .69 ± 18, .78 ± 19 and .72 ± 20, respectively, for the three measures. They found resistance to the two species was not correlated and suggested independent inheritance involving different genes.

Misuraca (1970) classified sweet potato seedlings as resistant, moderately resistant and susceptible. In crosses where both parents were resistant, 79% of the seedlings were resistant to moderately resistant. In resistant x susceptible crosses, the seedlings were evenly distributed among the three classes. In crosses of two susceptible parents, 93% of the seedlings were susceptible. He suggested resistance is a partially dominant quantitative character controlled by several genes. Three cultivars, Jewel Jasper and Travis, both with good resistance to *M. incognita*, have been released (Hernandez 1979; Hernandez *et al* 1980).

The Louisiana breeding program continues to emphasize the importance of resistance. All seedlings are screened for resistance to rootknot. A nursery has been established that contains only resistant parental lines with many good horticultural characters. Resistant selections are not immune as evidenced by a small degree of reproduction of the nematode which is known to occur but sweet potato genotypes are available which are resistant to all known races.

LSU selections are evaluated for rootknot resistance in a 1:1 (V:V) sand-soil mixture in the greenhouse. The plant roots are carefully examined and rated based on galls and egg masses. More than 85% of the seedlings tested in 1980 were rated intermediate or better in resistance to rootknot.

Advanced selections are also screened for reniform nematode reproduction in the greenhouse using larvae and egg mass count techniques. Total nematode count per gram of fibrous roots (eggs and larvae) ranged from 3839 to 21,966. Goldrush was lowest and Centennial was intermediate with 8529 per gram of roots. Several seedlings were equal to Goldrush in resistance. However, resistance to reproduction of the nematode is not related to growth and yield of the cultivars in infested soil because Goldrush is one of the most severely affected while Centennial is less severely affected.

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Examination of new AVRDC breeding materials.

Breeding Sweet Potato for Weevil Resistance

S.K. HAHN and K. LEUSCHNER

International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

INTRODUCTION

Sweet potato weevil species which are of economic significance in the world are *Cylas formicarius* (Fab) and *Cylas puncticollis* Boh. *C. formicarius* is pantropical while *C. puncticollis* is confined mostly to tropical Africa (Leuschner 1979b). These weevils are the most serious pests of sweet potato (*Ipomoea batata* (L) Lam) production in the tropics and subtropics. They attack storage roots, leaves and stems. The larvae tunnel through the pith system of the stem and often destroy the shoots. They seriously reduce the market value of storage roots and leaves and drastically reduce the quality of storage roots after harvest since the roots can become rapidly infected and destroyed during the weevils' 20 to 30-day life cycle. Yield loss due to these pests was reported by Dhit: ndia (1919 c f Leuschner 1979b) to be as high as 20% in Texas, 12% in Louisiana and 10% in Florida.

In traditional agricultural systems in the tropics and subtropics, where inputs are low, the use of cultural control measures and the cultivation of resistant cultivars is the most economic way of effectively controlling these insects.

There are several reports (AVRDC 1975-77; Cockerham and Deen 1947; Cockerham *et al* 1952; Rolston *et al* 1979; Waddill and Conover 1978) of sweet potato resistance to *C. formicarius*.

Realizing the importance of the pest problem, the International Institute of Tropical Agriculture (IITA) initiated a sweet potato breeding program for resistance in 1971. Since then, many sweet potato genotypes introduced from Africa, Asia and the Americas have been evaluated for resistance to *C. puncticollis*. As a result, resistance to the species has been identified (IITA 1972-1980; Leuschner 1980; Hahn 1981).

This paper reviews weevil resistance, breeding and entomological work with particular reference to the research results of IITA's sweet potato improvement program for resistance to *C. puncticollis*.

EFFECT OF ENVIRONMENT ON WEEVIL POPULATIONS

Weevil populations change with environment, and this provides useful information for efficient screening of breeding material for weevil resistance.

In the rainy season the wet soil also cracks less, thus giving the weevils less easy access to the storage roots and fewer places to breed. Although sweet potato is not grown commercially during the dry season, except on irrigated or hydromorphic land, the weevil population increases more rapidly on a dry season crop than in the rainy season crop. This is especially true when sweet potato is left unharvested for some time in the field. Planting material should be able to withstand the dry season, so that it is

available in the following rainy season. For these reasons, resistance of sweet potato to weevils is important in those regions of the tropics and subtropics with dry seasons of more than two months per year.

More weevils are observed in clay soil than in sandy soil because the former tends to exhibit more soil cracking, and thus affords more breeding places as storage roots grow.

The weevil population tends to decrease as elevation and latitudes increase, which may be due to the drop in temperature.

Rotation with other crops, and hilling-up, reduce the weevil population, and continuous sweet potato cultivation on a large scale encourages the weevil population to build up.

SWEET POTATO PLANT-WEEVIL RELATIONSHIP

Understanding the relationship between the sweet potato plant and the weevil is a prerequisite for screening breeding material for weevil resistance.

Adult weevils feed on leaves, stems and storage roots. Cockerham (1954) reported that weevils prefer storage roots to stems and leaves by a ratio of about seven to one. The females use storage roots for oviposition rather than as a source of food (Leuschner 1979b). But in experiments mortality levels in a weevil population increased when it was reared solely on storage roots for five generations. On the other hand, weevil mortality decreased when the population was fed leaves; the females laid more eggs, which indicates that leaves are essential to the adults for a balanced diet (Leuschner 1979b). Weevils lay eggs on stems at an early sweet potato growth stage when storage roots are not yet available. Stems also serve as breeding places for weevils. Leuschner (1979b) observed an average of three to four larvae on the main stems 20 cm above the ground. The older, lower and tougher part of the stem is preferred by weevils to the younger, higher and more tender part. The larvae tunnel through the soft pith but not through the harder vascular bundles. The stem damage caused by weevils can result in yield loss.

Most breeding takes place in the storage roots. Weevils do not stay deep below the soil surface and cannot mine through soil to reach storage roots deep underground. They normally attack only the upper parts of storage roots exposed by soil cracking and by the enlargement of the roots themselves. Deeply placed storage roots are not easily attacked by weevils unless there is access through soil cracking.

METHODS OF WEEVIL RESISTANCE SCREENING AND RATING

Weevil resistance screening in the field is normally practiced in both the rainy and dry seasons. However, since the weevil population is higher in the dry season than the rainy season, it would appear to be better to screen breeding material for weevil resistance in the dry season. For dry season trials, planting sweet potato is done two to three months before the end of the rainy season in order to ensure good early plant growth in the rainy season followed by good exposure of shoots and storage roots to high weevil populations. The breeding clones are evaluated for shoot resistance to weevils before harvest and for root resistance at harvest.

Root damage ratings are based on six classes of infestation severity: class 0 - no visible damage; class 1 - a few, small feeding punctures of adults on the surface of the upper portion near the neck of 1% of the roots; class 2 - small feeding punctures of adults on the surface of the upper one-fifth portion of 5% of the roots; class 3 - moderate feeding punctures of adults and larvae on the surface and interior of the upper one-fourth portion of 25% of the roots; class 4 - extensive damage caused by adults and larvae on the upper one-fourth portion of 50% of the roots; and class 5 - severe damage caused by adults and larvae of the upper one-third or more of 75% of the roots.

The shoot damage ratings are based on six classes of shoot infestation severity including leaves and stems: class 0 - no visible damage; class 1 - feeding punctures caused by adults on 1% of leaf area, but causing no wilting of shoots; class 2 - feeding punctures caused by adults on 5% of leaf area but causing no wilting of shoots; class 3 - feeding punctures caused by adults on 25% of leaf area and mild wilting of shoots (mainly due to stem damage by larvae); class 4 - feeding punctures on 50% of leaf area and severe wilting of shoots; and class 5 - feeding punctures on 75% or more of leaf area and complete die-back on shoots.

Field evaluation of breeding clones selected on the basis of preliminary results is continued for confirmation of resistance as the breeding stages advance. Clones showing most promise in field evaluation are retested in the laboratory to reconfirm their resistance. In the laboratory test, storage roots from each clone are tested for adult weevil emergence, preference for oviposition and feeding and for mortality and growth of larvae.

RESISTANCE OF SWEET POTATO TO WEEVIL

Many weevil-resistant sweet potato clones have been identified, and their resistance has been incorporated into cultivars and populations, since the weevil resistance breeding program started at IITA in 1971 (IITA 1972-80). However, their degree of weevil resistance has not been quantified, and the mechanism of the resistance involved has remained unknown until recently.

The storage root and shoot resistance tests carried out in both rainy and dry seasons showed significant differences among cultivars (Table 1). TIS 3053 and TIS 3030 showed the least mean root weevil damage while TIS 2532, TIS 3017 and TIS 3030 showed least mean shoot weevil damage. The relationship between weevil damage scores of roots (Y) and shoots (X) was highly significant with a correlation coefficient of $r = 0.74$ (Figure 1). This strong relationship indicates that the differences among cultivars in weevil damage to shoots may be associated with similar differences in storage roots. Therefore, it may be possible to increase efficiency of storage root resistance selection by evaluation of shoot resistance in the late dry season.

Clones derived from a few seeds of the source that showed resistance to *C. punctticollis* supplied from IITA's collection also showed resistance to *C. formicarius* (Rolston *et al* 1979). However, the question of whether resistance to *C. punctticollis* will also be associated with resistance to *C. formicarius* in other countries and continents needs to be further examined.

Table 1. African sweet potato weevil root and shoot damage scores and dry matter percentage for 20 sweet potato cultivars

Cultivar	Weevil damage (score)[z] root	shoot	Dry matter
TIb 4[y]	3.3 a	4.8 ab	29.6
TIb 11[y]	3.2 ab	4.3 abc	26.5
TIS 1145	3.0 abc	4.5 ab	29.5
TIb 2	2.9 abcd	5.0 a	28.9
TIS 2330	2.8 bcd	4.0 bcd	22.2
TIb 10	2.7 cd	4.5 ab	30.1
TIS 3247	2.5 de	4.3 abc	28.4
TIS 3270	2.5 de	3.3 de	28.4
TIS 1487	2.3 ef	2.8 efg	32.7
TIS 2498	2.3 ef	3.0 ef	31.7
TIS 1499	2.2 efg	2.0 fgh	28.1
TIb 8	2.0 fgh	2.8 efg	32.8
TIb 9	2.0 fgh	3.0 ef	36.0
TIS 2532	1.9 fgh	1.0 i	29.3
TIS 3017	1.9 f[illegible]	1.5 hi	32.1
TIS 3290	1.9 [illegible]gh	3.0 ef	34.1
TIS 2153	1.8 gh	3.0 ef	38.0
TIS 2154	1.8 gh	3.0 ef	37.6
TIS 3030	1.6 hi	1.8 ghi	31.1
TIS 3053	1.4 i	3.5 cde	29.4

[z]Scores from 0 to 5; 0 = no weevil damage, and 5 = severe damage. Means having common letters within a column are not significantly different at 5% level according to Duncan's Multiple Range Test
[y]Orange-fleshed cultivars

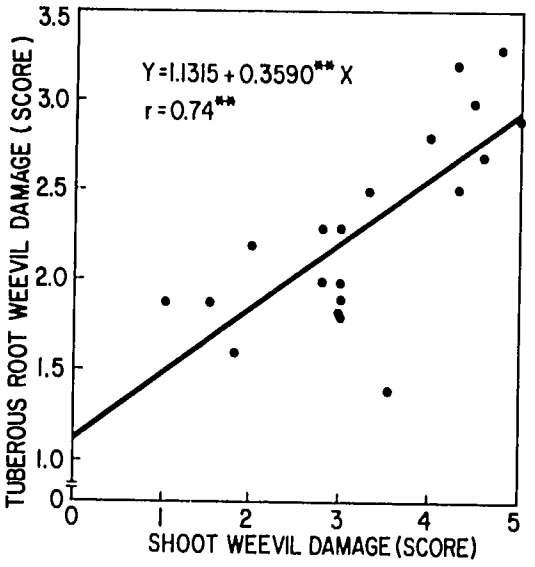

Figure 1. Relationship between weevil damage scores of roots and shoots

MECHANISM OF RESISTANCE TO WEEVIL

The mean weevil damage of orange-fleshed cultivars was significantly more severe than the mean weevil damage of white-fleshed cultivars (Table 1). However, some white-fleshed cultivars suffered as much damage as the orange-fleshed cultivars. It is, therefore, difficult to postulate whether the orange flesh characteristic (associated with a high carotene content) influences resistance of sweet potato to weevils.

Significant correlation between weevil damage of storage roots and shoots may be an indication that shoots play an important role in reducing the weevil damage to storage roots by reducing the weevil population on the plant. The fact that fewer eggs are laid and fewer adults hatch on the stem of the weevil resistant cultivars supports this hypothesis (Leuschner, unpublished data, 1979).

No significant correlation ($r = 0.24$) was observed between weevil damage scores of storage roots of any of the tested varieties and root yield. Neither was there significant correlation ($r = 0.04$) between weevil damage scores of storage roots of any of the varieties and average storage root weight. However, the correlation of storage root damage scores with dry matter percentage was -0.56 and was highly significant (Hahn 1981). This indicates that the cultivars with high dry matter percentage, and thus high starch content, tend to be less frequently attacked by weevils. Contrary to the report by Cockerham and Deen (1947) who studied *C. formicarius*, dry matter percentage was significantly associated with weevil resistance. The cultivars with high dry matter percentage showed a general tendency to lower weevil infestation.

It is not known whether the differences among cultivars in weevil resistance are due to chemical or physical factors of shoots or storage roots. However, the relationship between weevil damage of storage roots and dry matter percentage suggests that chemical or physical factors may be associated either with nonpreference or antibiosis against weevils. In two related experiments, roots were infested with an equal number of males and females: this was repeated four more times, each time using insects from a different generation. The weevils laid significantly lower numbers of eggs on resistant cultivars TIS 3030, TIS 3017, and TIS 2532 than on susceptible cultivar TIb 4, and these eggs hatched four to six days later than on TIb 4. Larvae on the resistant cultivars suffered higher mortality rates, and adult males achieved a lower average weight gain (Leuschner 1979a, 1979b). All these factors strongly indicate the operation of antibiosis as the most plausible mechanism behind storage root resistance. However, this needs to be investigated further.

In order to test the preference of larvae for feeding on the flesh of different storage roots, two known weevil resistant cultivars (TIS 2532 and TIS 3017) were compared with one susceptible cultivar (TIb 4) using the 'sandwich method' (Leuschner and Tomu 1980). Slices of uniform 3 mm thickness were cut from roots of each of these three cultivars and were sandwiched together in various combinations. In each case the two outer slices of the sandwich came from the same cultivar. Each sandwich was placed between glass plates to reduce water loss. The results showed larvae preferred to feed on TIb 4 rather than on TIS 2532 or TIS 3017.

BREEDING METHODS

The strong relationship between weevil damage ratings of storage roots and those of shoots for the same variety in the dry season indicates that it might be possible to improve sweet potato weevil resistance by intercrossing clones or individual plants of families which survive the dry season. Most sweet potato genotypes flower under IITA conditions during the dry season with shorter daylength and cooler temperature than the wet season. Broad sense heritability of resistance to weevil was estimated as $H = 0.84 \pm 0.03$ in the shoot test (Hahn 1981). The heritability estimate using shoot resistance data was almost the same as that for the storage root resistance data. This high heritability for the shoot test indicates that it may be possible to apply mass selection methods for breeding weevil resistant sweet potato in addition to the conventional sweet potato breeding methods. However, since appreciable cultivar x year interaction was present in the root test, and since cultivar x site interaction was observed in the shoot test caution is needed in considering results of weevil resistance tests in the field.

CONCLUSION

Sources of resistance of sweet potato to *C. punctiicollis* are available and the resistance has been incorporated into cultivars and populations. Antibiosis seems to be the most likely mechanism influencing the resistance to roots and shoots of sweet potato to weevils. The facts that female weevils prefer to lay eggs on susceptible varieties, and that on resistant varieties egg hatching is delayed, larval mortality is higher and adult weight gain lower, all support this hypothesis.

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Progress in Selection for Resistances in Sweet Potato to Soil Insects of the WDS Complex

A. JONES, J. M. SCHALK and P. D. DUKES

US Department of Agriculture, Science and Education Administration, Agricultural Reasearch, US Vegetable Laboratory, 2875 Savannah Highway, Charleston, South Carolina 29407, USA

INTRODUCTION

At the US Vegetable Laboratory, Charleston, South Carolina, we are conducting a comprehensive sweet potato breeding program (Jones *et al* 1976) in which our first or primary objective is to develop multiple pest resistant breeding lines that we and other breeders may use to increase marketable yields and decrease production costs. Our second objective is to develop cultivars which combine various disease and insect resistances in combination with the many cultural and culinary requirements of the US sweet potato industry. This work is pursued by the authors in very close cooperation with Dr M. G. Hamilton of Clemson University, Edisto Experiment Station, near Blackville, South Carolina, about 100 miles west of Charleston. We also cooperate extensively with other US scientists. Originally, Mr F. P. Cuthbert, Jr (USDA, retired) was the entomologist on this team and much of our early progress is due to his efforts.

We follow the mass selection procedures advocated by Jones (1965) with populations of sweet potato originated from diverse sources. Mass selection populations or polycross nurseries are grown on trellises in isolation from other flowering sweet potatoes with all crossing accomplished by naturally occurring insects (Jones 1980). Mass selection is used to combine the various traits as rapidly as possible and to increase the expression of desirable characters such as high levels of resistances, dark orange flesh, high yields, good baking and canning qualities, and so on. In the mass selection process each genetic cycle progresses from true seed to true seed (Figure 1). In other words, no selected plant is entered again in subsequent generations. Only true seed from selected plants is used. This provides for more rapid progress in increasing the levels of expression of desirable traits and in sexual generation each year, and this allowed for very rapid progress toward limited goals (Cuthbert and Jones 1972). Recently we have changed to a two-year cycle in order to select for such characteristics as good storage life and plant bed traits and to allow the screening for insect resistance to be done in two years and thus avoid problems associated with escape from injury (Jones *et al* 1976).

Selections from the mass selection populations are used in polycross nurseries along with selections from various other sources. The polycross nursery is restricted to 30 entries and plants are used for as many years as seems desirable. Each year new selections are added and each time this is done some line must be removed. By limiting the number of polycross entries a dynamic breeding nursery will certainly gradually improve each year (assuming that our selection has been effective). Thus, five or ten years from now we will be crossing a different set of plants, much improved over those now in use, rather than screening seedlings from the same crosses used

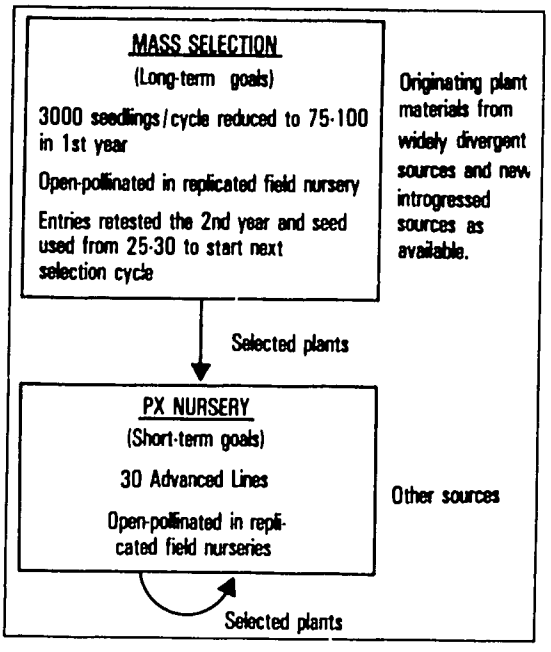

Figure 1. Breeding schemes followed at the US Vegetable Laboratory, Charleston, SC where mass selection is used to develop breeding lines from germplasm of diverse origins and selections are entered into polycross nurseries with lines from other sources showing promise as cultivars

this year or even five or ten years ago (a situation that, unfortunately, appears to be far too common in many breeding programs).

EARLY SOIL INSECT STUDIES

Cuthbert and Reid (1965) mentioned 14 insect species that feed on sweet potato roots in the US and Cuthbert (1967) expanded this list to 19 species (Table 1). It is difficult to distinguish between the damage caused by a number of these at harvest, after the insects have left and damage has been altered by subsequent growth of the roots. For convenience, we screen for resistance by evaluation of four kinds of injury. Grub injury is easily recognized as the grubs gouge broad, usually shallow, channels in the roots. Feeding by sweet potato flea beetles leaves narrow channels or grooves just under the root skin and is easily distinguished from other types of injury. Sweet potato weevils are generally studied under controlled conditions and are one of the few species where the insect is still in the root at harvest and can be identified directly. A number of insects make feeding holes or scars in the roots that may be healed by harvest time and distorted by root expansion. We rate such injury with an index of injury caused by the wireworm-*Diabrotica-Systena* (WDS) complex as developed by Cuthbert and Davis (1970). Quite often resistance is found that is effective against the entire complex but sometimes lines that appear resistant in one environment may appear more susceptible in another location apparently due to different mixes of WDS species. However, unless adult insect population surveys are made or soil larval populations are monitored, it is difficult to define the species responsible for the location differences.

In 1966 the first evaluations of materials from the mass selection program for WDS resistances were made by Cuthbert and Davis (1970) who had been looking for resistances in other US sources since 1961 with relatively little success. True seed of C/4 (mass selection population C, generation 4) was screened by them and although there had previously been no selection except

Table 1. Soil insects of sweet potato in the United States

Scientific name	Common name/description
WDS Complex (selection for resistance on basis of similar injury)	
Conoderus falli Lane	Southern potato wireworm
C. vespertinus Fabricius	Tobacco wireworm
Diabrotica balteata LeConte	Banded cucumber beetle
D. undecimpunctata howardi Barber	Spotted cucumber beetle
Systena blanda Melsheimer	Pale-striped flea beetle
S. elongata Fabricius	Elongate flea beetle
S. frontalis Fabricius	A flea beetle
Grubs (selection for resistance on basis of similar injury)	
Phyllophaga ephilda Say	A white grub
Plectris aliena Chapin	A white grub
Sweet potato flea beetle (selection for resistance on basis of typical injury)	
Chaetocnema confinis Crotch	Sweet potato flea beetle
Sweet potato weevil (selection for resistance in controlled tests)	
Cylas formicarius elegantulus Summers	Sweet potato weevil
Others (no selection for resistance except in association with above groups)	
Conoderus amplicollis Gyllenhal	Gulf wireworm
Euzophera semifuneralis Walker	American plumborer
Melanotus communis Gyllenhal	A wireworm
Metriona spp	Tortoise beetles
Notoxus calcaratus Horn	A flower beetle
Peridroma saucia Hubner	Variegated cutworm
Scolytid	Ambrosia beetle
Typophorus nigritus viridicyaneus Crotch	Sweet potato leaf beetle

for flowering and seedset, the population had a high frequency of resistance to WDS. Fifty of 485 seedlings tested had resistance superior to variety Centennial and as good as L3-64, the best line identified in prior tests. We attribute this high frequency of resistance to the much wider gene base represented in population C than represented in other US breeding programs at that time. This marked the beginning of our cooperative efforts to develop insect resistant lines for use in cultivar development.

MASS SELECTION FOR WDS RESISTANCE

After initial successes we intensified our efforts and initiated a recurrent selection program with no selection applied except for soil insect resistances. A comparative test was conducted using remnant seed of C/4 as the control to represent the initiating population and a random sample of open-pollinated seed from resistant plants after three cycles of selection (Cuthbert and Jones 1972). The percentage of clones with acceptable levels of resistance had increased from 10 to 31%. In addition, 5% of the seedlings from the selected population had higher levels of resistance than found in the control population. Thus, in only three generations of selection we had

markedly increased not only the frequency of resistances but the levels of resistance as well. Studies of associations with other traits indicated that genetic control of resistance was generally independent of that for other desirable traits (Jones and Cuthbert 1973).

Two insect-resistant breeding lines (W-13 and W-178) were released to other breeders in 1975 by Jones, Dukes and Cuthbert. These lines also had other useful characters such as resistances to rootknot nematodes and diseases, orange flesh, and good flowering and seedset. The insect resistance of W-13 was shown to be more effective than the most commonly recommended chemicals in reducing insect injury to roots (Cuthbert and Jones 1978). Even an intermediate level of resistance gave as good control as the chemical applied to a highly susceptible cultivar.

COMBINING WDS RESISTANCE WITH OTHER TRAITS

Insect resistant selections from this early work were used in combination with plants from other sources to initiate a new mass selection population labeled 'I'. A sequential type of selection has been followed in that population in order to combine the WDS resistance with all the other necessary traits for a successful cultivar. Progress toward that goal has been very encouraging (Jones [illegible] 1976). That population, now in its tenth selection cycle, has high frequencies and levels of resistances to the soil insects, nematodes, and diseases, along with orange flesh, good storage and bedding traits and good cultural and culinary qualities. However, no line has yet been released that is acceptable in all respects for the US sweet potato industry.

HERITABILITY AND MECHANISMS OF WDS RESISTANCE

Heritability for WDS resistance in sweet potato has been estimated as 0.37 ± 0.11 (Jones [illegible] 1979) when measured by the same indexing procedures as used in earlier work. Work by Cuthbert and Davis (1971) suggested that a major factor for WDS resistance was located in the skin but that factor was not identified. To date we know very little more regarding the mechanism of resistance involved. Thus, our selection success through the years has been made in spite of very limited basic information. Since we knew neither the mechanism of resistance nor the genetic control of that resistance, our techniques could be described as rather crude. Yet, the mass selection techniques worked admirably.

PROGRESS AND FUTURE NEEDS

To maintain the momentum of selection advance for WDS resistance attained to date it will probably be necessary to improve our techniques in the future. We need better definitions of the mechanisms, genetic and physiological, involved and we need to attain more uniform insect infestations (evaluations) to reduce the effects of escapes. Recent efforts have been devoted to these problems and we can now artificially infest with [illegible] LeConte eggs in small plot tests (Schalk [illegible] 1979).

Each year we select a limited number of clones that appear promising enough to warrant further study as potential cultivars or breeding lines. One measure of our success in selecting for WDS resistance is therefore the

Table 2. Progress in advanced sweet potato selections for resistance to the WDS[z] complex of soil insects, 1974-1979

Resistance level	Year						Total no. lines	Percent of lines
	1974	1975	1976	1977	1978	1979[y]		
	(percent of lines)							
Highly resistant	21	11	19	20	31	19	31	21
Resistant	25	44	33	56	46	46	62	41
Intermediate	43	17	37	20	23	27	43	29
Susceptible	11	28	11	4	0	8	14	9
Total no. lines	28	18	27	25	26	26	150	100

[z]WDS = wireworm-*Diabrotica*-*Systena*
[y]Relaxed selection for WDS resistance to allow selection for soilrot resistance which is from WDS susceptible sources

ıprovement in our advanced selections for that trait (Table 2). From 1974) 1979 we have increased the percentage of our advanced lines with resi t- ıce to WDS from about 45-50% to about 70-75%. In 1979 we reduced selection ı insect resistance a little to allow more selection pressure for high ield and resistance to soilrot caused by *Streptomyces ipomoea* (Person and ırtin) Waksm and Henrici. The soilrot resistance was acquired from insect- ısceptible lines, thus the frequency of insect-resistant lines saved was ıduced. Over the six-year period we have made 150 advanced selections ıd 62% of those have had WDS resistance.

Another measure of our progress would be to look at some of our more ıcent WDS-resistant selections and see what their other attributes are able 3). Obviously, the WDS resistance is occurring in lines with many ıher desirable combinations of traits. Recently six breeding lines, W-71, 115, W-119, W-125, W-149 and W-154, with good combinations of insect sistance, disease resistances, culinary qualities, production traits and owering traits were released (Jones *et al* 1980). Apparently our selection ntinues to be favorable and we can expect to meet our goal of a WDS resist- t cultivar in the near future. (For Table 3, see p. 336)

Table 3. Character combinations[z] in recent WDS resistant sweet potato selections

Entry	Internal cork[y]	*Fusarium* wilt[x]	Southern rootknot[w]	Sclerotial blight[v]	WDS[u]	Flea beetle[t]	White grub[s]	Weevil[r]	Yield[q]	Baking index[p]	Canning index[p]
W-71	R	HR	R	LS	HR	R	I	R	80	96	-
W-99	R	I	R	IS	R	R	I	I	127	85	112
W-115	R	R	R	IS	R	HR	I-R	R	133	111	94
W-119	R	HR	HR	IS	HR	R	R	R	101	112	105
W-125	R	R	R	IS	R	HR	R	I-R	119	102	105
W-138	-	I-R	HR	LS	R	R	R	S	106	92	-
W-149	-	HR	HR	IS	R	R	I-R	R	121	104	107
W-151	-	I-R	R	LS	R	I	R	I	102	102	106
W-152	-	I-R	HR	LS	R	R	R	I-R	166	98	111
W-154	-	R	HR	HS	R	R	R	I-R	133	82	-
W-155	-	HR	R	IS	R	R	I	S	105	68	-
Controls											
Jewel	R	HR	R	LS	S	R	S	S	100	100	100
Centennial	I	I	S	LS	S	R	S	S	-	-	-
Nemagold	S	S	HR	LS	R	I	S	-	-	-	-

[z]HR = highly resistant, R = resistant, I = intermediate resistance, I-R = intermediate side of resistance, S = susceptible

[y]Internal cork is a viral disease. The corky lesions develop in stored roots

[x]Also known as stemrot incited by *Fusarium oxysporum* f sp *batatas*

[w]*Meloidogyne incognita*

[v]Sclerotial blight incited by *Sclerotium rolfsii*. LS = lower susceptibility, IS = intermediate susceptibility, HS = highly susceptible

[u]The wireworm-*Diabrotica*-*Systena* complex of soil insects, see text

[t]*Chaetocnema confinis* larva

[s]*Plectris aliena*

[r]*Cylas formicarius elegantulus*. R = 65-70% control and I-R = 50-64% control compared to Centennial when averaged over 6 to 13 laboratory and field observations

[q]Relative to Jewel, average of 4 or 5 replicated tests over 2 years, except W-154 (2 tests, 1 year)

[p]Relative to Jewel. Data for entries with both baking and canning indexes were obtained by R. A. Baumgardner, Department of Horticulture, Clemson University, Clemson, SC

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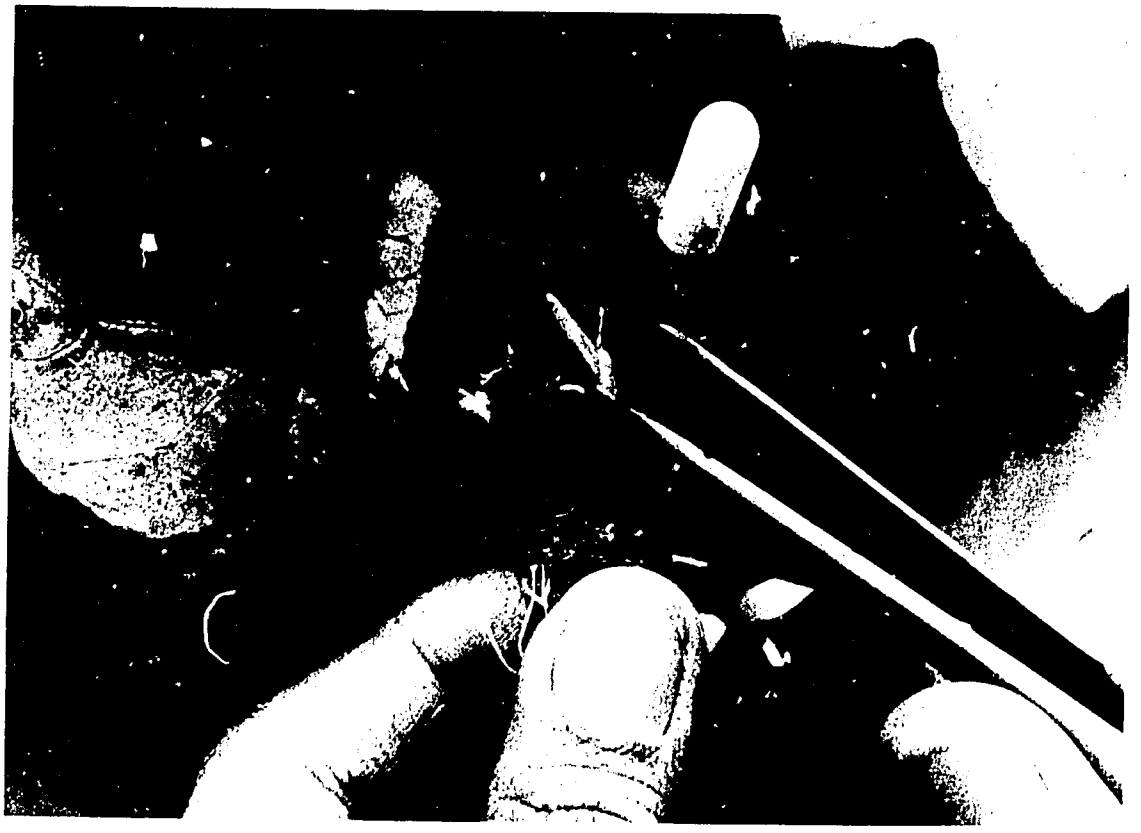

Hand-pollinating sweet potato flowers.

Breeding for Increased Protein Content in Sweet Potatoes

L. Li

Chiayi Agricultural Experiment Station, Taiwan Agricultural Research Institute, 2 Min-Cheng Rd, Chiayi 600, Taiwan

INTRODUCTION

In Taiwan more than 70% of sweet potatoes are used as feed for hogs and other animals. The planted hectareage in 1979 is about 10 million hectares and total production is about 150 million tons. The importance of sweet potatoes among field crops is next only to rice. However, protein content of sweet potato roots is low (about 3-4% dry basis) when compared to other dryland crops. For this reason, selection and breeding for high protein content and high yield potential for animal or human consumption is an extremely important task in our sweet potato research program. Studies on protein content of sweet potato began at Chiayi Agricultural Experiment Station, Taiwan Agricultural Research Institute (TARI) in 1973. The present study was designed to develop protein-rich and high yielding sweet potato entries, and to gather some basic information which may be useful to the breeding program.

MATERIALS AND METHODS

To determine the variation in protein content of sweet potato, 141 native varieties, 66 improved varieties and 93 foreign introductions were grown under similar cultural management in fall planting (Aug 1972). The protein content of roots and tops (40 cm long tips) was determined by the Kjeldahl method using the factor N x 6.25. Samples for protein analysis were obtained from composite samples of each plot. All protein determinations were made on duplicate samples on a dry basis (at 5% moisture).

Data on factors affecting protein content of sweet potatoes were obtained from four experiments.

Experiment 1 examined the effects of nitrogen (50 and 150 kg/ha), potassium (100 and 200 kg/ha) and plant spacing (100 cm x 20 cm and 100 cm x 30 cm) on protein content of two sweet potato varieties (Okinawa and Red Tuber Tail). This experiment involved 16 treatments which were tested in randomized block design with four replications. The seasonal effects on protein content were determined by evaluating the 16 treatments in spring (March), fall (August) and winter (October) plantings. A composite sample of roots and tops from four replications of each treatment was analyzed from each experiment.

Experiment 2 measured the effect of different years on protein content of 12 sweet potato varieties grown at Chiayi. The randomized block design with three replications was used. The sampling procedure was the same as described in Experiment 1.

In Experiment 3 the effects of location, variety, and their interaction were calculated by analyzing protein contents of ten varieties grown in fall

plantings at five locations in 1975. These tests were grown in a randomized block design with six replications. Homogeneity of error variances was tested by Bartlett test and a combined analysis of variance was carried out.

A parent-offspring study of 30 parent clones and their respective open-pollinated progeny (F_5 generation) were grown at two locations in one year.

Experiment 4 involved the inheritance of protein content and its relationship to root yield in sweet potatoes. A parent-offspring study of 30 parent clones and their respective open-pollinated progeny (F_5 generation) were grown at two locations in one year. The experimental design in each environment was a randomized block with three replicates and 12 plant plots. The traits examined in the correlation studies included: percentage crude protein content in roots; percentage of soluble solids in root juices; percentage dry matter of roots; root flesh color; fresh root yield; dry matter yield and fresh stems and leaves weight. The data were recorded on an individual plant per plot basis and statistical analysis was computed on a mean per plot basis. Statistical analyses were estimated in accordance with the procedures described by Jones (1969) and Falconer (1960).

The data on fresh root yield, percentage crude protein content and dry matter yield obtained from advanced trials of newly developed sweet potato entries grown at three locations over a period of two years were subjected to stability analysis. Nine entries and one variety of sweet potato in each environment were tested in a randomized block design with four replications. Protein analysis based on a sample of three to five roots selected at random from each plot were measured from each environment. Estimates of the stability parameters were obtained by methods similar to that outlined by Tai (1971). The amino acids composition of protein in the newly developed sweet potato entry C64-18 planted in the fall crop season was measured by means of an automatic amino acid analyzer by the Department of Agricultural Chemistry, TARI, and the Department of Animal Nutrition, Taiwan Livestock Research Institute (TLRI), respectively. It may give further information regarding the nutrition value of this newly developed sweet potato entry.

RESULTS AND DISCUSSION

Varietal differences of protein content

The frequency distributions of protein contents of the roots and the tops (40 cm long tips) of the different varieties are given in Figures 1 and 2, respectively. Protein content in roots of the various sweet potato varieties ranged from 1.3 to 10.1 , and in the tops from 12.1 to 25.7% on a dry weight basis. Most varieties contained between 4.4%-5.2% protein in roots and between 19.5 -20.5 protein in the tops. These results showed that large varietal differences in the protein content of sweet potatoes exist. The results agree with those reported by Purcell [illegible] (1972) in that the protein content of the various cultivars and selections ranged from 1.7% to 9.1%. AVRDC (1974) also screened 125 sweet potato varieties and indicated protein contents in roots ranging from 2.2 to 9.2 on a dry basis.

The average protein content in roots of native varieties was 4.4%, ranging from 1.3 to 7.2 , and that of improved varieties was 4.7%, ranging from 2.5 to 8.0 , while in the foreign introductions the mean value was 5.4 , ranging from 1.9 to 10.1%. The foreign introductions had more protein

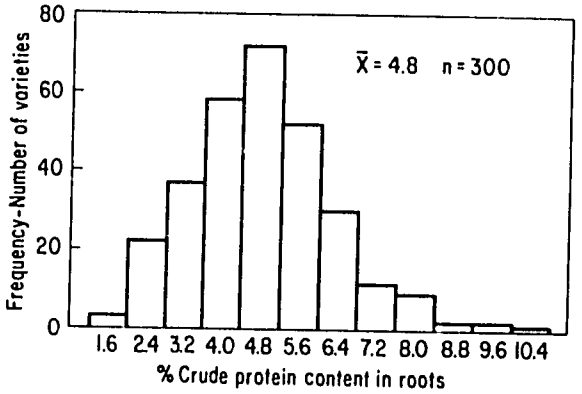

Figure 1. Frequency distribution of % crude protein content of roots in the sweet potato varieties in fall planting

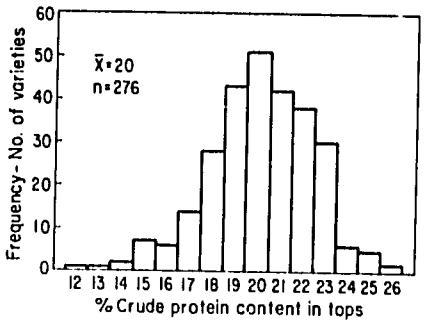

Figure 2. Frequency distribution of % crude protein content of the tops in the sweet potato varieties in fall planting

and wider variation than the native and improved varieties. This showed that utilization of foreign introductions should be very effective for the improvement of protein content of sweet potato. The variation of protein content in the tops was large in native varieties (12.1%-25.7%) and in foreign introductions (13.2%-25.3%), but small in improved varieties (15.4%-23.3%).

From this study, it seems clear that varieties vary to a considerable extent in their protein levels and that it should be possible through breeding programs to select new varieties for both high yield and high protein. These results are in agreement with those reported by Purcell *et al* (1972).

Environmental influence on protein content

The protein contents of ten varieties grown at five locations, and of 12 varieties grown for two years at single location are given in Figures 3 and 4, respectively. The analysis of variance indicated that the differences in protein content of roots among varieties, locations and years were significant at the 1% level. Varieties grown in the Yunlin and Tainan areas generally had a higher protein content than when grown at the other locations. Porto Rico, an introduction from the United States, had the highest average protein content of roots. The average protein content of roots among varieties varied from 3.2% to 8.3%, among locations from 2.8% to 6.5%, and between the two years from 4.3% to 5.8%. The variety x location interaction was highly significant, indicating the importance of testing in different locations. There was no significant year x variety interaction for protein content of roots, indicating that varieties ranked similarly in each year.

The protein contents of two sweet potato varieties with each of two levels of nitrogen, potassium and plant spacings are given in Table 1.

Among the different crop seasons, highly significant differences in protein contents of roots and tops were found, varying with varieties and

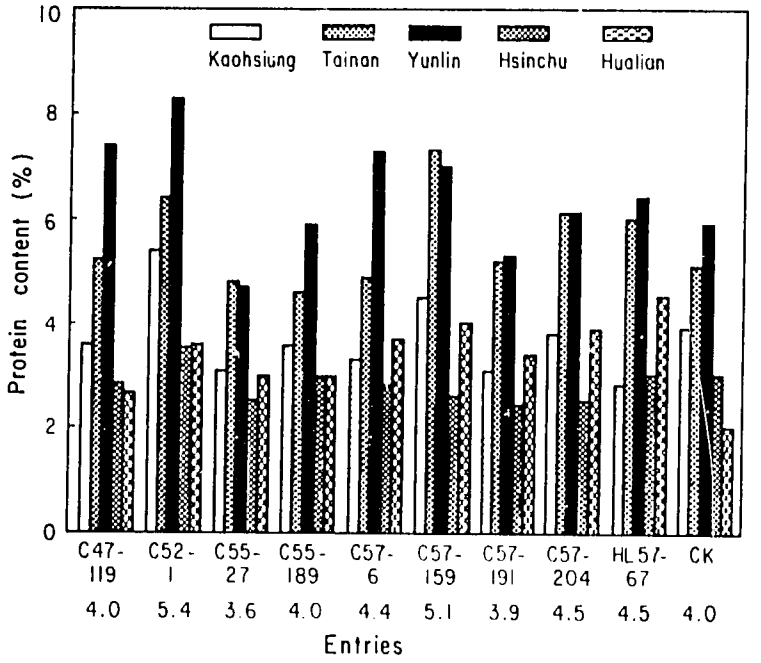

Figure 3. Percentage of crude protein content in roots of ten sweet potato entries grown in fall season at five locations. Values below the entries' names represent the mean of protein content in roots of each entry at five locations

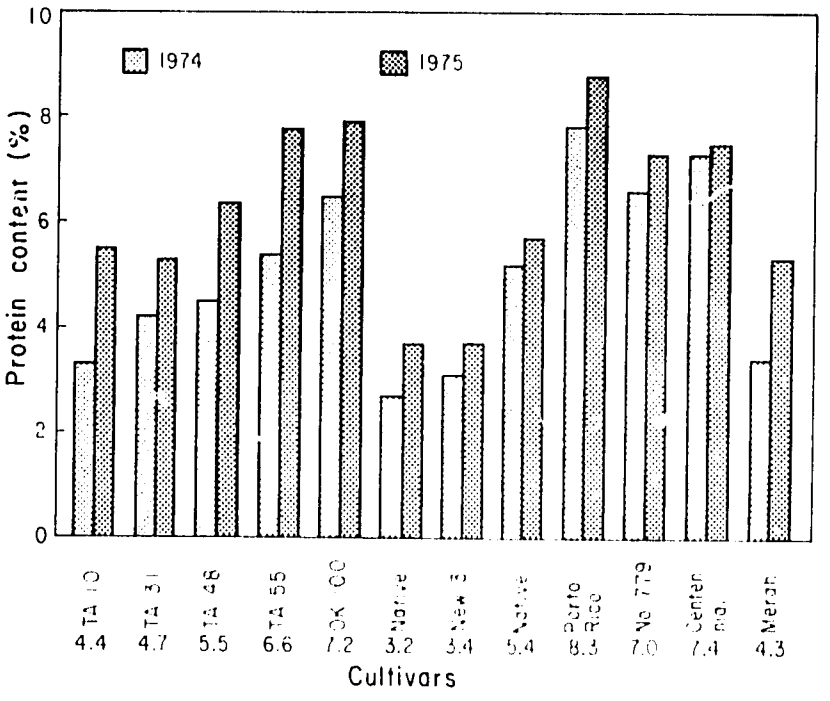

Figure 4. Percentage of crude protein content in roots of 12 sweet potato cultivars grown in fall season for two years. Values below the cultivars' names represent the mean protein content in roots of each cultivar for two years

Table 1. Effects of different varieties, plant spacing, N and K applications on protein content in roots and tops of sweet potato

Treatment	Protein content (% dry basis)							
	Fall[x]		Winter[y]		Spring[z]		Combined	
	roots	tops	roots	tops	roots	tops	roots	tops
Varieties								
Okinawa 100	7.5	18.8	6.0	17.3	3.6	17.8	5.7	18.0
Red Tuber Tail	4.6	19.4	3.9	19.6	3.1	16.2	3.9	18.4
N applied								
50 kg/ha	5.5	18.1	4.4	17.7	3.0	15.4	4.3	17.1
150	6.6	20.0	5.5	19.2	3.8	18.6	5.3	19.3
K applied								
100 kg/ha	6.0	18.7	4.9	18.8	3.5	17.1	4.8	18.2
200	6.1	19.4	5.0	18.0	3.3	16.9	4.8	18.1
Plant spacing								
100 x 20 cm	6.2	19.2	4.9	18.1	3.4	17.3	4.8	18.2
100 x 20	5.9	18.9	5.0	18.9	3.3	16.7	4.7	18.2
LSD 5%	0.63	0.58	0.31	0.76	0.22	0.76	0.24	0.39
1%	0.85	0.77	0.41	1.01	0.29	1.02	0.32	0.53

[x]Planted 15 Aug 1973 and harvested 13 Jan 1974 (150 days)
[y]Planted 25 Oct 1973 and harvested 20 April 1974 (168 days)
[z]Planted 10 March 1974 and harvested 6 Aug 1974 (150 days)

nitrogen levels. No effect on protein content was found to result from using different levels of potassium and different plant spacings. Protein content of the roots was increased from 4.3% to 5.3% by applications of 50 and 150 kg/ha of nitrogen, respectively. The protein content of the tops was likewise increased from 17.1 to 19.3%, respectively. Differences in protein content of roots and tops at different crop seasons were also highly significant. The protein content in roots at different crop seasons varied from 3.4% to 6.1% and that in tops ranged from 17% to 19.1%. Protein contents in the fall and winter plantings were significantly higher than in the spring planting. The differences in protein content between fall and winter plantings were not significant (Li 1975).

In addition, a field experiment was conducted at Chiayi AES farm during the 1974 fall season. Okinawa 100 and Red Tuber Tail were grown under five levels of nitrogen (0, 80, 160, 240 and 320 kg N/ha). There was a tendency for protein content of the roots to increase with the 160 kg N/ha application and to decrease dry matter of the heaviest N dosage applied (Li 1975). Most of our results agree with those reported by Constantin *et al* (1974) in that increasing N levels up to 100.9 kg N/ha resulted in a linear increase in protein content of sweet potatoes.

Differences in protein content at two root sizes in a single hill were not significant (5.2% for large roots above 300 g, and 5.4% for small roots below 160 g). It was found that protein content was not uniformly distributed within the root. Concentration was highest at the stem end of the root.

There was no significant difference between the protein content of the middle portion and that of the end of the root opposite to the stem. The range of protein contents in the three positions varied from 4.8% to 5.7%. Variation of protein content in roots from an individual hill within varieties is relatively large (5.3% to 6.5%). Li (1975) attributed these large variations to various environmental and developmental factors.

Inheritance of protein content and correlation studies

Separation of the genetic components of variance estimates into additive (σ^2A), and additive x additive (σ^2AA), and non-additive components is shown in Table 2.

The combined data showed that a large portion of the phenotypic variance of protein content was accounted for by the genetic component. The value of the genetic component was 73% (σ^2_G/σ^2_P = 0.326/0.449 = 0.73). The additive component of genetic variance was more important than the non-additive part for protein content of roots (σ^2_A + 1/2 σ^2AA)/σ^2_G = 0.257/0.326 = 0.79; (1/2 σ^2AA + non-additive)/σ^2_G = 0.69/0.326 = 0.21 (Li 1977). Estimates of heritability for protein content was 57%. No estimate of protein heritability in sweet potatoes could be found in the literature to compare with the value obtained in the present study. However, our estimate of protein h^2 was higher than those obtained for fiber content and other traits in sweet potatoes (Jones et al 1978). Predicted genetic advance from mass selection of the best 10 of the parents was 6.9% of the mean. The observed genetic advance obtained in offspring of the selected plants was 7.2%. The results indicate that a mass selection technique would be effective in improving this trait.

The phenotypic, genotypic and environmental correlations among the six traits were calculated and these are presented in Table 3.

There were small negative correlations, both phenotypic and genotypic, between protein content and fresh root yield and between dry matter yield of roots and protein content. This differs in magnitude from results reported by AVRDC (1976) where correlations of -0.30, -0.83*, -0.87** and 0.68 were observed between protein content and fresh root yield in four sweet potato trials. Li (1974) studied this in a variety trial involving a large number of varieties and found a small positive partial correlation of 0.07 between protein content and root yield.

Based on the results of this investigation, it is suggested that small negative correlations exist between protein content and yield in sweet potato, indicating that protein is not strongly negatively associated with root yield. Therefore, the chances of obtaining high percentage protein contents and high yield appear likely.

Stability analysis of protein content and yield

The results of the combined analysis of variance for root yield, protein content and dry matter yield indicated that the mean squares for entries (or varieties), environments and entries x environment interactions were all highly significant (Li 1979). The significance of the first order interaction showed that the relative performances of entries were quite different when the entries were grown under various different environments. This response was similar to that reported by Li (1975).

Table 2. Genetic components of variance, heritability, phenotypic variance, parent and offspring mean and percent of genetic advance for each location and combined locations

Locations	Partition of σ^2_G into genetic variance component			h^2	σ^2_P	Parent mean	Offspring mean	% of genetic advance (with 10% selection intensity)	
	σ^2_A	σ^2_{AA}	non-additive	(%)		(%)	(%)	predicted	observed
Shan Tzu Tin	0.34	0	0.12	55	0.62	5.13	5.43	7.41	7.18
Shui Yuan Ti	0.47	0	0	89	0.53	4.62	4.54	12.37	10.13
Combined	0.26	0	0.07	57	0.45	4.87	4.98	6.92	7.23

Table 3. Correlation coefficients between percent crude protein and other traits in sweet potato

Traits	correlated	Correlation coefficients		
		Phenotypic (r_p)	Genotypic (r_G)	Environmental (r_E)
% Crude protein	x fresh root wt	-0.30	-0.12	-0.56**
	x dry matter wt	-0.17	-0.13	-0.29
	x fresh top wt	-0.92**	-0.92**	-0.99**
	x root flesh color[z]	0.89**	0.35	-
	x % dry matter[z]	0.30	0.15	-
	x % soluble solids[z]	0.38**	0.17	-
Fresh root wt	x root flesh color[z,y]	-0.19	G1 = -0.93** G2 = -0.52**	-
	x % soluble solids[z]	-0.41*	-0.53**	-
	x % dry matter[z]	-0.42*	-0.75**	
% Soluble solids (Brix)	x root flesh color[z]	0.42*	0.46*	-
	x % dry matter[z]	0.96**	0.78**	-
Root flesh color	x % dry matter[z]	0.17	0.09	-

[z]Because of the high h^2 of % soluble solids in root juices, root flesh color and % dry matter of roots, r_E were not computed

[y]The two estimates of r_G were different at the 1% level of probability, they were not averaged

*,** Significant at the 5% and 1% levels, respectively

The estimates of the parameters $\hat{\alpha}$ and $\hat{\lambda}$ for the entries with mean root yield, protein content and dry matter yield of roots are shown in Table 4.

Table 4. Mean root yield, protein content and dry matter yield of roots and stability statistics in ten sweet potato entries

Entries	Fresh root yield			% Crude protein			Dry matter yield		
	$\bar{x}$ (t/ha)[a]	$\hat{\alpha}$	$\hat{\lambda}$	$\bar{x}$ (%)[a]	$\hat{\alpha}$	$\hat{\lambda}$	$\bar{x}$ (t/ha)[a]	$\hat{\alpha}$	$\hat{\lambda}$
C64-3	23.6 a	0.00	1.71	4.5 a	0.30	2.23	7.3 c	0.04	2.48[x]
C64-4	19.2 c	-0.23	2.71[x]	4.2 ab	-0.31	1.14	5.2 d	-0.14	2.93[x]
C64-7	33.6	0.53	12.94[x]	3.6 ef	-0.13	1.54	7.8 ab	0.32[y]	4.35[x]
C64-9	18.9 c	-0.33[y]	0.42	4.1 bc	-0.08	0.68	5.6 d	-0.31[y]	0.66
C64-44	23.9 a	-0.07	0.48[x]	4.1 bcd	-0.01	3.35	8.2 a	-0.13	5.95[x]
C64-18	27.9 b	-0.08	2.06	6.5	-0.14	2.41	7.7 bc	-0.09	1.55
C64-22	30.3	-0.39[y]	2.15	3.9 cde	0.17	0.16	8.6	-0.46[y]	3.01[x]
C64-27	29.1 b	0.38	6.52[x]	4.2 ab	0.27	1.53	7.7 bc	0.16	7.13[x]
C64-87	24.1	-0.11	1.35	3.8 de	0.17	3.53[x]	7.2 c	0.10	0.94
Tainung 57	25.5	0.14	5.12[x]	3.3 f	-0.23	0.83	7.9 ab	0.24	7.11[x]

[a]Any two means in each column not sharing the same letter or letters were significantly different at 5% level according to Duncan's multiple range test
[y]Indicate $\hat{\alpha}$ values significantly different from $\alpha = 0$ at the 5% level
[x]Indicate $\hat{\lambda}$ the F values for greater than the Fa values found from F-table with $n_1 = n-2$, $n_2 = n(m-1)(r-1)$ degrees of freedom at the 5% level of significance

The statistic $\hat{\alpha}$ is a measure of the linear response to environmental effect, and $\hat{\lambda}$ is observed for the deviation from the linear response. A perfectly stable variety has the values of $\hat{\alpha} = -1$, and $\hat{\lambda} = 1$, and a variety with average stability has the values of $\hat{\alpha} = 0$ and $\hat{\lambda} = 1$ (Tai 1971). The results indicated that C64-18 has the best average stability over all environments. This entry showed a significantly higher mean root yield and protein content than the check variety but the dry matter yield was the same as the check (Table 4). Therefore, C64-18 would have good general adaptability. The root yield of C64-18 ranged from 17.2 to 40.5 t/ha and protein content ranged from 5.6 to 9.2 . The Tainung 57 check plots yielded 13.2 to 38.8 t/ha and protein contents from 2.6 to 4.7 .

The essential amino acids of C64-18 are presented in Table 5. The entry C64-18 showed that it contains all kinds of essential amino acids. Total sulfur-containing amino acids and methionine are deficient compared to the FAO reference protein, but other amino acids are in excess. Similarly,

Table 5. The amounts of essential amino acid contents of the entry C64-18 as compared with that of the FAO reference protein

Source	g amino acids/100 g protein									Total sulfur	Protein (%)
	Ileu.	Leu.	Lys.	Met.	Phe.	Thr.	Val.	Tyr.	Try.		
A[a]	3.9	6.2	4.9	2.3	5.1	6.1	8.2	2.1	-	3.9	5.4
B[y]	5.1	7.9	4.3	1.1	6.3	5.1	4.9	3.8	-	3.0	7.3
FAO[x]	4.2	4.3	3.2	2.2	2.8	2.8	4.2	2.8	1.4	4.2	-

[a]Source: Department of Agricultural Chemistry, TARI (1977)
[y]Source: Department of Animal Nutrition, TLRI (1978)
[x]Source: Purcell et al 1972

Purcell *et al* (1972) reported the amino acids composition of six selected cultivars of sweet potatoes and found that total sulfur-containing amino acids and tryptophan were limited by comparison with the FAO reference protein, and that most other essential amino acids were in sufficient excess to supplement other plant proteins.

Selection for protein-rich sweet potato

Selection for high protein content was undertaken among the progenies and seedlings derived from hybridization and polycrossing. A total of 8500 seedlings were tested in the fall season of 1979, and 32 seedlings were selected at harvest 150 days after planting. These seedlings had better phenotypic characters than the check varieties. Average root yield varied from 0.68 to 2.4 kg per hill. The protein content of roots of these seedlings ranged from 5.5% to 9.5% on a dry basis. The dry matter content of these seedlings varied greatly, ranging from 21% to 32%. In the meantime, the 11 seedlings with highest dry matter content were also selected. The average root yield varied from 0.88 to 1.58 kg per hill. The dry matter content of roots ranged from 36% to 39%.

Most of the seedlings with high protein content tended to have orange root flesh color. The positive correlation observed between protein content and root flesh color was not significant at the genotypic level, but was significant at the phenotypic level (Table 3). The results seem to indicate that selection for high protein will give sweet potato with orange root flesh color.

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Potential for Increasing Nutrional Value of Sweet Potatoes

W. W. COLLINS[a] and W. M. WALTER, JR[b]

[a]Department of Horticultural Science, North Carolina State University, Raleigh, North Carolina 27650, USA

[b]US Department of Agriculture, Science and Education Administration, Agricultural Research, South Region, North Carolina State University

NUTRITIONAL ANALYSIS OF SWEET POTATOES

Sweet potato is undeniably one of the world's most important food crops. Its main importance as food has been the carbohydrate content or starch source as a dietary staple. However, sweet potato can also be a source of other nutritionally important dietary factors. The nutritional composition of sweet potatoes has been reported by Watt (1963), Edmond and Ammerman (1971) and by a new report prepared by the S-101 Regional Technical Research Committee (1980). Efforts to increase consumption of sweet potatoes must go hand in hand with efforts to educate consumers on nutritional benefits of eating sweet potatoes. A short discussion of the major nutritional components of the sweet potato follows.

Vitamins

Vitamin A: Sweet potatoes are an excellent source of provitamin A (carotene) which is converted into vitamin A (retinol) by the body (Table 1). Many factors affect the level of carotene in sweet potatoes but the varieties now being grown in the United States can easily supply the recommended dietary allowance (RDA) of this vitamin.

Vitamin B complex: A 113 g serving of sweet potatoes can supply 2-6% of the recommended dietary allowance of niacin, 3-5% of the riboflavin requirement and 1-7 of the thiamine requirement. The main source of these vitamins is usually meat or meat products. There seems to be little variation in concentrations of vitamins from the B complex in sweet potatoes; the range of those tested is extremely narrow.

Vitamin C (ascorbic acid): Sweet potatoes currently being grown differ in ascorbic acid content with cooking method. They can supply between 25% and 50 of the recommended dietary allowance of vitamin C depending on whether the roots are canned or baked (S-101 Technical Committee 1980).

Carbohydrates and energy

The major energy supply to the human body is carbohydrates. Most of the current sweet potato varieties grown in the United States contain 25-30% carbohydrates in the roots and approximately 98% of those carbohydrates are easily digestible. Vines are much lower in carbohydrate content. The tremendous yielding capacity of sweet potatoes (up to 85 t/ha in experimental plots according to Collins in 1980) makes it an important carbohydrate source for areas where populations depend mostly on carbohydrates for their food source. A 113 g serving of sweet potatoes per day can supply 5% of the energy requirements for a 23-50-year-old male.

Table 1. Nutritional analysis of canned sweet potatoes (variety Jewel)

	Root content	RDA[a]	% RDA supplied in 113 g sample
	(%)	(g)	
Solids	28.7		
Fats	0.3		
Protein	1.2	56	2.1
Carbohydrates	26.7		
Ash	0.5		
	(mg/100g)	(mg)	
Calcium	11	800	1.6
Iron	0.9	10	10.4
Sodium	20[b]	1000	2.3
Potassium	192[b]	2000	10.8
Thiamin	0.02	1.4	1.4
Riboflavin	0.03	1.6	1.9
Niacin	0.3	18	1.7
Vitamin C	10	45	25
	IU[c]/100g	IU	
Vitamin A	5345	5000	121

[a]Recommended dietary allowance
[b]From Lopez, Williams and Cooler (1980)
[c]International units

Minerals

The major inorganic elements necessary for body processes are sodium, potassium, calcium and iron. The recommended dietary allowances for calcium, iron, sodium, and potassium are 800, 10, 1000, and 2000 mg/day respectively.

A 113 g sample will supply 1.6% of the calcium RDA and 10.2% of the iron RDA (S-101 Technical Committee 1980). It will also supply 2.3% of the sodium and 10.8% of the potassium RDA (Lopez *et al* 1980).

Protein

The recommended dietary allowance for protein is 56 g for a 23-50-year-old-male. A 113 g serving of sweet potato roots can provide 3-4% of the RDA (S-101 Technical Committee 1980).

POTENTIAL FOR INCREASING NUTRITIONAL COMPONENTS IN SWEET POTATOES

Efforts to increase nutritional components in sweet potatoes can be limited to specific areas which show greatest promise for a significant increase. Sweet potato is already recognized as an important source of carbohydrates in many areas of the world. The total production of carbohydrates is directly linked to yield. Average yield in the United States in 1980 was 12 t/ha with a high of 18.5 t/ha. In experimental plots we regularly obtain selections with total yield well over 56 t/ha. In many areas where a carbo-

hydrate source can be exploited for human consumption and where yields are low, breeding and cultural efforts should be directed toward increasing yields.

Mineral content of sweet potatoes is very low in terms of the percentage of the RDA supplied by eating a 140-170 g serving. Sweet potato breeding efforts are unlikely to increase significantly the levels of calcium. However, there does appear to be a possibility that levels of iron and/or potassium might be significantly increased provided high-iron and high-potassium germplasm can be located. In those genotypes tested, there appears to be little variation from genotype to genotype but a large root-to-root within-genotype variation. At present, data are not extensive enough to predict results of efforts to increase iron and potassium levels.

Sweet potatoes are an excellent source of provitamin A. Since high-carotene types favored mostly in the Western Hemisphere were induced to bloom and set seed, the carotene content in the popular types has risen from 6.2 mg/100g to 17.4 mg/100g (Miller and Hernandez 1970). Since high-carotene germplasm is easily available and present in high levels in all breeding programs in the United States, this character does not appear to be a critical nutritional character at this time from a breeding standpoint. The problem associated with high-carotene types of sweet potatoes is personal preference of many populations for the low-carotene or non-carotene types. Overcoming this preference in situations in which this carotene source is needed will require an extensive educational effort.

Most vitamins in the B complex in sweet potatoes appear to be present in concentrations which vary little from genotype to genotype. The range of values reported is extremely narrow. Only a very small portion of the RDA for this complex can be supplied from sweet potatoes. An intense breeding effort could possibly double the concentration provided high concentration types are found for each of these vitamins. This would still supply only a small percentage of the RDA. It thus appears that an intense breeding effort in this area would be unwise.

This leaves two areas which we feel offer much potential for increase either through breeding or through cultural manipulation: vitamin C (ascorbic acid) and protein.

Vitamin C

Cultivars which are currently grown in the United States contain 11.4-12.5 mg/100g of ascorbic acid in the canned product, which supplies 25-28% of the RDA. In fresh tissue we have measured concentrations as high as 19 mg/100g (Table 2). Genotypes range from 0 mg/100g up to this value of 19 mg/100g (fresh weight basis). Although no breeding efforts have been undertaken to increase ascorbic acids content in this collection, it is conceivable to do so since variability exists between compatible types.

In addition, ascorbic acid content depends heavily on genotype, size, harvest date and curing/storage conditions (Junek and Sistrunk 1979). Vitamin C decreases with curing and storage, increases with late harvest, and is present in higher quantities in large roots and roots that have been baked.

Table 2. Evaluation of North Carolina breeding material for dry matter, percent protein (dry weight and fresh weight basis) and ascorbic acid

Genotype	dry matter	protein (dry wt)	protein (fresh wt)	Ascorbic acid (mg/100 gm fresh wt)
W-77	24	13.1	3.1	2.6
Rose Centennial	25	9.7	2.3	14.1
Leeland Bunch	22	9.4	2.1	10.5
Jewel	21	8.8	1.8	4.4
215	21	8.7	1.8	6.9
234	30	8.4	2.5	10.9
213 x 228-1	22	8.1	1.8	7.3
212	26	8.1	2.1	7.1
Redgold	22	8.0	1.8	4.7
Kandee	24	7.8	1.9	4.2
Centennial W-1	21	7.7	1.6	11.3
W-178	26	7.6	2.0	4.5
356	23	7.6	1.7	0.0
Nancy Hall	20	7.5	1.5	19.0
TI-1895	16	7.5	1.2	8.3
246	24	7.5	1.8	6.8
Painter	23	7.2	1.7	8.7
California Red	15	7.2	1.1	7.0
353	20	7.1	1.4	2.0
311(1)	23	7.0	1.6	16.2
Nemagold	20	7.0	1.4	9.8
Old Goldrush	24	6.9	1.7	6.9
241 x 213	29	6.9	2.0	-
284	24	6.8	1.6	6.1
White Jewel	18	6.5	1.2	4.1
PI 296116	20	6.4	1.3	1.7
273-0-42	23	6.2	1.4	7.5
Carver	19	6.1	1.2	4.7
241 x 273-1	25	6.1	1.5	8.8
Beauliff	22	5.9	1.3	4.2
299	30	5.9	1.8	14.8
Coastal Sweet	34	5.8	2.0	5.6
Carmex	21	5.6	1.2	-
TI 1894	22	5.6	1.2	4.2
Centennial	23	5.6	1.3	7.8
Southern Queen	23	5.5	1.3	17.4
W-13	18	5.4	1.0	7.4
White Star	23	5.4	1.2	4.8
Pelican Processor	20	4.7	0.9	5.9
311(2)	21	4.6	1.0	3.4
339	22	4.4	1.0	6.9
288	23	4.2	1.0	3.3
PI 399163	24	4.0	1.0	0.0
TI 1892	19	3.8	0.7	6.1
PI 344234	25	3.1	0.8	0.0

Protein

Protein is one of the most important chemical compounds involved in nutrition because of its involvement in so many of the basic processes and structures of the human body. Most people in the United States have an adequate intake of protein even if they are not meat or meat product eaters. Many vegetables contain adequate amounts of proteins.

However, there is now the distinct possibility that sweet potatoes will be used as a source of carbohydrate in the US for production of ethanol by microbial fermentation. Such a process would lead to highly concentrated sweet potato protein which would be available for incorporation into human food. In some parts of the world, sweet potatoes are consumed in large quantities and can be an important source of dietary protein; foods containing 5 utilizable balanced protein can sustain health if eaten in sufficient quantity. For these reasons, information on factors affecting crude protein in sweet potato plants as well as the quality and composition of that protein is important.

Several environmental factors have been shown to influence protein content in sweet potatoes. Purcell *et al* (1976), studying length of growing season, determined protein and dry matter contents for 16 sweet potato genotypes harvested on four different dates. They found that protein content decreased at the rate of 0.0067% per day after 102 growing days with dry matter decreasing by 0.233% per day after 102 growing days. However early harvest, while maximizing protein, would not offset the extra total protein obtained with later harvest because of increased yields.

Fertilization also affects crude protein in sweet potatoes. Purcell *et al* (unpublished) found that fertilizer had an effect on nitrogen content of the roots but did not change the non-protein N/N ratio (Table 3). An increase in the N content of the fertilizer caused a corresponding increase in N content in the harvested roots. Varying the amount of sulfur in the fertilizer had no effect on the composition of the roots. Apparently the soil used contained enough sulfur so that N uptake was not limited, or the ability to respond to sulfur fertilization does not occur in sweet potatoes as it does in some other crops (Rabufetti and Kamprath 1977). Potassium was also shown to have no effect on stored N in the root or on the NPN/N total ratio. These data suggest that the amount of protein in sweet potatoes could be increased by increasing N fertilizer; however, this would have to be managed very carefully since excess N at critical periods in the root enlargement phase of growth can decrease yields.

The effects of genotype on crude protein content are well described. Several studies have reported significant differences between genotypes (Purcell [illegible] 1972; Edmond and Ammerman 1971). Table 2 shows protein content of North Carolina breeding materials in a 1980 survey evaluation. There are clearly differences between these genotypes which can be used in a breeding program to enhance protein content.

Crosses are underway now between high protein and high dry matter types in an effort to develop cultivars ideal for fuel alcohol production as well as cultivars for fresh market production with enhanced protein content. It appears that an important by-product, or perhaps even the most important product, of a sweet potato fuel alcohol operation will be a high protein con-

Table 3. Effect of N and S on total N and non-protein-N/N ratio of sweet potatoes (variety Jewel)

Treatment[y]	% Total N[z]	NPN/N
N = 0, S = 0	0.78 a	0.25
N = 0, S = 71	0.82 a	0.24
N = 51, S = 0	1.04 b	0.24
N = 51, S = 71	0.92 ab	0.26
N = 101, S = 0	1.24 c	0.25
N = 101, S = 71	1.22 c	0.25

[y]Figures with the same superscript are not significantly different at the 0.01 level using Duncan's New Multiple Range Test
[z]Treatments included 168 kg K/ha and 40 kg P/ha

Table 4. Dry matter, fermentation alcohol yield, and protein yield in fermentation residue of five sweet potato cultivars

Cultivar	% dry matter	Alcohol yield (ml/kg)	% protein in residue
Centennial	25.9	94	30.1
Pelican Processor	26.7	118	32.5
Rojo Blanco	24.9	107	39.3
Whitestar	26.4	113	33.6
Vogel White	28.2	126	26.6

centrate extracted from the residue. This concentrate is suitable for human consumption. Shown in Table 4 are five cultivars which we have so far studied in connection with alcohol yield. Although the dry matter in these cultivars is 10-15 less than some of the highest reported, the protein content in the residue is exceptionally high. Using higher dry matter types should increase this percentage even more.

The effect of genotype x environment interactions in sweet potato protein determinations was investigated in a study of six sweet potato genotypes grown at six locations for three years (eighteen environments). Protein content (reported on dry weight basis) varied tremendously during this period The analysis of variance for this study is shown in Table 5.

Protein quality

Amino acid analyses of sweet potato protein are published. It has been shown by Purcell [illegible] (1972) to be of good nutritional quality but marginal in lysine and deficient in total sulfur in comparison to FAO protein. It has also been shown to be deficient in tryptophan in terms of FAO standards

Table 5. Analysis of variance of protein genotype x environment interaction study

Source	d.f.	Significance
Genotype	5	**
Environment	71	**
Years	2	**
Locations	5	**
Years x Locations	10	**
Rep (Year x Loc)	54	**
Genotype x Environment	85	**
Year x Genotype	10	ns
Loc x Genotype	25	**
Year x Loc x Gen	50	**

**Significant at 1% level
ns = not significant

although some cultivars contain more tryptophan than the FAO minimum (Splittstoesser and Martin 1975). However, no measure of the protein efficiency ratio (PER) of sweet potato has been reported until now.

Walter and Catigliani (1981) extracted white protein (protein isolate) and a grayish-white powder which is the protein concentrate or chromoplast protein from washed sweet potato roots of varieties Jewel and Centennial. The essential amino acid patterns for this chromoplast protein and for white protein are compared to FAO protein in Table 6. The total sulfur appears to be better in this protein than in white protein for Jewel. Lysine scores in the chromo protein of both cultivars were higher than in the white protein, and exceeded the FAO value.

The PER-using rats was measured to determine the biological quality of sweet potato protein. The PER is the weight gain of the rats divided by protein consumed (under standardized conditions as described by the AOAC). In addition the NPR (net protein ratio) was also determined. NPR corrects for body maintenance protein requirements. One group of rats is fed a no-protein diet and the weight loss of this group then can be used to credit the test protein for its maintenance function.

Results are shown in Table 7 for white protein and for chromoplast protein. For white protein, both cultivars appear to be slightly better than casein but not statistically better. There is about 135 g weight gain over the 28-day period for 47 g protein consumed. For chromoplast protein, the PER is closer to casein and is not quite as good numerically as the white protein; however, there are no statistically significant differences.

NPR values are shown in Table 8. They are better than PER values, of course, and the white sweet potato protein may be slightly better than casein which indicates that sweet potato protein is of high nutritional quality.

Table 6. Comparison of essential amino acid patterns for chromoplast and white protein in Jewel and Centennial sweet potato roots to FAO protein

Amino acid[z]	Chromo		FAO	White	
	Jewel	Centennial		Jewel	Centennial
Threonine	5.77	5.67	4.0	6.43	6.39
Valine	7.83	7.68	5.0	7.90	7.89
Methionine (Total S)	2.26 (4.04)	2.10 (2.77)	(3.5)	2.03 (3.11)	1.84 (2.75)
Isoleucine	6.01	5.89	4.0	5.63	5.71
Leucine	9.64	8.95	7.0	7.40	7.44
Tyrosine	6.71	6.41	6.0	6.91	7.09
Phenylalanine	7.08	7.15		8.19	7.94
Lysine	7.03	6.43	5.5	5.16	5.21
Tryptophan	1.56	1.77	1.0	1.23	1.44

[z]g amino acid/16 g N

Table 7. White and chromoplast protein of Jewel and Centennial sweet potatoes compared to casein in rat weight gain studies

	PER	Corrected PER	Weight gain (g)	Protein consumed (g)
		'Chromoplast' protein		
Casein	2.73 ± 0.10	2.50 ± 0.09	109.5 ± 7.8	39.4 ± 2.53
Jewel	2.75 ± 0.09	2.52 ± 0.09	117.6 ± 11.3	43.1 ± 3.95
Centennial	2.82 ± 0.10	2.58 ± 0.10	122.2 ± 14.9	43.8 ± 4.45
		'White' protein		
Casein	2.81 ± 0.11	2.50	134.3 ± 11.7	47.8 ± 3.8
Jewel	2.91 ± 0.10	2.63 ± 0.09	138.9 ± 11.7	47.7 ± 2.9
Centennial	2.96 ± 0.07	2.64 ± 0.07	140.3 ± 12.4	47.3 ± 3.5

Table 8. PER and NPR values of Jewel and Centennial sweet potatoes compared to casein

	PER	NPR
Casein	2.81	3.95
Jewel	2.91	4.15
Centennial	2.96	4.20

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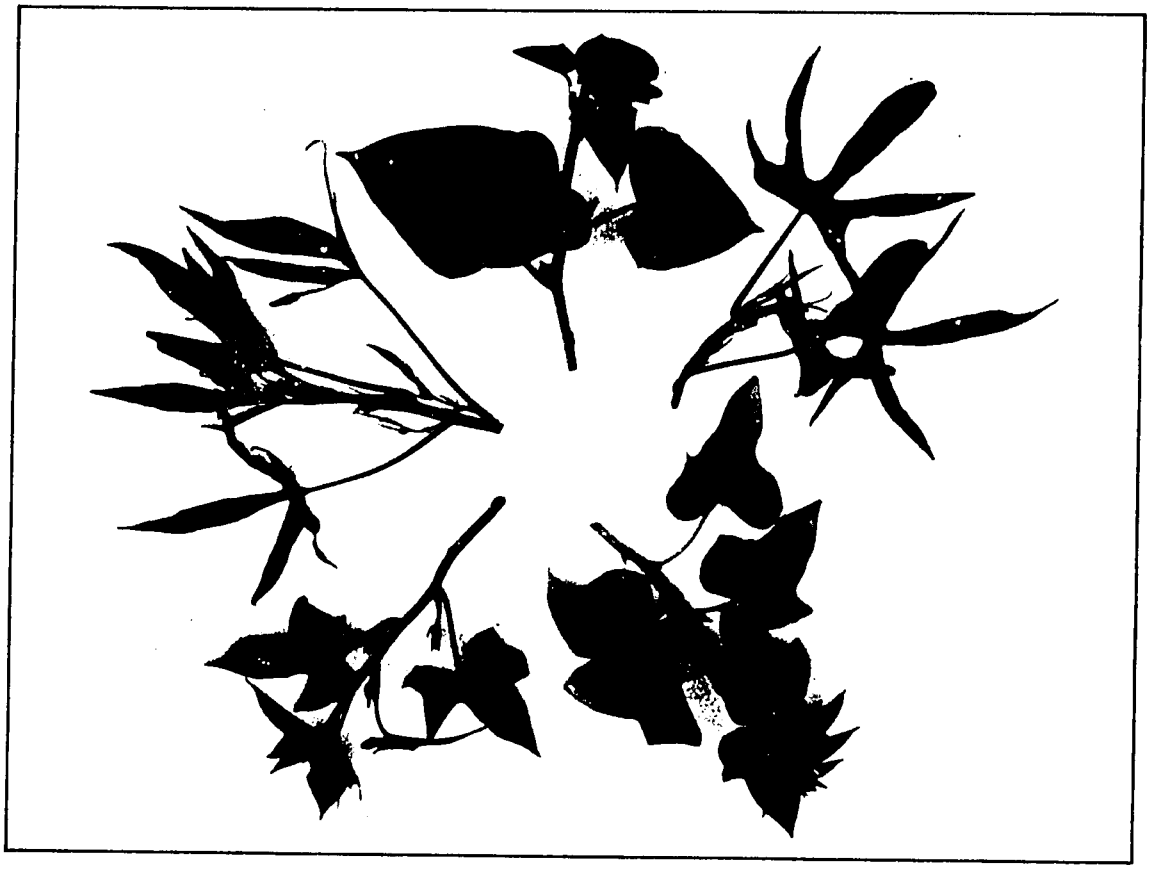

Sweet potato greens suitable for vegetable consumption.

General Discussion

(Session V)

BARTOLINI: The wild ancestors of sweet potato are not root bearing and you made mention that by gene mutation the present day sweet potato evolved and developed roots. How could you explain the presence of high carotene pigments in sweet potato? Has it developed by gene mutation also? I am confused; the sweet potato has no relation to the carrot.

NISHIYAMA: Several colors of skin and flesh of roots, which occasionally are somewhat thickened, were observed in different lines of hexaploid *trifida*.

HSIEH: Sweet potato has as many as 90 chromosomes. It seems difficult and laborious to make genome analysis by chromosome counting. What is the possibility of using electrophoretic isozyme patterns to analyze the genome in sweet potato?

NISHIYAMA: Genome analysis is primarily based upon chromosome homology and chromosome pairing in hybrids. Isozyme pattern analysis can support the result of genome analysis.

JONES: Though Dr Nishiyama and I have different opinions regarding phylogenetic relationships of sweet potato and its relatives, I would like to commend the Japanese for their progress in this area. I would like to correct one apparent misinterpretation of my work. I have not reported 2X and 4X cultivated genome A. I did suggest however that one or more of the three genomes of *I. batatas* may be genome A.

NISHIYAMA: Based on the genome analysis reported in the present paper, sweet potato and its relatives are autoploids with the duplication of genome B. Cytological difference between genome B and A is not yet observed because hybrids with A and B genomes have not yet been obtained.

OKA: What is the present status of genetic resources conservation in the sweet potato?

VILLAREAL: The International Board for Plant Genetic Resources working group on the genetic resources of sweet potato expressed great concern over the narrow genetic base of existing collections of sweet potato with its closely allied species. The working group recommended to the board to remedy this situation through: (1) collecting activities in the center of origin, (2) collecting in the secondary centers of variation and (3) establishment of repositories to hold these global collections. As far as we know, IBPGR approved these recommendations.

ANONYMOUS: The compatibility-incompatibility relationship of *I. batatas* seems to be similar to a plant-parasite relationship, whose mechanism is assumed to be the combination of a protein in a plant and a specific protein in the parasite. Do you think that such a mechanism is also applicable to the compatibility and incompatibility relationship in *I. batatas?*

MARTIN: Studies of the physiological basis of self-incompatibility in other

crops implicate proteins as the substances involved in the recognition process and selective mechanism by which some pollen grains are stimulated to germinate and others are inhibited. This occurs in *Brassica*, which has the same system of genetic control of incompatibility as *Ipomoea*. It is rational to suppose that the physiological control is the same, but there is no evidence or investigation concerning this question.

OKA: Is self-incompatibility partial in some cases? What is the magnitude of sterility which is independent of self-incompatibility? Which is more pronounced, self- or cross-incompatibility.

MARTIN: I believe incompatibility is partial at times. This is expressed as germination of some and inhibition of germination of other pollen grains. This is distinguished from complete compatibility only with difficulty, by examining stigmas after pollen action. Self- and cross-incompatibility are the same phenomenon, and thus of equal strength. In any particular cross, either incompatibility of sterility could be the factor limiting reproduction. Some sterility is always present.

ANONYMOUS: With regard to post-fertilization sterility, do you have any information as to the cause of the phenomenon?

MARTIN: Poor seed production in fertile crosses can be associated with damage by fungi and insects. Some of the remaining sterility is assumed to be due to genic imbalance expressed in poor embryo or seed development.

VILLAREAL: Your yields are very impressive! Are those marketable? What is the crop duration? Soil fertility? Did you use any special cultural practices to obtain those yields?

MEYNHARDT: Yes, they are marketable yields obtained from a five-month crop. Basic NPK fertilizer is usually applied, followed up by one or more N top dressings. Results indicate that in the summer rainfall production areas, sweet potato yields in South Africa react favorably to N fertilizer. Good farming practices, which included land preparation, use of fertilizers, pest control, and especially the use of disease-free planting materials, were adapted to obtain the high yields I reported.

HSIEH: You mentioned that a yellow leaf is one of your objectives in breeding for sweet potato tips as vegetables. However, according to Professor Lu of the Department of Economics, Shieh-Chien College in Taipei, cooked yellow leaves have poor color which affects the appetite of consumers. Therefore yellow leaves seem undesirable. What do you think about that?

VILLAREAL: So far there is only one yellow-leafed sweet potato variety that is available for tasting which unfortunately becomes discolored upon cooking We think home economists in developing countries can find a suitable way of cooking that minimizes this discoloration. Meanwhile, we will continue to search for other yellow and purplish leaves that can retain their color upon cooking.

ANONYMOUS: You have edible *Ipomoea* species such as *I. aquatica*. Do you think that the quality of this plant can be used as a basis for breeding *I. batatas* as a vegetable?

VILLAREAL: Although *I. aquatica* has tender stems and leaves, its flavor and eating quality are vastly different from sweet potato. We are thinking of sweet potato tips as another distinct leafy vegetable.

ANONYMOUS: Do you think that visible symptoms such as brown spot are the result of resistant action of sweet potato to infection by internal cork virus?

HAMMETT: Yes.

VILLAREAL: What breeding techniques do you advise Asian plant breeders to use in their programs?

JONES: The mass selection technique applied to populations to develop improved breeding lines with favorable combinations of desirable types. The use of polycross nurseries of limited size so that each time a new line is added some lines must be dropped thus forcing change with time.

ANONYMOUS: Were the sweet potato protein concentrates which you used for feeding experiments cooked or not? Do they contain any trypsin inhibitor activity?

COLLINS: Yes, they have been heated several times during the extractive procedure which effectively cooked them. They would therefore not show any trypsin inhibitor activity.

YANG: I am interested in your sweet potato sample with 7% lysine. Would you please give more detail about it?

COLLINS: Chromoplast protein was analyzed and lysine content was found to be 7.03 g/16g nitrogen in Jewel and 7.15 g in Centennial. This is much higher than casein, the white protein fraction, or the FAO standard.

ANONYMOUS: How did you prepare 'chromoprotein'? Please tell us the method of centrifugation more precisely. Is carotene mostly contained in this fraction?

COLLINS: Carotene was contained in the chromoplast protein fraction at the first purification. However it was then extracted with hexane-acetone until the filtrate was faintly yellow.

RAJAPAKSE: According to your table there are differences between varieties TIB 9 and TIS 2532 in terms of egg-laying and of larvae feeding. Could you explain the basis of these differences?

HAHN: The basis of this difference was not studied.

ANONYMOUS: In response to the infestation, bitter substances are produced. Do you think that the content of the substances produced is correlated with resistance to sweet potato weevil infestation?

HAHN: Bitter substances were not checked in relation to weevil resistance.

TALEKAR: I notice that you did not use statistics to show the differences in consumption of roots of resistant and susceptible cultivars or weevil hatching. In all other tables you have used statistics to show the differences.

Is this because, despite the seemingly large differences, the data were not statistically significant, I suspect thanks to large variations within replicates? This is a very very common problem in all sweet potato weevil resistance work.

HAHN: The paired comparison of the test was employed to test the difference and highly significant differences were observed.

TALEKAR: Since your data show that the mechanism of resistance is antibiosis, I would like to urge that IITA conduct a rat feeding study (if it has not already been done) to study the possible adverse effect of the antibiosis factors in the resistant material. This is just to make sure that such factors factors are not detrimental to human health. This has happened in some other crops especially in sorghum in the US and since IITA's sweet potato program is aimed as sweet potato for human consumption such work needs to be done even

TALEKAR: Since your data show that the mechanism of resistance is antibiosis, I would like to urge that IITA conduct a rat-feeding study (if it has not already been done) to study the possible adverse effect of the antibiosis factors in the resistant material. This is just to make sure that such factors are not detrimental to human health. This has happened in some other crops especially in sorghum in the US and since IITA's sweet potato program is aimed as sweet potato for human consumption such work needs to be done even before these resistant parents are used in breeding programs.

HAHN: This point became very important because weevil resistance appeared to be due to chemical antibiosis and because vegetative storage roots are used as food and feed. This aspect will be studied.

TALEKAR: How many roots per cultivar are used to study egg-laying activity on susceptible and resistant cultivars?

HAHN: Four randomly chosen storage roots and three replications within a tuberous root were used for oviposition tests for each cultivar.

TALEKAR: In view of the fact that distribution of many chemical constituents in sweet potato roots varies greatly within each cultivar from plant to plant, within each plant from root to root, and even within a single root from one section to the other, do you think the technique of confining weevils on single roots is useful in the long term? Besides host plant variation there is the problem of insect behavior which most likely will not be identical in the lab study and field study.

HAHN: Variation of chemical constituents between plants and storage roots and within a storage root was taken into account. For each cultivar random selection of plants, storage roots and test sites on the surface of storage roots roots was made to minimize experimental error.

The screening procedure for weevil resistance is first to screen sweet potato breeding clones in the field and then to confirm the resistance in the laboratory.

TALEKAR: Do the cultivars that show less damage in the laboratory bioassay also show less damage to the roots in the field?

HAHN: Yes.

LIN: Did you find any biotype of SPW in your resistant cultivars? What's the frequency and reproductive rate of the biotype in the weevil population? We already know that insects may mutate or evolve to forms that are virulent against previously resistant cultivars.

HAHN: Variation of weevils within *Cylas puncticollis* has not been studied. However the source of resistance to *C. puncticollis* showed resistance to *C. formicarius* in the United States and Fiji, indicating the variation within a weevil species may not be a serious problem. This needs to be further studied,

VILLAREAL: How long does it take to show infestation of weevil in your sandwich-choice method of evaluating resistance to weevil?

HAHN: Seven to ten days.

VILLAREAL: How would the resistant selection in the lab perform in the field?

HAHN: The field results of resistance are very closely related to the laboratory results.

VILLAREAL: Did you conduct any rat-feeding experiments of your resistant materials? What would happen to a rat fed with these materials since you postulate antibiosis as the mechanism of resistance?

HAHN: No. We will conduct a rat-feeding experiment with the weevil resistant-cultivars.

ANONYMOUS: You indicated that the sandwich method could be used to detect cultivar differences in weevil preference. Does it also detect antibiosis? Is there a good source of antibiosis to use in a breeding program?

HAHN: The sandwich method is mainly used as a weevil preference test. However, it could be used to detect antibiosis if so designed by using one genotype alone. The weevil resistance of our genotypes appears to be due to antibiosis.

ANONYMOUS: In breeding sweet potato resistant to weevil, do you use manual crossing between resistant and susceptible or any other crossing techniques?

HAHN: Two approaches are used in crossing for breeding sweet potato weevil resistance: hand crosses between selected parent cultivars and open pollination of several selected parents in an isolate.

SESSION VI

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Sweet Potato Processing and By-Product Utilization in the Tropics

F.G. WINARNO

Food Technology Developement Center, Bogor Agricultural University, PO Box 61, Darmaga Campus, Indonesia

INTRODUCTION

Sweet potato, an inexpensive source of energy, carotene, ascorbic acid, niacin, riboflavin, thiamin and minerals, is the succulent tuberous root of *Ipomoea batatas* L. This is a slender, perennial, herbaceous vine and the only food plant belonging to the Convolvulaceae family of a relatively large group, the dicots. It is an ancient food plant of tropical America and the Pacific islands, and several varieties of sweet potato are now extensively cultivated in many parts of the world. The major producing countries are Japan, Indonesia, Brazil, Korea, China, India and Uganda, with their production ranging between one and four million tons per year. Substantial quantities are also produced by the Philippines, the USA, Malaysia and several other countries.

Sweet potato can be grown in well drained loamy soil which is rich in humus to provide a warm and moist environment to the root. In Indonesia where rice is the choice food crop, sweet potato is cultivated only on dry lands (annual rainfall 500-1000 mm), and is frequently intercropped with maize or grown between two rice seasons when enough water for irrigation is not available. The latter is harvested early (65 days) to allow sufficient sunshine for the sweet potato to attain full maturity. Most varieties are harvested in 70-90 days but high yielding varieties (HYVs) take 120 days to mature (Suryanta 1981). Though the average annual yield from three sweet potato cropping seasons is only 7.3 t/ha (Directorate of Food Crops 1979), moderate application of NPK fertilizer more than doubles the yield to 15 t/ha and the recently introduced HYVs promise a yield of 20-30 t/ha/year (Table 1 and 2). In Indonesia, where sweet potato farming is being linked with a transmigration and resettlement project, some 15 million hectares of dry lands are expected to be brought under root and plantation crop cultivation.

This paper briefly reviews the technologies and practices for the utilization of the sweet potato with emphasis on its use as food. While dealing with the processing and utilization of sweet potato, technologies developed in non-tropical advanced countries have also been examined in some detail for their possible application in the developing countries of the tropics.

NUTRITION AND UTILIZATION

The sweet potato provides more calories than the potato (113 vs 75/100 g). It is also an exceptionally rich source of vitamin A (100 g provide 7,100 IU, about two-and-a-half times the daily minimum requirement for adults) and with its appreciable quantities of ascorbic acid, thiamin, riboflavin, niacin, phosphorus, iron and calcium, the sweet potato, in combination with legumes, can form an ideal food to combat protein calorie malnutrition (PCM) which is so widespread in almost all developing countries.

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Table 1. Yield of HYVs of sweet potatoes in t/ha

Clone No.	MK 1977		MK 1978			MK 1979		MP 1979-80	Average yield
	Pacet	Jambegede	Muara	Kuningan	Yogya	Magawo	Kr Anyar	Sukamandi	
I 57	6.7	24.9	25.0	-	-	21.2	25.7	15.0	19.8
No. 6-2	-	-	19.4	26.0	46.4	25.3	43.1	18.0	29.7
No. 3-6	-	-	6.3	23.9	34.9	11.6	14.7	5.5	16.2
No. 22-2	-	-	16.3	21.2	38.0	16.0	18.1	11.4	20.2
No. 17-1	8.5	20.4	12.2	21.5	36.7	16.5	23.0	12.6	18.9
No. 17-5	6.7	22.6	13.8	30.8	36.8	19.0	22.4	7.6	20.0
No. 17-7	8.0	25.0	16.3	20.5	32.6	16.2	19.8	10.0	18.6
No. 20-9	4.2	20.6	18.7	-	-	13.6	22.7	11.1	15.2
No. 31-1	-	-	13.7	-	-	18.2	22.4	8.9	15.6
AIS 128	11.4	17.0	4.0	-	-	21.2	27.8	14.1	15.9
Local	11.5	9.3	8.0	23.3	33.5	14.8	21.8	8.3	16.3
No. 380	10.9	20.8	20.9	38.6	43.3	23.8	25.8	10.3	24.3

Source: Suryatna (1981)
MK = dry season; MP = food scarcity season

Table 2. Yield and characteristics of some yellow sweet potato varieties

Variety	Yield t/ha	Crop duration m	Starch content %	Vitamin C content mg	Carotene content mg	Taste
Daya	23.7	4	27	4	2.80	delicious
Gedang	22.3	4	-	4	8.11	sweet
No. 3-6	23.0	4	28	4	12.26	sweet
No. 6-2	27.0	4	28	4	6.14	sweet

Source: Suryatna (1981)

The composition of sweet potato and other common foods is shown in Table 3 (AVRDC 1976), that of common Indonesian sweet potato varieties in Table 4 (Hardjo 1952) and that of HYVs in Table 2 (Suryanta 1981).

In most developing countries, the sweet potato is consumed immediately after harvest without any intermediate storage. Sweet potato may be consumed after baking, boiling, steaming or frying; it may be candied with syrup, sliced into chips or pureed. During cooking, some starch is hydrolyzed to maltose and dextrins by beta amylase action. Sweet potato is sometimes sliced and dried in the sun, then ground into flour for baking bread and confectionery. In Indonesia, sun-dried chips are fried and packed in polyethylene for retail sale (Winarno *et al* 1980). In some African countries, boiled or roasted roots are pounded with peanuts to produce 'futali'.

Table 3. Composition of sweet potato and some common foods per 100 g

	Rice	Soybean	Mungbean	Sweet potato	Potato
Moisture (g)	13	8	11	70	67
Fiber (g)	0.5	18	1.1	0.3	0.1
Cal	354	325	320	113	75
Protein (g)	6.5	36.8	22.9	2.3	2.3
Fe (mg)	0.6	7.4	4.9	1.0	0.7
Ca (mg)	15	216	86	46	7
Vitamin A (IU)	0	20	70	7.10	0
Vitamin B1 (mg)	0.11	0.44	0.52	o.08	0.07
Vitamin B2 (mg)	0.04	0.31	0.29	0.05	0.04
Niacin (mg)	1.4	3.2	3.1	0.9	1.0
Vitamin C (mg)	0	0	0	20	7

Source: AVRDC (1976)

Table 4. Composition of some sweet potato varieties of Indonesia, %

	Porto Rico	Loma	Jarak	Bainum	Paris	Papaya	Tanjung kulit	Kuntul
Moisture	68.5	60.2	69.2	65.4	67.7	72.4	75.0	65.6
Dry matter	31.5	39.3	30.8	34.6	32.3	27.6	25.0	34.6
Protein	0.7	0.8	0.6	0.7	0.6	0.6	0.6	0.6
Ash	1.1	0.9	0.8	1.4	0.8	1.0	1.2	1.1
Fat	0.4	-	-	0.4	-	0.9	-	0.8
Fiber	-	0.8	1.0	0.7	1.0	0.9	0.9	0.4
Unknown matter	28.3	36.7	28.0	31.4	29.1	24.3	21.9	31.5
Flour	30.1	39.3	26.1	31.7	26.6	26.6	19.5	33.2

Source: Hardjo (1952)

Sweet potato leaves are also eaten in Indonesia and other countries of the region. The leaf is more nutritious than the root. It contains on a dry matter basis: starch (8%), sugar (4%), real protein (27%) and ash (10%). It also has 56 mg of carotene/100 g dry matter (Onwueme 1978). The respec-

tive per capita consumption of sweet potato and cassava in Indonesia is 43.95 g/d and 208.13 g/d, respectively providing 42 and 204 cal daily (Biro Pusat Statistik 1978). The sweet potato contributed only about 2% of the total calorie intake.

In the USA, about 60-70% of the sweet potato crop is consumed as human food in the form of fresh roots, or as canned, frozen or dehydrated foods and is used in a variety of products such as pie fillings, purees, candied pieces, souffles, baby foods and so on. In Japan, about half of the total crop is utilized for the production of starch for use in the textiles, paper, cosmetics, adhesives, glucose syrup and food manufacturing industries. During the production of food products or starch, the peels and other residues may be advantageously extracted for pectin or compounded with vine tops and leaves to serve as animal feed.

FRESH HANDLING, CURING AND STORAGE

Handling

The roots are usually allowed to remain in the ground for one week after cutting the top vine to facilitate the sweetening process. They are then carefully dug out, and partially sun-dried before marketing. Alternatively, after harvesting, sweet potatoes are graded as closely as possible and stored in crates stacked 3 cm apart and at least 10 cm off the floor and 15 cm away from the walls in a well ventilated storehouse.

Storage rots of sweet potatoes are caused by various fungi, some of which are carried by the roots from the field. Proper cleaning and disinfection of the storehouse and periodic elimination of infected roots is therefore important. Chloropicrin is the common fumigant used in the USA.

Excessive sprouting during storage results in reduced quality of the roots. Some plant growth regulators like isopropyl N-(3-chlorophenyl carbamate), in the trade called CIPC, and exposure to gamma radiation inhibit sprouting (Bramlage and Lipton 1965; Patterson 1957; Simon and Scott 1952).

Curing

Roots intended for storage are harvested a little later than normal and are cured to harden the skin and hasten the healing of any surface wounds. During storage, the weight of roots decreases due to biological processes like respiration and transpiration, sprouting and microbial activity. Booth (1974) reported that loss in weight in sweet potato after 113 days storage was 17% in the cured sample and 42% in the uncured one.

During curing and storage and to a greater extent during cooking, some root starch is converted into sugars and dextrins which improve the eating quality of sweet potato. Short chain saturated fatty acid content decreases and tetracosenoic acid content correspondingly increases (Boggess *et al* 1967). Sweet potatoes are also stored in pits between layers of wood ash, earth and straw (Wargiono 1960).

The traditional methods of curing and storage are typified by the Indian practice of spreading the root in the sun for one week, providing a suitable

waterproof cover during the night, and then storing in a well ventilated room with frequent inspections to elimate any unhealthy roots (Indian Council of Agricultural Research 1956).

In the USA, where the sweet potato processing industry is well developed, the common practice is to cure at about 30°C with a RH of 85-90% for seven days, and to extend the period up to 20 days if the sky is overcast, and to follow this by storage of cured roots at 13-16°C with RH of 85-90%.

Wang (1975) has also suggested curing conditions of 26.7-29.4°C with high RH for a period of 10-20 days, depending on local climate and on root variety. While low storage temperature, as in vogue in the USA, prevents the development of corky areas caused by an internal cork virus, it is far below the optimum for commercial practice in most developing countries in the tropics. An alternative approach to combat internal cork virus is thus called for, especially when the use of higher curing and storage temperature helps in reducing blackrot damage.

It may be advantageous to re-examine the traditional curing and storage practices with a view to upgrading them with inputs of modern science and technology.

PROCESSING

Canning

Considerable quantities of sweet potatoes, particularly orange types, are canned in the USA in several styles of packing. Examples are canned whole slices or puree, in syrup or water, using conventional canning methods and equipment. Since the chemical composition and texture of sweet potatoes varies widely according to cultivar, climatic and soil conditions, the degree of maturity and duration of storage after harvesting, canneries usually carry out their own inspection and standardization of the raw material. Freshly dug roots are preferred to cured and stored ones.

To pack fancy wholes, the canner is interested in 25-45 mm wide and 50-175 mm long roots. The essential processing steps are shown in Figure 1. Preheating (63°C, for eight minutes) drives out intercellular gases and helps in attaining a good can vacuum. In lye peeling, 10% lye solution and a temperature of 93-94°C for eight to ten minutes are commonly used though higher lye concentrations and temperatures are also used. The addition of surfactants aids peel removal.

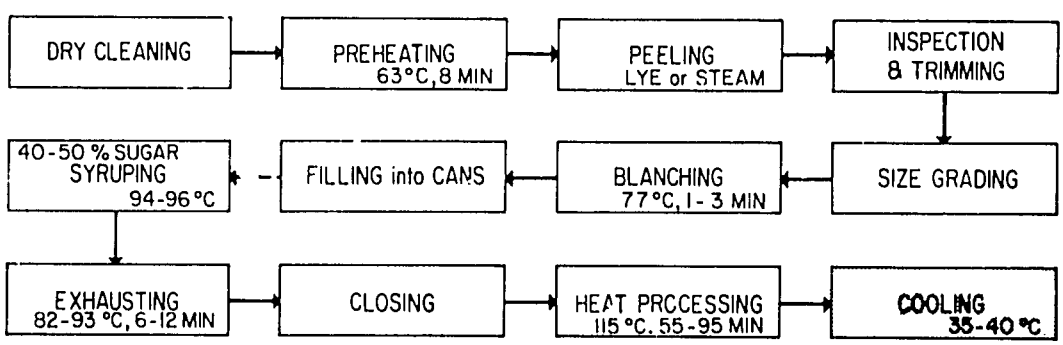

Figure 1. Canning of sweet potatoes

Steam peeling is a recent development which uses a steam temperature of 150°C and retention time between a few seconds and 1.5 minutes.

Discolored areas, fibrous ends and damaged parts are removed during inspection, trimming and sorting. After blanching, the material is immediately packed in cans and covered with syrup to prevent discoloration. Any holding is done under water to which a little citric acid has been added. The syrup should be brought to 94-96°C before filling (Edmond and Ammerman 1971).

Though canning is an established method of preserving food, the market for canned sweet potato is likely to be limited in the developing countries due to its high cost, mainly as a result of the cost of the can. Until alternative packaging technology is developed, canned roots can only be manufactured for export.

Chips, flakes and flour

Dehydration of fresh and precooked sweet potatoes by sun-drying has been practiced in the developing countries for a long time to produce chips and flour. Both white and colored varieties are suitable for sun-drying. The roots are cut in 2-3 mm slices, and submerged into boiling water for six minutes. Blanched or unblanched slices, with or without sodium metabisulphite treatment, are sun-dried to 60% moisture. The slices are now brittle and can be ground into flour. Both slices and flour remain in good condition for a long time if kept under dry conditions (Jackson and Mohamed 1969). A similar process, but using artificial drying was in use in the USA during the early twenties (Hard and Cokerham 1921).

In Indonesia, fresh roots are sometimes soaked in 8-10% salt solution for about one hour before cutting into chips and sun-drying. The brine treatment is reported to inhibit microbial growth during drying. The Food Technology Development Center, Bogor has developed an inexpensive manually operated chipper called Rasingko and a solar shelfdrier for cutting and drying of sweet potato and other roots (Namaken 1979).

The modern sweet potato dehydration practice, however, involves many more unit operations, some being common with the canning process (Spadaro and Patton 1961). The essential unit operations are shown in Figure 2. For chips, the peeled roots are rinsed to remove excess starch and after slicing are then deep fried and packed. To produce dehydrated flakes, thicker slices (13 mm) are cut, blanched and pureed. The puree (20% solids) is

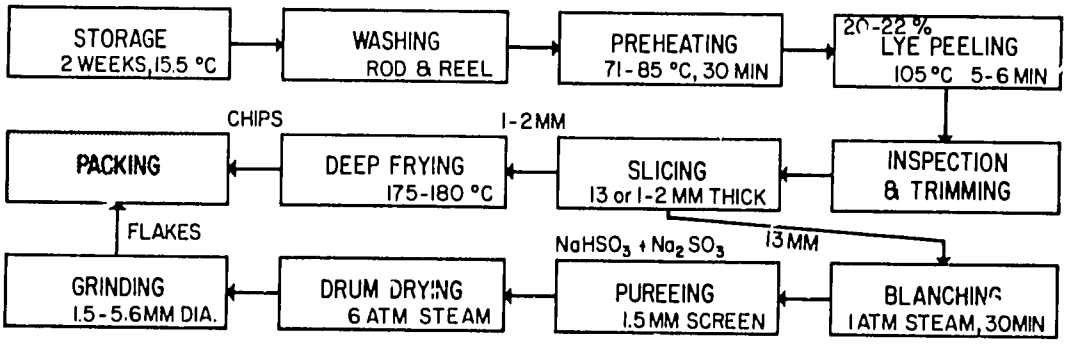

Figure 2. Dehydration of sweet potatoes

passed through steam-heated drums (0.13 mm apart; speed 2 rpm; retention time 20 sec; steam pressure 6 atm). The moisture content of the flakes is around 2-4%. The flakes are finally ground in a coconut grinder and packed.

The high sugar content of sweet potatoes causes chips to turn dark brown and give a burnt flavor when deep fat-fried. Wiley and Bouwkamp (1979) have developed a technique to extract sugars from sweet potatoes and other vegetables and fruits by liquid extraction before they are to be fried.

In India, sweet potato flour is produced by dehydration (usually sun-drying) and grinding of the peeled, sliced roots and is used as a supplement to cereal flours in bakery products, pancakes, puddings, and so on. It acts as a dough conditioner in bread manufacturing and as a stabilizer in ice-cream. It is also consumed in some food preparations along with peanut cake. Sweet potato flour can also be produced by spray drying or cabinet drying of the peeled sliced roots. The use of sweet potatoes in breadmaking was studied by Gore (1923) and more recently by Hamed *et al* (1973). The peeled and sliced roots were dried in an air oven at 60°C for ten to 12 hours and milled in a disc mill to produce flour. A metabisulphite treatment (dipping the sliced root in 0.5 sodium metabisulphite solution for two minutes) before drying produced flour of acceptable color.

Dehydration of sweet potato appears to have a great potential as a method of preserving food in developing countries. Since steam is the major energy input, countries having geothermal energy resources, as Indonesia and the Philippines do, can operate dehydration plants quite cheaply. In Indonesia, sweet potato is cultivated in the vicinity of some geothermal energy sources.

Starch

Sweet potato varieties which have a high starch content and light flesh are used for the manufacture of starch. The processing steps are similar to those for starch making from other roots except for color removal. In the USA, an experimental sweet potato starch plant was established in 1934 at Laurel, Mississippi and a commercial plant was set up at Clewiston, Florida in 1945. The plants, however, were closed down due to high production costs, poor quality of starch and low returns per acre of crop.

On the other hand, the Japanese small scale and cottage scale sweet potato starch industry is not only well organized but is able to face competition from other starches due to its ability to adapt to demand changes, its close personal relationships with its employees, its cooperative relationships with larger enterprises and users, and abundant cheap power. The ability to utilize all by-products, to provide cheaper unbleached grades to consumers where color has no consequence, and the ready market, further add to the economy of scale. The capacity of a Japanese starch plant is seldom higher than 10 t/day and it operates for only three months (October-December) per year, usually in close association with a cannery which takes roots unsuitable for starch production (Anon 1968).

The process for sweet potato starch production is kept alkaline throughout (pH 8.6) by using lime which flocculates the impurities and dissolves pigments. The tubers are ground in lime water and starch is separated from the pulp by washing over a series of screens. The starch

suspension is then bleached with sodium hypochlorite, if required, and centrifuged. Starch is stored wet in concrete tanks or dried to a moisture content of about 12% in a vacuum drier, pulverized and screened. The yield is 20-26%. A flow diagram of the process is shown in Figure 3. In the late sixties, the components of cost of production of starch in Japan were: raw material 70%, other materials 7.3%, labor 14.6%, other expenses (like interest depreciation and so on) 8.1%. The by-product returns contributed about 6% in the reduction of the cost of production. With wages, interest rates. raw material and other costs having gone up since then, the picture must have changed somewhat. The small part played by the wage bill in the total cost of production is however worth noting.

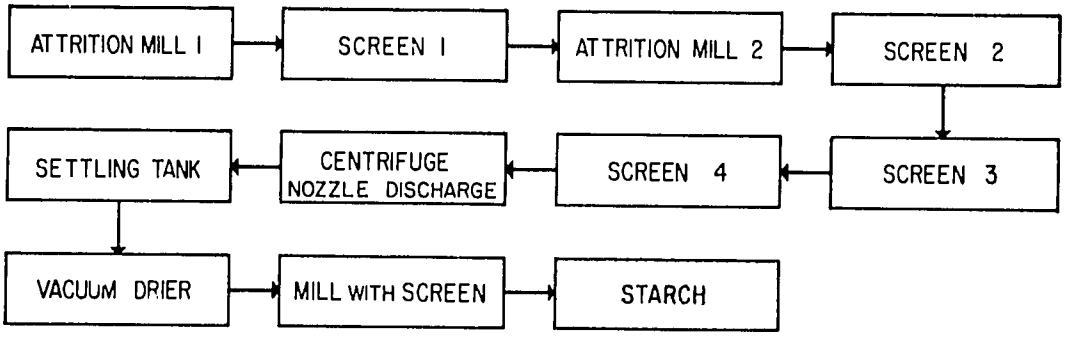

Figure 3. Sweet potato starch production

Sweet potato starch has no special character of its own to justify any price premium. Its properties lie intermediate between white potato starch and corn/cassava starch in terms of viscosity behavior and other characteristics.

Glucose

Sweet potato starch can be advantageously converted into glucose by acid or enzymic hydrolysis. While acid hydrolysis gives a better conversion, the enzymic hydrolysis product has better flavor and color (Santosa 1977). In acid hydrolysis dilute hydrochloric acid is added in an antoclove to a 35-40% suspension of starch in water (final acid concentration 0.015-0.02 N) and heated to 140-160°C for 15-20 minutes. The product is then neutralized, treated with active carbon, heated again and filtered hot through a centrifuge. Glucose crystallizes from the filtrate on cooling. Yield is 75-80%. Agra *et al* (1969) have reported satisfactory yields of starch by boiling a 13% suspension of sweet potato starch with 0.2 N hydrochloric acid for three hours.

In enzymic hydrolysis, the roots are cooked in water, pulped and saccharified by treatment with malt (0.2%) at 60°C. The solution is clarified and concentrated to a concentration of 70% solid content. The product is not as sweet as cane sugar and contains 30.1% water, 43.0% maltose, 7.0% sucrose and 14.0% dextrins (Dawson 1951).

ANIMAL FEED BY-PRODUCT UTILIZATION

Low grade sweet potatoes are utilized in the USA as a carbohydrate-rich feed for livestock, especially for pigs, after chopping and dehydration.

The dried material is equal to corn in total digestible nutrients but low in proteins. However if cottonseed meal is added to sweet potato meal, it performs satisfactorily as an animal feed. The average composition of dried sweet potato meal is: 90.2% dry matter; 4.9% protein; 0.9% fat; 3.3% fiber; 77.0% N-free extract; 4.1% minerals; 0.15% Ca and 0.14% P.

Considerable work has been done in the USA to evaluate sweet potato as an alternative to corn as an animal feed. Fleshy roots were found to be a satisfactory feed for horses, mules and hogs. Sweet potato meal was found to be 90% efficient as a feed for lactating dairy cows when compared to corn meal feed and could be substituted up to 25% as poultry feed. Since shredding or slicing was necessary to facilitate drying, several inexpensive machines were developed. Drying was carried out under natural and artificial conditions. However, sweet potatoes have not yet replaced corn as an animal feed in the USA to any appreciable degree, mainly due to high dehydration costs (Edmond 1971).

The vines serve as a nutritive and palatable green feed for cattle. The average vine yield in Madras, India is reported to vary from 9 to 33 t/ha, and when grown only for fodder during November-December, the yield can be up to 65-80 t/ha from three or four cuttings (Mudaliar 1950). The feeding value of vines is close to that of alfalfa. The dry vines have 90.7% dry matter; 16.6 protein; 19.1 fiber; 3.3% fat; 45.4% N-free extract; 10.2 minerals; 8.9 digestible protein and 51.7% total digestible nutrients (Sen 1949).

Bennett and Gieger (1940) and Hall [illegible] (1954) studied ensiling of sweet potato vines alone and in combination with molasses and roots. The sweet potato silage was found to be equal in performance to corn silage when fed to dairy cows.

ENRICHED PULP, YEAST, CAROTENE AND PECTIN

The possibility of developing products other than starch from sweet potatoes was investigated in the USA (Dawson 1951; Thurber 1951). The products are beta carotene, pectin, protein-enriched pulp and feed yeast. Both the liquid extract and pulp contain carotene which can be concentrated in air-dried material to 2000 ppm. The liquid extract is centrifuged to remove starch, acidified (pH 3.8) and heated to about 80°C to coagulate proteins. The coagulant is added to the pressed pulp which results in a feed containing 10-12 protein. Feed yeast can also be grown on fruit water utilizing the sugar content to get highly proteinaceous feed.

Sweet potato pectin is comparable to apple pectin in jelling properties. It is obtained as a by-product from the peel and trim wastes of starch manufacture and sweet potato canneries. The starch is solubilized by treatment with amylase and pectin from the residue. Carotene concentrates have also been prepared from carotene rich varieties. The commercial application of these developments is, however, not known.

ENERGY

Alcohol

Sweet potatoes, like other starch grains and roots, are a raw material

for fermentive production of industrial alcohol, lactic acid, acetone, butanol, vinegar and yeast. In Japan, raw roots and pressed juice are employed for the preparation of alcoholic beverages after saccharification with liquid 'koji'. Similar local wines are made in Africa and in other Asian countries. Currently, only relatively small quantities of food materials are used in the production of alcohol and other fermentation products. But with the recent accent on 'energy farming' large volumes of food materials, grains, tubers and sugarcane, are planned to be used for alcohol production to an extent that the very availability of food at reasonable prices is threatened.

For the first time since agriculture began, the world is faced with a dangerous diversion of food resources and it has come at a time when the world food output is losing momentum, food prices are increasing and malnutrition and hunger are on the rise. Alcohol may well be produced from abundant non-food biomass in the form of agricultural and forest wastes.

Apart from impinging on human food resources, the green energy program will have other socio-economic implications. The danger of the easy availability of potable liquor to young and old, practically in the backyard, should not be underestimated. The disposal of enormous quantities of distillery effluents will also cause a serious problem. Each liter of alcohol will produce ten liters of spent wash which is acidic (pH 4.5) and has a high BOD (50,000-100,000 ppm). The total solid content is also likely to be high (Bhusban 1977).

The technology for the production of alcohol from carbohydrates is well known. Sugars are directly converted into alcohol and carbon dioxide by the action of enzymes present in living yeast. But if starchy materials like sweet potatoes and other roots and grains are to be converted into alcohol, the starch is first enzymatically converted into sugar (glucose). Fermentation must be carried out in dilutions which permit yeast cells to survive and multiply. The resultant product therefore is diluted alcohol which is rectified by fractional distillation. To remove the last traces of water from rectified spirit (95 alcohol), azeotropic distillation, usually with benzene, is carried out. Fermentation is traditionally carried out in large wooden vats by the potable alcohol industry, though other materials of construction can also be used. Rectification and azeotropic distillation involve the use of tall fractionating columns.

In Indonesia, where 2000 alcohol plants are planned to be set up, sweet potato, cassava and sago will be used as raw materials. Preference is being given to sweet potato since it can be harvested thrice in a year as opposed to cassava, which is harvested once every eight to 12 months (Anon 1980).

CONCLUSION

Sweet potato processing has a great potential in the tropical countries to augment available food resources. In combination with legumes and other protein rich foods, sweet potato can be used to combat malnutrition. Because of the perishable nature of the root, its contribution to total calorie intake per capita is at present rather low (only 2 in Indonesia) but it can be increased substantially if appropriate and inexpensive technologies are introduced to process sweet potato.

A review of the existing technologies and practices to process sweet

potato suggests the need for science and technology inputs to upgrade the traditional technologies and to modify or adopt such processing technologies which not only strengthen the existing cottage scale industry but also promote more labor-intensive small investment food industries.

ACKNOWLEDGEMENT

For their valuable assistance in the preparation of this paper, the author is deeply indebted to Mr Bharat Bhushan, Deputy Director of Regional Research Laboratory, Hyderabad, India, who is presently serving as a consultant to the Food Technology Development Center and to Mr Yadi Haryadi, staff member of FTDC presently at the CFTRI, Mysore, India.

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Utilization of Sweet Potatoes for Animal Feed and Industrial Uses : Potential and Problems

T. P. YEH

Pig Research Institute of Taiwan, Animal Industry Research Institute, Taiwan Sugar Corporation, Chu-Nan, Miao-li, Taiwan 350

INTRODUCTION

In 1978 in Taiwan, 73% of sweet potatoes produced were utilized as animal feed while 11% and 16% of sweet potatoes were used for human food and for the starch industry, respectively. Sweet potato vines were used almost exclusively for animal feed. Although imported corn rather than sweet potato is widely and very efficiently used as the main carbohydrate source for pig diets in our feed industry at the present time, continous efforts have been made to obtain better utilization of sweet potatoes as animal feed. The following aspects of the problem have been studied here.

(1) Determining the optimum proportion of sweet potatoes to corn in a pig diet,

(2) Defining the most effective process to enhance the nutritive value of sweet potatoes,

(3) Establishing the effects of feeding sweet potatoes on the carcass quality of fattening pigs,

(4) The feeding of a high-protein sweet potato cultivar to pigs,

(5) The possible application of sweet potatoes as cattle feed, and

(6) Increasing the nutrient production of sweet potatoes.

This paper is intended to discuss the better utilization of sweet potatoes for animal feed in terms of the above six aspects of current research work.

DIGESTIBLE NUTRIENTS OF SWEET POTATOES FOR PIGS

Yang et al (1975) reported that the crude protein contents of sweet potatoes varied from 3.5 to 7.1% on a dry weight basis, and that the protein and lysine contents are significantly influenced by variation between varieties. One example of data analysis of amino acids for sweet potato chips is shown in Table 1 indicating comparatively lower contents of methionine, cystine, tryptophan and tyrosine in Tainung 57 than HP-18 (high-protein cultivar). The digestible energy (DE), metabolizable energy (ME) and net energy (NE) of sweet potato chips and corn for pigs have been estimated by Hu (1980). The results showed that DE and ME of sweet potato chips were 91% of those of corn while NE of sweet potato chips was only 79% of that of corn. Thus, sweet potato chips are not comparable with corn as a pig diet in terms of either quantity or quality of digestible protein and energy.

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Table 1. Comparison of selected amino acids between Tainung 57 and HP-18 (chips, % air dry sample)

Amino acids	Sweet potato chips[z]		Yellow corn[y]
	Tainung 57	HP-18	
Dry matter	90.50	90.40	89.00
Crude protein	2.90	6.35	8.90
Cystine	0.03	0.10	0.09
Isoleucine	0.12	0.24	0.45
Lysine	0.13	0.26	0.18
Methionine	0.04	0.12	0.09
Phenylalanine	0.13	0.31	0.45
Threonine	0.11	0.29	0.36
Tryptophan	0.41	-	0.09
Tyrosine	0.05	0.27	0.39

[z]Source: Yeh *et al* (1979)
[y]Source: Livestock Res. Inst. (1976)

FEEDING SWEET POTATOES AS A PIG DIET

Feeding efficiency and growth rates

Koh *et al* (1976) have reported that a daily crude protein intake of 334 g and a daily gross energy intake of 8.5 Mcal results in satisfactory growth performance for growing-finishing pigs fed diets containing raw sweet potatoes or dried sweet potato chips. Raw sweet potatoes as a feed for growing-finishing pigs needs more added soybean meal or some other protein supplement to obtain satisfactory performance than does a feed of dried sweet potato chips. The cost per kg gain of the former is also higher than that of the latter. The above results indicate that the utilization of sun-dried chips is more economical than use of raw sweet potatoes (Table 2). The results of many feeding experiments (Koh *et al* 1960; Tai and Lei 1970; Tai and Lei 1979; Yeh *et al* 1979 and Yeh *et al* 1980) confirmed that the performance of pigs fed diets with dried sweet potato chips was not comparable to that of of pigs fed diets with corn, but daily gain and feed-to-gain ratio were slightly superior when the pigs were fed diets formulated with dried sweet potato chips substituting 25 of the corn in the ration (Table 3).

Carcass quality of pigs fed sweet potato chips

Tai and Lei (1970) reported that the backfat thickness of pigs becomes thinner as the proportion of sweet potato chips is increased in the pig ration. Thinner backfat and a higher percentage of lean cut is obtained when the pigs' diets are formulated with sweet potato chips to substitute half or all of the corn (Yeh *et al* 1979 and 1980; Table 4). Porcine fat melting point, and unsaturated fatty acid content, are significantly ($P<0.05$

Table 2. Feeding fresh and sun-dried sweet potato chips for fattening pigs (body wt 26-90 kg)[z]

Treatment avg daily intake (kg)		Avg[y] daily gain (kg)	Backfat[z,y] thickness (cm)	Feeding days to 90 kg body wt
1. Corn-soybean meal balanced diets	2.02	0.78 a	2.89 a	83
2. Soybean meal	0.41	0.66 b	2.61 ab	98
Corn	1.42			
Sweet potato vine	1.03			
3. Soybean meal	0.61	0.63 b	2.25 b	102
Dried sweet potato chips	1.45			
Sweet potato vine	1.04			
4. Soybean meal	0.64	0.54 c	2.46 ab	118
Fresh sweet potato chips	4.59			
Sweet potato vine	1.00			

[z]Source: Koh *et al* (1976)
[y]Values on the same column followed by different small letters differ significantly (P<0.01 or P<0.05)

Table 3. The performance of fattening pigs fed different proportions of corn and sweet potato chips

Treatment: corn % in diets	Treatment: sweet potato chips, % in diet	Daily[z] gain (kg)	Feed/[z] gain (kg/kg)	Source
65 - 83	0	0.53	3.93	Koh *et al* (1960)
0	56 - 72	0.37	4.79	
30 - 39	30 - 39	0.48	3.83	
63 - 81	0	0.65 ab	3.38	Tai and Lei (1970)
45 - 58	15 - 20	0.66 a	3.37	
29 - 37	29 - 37	0.62 b	3.54	
14 - 18	42 - 54	0.58 c	3.74	
0	54 - 68	0.56 d	3.81	
72 - 84	0	0.60 a	3.08 b	Yeh *et al* (1979)
35 - 41	35 - 41	0.48 b	3.84 b	
0	69 - 81	0.44 e	4.08 a	
69 - 75	0	0.69 a	2.95 b	Yeh *et al* (1980)
0	63 - 68	0.60 c	3.37 a	
33 - 36	33 - 36	0.66 b	3.13 b	
72 - 84	0	0.56	3.14	Lee and Lee (1979)
35 - 41	35 - 41	0.49	3.71	
0	69 - 81	0.48	3.80	

[z]Values in the same column followed by different small letters differ significantly (P<0.01 or P<0.05)

Table 4. The carcass measurements of growing-finishing pigs fed different proportions of corn and sweet potato chips

Treatment		Backfat thickness (cm)	% lean cut	Source
corn % in diets	sweet potato chips, % in diets			
63 - 81	0	4.47	-	Tai and Lei (1970)
45 - 58	15 - 20	4.34	-	
29 - 37	29 - 37	3.81	-	
14 - 18	42 - 54	3.53	-	
0	54 - 68	3.84	-	
72 - 84	0	3.57	47.19	Yeh *et al* (1979)
35 - 41	35 - 41	3.20	47.35	
0	69 - 81	3.30	47.43	
69 - 75	0	3.25	52.77	Yeh *et al* (1980)
0	63 - 68	3.22	54.12	
33 - 36	33 - 36	3.10	54.89	

or P<0.01) lowered when sweet potato is fed to pigs (Kawaita *et al* 1979). These experimental results indicate that dried sweet potato chips could improve the carcass quality and porcine fat quality of growing-finishing pigs.

FEEDING SWEET POTATOES AS A CATTLE DIET

The feeding value of sweet potato vines for cattle was evaluated (Chen *et al* 1979; Chen and Chen 1979; Chen *et al* 1979). Fresh sweet potato vines are palatable to cattle, and a cow of 400-500 kg can consume 50-70 kg daily. An increased proportion of fresh sweet potato vines produced more milk. No ill effect on health or milk pH, acidity, or specific gravity were found to follow the feeding of fresh materials as the sole roughage. The high cost of mechanical dehydration and the reduction of palatability means that the use of dehydrated sweet potato vines would be less practical than that of fresh, sun-dried, or silaged vines for feeding to growing heifers.

POTENTIAL AND PROBLEMS OF INDUSTRIAL USE OF SWEET POTATO

Dry-heating process for pig diets

The starch availability and nutritive value of dried sweet potato chips are not improved by either micro-wave heating (80-90°C, 1.5-4.5 min, wave frequency 2450 MHZ) nor by rapid high temperature drying (390-430°C, 1 min). But popping the chips (in the same way poprice is made, 6-8 kg/cm^2 pressure at 164-178°C) can improve their starch availability and nitrogen digestibility (Yeh *et al* 1977; 1978; 1980 and Wu 1980; Table 5). Also, the trypsin inhibitory activity of the chips can be completely eliminated by the popping treatment, but not by the rapid high temperature drying process, which is designed for large scale production. Available lysine in the chips is reduced by high temperature heat-drying (Yeh *et al* 1978 and Yeh *et al* 1980). The results of feeding trials showed that daily gain and feed efficiency of the pigs fed with popped dried chips were significantly (P<0.05 or P<0.01) improved as compared to those of pigs fed untreated dried chips,

Table 5. Starch availabilities of sweet potato chips treated with dry-heating

Treatment	Starch availability ml CO_2/g DM/hr	% improvement	Source
Micro-wave heating[z]			
Non-treated	20.50	-	Yeh *et al* (1977)
Heating for 1.5 min 80-90°C	19.87	-3.17	
for 3.0 min 80-90°C	19.90	-3.00	
for 4.5 min 80-90°C	19.85	-3.17	
Popping[y]			
untreated	19.26	-	Yeh *et al* (1977)
6 kg/cm^2, 164°C	52.02	170.09	
8 kg/cm^2, 175°C	53.65	178.56	
12 kg/cm^2, 191°C	46.64	142.16	
Popping[x]			
untreated	15.21	-	Yeh *et al* (1978)
6 kg/cm^2, 164°C	47.77	194.35	
8 kg/cm^2, 175°C	42.56	179.82	
Dry air for 1 min passing			
untreated	10.58	-	Yeh *et al* (1980)
at 390°C	11.35	7.28	
at 430°C	15.15	43.19	

[z]Sweet potato Tainung 57, moisture content of chips 8.75%
[y]Sweet potato Tainung 57, moisture content of chips 8.16%
[x]Sweet potato Tainung 57, moisture content of chips 9-10%

and the performance of pigs was comparable to that of pigs fed corn diets. The daily gain and feed-to-gain ratio of growing-finishing pigs fed unpopped dried chips substituted for 40% of the corn in their ration were significantly ($P<0.01$) inferior to those of pigs fed corn or popped dried chips (Yeh *et al* 1978; Wu *et al* 1980).

A high protein cultivar HP-18 for pig diets

Lin and Chen (1980) pointed out significant differences of trypsin inhibitory activity (TIA) among cultivars, as high as 90% inhibition with HP-18 and as low as 20 inhibition with Tainung 48. A significant positive correlation ($P<0.05$) between TIA (percentage inhibition) and amount of total crude protein was found. TIA of the chips prepared from cultivar HP-18 could not be eliminated by pelleting at room temperature or at 80°C, and the performance of pigs fed chips pelleted at 80°C was inferior to those of pigs fed the same diet, but where pelleting had been performed at room temperature. There was still a tendency towards poorer performance of pigs fed diets with dried chips of HP-18 as compared to those of pigs fed corn diets. (Yeh *et al* 1979; Table 6). Rapid high temperature dry-heating at 390°C of dried chips of HP-18 also could not eliminate TIA, and reduced the percentage of available lysine with no improvement of starch availability. Thus, the

Table 6. The effects of pelleting temperature on the performance of grow-finishing pigs (19-90 kg body wt)[a]

Treatments		Daily gain[x] (kg)	Feed/gain[x] (kg)
Main carbohydrates[b]	Pelleting temp		
Corn	Room temp	0.61 a	3.06 a
	80°C	0.60 a	3.10 d
½ Corn + ½ sweet potato chips	Room temp	0.51 b	3.62 bcd
	80°C	0.46 c	4.05 bc
Sweet potato chips	Room temp	0.44 cd	4.11 abc
	80°C	0.44 cd	4.06 bc
Sweet potato chips + Sweet potato vine	Room temp	0.34 e	5.16 a
	80°C	0.36 de	4.84 a

[a]Source: Yeh *et al* (1979)
[b]Sun-dried chips of HP-18 and dehydrated meal of HP-4 were used for chips and vine, respectively
[x]Values on the same column followed by different letters differ significantly at ($P<0.05$) or highly significant at ($P<0.01$)

performance of pigs fed this diet was not only inferior to those on corn diets but also to those fed untreated chips (Yeh *et al* 1980; Table 7). With reference to fertilizer application to cultivar HP-18, increasing nitrogen application also increased the protein and lysine contents of roots, stems and leaves (Yeh *et al* 1980).

Starch urea (starea) for cattle

A series of experiments were conducted to evaluate the effectiveness of gelatinizalion of urea-sweet potato meal (GUSP), by Chen *et al* (1978). The cattle receiving soybean meal diets performed significantly better than on urea diets and GUSP diets, though the feeding value of GUSP diets was better than urea diets. Results from metabolism studies appeared to show that the effect of GUSP on the digestibility of dry matter, as well as on crude protein, crude fiber, and nitrogen retention of blood urea level was similar to the effect of soybean meal, but urea alone was inferior to soybean meal in these respects.

CONCLUSION

Sun-dried sweet potato chips are seen to be most economical as a pigfeed. It is clear from a series of feeding trials that when chips replaced 25% of corn in a pig ration the results were comparable to that of a whole corn ration. The carcass quality of pigs, including the percentage of lean cut, could be improved if the pigs are fed diets containing more than 50% of sun-dried chips to replace corn in the ration.

With a view to enhancing the nutritive value of sun-dried sweet potato chips for more efficient utilization in a pigfeed, several dry-heating processes have been studied. The starch availability and nutritive value of

Table 7. The effects of high temperature momentary dry-heating on the performance of growing-finishing pigs (20-90 kg body wt)[#]

Treatment[/]		Daily gain[x] kg	Feed/ gain[x] kg/kg	% of lean cut
Main carbohydrates	Dry-heating			
Corn	Non-heating	0.69 a	2.95 c	52.77
Sweet potato chips	Momentary heating at 390°C	0.61 c	3.29 ab	52.92
½ corn + ½ sweet potato chips	Momentary heating at 390°C	0.65 bc	3.18 ab	52.60
Sweet potato chips	Non-heating	0.60 cd	3.37 a	54.12
½ corn + Sweet potato chips	Non-heating	0.66 ab	3.13 bc	54.89
Sweet potato chips + tallow	Non-heating	0.61 bc	3.27 ab	52.37

[#]Source: Yeh *et al* (1980)
[/]Sun-dried chips of HP-18 were used
[x]Values on the same column followed by different letters differ significantly at ($P<0.05$) or highly singificant at ($P<0.01$)

sun-dried chips were improved and trypsin inhibitory activity (TIA) was completely eliminated by popping (6-8 kg/cm^2 pressure at 164-175°C) the chips, and also resulted in good performance of pigs. But high temperature dry-heating (390°C, 1 min) or pelleting at 80°C of the sun-dried chips of high protein cultivar HP-18 failed to eliminate TIA and to improve feeding values, and inferior performance of pigs was observed.

Increasing nitrogen fertilizer application increased the protein and lysine contents of roots, stems and leaves of HP-18. Dehydrated sweet potato vines would be less practical than fresh, sun-dried, or silaged vines as a feed for cattle. Sweet potato chips supplemented with urea for growing cattle was seen to be the most economical combination, and starch urea for feeding cattle was better than urea alone, indicating there is potential for gelatinization of urea-sweet potato meal as a cattle diet.

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Commercial Production of Sweet Potatoes for Flour and Feeds

J. M. TAYLOR

Field Agro Industries Inc, Peter Go Bldg., Mango Ave, Cebu City, the Philippines

SUMMARY

The project under discussion involves the growing of improved varieties of sweet potato (*Ipomoea batatas*) in a pilot area in Bohol, Central Visayas, the Philippines, and the processing of the crop into a wheat flour extender from selected high quality roots and into an animal feed product from the lower quality roots, peelings and vine tops.

The proposed flour processing plant will have a starting capacity of 1000 kilos daily of finished product from approximately 5000 kg of fresh roots. The end product will be sold as a wheat extender to substitute for at most 20% of the wheat flour ingredient in the baking industry, specifically in the production of 'pan de sal', a kind of local bread. The capacity of the project will be increased in line with market conditions. It is also hoped to supply government agencies involved in nutrition intervention programs in schools and depressed communities.

Operations will be designed to ensure a regular supply of raw materials for the flour processing plant. The scheme calls for a system of contract farming with independent small landowners in the area, with crop financing to be made available through the rural banks in the province.

The project will be managed by Field Agro-Industries, Inc, a Cebu-based firm engaged in food production and distribution. A new corporation will be formed for this agro-industrial venture with equity participation by the rural banks, the sweet potato growers, and the managing company, Field Agro-Industries. The research and development work for this project is being initiated with special assistance from FMC International, SA for the field trials in Bohol, and the University of the Philippines Institute for Small-Scale Industries for the preparation of the project feasibility study. Generally, the project analysis that follows is limited to feasibility aspects in the market, the workability of the production process, the investment decision and the financing scheme proposed. Detailed engineering of the proposed flour plant commences as soon as ensuing market tests on a commercial scale have been implemented and the results thereof have proven satisfactory.

HIGHLIGHTS OF MAJOR ASSUMPTIONS

The initial plantings of sweet potato will be undertaken by Field Agro-Industries in a 5 ha demonstration farm located in Trinidad, Bohol. The variety of sweet potato to be planted will be mainly the BNAS 51 line developed at the Visayas State College of Agriculture in Baybay, Leyte. This line is well adapted to Philippine conditions and has shown yield potentials of up to 35 t/ha in a five-month growing season. Planting materials of this variety, and other high yielding strains, will be made available to farmer-cooperators in the project.

Expansion of the areas to be planted to sweet potato will be through production loans from rural banks in Bohol. These loans will be used for land preparation, purchase of fertilizer and pesticides, labor expenses for weeding and harvesting, and will amount to ₱2500/ha. The approximate conversion rate in 1981 is 1US$ = ₱7.50. Borrowers will agree to sell their crop to the processing plant at ₱0.25/kg. Assuming a conservative yield of 15 t/ha, for marketable roots, a gross income of ₱3750/ha is computed. Additional income from the sale of dried sweet potato tops and vines for animal feed will also contribute an average of ₱1500/ha of additional income.

A pilot processing plant with a capacity to convert 5000 kg of fresh roots into 1000 kg of sweet potato flour daily will be established by a new company which will be called the Food Resources Corporation. The new corporation will be capitalized at ₱550,000 and will have equity participation from the farmer-growers, the rural banks financing the crop loans and the managing company, Field Agro-Industries, as well as from other outside investors. Equity participation will be ₱250,000, while ₱300,000 will be borrowed from the bank at 16% interest pa.

The primary product of the processing plant, sweet potato flour, will be sold in 50 kg bags at ₱2.75/kg, landed Cebu. The secondary product will be an animal feed ingredient consisting of finely chopped sweet potato vines mixed with rejected roots and peelings, having a protein value of approximately 16%. This will be sold to feed millers and animal-raisers at ₱1.00/kg landed Cebu.

Multi-purpose driers using agro-wastes as fuel will be used in the preparation of fresh sweet potatoes into dried chips prior to milling, thus reducing the drying cost to a maximum of ₱0.05/kg of dried product. An anti-browning agent such as sodium bisulfite may also be used to retain the fresh color of the sweet potato. Total processing cost is computed at ₱0.72/kg of dried product, with an additional ₱0.42 for administrative and selling expenses. A recovery rate of 20% of dried flour from fresh roots is assumed.

GENERAL INFORMATION

The product

The product to be offered by the new corporation is considered as a new one for the consumer industry. It is the first time that a flour processed from sweet potatoes will have been marketed in the Philippines. The industry is dominated by wheat flour. The main advantages of the new product are that it is much cheaper and much sweeter and it contains more calories than wheat flour. It is also much higher in vitamin A and in the amino acid lysine than wheat flour. The total nutritive value of bakery products is enhanced when a flour mix containing both wheat and sweet potato flour is used. Generally, the primary reason for sweet potato flour development is its potential as a wheat extender, bearing in mind rising prices of wheat products today. The substitution for at least a portion of wheat flour in bakery products (the optimum is experimentally proven to be 10 to 20% of the wheat flour mix) is recommended in this study. Sweet potato flour mix has been found to be acceptable in the production of bakery products like pan de sal, margarine cake, margarine cookies, hot cakes and other local delicaries.

Sweet potato flour will reduce the cost of bread flour and contribute to savings in foreign exchange, apart from creating local agro-based industries. Table 1 shows the volume and value of wheat flour imports over the last nine years. Table 2 on the other hand presents the annual demand of flour in the country.

Table 1. Wheat imports of the Philippines, 1970-1978

Year	Volume (tons)	Value (US$)	Source
1970	508,492	31,003,882 FOB	USA
1971	600,597	38,353,040 FOB	USA
1972	747,285	48,950,282 FOB	USA & Canada
1973	522,269	51,768,871 FOB	USA & Canada
1974	470,695	78,800,000 C&F	USA & Canada
1975	449,829	88,458,615 C&F	USA & Canada
1976	618,173	85,188,202 C&F	USA & Canada
1977	753,914	99,807,302 FOB	USA
1978	803,798	129,526,672 FOB	USA

Source: National Grains Authority

Table 2. Total annual flour demands of the Philippines

Year	25 kg bags	Value (₱ 000,000)
1975	15,689,000	914.3
1976	18,822,000	1,129.3
1977	21,704,000	1,302.2
1978	25,222,000	1.513.3
1979	26,097,000	1,826.8
1980	26,490,000	2,039.7

Source: Philippine Association of Flour Millers

Wheat accounts for 90% of the cost of producing and selling flour. It requires 33 kg of wheat to produce 25 kg of flour (75.7% recovery). The present price (1981) of wheat grain is ₱2,100/t and wholesale price of wheat flour is ₱77 per 25 kg bag (₱3.08/kg). The sweet potato flour will be sold slightly cheaper than wheat flour - ₱2.75/kg. It will be distributed by the Philippine Multi-Foods Corp, a semi-government agency concerned with nutrition intervention programs, and will be promoted for its higher nutritional value, particularly in vitamin A.

Farmer benefits from sweet potato as a cash crop

From the farmer's viewpoint, a gross income of ₱4,750/ha could be obtain-

ed in one crop season, assuming a yield of 15,000 kg of marketable roots and 2000 kg of dried vine tops with a value of ₱0.25 and ₱0.50 per kilo respectively. The maximum cost of per hectare of sweet potato production is ₱3000. Thus a net income of ₱2000/ha could be realized in one crop season of four to five months. Since a guaranteed market for his farm produce, as well as crop financing, is to be made available to the farmer, the promotion of this crop as a new source of income will be readily accepted. The farmers in this pilot area are traditional sweet potato growers but their plantings have been on a limited scale because of the small market they could find for their fresh produce.

The pilot plant will have the capacity to process 5000 kg of fresh roots a day and operate for 250 days a year. The land area required to feed it will be approximately 85 ha. The planting of the sweet potato crop will be timed to assure deliveries to the processing plant for about ten months of the year. A system of supervised credit will be practised by the rural banks financing the crop to see that the proper inputs are made. This would include the planting of high yielding lines, the correct use of fertilizer, and the use of pesticides to control sweet potato weevil, the most serious pest attacking this crop. Recommended fertilizers are four bags of 14-14-14 NPK kg/ha and two to three bags of the pesticide-nematicide Furadan which has been tested and proved effective against the weevil. No traceable residue of the pesticide is found in the roots when applied correctly, since it is completely biodegradable. A maximum of three bags of Furadan is recommended per hectare for controlling the sweet potato weevil. Cost of fertilizer and pesticide is estimated at ₱850 to ₱950/ha respectively.

Given below are the estimated costs of growing one hectare of sweet potatoes, under Philippine conditions (Table 3).

Fertilizer and pesticide applications are to be timed to obtain the maximum benefits. The first application is done at time of planting; the second two months after planting and the third three months after planting.

Rate of application is to be equally divided by three, which would be equal to 66.7 kg of complete fertilizer mixed with 16.7 kg of Furadan 3G per application.

Food uses of sweet potatoes

Sweet potato has been cultivated in the Philippines since the early days of the Spanish regime. It is grown practically in all parts of the country, in fields and backyards or in the wild. It is a hardy crop, maturing in between three and six months and it produces large returns. It can be grown successfully in almost all types of climate and soils, needing only a small amount of water.

Sweet potato is high in caloric value. For example, a hectare of this crop can support twice as many persons as rice and five times as many as corn (Table 4). The high energy value of sweet potato should be exploited to overcome the complex problem of protein crisis. What diets lack is adequate energy food and this requires protein intake (Payne 1975).

Villareal (1970) cited that sweet potato is a good source of both protein and calories. It is also rich in minerals and vitamins (Table 4). A

Table 3. Cost of production per hectare of sweet potato

Item	Cost (₱/ha)
Land preparation	
Plowing	450
1st harrowing	250
2nd harrowing	200
Hilling up	200
Planting	
Cost of cuttings	150
Cost of planting	150
Fertilizer and pesticides	
Complete (14-14-14)	
Fertilizer, 4 bags	400
Furadan, 3G, 3 bags	475
Weeding and harvesting	
Two weedings and cultivation	300
harvesting	400
Total production cost	2975

hectare of sweet potato can provide the calcium requirements of 50 times as many people as one of rice. It can provide the necessary iron for 12 times as many, the thiamine for eight times as many, and the riboflavin for 11 times as many. Although protein enrichment is the main concern in increasing the quali[illegible]iet, it is desirable that vitamins should supplement it. Yellow fleshed or orange fleshed varieties of sweet potato contain a considerable amount of vitamin A.

Villareal (1977) also cited five reasons in favor of the utilization of sweet potato in today's diet:

(1) It has a tremendous yield potential despite its being a neglected crop in the Philippines. Even limited research could increase its yield. How much more could it be increased if a sustained program were carried out to solve many of its production problems? In 1977, Villareal also noted that yields ranged from about 15 t/ha in Taiwan to 28 t in the Ryuku Islands.

(2) It has a high nutrient yield per hectare per day. Again Table 4 shows the comparison between sweet potato and other crops as sources of different nutrients (protein, minerals and vitamins) in the Philippines. The comparison is based on the number of persons that a hectare of a given crop can support in terms of the daily requirement of different nutrients. From this table, it can be seen that sweet potato can support more persons for their requirement of more different nutrients than either rice or corn, which between them form the main bulk of the Filipino diet.

Table 4. Number of persons a hectare of crop can support per day in terms of different nutrients

Crop	Calories	Calcium	Iron	Vitamin A	Thiamine	Riboflavin	Vitamin C
Rice	61.3	2.2	33.38	0	18.5	[illegible]	0
Maize	27.4	1.0	9.7	25.3	42.1	24.2	480.0
Sweet potato	138.3	138.0	405.0	991.8	140.8	106.7	1370.0
roots	122.4	85.0	105.0	324.0	100.0	40.0	1050.0
leaves	15.9	53.0	300.0	667.8	40.0	66.7	320.0
Taro	55.4	86.4	178.3	770.8	120.0	61.5	660.0
Corms	45.8	28.8	71.7	0	107.9	24.0	180.0
Leaves	6.3	40.9	65.8	747.4	10.2	33.6	433.3
Petiole	3.3	16.7	40.8	23.4	1.9	3.9	46.7
Cabbage	41.6	178.0	194.2	50.0	92.8	74.0	3441.0
Mungo	29.5	17.0	78.8	4.3	60.9	20.3	27.7
Pod	42.0	159.6	150.0	347.7	158.7	168.0	1008.3
Drybean	63.6	18.0	193.4	0.7	129.0	61.5	0
Soybean (dry)	33.6	41.0	168.8	0	40.6	16.7	trace
Soybean (green)	36.0	87.0	194.0	6	1257.0	614.0	251.0
Mango	1.02	0.24	501.5	18.4	1.8	1.0	279.0
Tomato	16.6	26.0	115.7	257.2	58.3	38.9	845.8
Banana	2.6	110.5	2.3	1.1	0.9	2.1	237.0

Source: Villareal 1970

Vegetable and field legumes can support the greatest number of persons in terms of their protein requirements. But though not so high in protein as these vegetables, combined sweet potato roots and tops can provide the protein requirements of 24 more people than rice and 45 more people than corn, per unit area.

(3) It is dependable; the dependability of sweet potato is due primarily to its drought tolerance and ability to withstand typhoon conditions.

(4) It is acceptable to consumers because of its palatability.

(5) It is inexpensive.

In the recent Philippine Food and Nutrition Program on Indigenous Foods, sweet potato was among the crops chosen to extend the wheat supply and to serve as a base for weaning and supplementary foods (Barba 1976; Madamba *et al* 1977). It was within this context that these researchers studied the potential of sweet potato flour as a substitute for wheat flour and as a base for snack/dessert items. They reported that sweet potato flour can be used as wheat extender in the making of pan de sal. Substitution of 10-20% of flour from eight different varieties of sweet potato with wheat flour made pan de sal acceptable to the laboratory test panelists.

Consumption patterns in the Philippines show that pan de sal is the most popular wheat product (Engel 1973). It is widely used not only as a snack item but for breakfast. With the introduction of equipment for production of pan de sal, people have been able to open small businesses to sell bread throughout the day. Hot pan de sal when made from composite flour can help improve the caloric-protein intake of children. It is also within the reach of many because it is easy to prepare, acceptable and always available.

Nutritional and economic benefits of the product

Malnutrition is one of the most prevalent socio-economic problems in Asia and a major contributor to child mortality in the Philippines.

The series of surveys conducted in ten regions of the Philippines from 1958-1967 by the Food and Nutrition Research Center, Manila, showed that the Filipino diet when compared with the nutritional standard set by the FNRC was found to be inadequate both in quantity and quality (Quiogue *et al* 1969). Results of the FNRC survey showed that in the first three months of life, the growth pattern of the average Filipino infant is comparable to that of the average American infant; beyond this age, however, the Filipino infant begins to lag behind (Bayan *et al* 1972). It was also discovered that Filipino toddlers and preschool children, particularly those in the rural areas, were the most critically affected. This was noted in the body weight survey in the province of Laguna where only 12.6% of the children, ages 6-7 months, had normal weights, the rest being affected with varying degrees of malnutrition (Matawaran and Gervasio 1971). The same study showed further that the body weight of the urban children were higher than that of the barrio children.

A critical look at the malnutrition problem in the Philippines tends to show that calorie-protein deficiency which primarily affects preschool children is a major public health problem.

Marasmic-kwashiorkor was fairly widespread especially among children in low-income urban slums and the rural farming sectors. Retardation of growth and excessively high mortality rates are the most obvious effects of calorie-protein deficiencies (Scrimshaw 1977). Severe forms of marasmic-kwashiorkor do not only make children more susceptible to infections, but may also result in physical stunting and permanent brain damage. Since calorie-protein deficiencies have been shown to have long term consequences amo g survivors, the recommended level of caloric-protein for different age groups of children should be met so that incidence of marasmic-kwashiorkor will be minimized if not entirely eradicated.

Because of the seriousness of the problem, malnourished children are the target of a nationwide nutrition program. Nutrition experts of the country believe that malnutrition is a multi-faceted problem which is large in scope and difficult to remedy. There can be no single answer to the complex problems involving nutrition for the, are interwoven with such factors as limited supply of good quality protein, high cost of other nutrition foods, the prevalence of parasites and infectious diseases and the lack of proper knowledge of mothers on the food needs of their children. Two other problems are the people's lack of awareness of the right kinds of foods, and the non-utilization of available local food resources.

For any food item's nutritional value to be useful, it must be within the reach of the individual who needs it at a price he can afford. One of the great challenges to researchers today is the development of inexpensive foods which are nutritionally superior and at the same time acceptable to the intended consumers.

Since Filipino children, by and large, do not have a liking for vegetables and other plant sources of calories and protein, various ways of increasing their present intake in other forms must be studied.

Several approaches to solving this problem have been tried and one strategy is to replace, at least in part, imported wheat flour used in breed-making by other flours such as that made from sweet potato.

The growing popularity of wheat products, particularly bread, has increased in many parts of the world where previously bread was not part of the daily diet.

Since the major suppliers of wheat are located in only a few countries, particularly in the USA, Canada, Argentina, and New Zealand, the expanding demand for wheat and bread may create a detrimental effect on the economy of developing countries like the Philippines.

Analysis of dried yellow sweet potato as reported in the Philippine Food Composition Table is 47,000 IU per 100 grams.

Assuming that 10 of the wheat flour weight is substituted with yellow camote flour in the baking of pan de sal, which is the most common type of bread eaten in the Philippines, then a piece of yellow camote-enriched pan de sal weighing 20 g will contain 587 IU vitamin A. This value is approximately 25 of the RDA for vitamin A for Filipino preschool children.

Since vitamin A deficiency is a major nutritional problem especially

ıng preschool children, incorporation of yellow camote into their diet will eviate this deficiency.

production process

Seven basic steps are involved in processing fresh sweet potato roots o flour, from the unloading of the raw material in the processing plant the bagging of the final product for warehousing or delivery. The pro- s is described in Figure 1.

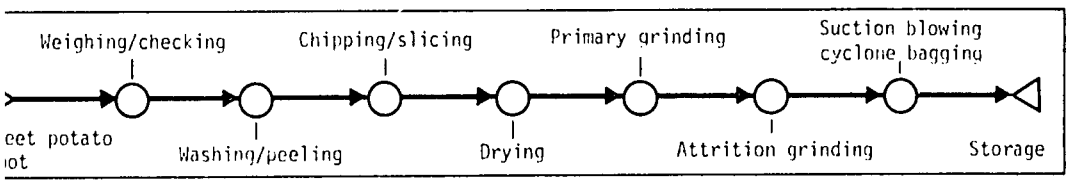

Figure 1. Processing fresh sweet roots into flour

Fresh roots from the field are delivered to the plant site and weighed a platform scale. Receipts are issued for the accepted roots and payment the farmer is based on these supporting receipts. One weigher/checker is only manpower needed.

The weighed roots are then loaded into a rotary screen friction peeler ch is turning at 30 RPM, and subjected to water spraying at 120 liters/ . This machine measures about 3.7 m in length and 0.9 m in diameter and driven by a 1.5 HP electric motor. It washes and peels at the rate of kg fresh roots per hour. The manpower requirement is two, but one of se workers will be the same weigher/checker described above.

The washed roots, with the fine peeling scraped off by friction against rotary screen, are then selected for quality and fed to a chipper/slicer hine. The rejected roots and tips are separated for conversion into mal feed. This chipper/slicer is provided with an adjustable drive and rates at 1000 RPM with a 5 HP motor. It reduces the roots to fine chips flakes of about 8 mm thickness to allow for faster drying. The manpower uirement is for one worker.

A horizontal consecutive belt type dryer is used next, and consists of r layers of screen belts approximately 20 m long and 1½ m wide, with a tance between belts of 25 cm. Each screen belt is mounted on a roller ch moves in a direction opposite to that of the belt below. The lower t protrudes over the end of the line of the belt above, thus allowing it catch the flakes that drop from the higher belt and continue to move them ough the dryer. The final belt carries the dried flakes to a receiver at bottom of the dryer. The heat exchanger for this dryer is fired by o-wastes, in this particular case coconut husks which are abundant and xpensive. Cost of coconut husks is ₱0.05 a pair (2 halves) and the burn- rate in this dryer is 50 pairs per hour, with a temperature inside the er of between 60° to 80°C. Blowers are also provided to produce a forced ught within the dryer. Drying rate is approximately 420 kg of fresh kes per hour, which reduces moisture from 70% to 12%. Direct cost of l for the heat exchanger is estimated at ₱0.03/kg of dried product. Power uired to propel the rollers of the continuous screen belts and for the wers to the heat exchanger is rated at 5 HP. Two men are required.

The dried flakes are continuously conveyed to a small hammermill which further reduces the flake sizes in the presence of heated air to prepare them for final grinding in an 'attrition' grinder. This primary grinder is powered by a 5 HP motor which produces a speed of 2000 RPM. This is directly connected by a chute with heated air to a Jiju mill to undergo the final process of attrition grinding.

The attrition grinding mill is designed to meet food grade standards and uses stainless steel to pulverize the dried finer chips into a 300 mesh fine flour. This mill has a capacity of processing up to 150 kg of ground product per hour and is powered by a 7.5 HP motor delivering 2000 RMP. Two men are needed to operate the grinder.

The final process prior to storage or delivery uses a suction blower with a 1 HP motor to separate air from the ground flour and to feed the flour with heated air into a cyclone type bagging machine. This process reduces the moisture content of the flour further to about 5%. This is a small unit designed to deliver an output of 20 bags of 50 kg each per eight hours. Two men are needed.

Machinery and equipment

The pieces of equipment and their estimated costs are given in Table 5.

Table 5. Machinery and equipment for the processing of sweet potato flour

Item	Cost (₱)
Machineries:	
Weighing scale, 500 kg capacity	12,000
Washer/peeler	12,500
Water pump with 5 HP motor	12,500
Chipper/slicer	10,000
Dryer with blowers	25,000
Primary and attrition grinder	25,000
Suction blower and cyclone bagger	5,000
	102,000
10% contingency	10,200
	112,200
Generator	115,000
Subtotal	227,200
Furniture and fixtures and office equipment	20,000

Manpower requirements

A total of nine direct workers, a supervisor and a maintenance mechanic will be needed.

Plant size

The plant will be able to process 5000 kg fresh sweet potato roots into 1000 kg sweet potato flour per day for 250 working days in a year. This means a total production of 250,000 kg sweet potato flour for one year. In addition, it could also prepare 166,000 kg dried sweet potato vines as an animal feed mix component.

Financial aspect

Project cost

The estimated total project cost is ₱550,000, summarized as follows:

Fixed cost:		
Land and building	₱150,000	
Machinery & equipment	227,200	
Furniture & fixtures	20,000	
Total fixed cost		₱397,200
Working capital:		
Raw materials (6 days)	9,890	
Accounts receivable (1 month)	63,000	
Minimum cash balance	20,000	
Total working capital		₱ 92,890
Pre-operating expenses		60,000
Total project cost		₱550,090
	or	₱550,000

Projected financial statements

The projected income statement is as follows:

Sales: Sweet potato flour, 25,000 kg	₱853,500	
By-products, 166,000 kg	166,000	
		₱853,500
less: Discounted sales: (by-products, 3%)		4,980
total sales		₱848 520
less: Cost of goods manufactured and sold:		
Sweet potato flour	₱490,690	
by-products	124,500	
Total Cost of Sales		₱615,190
Gross profit:		₱233,330
less: Operating expenses (including salaries, transportation, supplies, depreciation, taxes, etc)		₱113,525

Net profit before interest		₱119,805
less: Interest expense		48,000
Net profit before income tax		₱ 71,805
Financial evaluation:		
Profit to sales ratio	-	8.46%
Payback period (recovery of the owner's equity)	-	3.482 years
Return on investment (ROI)		
Total investments (assets)	-	13.06%
Equity (owner's equity)	-	28.72%
Break-even analysis		

Break-even sales is ₱684,366 which is about 81% of total capacity.

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The Storage, Marketing and Utilization of Sweet Potatoes in Korea

E. H. HONG

Upland Crops Research Division (I), Crop Experiment Station, Office of Rural Development, Suweon 170, Korea

INTRODUCTION

Sweet potato is the third most important summer upland crop in Korea on a quantitative basis, after rice and barley. It is mainly used for food, as an industrial raw material and as an animal feed. But in recent years, the area planted and the production have shown a tend ncy to decrease. This is thought to be due to the following three major factors: farmhouses have no storage facilities capable of handling large amounts of sweet potato for a long time after harvesting in autumn; farmers do not have facilities or labor for drying processes; and sweet potato itself generates relatively low income compared with many other competing summer upland crops.

As shown in Table 1, the area planted to sweet potatoes in Korea has decreased annually from 127,000 ha in 1970 to 61,000 ha in 1979. The amount produced has also fallen from 2,136,000 to s in 1970 to 1,387,000 tons in 1979. But yield per unit area is relatively high compared to many other sweet potato producing countries. It was 22.7 t/ha in 1979, which was a 35% yield increase over 1970.

Table 1. The area planted to sweet potato and amount produced in Korea yearly since 1970

Year	Area planted (1000 ha)	Yield (t/ha)	Amount produced (1000 t)	Index (%)		
				Area planted	Yield	Amount produced
1970	127	16.8	2,136	100	100	100
1974	80	18.1	1,450	63	107	68
1975	95	20.7	1,953	75	123	91
1976	87	20.4	1,783	69	121	83
1977	77	20.2	1,560	61	120	73
1978	74	22.1	1,627	58	131	76
1979	61	22.7	1,387	48	134	65

Source: The Korean Ministry of Agriculture and Fisheries Statistics, 1980

Because sweet potatoes grow well under relatively high temperatures and are mostly cultivated after barley in Korea, the major sweet potato producing area is in the southern part of the country, especially in the province of Jeonla Nam-do. A lot of sweet potatoes are also cultivated on islands off the country's south coast where cereal crops cannot easily be grown because of strong sea winds.

This paper will deal with the general aspects of storage, marketing and utilization of sweet potatoes in Korea.

STORAGE

In Korea, sweet potatoes are stored for six to seven months after harvesting in late autumn to early spring under relatively low temperature conditions. Monthly mean temperatures during this period vary widely between the southern and the central regions in Korea. The range of monthly mean temperatures in the central regions during storage of sweet potatoes is from -5.2°C to 12°C, while that in the southern regions is -0.5°C to 15°C, which is between 1.7°C and 4.9°C higher than in the central regions.

The harvesting time of sweet potatoes in Korea is from late September to early October in the central regions and from early to middle October in the southern regions. Roots are dug out with a forked rake or a weeding hoe after removing all vines. Much attention is paid to avoiding damage to the root skins.

After harvesting, roots are first stored in the shade for 10-15 days to allow respiration and evaporation of moisture.

Sweet potato storage can be undertaken at temperatures between 10-17°C, but the optimum temperature range is 12-15°C. The optimum relative humidity range is 85-90% (Cho 1978).

Storehouses, storing boxes and incidental equipment should be sterilized before use. Chemicals such as copper sulfate, formalin, chloropicrin, methyl bromide, and sulfur are commonly used for sterilization. The storehouse is usually sprayed with 400X copper sulfate before storing while storing boxes are simply washed and dried. During storage, burning 1.5-2 kg sulfur per 300 cu m storage space is known to control effectively fungal diseases such as softrot *Rhizopus stolonifer* (Chung 1976).

Storehouses for sweet potatoes in Korea are designed to keep temperatures above certain levels during the storage period. The structure of the storehouse varies according to soil conditions, the amount to be stored, and the weather of the region. Because there are big differences in mean monthly temperatures between the central and the southern parts of Korea during storage periods, different storing methods are practiced in each region. In most storehouses temperatures are controlled not by artificial heating systems but by natural soil temperatures. The depth below the surface of an underground storehouse is chosen so that soil temperature is as near as possible to the optimum temperature (12-15°C) for sweet potato storage.

Several storage methods for sweet potatoes during winter are practiced in Korea (Tikasi 1942). Three are detailed below.

Indoor all-underground storage

This method is commonly practiced in the central region of Korea. As shown in Figure 1, a building is erected as protection from cold winds with an underground pit which has a volume of 12.6 cu m and is capable of holding about 7.5 tons of sweet potatoes. Experiments with this method (Table 2) have indicated that the temperature range in the pit was 6.3-9.0°C when empty of roots but 10.8-14.0°C when roots were stored in it, and that storability was 96%. Storability refers to the number of roots that remain good after storage divided by the total number of stored roots multiplied by 100. Sprouting of stored roots under these conditions was about 27%. The merits

Table 2. Results of experiment into four popular storage methods for sweet potatoes in Korea

Date		Temperatures of storage (°C)							
		full of roots				empty of roots			
		IAU[a]	'Ondol'	ISU[b]	tunnel	IAU	'Ondol'	ISU	tunnel
Nov	5	18.3	17.0	13.5	18.0	-	19.5	8.0	17.4
	15	12.0	15.0	17.0	17.6	6.8	16.0	-	16.2
	25	10.8	11.2	17.5	16.5	6.6	12.4	12.6	15.9
Dec	5	14.0	12.5	17.6	16.0	6.5	13.0	8.0	14.8
	15	14.0	12.0	18.6	16.0	6.5	13.0	8.3	13.5
	25	14.0	11.0	18.3	15.5	6.3	14.0	5.0	13.0
Jan	5	14.0	11.0	17.6	15.0	6.5	14.0	6.6	13.2
	15	14.0	10.0	18.1	14.0	6.5	13.0	3.9	12.2
	25	14.0	11.0	17.9	12.0	6.5	12.0	4.1	10.5
Feb	5	13.0	12.0	16.9	12.0	6.7	9.0	3.4	10.5
	15	14.0	13.0	15.4	13.0	6.9	11.0	2.7	10.5
	25	14.0	12.0	15.9	13.0	7.0	8.0	2.8	10.5
March	5	13.0	12.0	14.6	13.0	9.0	10.0	1.6	11.0
	15	12.0	13.0	15.0	13.5	9.0	9.0	5.1	14.2
Average		13.7	12.3	16.4	14.7	6.9	12.4	5.4	13.1

[a] Indoor all-underground storing method
[b] Indoor semi-underground storing method

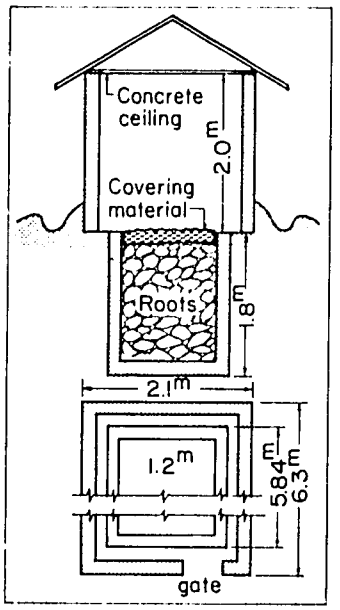


Figure 2. 'Ondol' storage of sweet potatoes in Korea

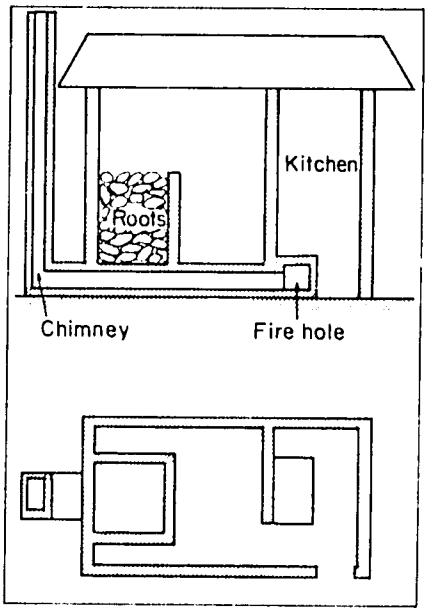


Figure 1. Indoor underground storage of sweet potatoes in Korea

of this method are that existing buildings can be used as the shelter, and that the temperature inside the pit is relatively stable. The major disadvantage, however, is that the control of the relationship between amounts stored and the heat generated by the roots is too difficult.

'Ondol' storage

'Ondol' is the name given to a traditional type of floor in Korean houses which is heated from below. Sweet potatoes can be stored in rooms heated in this way, and this method is also commonly practiced in the central part of Korea (Figure 2). About 1.2 tons of sweet potatoes can be stored in a medium sized room and an experiment with this storing method (Table 2) indicated 99% of storability. This method is appropriate for small quantities of sweet potatoes. It is easy to control room temperatures by adjusting the heating of the floor, but it is difficult to control moisture and the technique is apt to dry out too much of the root weight.

Indoor semi-underground storage

This method is used in the southern part of Korea. As shown in Figure 3, a building is erected above a pit with raised sides which has a volume of 57.4 cu m and can hold about 19-37 tons of sweet potatoes. The temperature range in the pit, as shown in Table 4, was 1.6-12.6°C empty and 13.5-18.6°C when filled with roots. The storability was 100% and sprouting of stored roots was 15%. The size of the storage pit can be adjusted with ease but the temperature varies greatly depending on outside temperatures.

Tunnel storage

This method is also commonly practiced in the southern part of Korea. As shown in Figure 4, the usual volume of the tunnel is about 27.6 cu m and it is capable of storing about 7 tons of sweet potatoes. A storing experiment with this method (Table 2) indicated the temperature of the hole during the storing period was 12.0-18.0°C, that the storability was 98%, and that the sprouting of stored roots was relatively high, 41%. The temperature in the

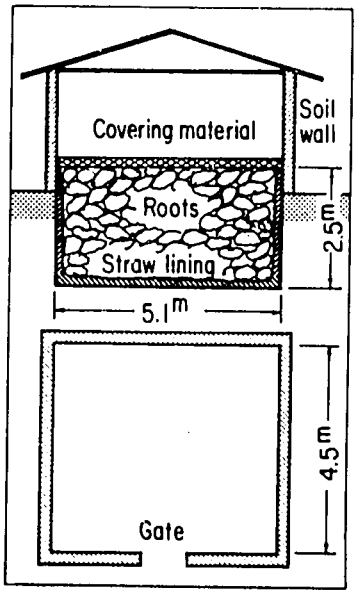
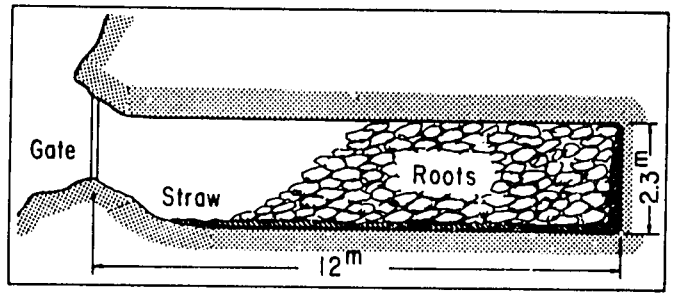


Figure 3. (Left) Indoor semi-underground storage of sweet potatoes in Korea

Figure 4. (Below) Tunnel storage method for sweet potatoes in Korea



tunnel was relatively stable, and the tunnel itself can be used almost permanently. But of course it can be made only on suitable terrain.

The above four methods are the most commonly used ones for storing sweet potatoes during winter in Korea.

MARKETING SWEET POTATOES IN KOREA

Marketing of sweet potatoes in Korea goes on from August, the time of early harvesting, to June of the following year. Sweet potatoes are sold for two main purposes: for food and for industrial use. As shown in Table 3, the percentages of sweet potatoes used for food, industry, and seeds over the last five years were 50%, 38%, and 3% of total production respectively.

Table 3. Demand for sweet potatoes for different uses in Korea

Year	Manufacturing		Foods		Seeds		Total (1000 t)
	amount	% of total	amount	% of total	amount	% of total	
1976	604	34	1,121	63	58	3	1,783
1977	619	39	886	57	55	4	1,560
1978	598	37	974	60	55	3	1,627
1979	543	39	798	58	46	3	1,387
1980	580	42	761	55	46	3	1,387
Average	589	38	908	59	52	3	1,549

Source: The Korean Ministry of Agriculture and Fisheries Statistics, 1980

In the case of sweet potatoes planted for industrial uses, of course, the whole crop is sold to the manufacturing factory. When the crop is planted for food only the amount which remains after farmhouse consumption comes onto the market. The percentage of sweet potatoes grown for industry rose from 29% in 1970 to 64.9% in 1975, while the amount consumed per city household has declined. As shown in Figure 5, the marketing channel for sweet potatoes grown for food is: producer → local collector → commission wholesale dealer → retail dealer → consumer. But there are three kinds of channel for sweet potatoes intended for industrial purposes:

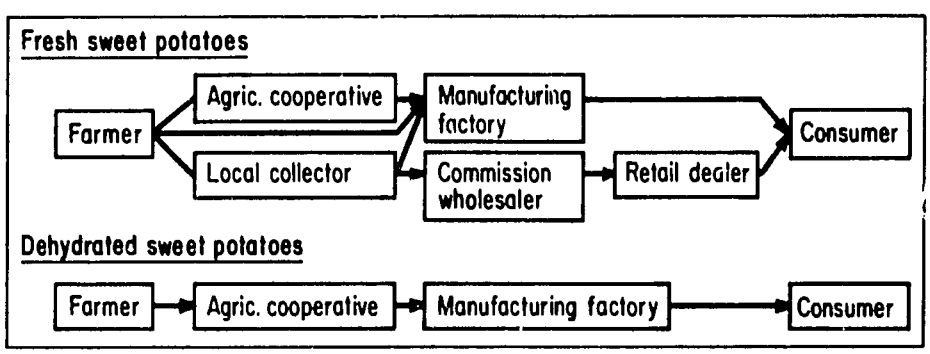


Figure 5. Marketing channels of fresh and dehydrated sweet potatoes in Korea (NACF 1979)

1) producer → agricultural cooperatives → manufacturing factory;
2) producer → manufacturing factory;
3) producer → local collector → manufacturing factory

All dehydrated potatoes take the first channel. The amount of sweet potatoes which agricultural cooperatives purchased in 1970 was only 313,000 tons, 14.7% of total production, but in 1978 it was 495,000 tons or 30% of total production (Table 4). The amount purchased by agricultural cooperatives had greatly increased since 1976. In that year for the first time the amount of dehydrated sweet potatoes purchased by agricultural cooperatives was greater than the amount of fresh ones. This is because producers can get more profit by selling their sweet potatoes in dehydrated form, whereas the manufacturing factory can more efficiently store dehydrated sweet potato than fresh roots. Dehydrated sweet potatoes can also be more easily handled in bulk than fresh ones. The purchase price offered by the agricultural cooperatives (Table 5) has been increased 453% and 556% from 1970 to 1978 for fresh and dehydrated sweet potatoes respectively. The purchase price per ton of fresh and dehydrated sweet potatoes in 1978 was US$52.5 and US$277, respectively.

Table 4. The amounts of sweet potatoes purchased by agricultural cooperatives in Korea from 1970-1978 (NACF 1979)

Year	Productions (A)	Amounts purchased by agricultural cooperatives			A/B (%)
		fresh	dehydrated[a]	total (B)	
	1,000 t				
1970	2,136	167.7	145.3	313.0	14.7
1974	1,450	131.9	144.1	276.0	19.0
1975	1,953	224.2	95.9	320.1	16.4
1976	1,783	217.4	313.8	531.2	29.8
1977	1,560	130.0	435.5	565.5	36.3
1978	1,627	64.4	431.0	495.4	30.4

[a]The amounts of dehydrated sweet potatoes were converted into fresh weight

Table 5. The purchase price paid by agricultural cooperatives for sweet potatoes in Korea between 1970 and 1978 (NACF 1979)

Year	Fresh (1st grade)		Dehydrated (1st grade)	
	price	index	price	index
	US$/t	%	US$/t	%
1970	11.6	100	49.8	100
1974	27.7	239	127.4	256
1975	36.3	313	175.4	352
1976	42.6	367	205.9	413
1977	49.8	429	240.8	484
1978	52.5	453	277.0	556

UTILIZATION

In the home, in general, sweet potatoes are steamed as food, but considerable quantities are fried or baked. Sweet potatoes, with a minimum of preparation, can also be made into delicious and nutritious foods such as hot cakes, gruel, noodles, candy, or they can be sweet-fried. All these are valuable subsidiary foods.

Starch production figures from sweet potatoes over the last five years are shown in Table 5. As shown, 21,600 tons of starch has been produced from 123,400 tons of sweet potatoes annually on the average. In 1978, 78% of the total starch produced from sweet potatoes was used for various kinds of noodles.

Starch can be mixed with wheat flour to make noodles, which will cut down flour consumption. The remaining 32% of starch production in 1978 was used for chemicals, medicines, and so on. Even more sweet potatoes are used for alcohol production. Alcohol production figures from sweet potatoes in 1978 are given in Table 6.

In total, 79% of the sweet potatoes grown for industrial purposes are used for alcohol production and the remaining 21% for starch.

Table 6. The amounts of sweet potatoes used for starch and alcohol production, and amounts of starch and alcohol produced in Korea (1976-1980)

Year	Raw materials (1000 t) for			Production	
	alcohol	starch	total	alcohol (D/M)	starch (1000 t)
1976	472	132	604	605	23.6
1977	517	102	619	653	18.3
1978	462	136	598	650	24.3
1979	426	117	543	-	17.4
1980	450	130	580	-	24.4
Average	465.4	123.4	588.8	636	21.6
(%)	(79)	(21)	(100)		

Sources: The Korean Ministry of Agriculture and Fisheries Statistics, 1980 and Korean Alcohol Association, 1979

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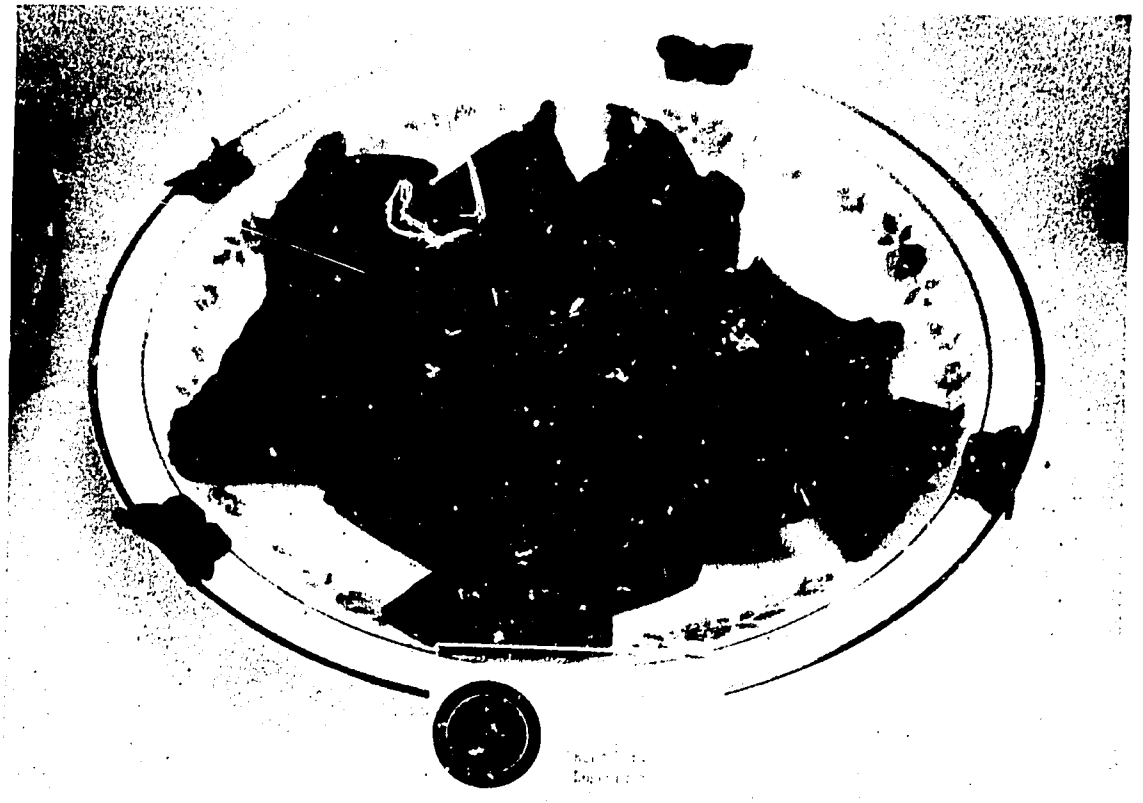

A snack prepared from sweet potato roots.

Marketing of Sweet Potatoes in Taiwan

H. Y. CHEN

Agricultural Marketing Division, Council for Agricultural Planning and Development, 37 Nan Hai Rd, Taipei, Taiwan

PRODUCTION

In recent years, sweet potato production has been declining in Taiwan. Peak hectareage (246,000 ha) was reached in 1964, and peak production (3.72 million tons) was recorded in 1967. Since then, both hectareage and production have declined, reaching only 74,000 and 1.22 million tons respectively in 1979 (PDAF 1980a). Total production decreased to only about one-third of the peak level when hectareage declined to 74,000 ha. This situation is especially surprising when seen against the dramatic upsurge in output of other farm products.

Many factors have contributed to the decline in the production of sweet potatoes in Taiwan. Two factors have predominated in bringing about this decline. Firstly, as the standard of living has risen in Taiwan people have tended to eat more rice at the expense of sweet potato. Secondly, hogfeed based on corn rather than on sweet potato has been adopted by the large-scale hog-raising industry that has developed over the past few years. Shrinking market demands have made the production of sweet potato relatively unprofitable compared with other crops in terms of both prices and returns.

A third and less important factor is the improvement of irrigation facilities, which has encouraged farmers to plant more rice, especially in the upland areas which were previously planted largely to sweet potato.

Sweet potato, however, is still by far the most important starchy root crop in Taiwan, accounting for about 4% of the total value of crops produced in 1979 (PDAF 1980a).

CONSUMPTION

Sweet potatoes are cultivated in Taiwan for three distinct uses: as human food, animal feed, and industrial raw material. According to the estimates made in the food balance sheet of Taiwan, these markets accounted for 84,000 tons, 771,000 tons and 245,000 tons respectively of the total 1.22 million tons harvested in 1979 with the balance of 125,000 tons disappearing as waste and seeds (CAPD 1979).

In the period 1940-44, the average annual per capita consumption of sweet potato was 91 kg. By 1979, the average consumption had decreased to only 4.8 kg per person per year (JCRR 1975 and CAPD 1979). Sweet potato is now considered to be an inferior food by the majority of people in Taiwan.

Customarily, fresh sweet potatoes for human consumption are mixed with white rice. They are also occasionally served deep-fried or peddled in the streets charcoal-baked. These forms, however, account for only an insignificant market share. Despite the overall decline of the industry, there have

Table 1. Disposal of sweet potato produced in Taiwan

Year	Total production	For use as				Percentage distribution (%)			
		animal feed	manu-facture	waste and seed	food	animal feed	manu-facture	waste and seed	food
	1000 t								
1935-39	1624	585	162	228	650	36	10	14	40
1940-44	1539	544	154	226	616	35	10	14	40
1945	1165	402	117	181	466	34	10	16	40
1950	2201	989	330	332	550	45	15	15	25
1955	2437	1101	366	362	609	45	15	15	25
1960	2979	1376	447	411	745	46	15	14	25
1965	3331	1610	470	426	626	48	14	13	19
1970	3441	2143	688	345	265	62	20	10	8
1975	2403	1513	480	245	164	63	20	10	7
1979	1225	771	245	125	84	63	20	10	7

Source: JCRR 1975; CAPD 1980

been some recent signs that sweet potato may be gaining in popularity again as a dessert or snack food.

As an animal feed, sweet potato is consumed by livestock either raw or in dried chips. Because of its bulk and susceptibility to decay, it tends to be given raw only to animals in the producing areas, very soon after harvest. The dried chip form can be much more easily stored or transported. In the past, both forms would be cooked before being fed to livestock: this is less often done nowadays, to save labor and fuel.

Sweet potatoes are used for industrial purposes mainly for the potato starch and alcohol they contain. If the end use of these components is human consumption, however, they are counted as human foods in the food balance sheet.

Sweet potatoes intended for table use and those destined for feed or industrial processing are distinctly different commodities. Those for table use must have acceptable flavor, taste and nutrition. These qualities are unnecessary of course in those varieties selected as feeds and raw materials.

MARKETING

A recent survey indicated that almost two-thirds of sweet potatoes harvested by farmers flows through marketing channels and the remaining one-third is used up on the farms by the farmers themselves (Hsu 1979).

In recent years, smallscale hog-raising, which used to be the mainstay of Taiwan's hog industry and which used to consume most of the home-grown sweet potatoes, has rapidly given way to very large scale commercial operations. This tendency has resulted in an increase in the percentage of the crop used industrially, because fewer and fewer growers use sweet potatoes grown on their farms to feed their own hogs. Instead, they sell the potatoes to other hog-raising farmers in the community, or even ship them to other localities. Even as recently as 1966, when hog-raising using home grown sweet potato was still very popular, the percentage of sweet potatoes marketed was as low as 30%.

Processing factories, shippers (traders who buy and distribute potatoes from small producers), county buyers, wholesalers, retailers and exporters all participate in marketing activities of sweet potato. The market shares of the various channels and agencies are presented in Figure 1 and Table 2.

The most important outlet for the potato growers to select when selling their produce is the shippers who are taking up 61% of the produce directly sold by the potato farmers. The next most important outlets are the processing factories which absorb about 25% of the potatoes marketed from the farm. These factories collect sweet potatoes either directly, by sending their own employees, or indirectly through commission agents. Other farmers make up the third most important purchasing group, and buy the potatoes mostly for feeding animals. These three major outlets absorb 97% of the produce directly sold by the farmer.

Of the sweet potatoes bought by the shipper, about 70% are resold to

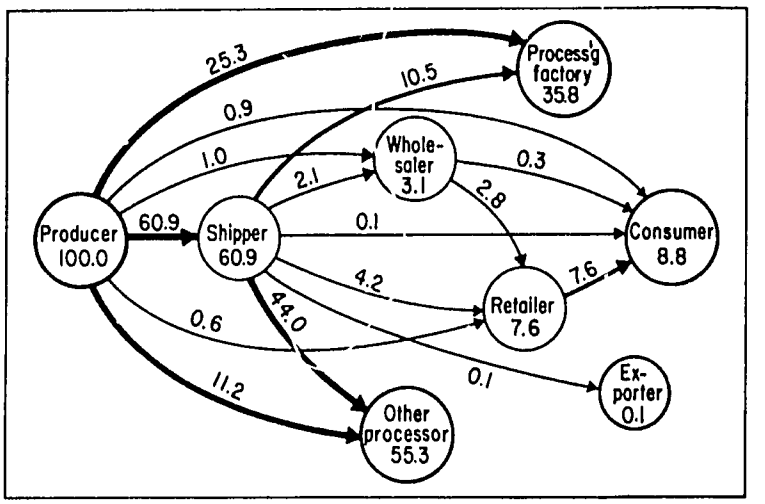

Figure 1. Marketing channels of sweet potatoes

Table 2. Distribution of sweet potatoes marketed off-farm in percent (1976)

	Farmer	Shipper	Wholesaler	Retailer	Exporter	Total
Processing factory	25.3	10.5				35.8
Shipper	60.9					60.9
Wholesaler	1.0	2.1				3.1
Retailer	0.6	4.2	2.8			7.6
Consumer	0.9	0.1	0.2	7.6		8.8
Other farmers	11.2	44.0				55.3
Exporter		0.1				0.1
Export					0.1	0.1
Total	100.0	61.0	3.0	7.6	0.1	

Source: Hsu 1979

other farmers mainly for feeding animals, and about 17% are delivered to processing factories to be used as raw materials. The wholesaler accounts for only 3% of the total market flow while the retailer accounts for about 8% of the total. Channels other than those mentioned above are comparatively minor in terms of handling this commodity.

Sweet potato business is not usually transacted at the terminal wholesale market for fruits and vegetables in Taiwan. However, the volume of this product bought and sold in Taipei terminal market has increased quite appreciably. The transaction record for the past four years shows that 1274 tons changed hands in 1977, 1150 tons in 1978, 1472 tons in 1979 and 2023 tons in 1980.

COST AND MARGINS

The cost and margins involved in marketing sweet potatoes in Taiwan are presented in detail in Table 3. From this table, it is clear that in 1976 the cost of marketing 100 kg of sweet potato was NT$164, or 43% of the retail price. Even after the bulk of the crop and its perishable nature are taken into account, sweet potato still seems to offer a fair return to the grower.

By far the most important cost item is the gross margins at both wholesale and retail levels which together account for about 66% of the total marketing bill. Although many people make the mistake of equating gross margins with profits, these margins in fact include all paid and imputed costs of the dealer, such as wages, risk premiums, interest or returns on capital, depreciation and taxes, in addition to net profit in the original sense.

Table 3. Marketing costs of fresh sweet potato by function (1976)

Function	Amount (NT$/100 kg)[a]		Percentage (%)	
Farm Price		216.67		
Transportation	13.62		8.33	
Packing	6.81		4.17	
Wholesale margins	31.73		19.40	
Loss and shrinkage	5.18		3.17	
Sub-total (1)		57.34		35.07
Wholesale price		274.01		
Transportation	9.64		5.90	
Packing	10.94		6.69	
Retail margin	75.73		46.31	
Loss and shrinkage	9.87		6.03	
Sub-total (2)		106.18		64.93
Retail price		380.19		
Total marketing costs = (1) + (2)		163.52		100.00
Farmer's share of retail price (farm price : retail price)				57.00

[a]Approximate conversion rate in 1976 was 1US$ = NT$38
Source: Hsu 1979

Second in importance among the marketing cost items is the cost of transportation needed for moving the commodity from the farmyard to the retail market. This accounts for 23% of the total marketing bill of this product. Packing expenses come third to account for 18% of the total. Other cost items are relatively unimportant.

In 1966, the farmer's share of the retail price of fresh sweet potato was 56% (Chen 1972). This can be seen as the farmer's share of the consumer's dollar. There has been practically no change in the farmer's share of the consumer's dollar for this commodity during the past decade. But gross margins of the wholesaler and retailer have increased a great deal during this period, resulting in a significant change in the structure of the marketing costs of this commodity. This tendency suggests that whatever savings in costs have been made for the physical distribution of this product, such as transportation and packing expenses, are offset by the increase in the gross margins.

PRICES

Farm prices of fresh sweet potatoes in Taiwan for the past 15 years are presented in Table 4. From data in this table, it can be seen that the farm price of fresh sweet potatoes was NT$0.89/kg in 1965. In November 1980, the price had risen to NT$2.70/kg, a net increase of about 200% in 15 years.

Table 4. Market price of sweet potato and rice[a]

Year	Farm price of sweet potato (NT$/kg)[y] (1)	Farm price of paddy (NT$/kg)[y] (2)	Index of price ratio (1) : (2)
1965	0.89	4.13	100
1966	0.82	4.15	92
1967	0.91	4.39	96
1968	0.90	4.63	90
1969	0.80	4.53	82
1970	0.90	4.72	88
1971	0.78	4.65	78
1972	0.77	4.93	72
1973	1.14	5.69	93
1974	1.71	10.20	78
1975	1.40	11.80	59
1976	1.76	10.62	77
1977	1.82 (2.63)[x]	8.90	95
1978	1.88 (3.42)[x]	9.08	96
1979	2.27 (4.33)[x]	10.98	96
1980 (Nov)	2.70 (4.5) [x]	14.24	88

[a]All data from PDAF 1980b except those figures with *x* superscript which were taken from TFVM (1978-80)
[y]Approximate conversion rate in 1980 was 1US$ = NT$36
[x]Average annual price of fresh sweet potatoes transacted at the Taipei Fruit and Vegetables Wholesale Market

Over the same period, the Taiwan economy has experienced rapid and steady inflation. The growth rates of prices of competing crops are in some cases higher than that of sweet potato. This makes the price of sweet potatoes relatively unattractive to the farmers compared to other farm products which the farmer can grow more profitably. The farm price of paddy, for instance, rose by 245% in the same period, leaving the price of sweet potato lagging far behind. The indices of the price ratio between sweet potato and paddy over the past 15 years, using 1965 as the base period, were all below 100 and in more than half of the years were even below 90. This means that compared to 1965, sweet potato growing now has become less profitable than rice growing if prices alone are taken into account.

Sweet potatoes bought and sold in the terminal markets of the consuming areas are for table use only and therefore fetch much higher prices. Figures in parentheses in Table 4 show the annual average wholesale price of fresh sweet potatoes bought and sold at Taipei terminal markets. The price in this market is 70-90% higher than those market in the producing areas. Even allowing for transportation costs, which is about NT$0.50/kg at present, dealers put the price up for sweet potatoes sold for table use.

PROSPECTS

As far as total production is concerned, Taiwan's sweet potato industry has now lost most of its past glory. This does not necessarily imply, however, that the future is hopeless. The crop could still be economically valuable if adequate steps were taken to improve production and marketing.

First of all, it is necessary to distinguish clearly between sweet potatoes for table use and those for animal feed. They are absolutely different commodities. Improvement measures must be tailored to reflect the market characteristics of sweet potatoes for these different uses.

Since ready-mixed feed is the most common type fed to the animals in modern hog-raising, it is extremely important to develop technology which will include sweet potato as a major ingredient in a balance hog ration. Only when sweet potatoes are used in large quantities by the feed-mixing industry can the market for this product be sustained and grow.

As regards sweet potatoes for table use, it is necessary to make the consuming public recognize its nutritional and market value. It is absolutely necessary to create an entirely new market image of the sweet potato for human consumption. Only when consumers become aware of the fact that the sweet potatoes they are eating are completely different varieties from the ones the hogs are eating will they feel attracted to sweet potatoes for home consumption.

The existing marketing channels for sweet potatoes were established primarily to accomodate the flow of this product for feed use. As such, they are far from appropriate for marketing sweet potatoes for table use. It is therefore necessary to develop new marketing channels and new handling techniques specifically designed to accommodate the market flow of this commodity for consumption in the house.

If all this is done, it may be reasonably expected that the domestic market of sweet potato will expand and grow far beyond the present level.

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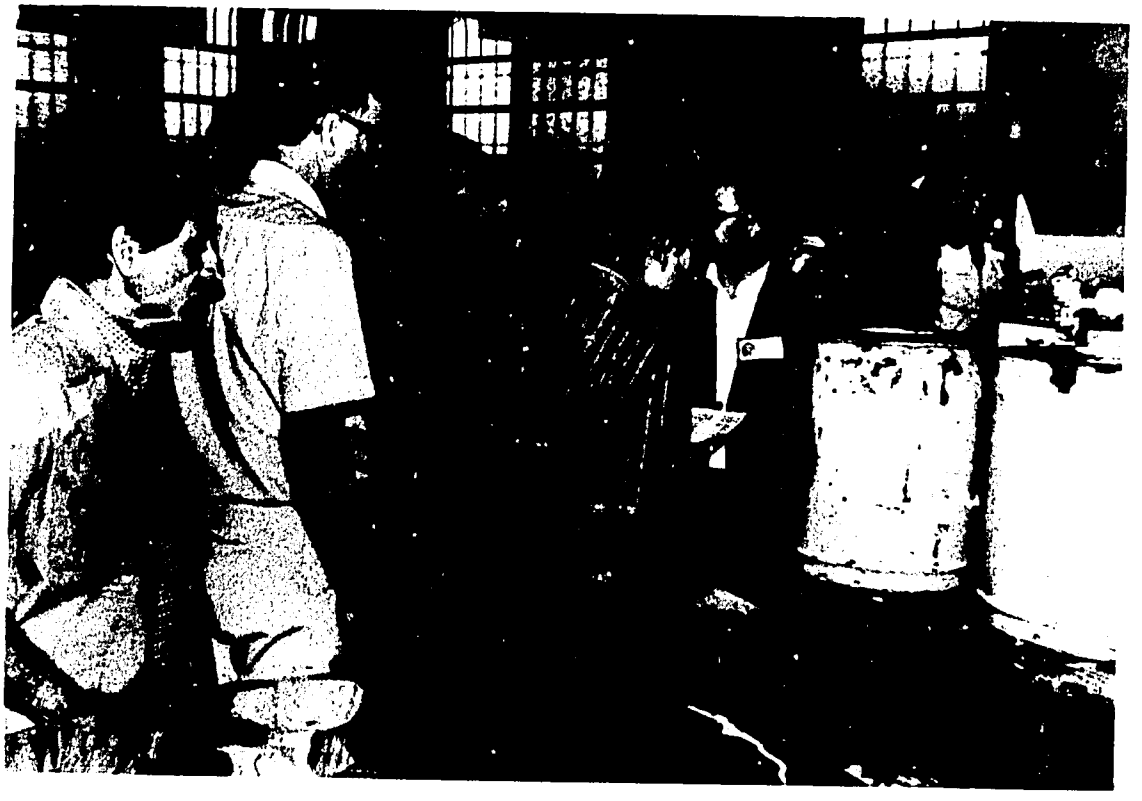

Delegates to the First International Symposium on Sweet Potato visit a sweet potato candy factory in Taiwan.

Postharvest Physiology and Pathology of Sweet Potato from the Biochemical Viewpoint

I. URITANI

Laboratory of Biochemistry, Faculty of Agriculture, Nagoya University, Chikusa, Nagoya 464, Japan

INTRODUCTION

The postharvest physiology and pathology of sweet potato presents many problems. These problems vary somewhat, however, between temperate and tropical regions. In temperate regions, chilling injuries may be important, since sweet potato is a tropical plant and sensitive to chilling (Lyons 1973; Uritani 1978b). When stored in a range of chilled temperatures lower than about 8°C, sweet potato roots normally suffer from physiological deterioration, and then from softrot, the pathogen which is some kind of rather saprophytic fungus, such as *Rhizopus stolonifer* (Fries) Lind (Shichi and Uritani 1956). Farmers in Japan store roots at a temperature range of 10-15°C in the winter season.

In tropical and subtropical zones, however, the most serious problems with sweet potato after harvest involve sprouting, a decrease in the content of carbohydrates (such as starch) and damage from fungal infection and insect infestation, leading to a lowering of value as food and feed. It is normally difficult to store roots at 10-15°C in tropical or subtropical regions.

This paper deals mostly with the mechanical wounding of sweet potato roots during and after harvest, with wound healing, and with subsequent deterioration following microbial infection, since these are common to both regions.

WOUNDING AND BIOLOGICAL REACTIONS

The factors causing injury can be divided into four categories: physical (including weather), chemical, biological, and physiological.

Root crops can normally be stored in a fresh condition for a long period compared with, say leaf crops. But root crops respond to mechanical injury strongly and show vigorous biological reactions which finally lead to wound healing. In cases where the healing is not complete, they are often attacked by various kinds of microorganism both pathogenic and non-pathogenic. Thus, mechanical injury is often accompanied by infection. Biological reactions to either mechanical injury or infection often cause changes in food and feed quality.

MECHANICAL INJURY

When sweet potato roots are harvested either by hand or by machine, they often suffer mechanical injury. This can occur at anytime in the course of storage, transport, packing and boxing. When mechanical injury is

visible to the naked eye, the market value is lowered. On the other hand, some mechanical injury is not visible but will also lower the quality sooner or later by the gradual appearance of biological changes.

Wound respiration

As with many tuberous roots, tubers and bulbs of root crops, respiration is enhanced in sweet potato roots in response to mechanical injury (Figure 1), and the roots become more sensitive to cyanide. Respiration increases two-fold after about 20 hours with a lag of several hours. Such increased respiration is called wound respiration (Uritani and Asahi 1980).

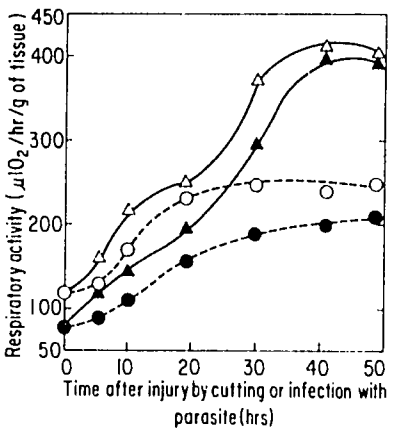

Figure 1. Increase in respiration of sweet potato root tissue in response to mechanical injury or *Ceratocystis fimbriata* infection. Tissue slices (about 3 cm in thickness) of sweet potato (cv Norin 1) roots were incubated at 30°C after incubation with or without the fungus. Thin (0.5 x 10 mm) slices were taken from the inner tissue (1-2 mm thick) adjacent to the cut surface, and from the noninfected tissue (1-2 mm thick) adjacent to the infected region, in both cases of mechanical injury and infection, respectively. The respiratory rate was measured by Warburg manometry, in the presence or absence of 10^{-3} M cyanide. ●---● , ○--○ , ▲—▲ , and △---△ : mechanically injured tissues with and without cyanide, respectively.

Generally speaking, the respiratory rate is controlled by the concentration of the initial substrate, the concentration of ADP related to oxidative phosphorylation, and the mass of the activity of the respiratory enzyme system.

The major initial substrates of respiration in sweet potato roots are starch and sucrose, and the minor ones are glucose and fructose.

In response to mechanical injury, monosaccharide derivatives such as glucose 6-phosphate seem to be used initially as the substrate, next comes sucrose, and then starch. Investigations so far indicate that it is not likely that the initial substrate is the limiting factor for wound respiration. In response to mechanical injury, acid invertase is formed *de novo* with a lag of several hours, and this activity reaches a peak at about 18 hr and then decreases. As shown in Figure 2, the activity is controlled by both the intrinsic enzyme and the proteinacious inhibitor. The amount of sucrose is decreased to a certain extent following the increase in the activity of acid invertase (Matsushita and Uritani 1974). It may be that soon after mechanical injury, sucrose is decomposed to glucose and fructose by increased activity of acid invertase, thus they are utilized as the substrate.

Finally, starch is decomposed to glucose with a lag of about 12 hr and this provides the substrate for wound respiration. The activity of both α-amylase and β-amylase is increased, but not to so marked an extent. We believe that the accessibility of those enzymes to starch granules in amyloplasts may be further strengthened by the change in amyloplast membrane in response to mechanical injury. As a result, reducing sugars such as glucose are increased (Kato and Uritani 1976).

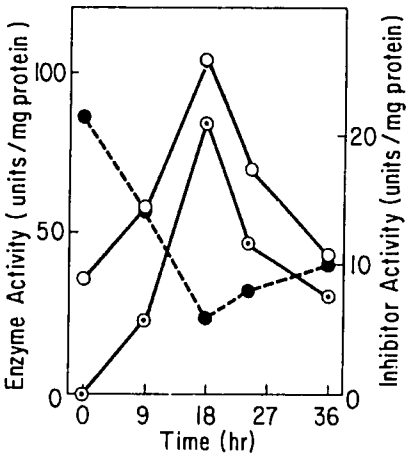

Figure 2. Changes in activities of apparent, intrinsic acid invertase, and the inhibitor in tissue slices (3 mm thick) of sweet potato (cv Norin 1) roots in the course of incubation at 30°C. ⊙—⊙ , O—O , and ●--● : activities of apparent, intrinsic acid invertase, and the inhibitor, respectively.

Decrease in starch and increase in reducing sugars in mechanically injured roots affects the quality of sweet potato as food and feed.

Regarding the concentration of ADP, adenine nucleotides including ATP, ADP and AMP are increased in the roots 3 hr after mechanical injury, and ADP itself is increased a little later. The increase in ADP may be due to the active operation of various ATP-utilizing events such as protein biosynthesis, and to the synthesis of adenine nucleotides (Takamura and Uritani 1973).

Regarding the mass of activities of the respiratory enzyme system, we have some evidence for increased activity of some enzymes in the glycolytic pathway and the pentose phosphate pathway. They are acid invertase, glucose 6-phosphate dehydrogenase and 6-phosphogluconate dehydrogenase. The later stage of the respiratory enzyme system is localized in mitochondria. The oxidative activity of mitochondria is stimulated in mechanically injured roots, when succinate and α-ketoglutarate are used as TCA-cycle intermediates. Furthermore, cytochrome c oxidase and succinate dehydrogenase, which are the enzymes bound to mitochondrial membranes, are synthesized *de novo*, preceding the increase in wound respiration (Maeshima and Asahi 1979).

Changes in enzyme activities reflect those in protein turnover (Uritani 1976). This means that individual concentrations of the intermediates and coenzymes, including vitamins, in the respiratory enzyme system are changed and the compositions of amino acids in the protein and amino acid pool are vigorously changed in mechanically injured roots. This leads to changes in taste and nutrition quality of sweet potato as food and feed. In fact, total ascorbic acid is increased during the increase of wound respiration, although the ratio of the oxidized type to the reduced type is higher in mechanically injured roots.

Polyphenol production

In response to mechanical injury, chlorogenic acid and isochlorogenic acid are produced in the roots after mechanical injury after about 12 hr (Uritani 1978a). Caffeic acid and its methyl ester are also produced though in lesser quantities. Production is highest in tissue very closely adjacent to the cut surface and gradually lessens in tissue inwards from the cut surface (Figure 3).

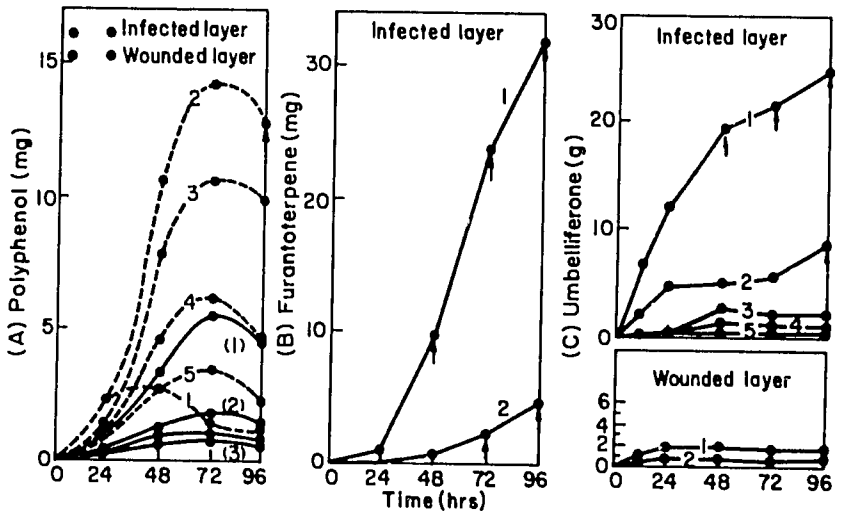

Figure 3. Production of abnormal secondary metabolites in different disc layers of tissue slices of sweet potato roots in response to mechanical injury or *Ceratocystis fimbriata* infection. Tissue slices (about 3 mm in thickness) of sweet potato (cv Norin 1) roots were incubated at 30°C after inoculation with and without the fungus, and were called "infected" tissue and "wounded" tissue, respectively. At appropriate periods slices were cut into discs (0.5 mm or 1.0 mm thick) starting from the cut surface and proceeding inwards, and different disc layers were analyzed for the three kinds of compound. (A) Polyphenol, mg (expressed as chlorogenic acid) per 15 discs (10 mm in diameter and 1 mm thick). (B) Furanoterpene, mg (expressed as ipomeamarone) per 15 discs (10 mm in diameter and 0.5 mm thick). (C) Umbelliferone, g per 10 discs (10 mm in diameter and 1 mm thick). ↑ shows the periods when more than 50% of the discs were infected. Numbers 1 to 5 indicate the disc layers (0.5 mm or 1.0 mm) from the surface inward to the inner tissue

RI and enzymatic experiments have shown that the shikimate pathway and phyenylpropanoid pathway are involved in polyphenol production in response to mechanical injury in sweet potato roots, as also in some other plants.

In response to mechanical injury, some enzymes pertaining to the shikimate pathway are formed, and phenylalanine ammonia-lyase (PAL) and trans-cinnamic acid 4-hydroxylase are synthesized a little later (Tanaka *et al* 1974). A combination of RI experimentation with immunochemical techniques has indicated that PAL is synthesized *de novo* perhaps through active operation of the masked DNA part by some plant hormone such as indoleacetic acid (Tanaka and Uritani 1977a, 1977b).

Peroxidase and polyphenol oxidase isozymes are synthesized *de novo* with lags of about 12 hr and 24 hr, respectively (Uritani 1976). Some of the former isozymes participate in the lignin layer formation, as described below. The latter isozymes are related to the browning reaction. In the intact tissue of mechanically injured roots, the isozymes are separated from polyphenols by the cellular membrane system. When such a tissue is homogenized or again injured, the browning reaction occurs, because polyphenol

oxidase isozymes freely oxidize polyphenols to *ortho* quinone, which is then combined with amino acids and proteins, producing the brown pigments. Thus, sweet potato roots suffering partial mechanical injury also suffer lowered food quality.

Wound layer formation

Wound respiration and polyphenol production are related to wound layer formation. In the case of sweet potato roots, the wound layer is composed of a lignin layer and a cork layer. Lignin is formed by the polymerized oxidation of the reduced type of phenylpropanoids with a lag of about 24 hr, perhaps by some specific peroxidase isozymes, called component H_1 and H_2 (Matsuno and Uritani 1972; Uritani *et al* 1975). Thereafter, the cork layer is formed immediately beneath the lignin layer. When humidity is high, a callus layer is also formed.

One treatment for such injury is to store the roots after harvest in a room at 30-35°C and 85-90% relative humidity for three to four days. This treatment is called curing. The wound layer formation is effective in protecting the roots from the attack of microorganisms and in minimizing the loss of water and nutritious components.

INFECTION

When mechanically injured, the injured parts of sweet potato roots are sometimes attacked by various kinds of microorganism, preceding the completion of wound layer formation. Soon after the infection of the injured parts, respiration and polyphenol production in adjacent non-infected tissue increase sharply (Figure 1 and 3) (Asahi *et al* 1979), and ethylene is rapidly produced. Furthermore, coumarins and furanoterpenes are produced in the infected region (Figure 3) (Uritani 1976, 1978a). Furanoterpenes are fungitoxic and belong to the phytoalexins (Müller and Börger 1940). The main component of furanoterpenes is called ipomeamarone (Hiura 1941; Kubota and Matsuura 1953), and now about ten components have been characterized by Burka *et al* (1977) and Uritani (1978a). Both coumarins and furanoterpenes are toxic to pathogens, and normally protect the root tissue from the penetration of pathogenic microorganisms. Those components are produced in relatively large amounts in parallel with the penetration of pathogenic microorganisms such as *Ceratocystis fimbriata* (Ell *et* Halst) Elliot (Uritani 1971), *Fusarium oxysporum* f *batatatis* (Wollenweber) Snyder *et* Hansen (Burka *et al* 1977), and *Botryodiplodia theobromae* (Arinze and Smith 1978).

When mechanically injured, sweet potato roots acquire the potential to produce coumarins and furanoterpenes rapidly and largely in response to the infection, although they are only barely present - or are quite absent - in uninjured roots. In response to mechanical injury, some parts of the biosynthetic pathway of furanoterpene production are induced, and the subsequent infection completes the pathway, leading to the biosynthesis of this compound (Figure 4) (Uritani 1971, 1978a; Uritani and Asahi 1980; Uritani *et al* 1981). Ethylene may take part in the above events, even if it only plays a small role.

When considered from the food science viewpoint, the production of those stress compounds including furanoterpenes, coumarins and polyphenols is undesirable. They are all more or less toxic, and harm the taste, especially furanoterpenes which are extremely bitter.

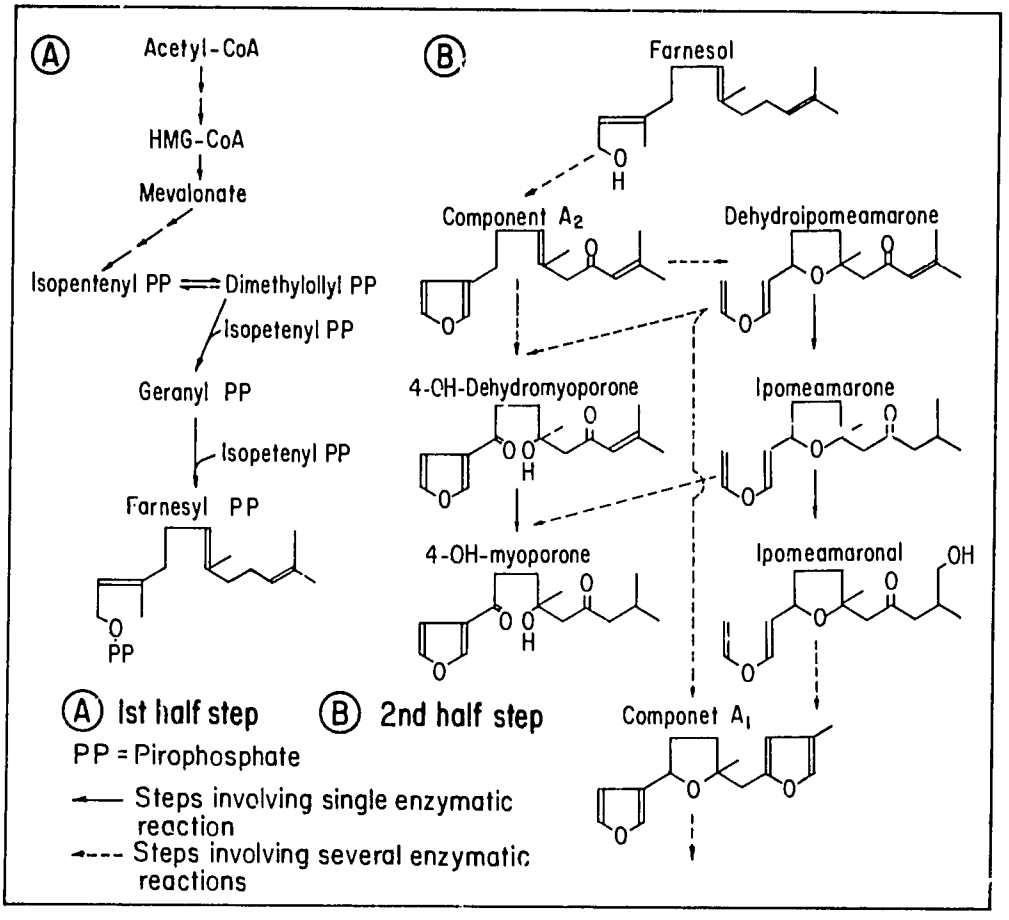

Figure 4. Pathway for the biosynthesis of furanoterpenes in sweet potato roots in resonse to infectious injury

CONCLUSION

The problems of postharvest storage and handling of sweet potato roots differ between temperate regions and tropical or subtropical regions. It is important to harvest sweet potato roots without causing injury and to store and to handle them without doing them either visible or invisible harm.

It would be an important advance to devise methods of harvest and post-harvest storage and handling which avoid mechanical injury. Further, it might be a worthwhile aim to try to breed sweet potato varieties with epidermal cells which are tough enough to resist injury.

It may be easy to cure sweet potato roots before hauling or storage, in tropical or subtropical regions, because of the relatively high-temperature climate. Should sweet potato roots become more highly appreciated as food by people in tropical or subtropical regions, as they are in some temperate zone countries such as the USA and Japan, it would be worthwhile to carry out curing in these regions.

It is not easy in tropical or subtropical regions to store sweet potato roots at about 10-20°C, as they are in the temperate regions. We should

devise ways of storing the roots without high carbohydrate consumption and sprouting even at 25°C or higher. One approach may be to test storage in precisely controlled atmospheres using plastic packing.

Sweet potato may have defense mechanisms to microbial infection other than the stress compound production described above. These may involve the recognition of microorganisms as 'non-self' by some lectin(s) in sweet potato (Uritani and Kojima 1979). The role of these lectin(s) in the defense against microbial infection should be further explored.

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Solar Dehydration of Sweet Potato

J. H. MOY and S.P.S. CHI

Department of Food Science and Human Nutrition, University of Hawaii, Honolulu, Hawaii 96822, USA

INTRODUCTION

Solar drying of crops and some food products has been practiced through the ages in various parts of the world. An economical means of converting a harvested product to its dried state with a reasonable shelf life, solar drying has the advantage of using a source of free and non-polluting energy for drying with minimal investment in equipment. Its drawbacks are that the energy input and product quality can seldom be controlled. Also, the crop or food being dried is easily contaminated by dust and insects. As a result, the quality of solar dried food, except grains, is often considered inferior to that of other dried foods.

Solar dehydration - a process combining drying and temperature control, air flow regulation, and other technical innovations - is emerging as a step towards improving the quality of sun-dried products and increasing the efficiency of the solar drying process. The potential of solar dehydration technology to reduce or eliminate many of the problems encountered in sun-drying, such as lack of hygiene, inefficient energy utilization, localized heating and inferior product quality, has only recently been recognized.

For centuries, the sweet potato was an important food plant in different parts of the world: notably in tropical America, the tropical Pacific and northern New Zealand. Spanish explorers in the early 16th century carried the plant in both the easterly and westerly directions and disseminated it to Europe, Africa, southeast Asia, North America and the East Indies.

Sweet potatoes are usually boiled, baked, roasted or fried for home consumption. Only since the early 1900s was sweet potato processed into dehydrated form (Ammerman and Edmond, 1971). In the United States, peak production of dehydrated sweet potato was reached in the Second World War with 25 million kg in 1944. Precooked dehydrated sweet potato flakes were manufactured with the following steps: raw material storage, washing, preheating, peeling, trimming, slicing, blanching, pureeing, drying, grinding, and packaging. While sweet potatoes are also marketed in canned and frozen form, it is quite likely that drying will reemerge as being more cost-effective than canning and freezing, especially because of the energy problem.

A survey of recent literature shows that very few processed sweet potato products are produced in other parts of the world. In the Philippines, sweet potato and aroids are grown and consumed as food quite extensively (Villanueva 1979). Processed products from sweet potato are very limited, which is due probably to a limited market, varied quality, inconsistent supply and unavailability of suitable processing technology for small scale and large scale operations.

In Papua New Guinea, sweet potato is processed into 'kaukau rice', by roller-crumbling, shredding and hot air drying of the roots (Siki 1979). It

is cooked and consumed in ways similar to rice. Deep fat fried sweet potato chips are also experimentally prepared there. Sun dried sweet potato chips are used primarily as pig and poultry feed.

In Taiwan, only 25% of the population consume sweet potato regularly (Calkins 1979), and mainly in boiled form. Starch is made from sweet potato but it cannot compete with white potato or cassava for this purpose. It is also used as an animal feed.

Worldwide consumption of sweet potatoes appears to be declining. To improve its storage stability and utilization, processing methods should now be found that are practical and economical in converting the sweet potato into a quality product. Solar dehydration might be one such method.

In a recent study at the University of Hawaii at Manoa, sweet potato was one of several under-utilized tropical root crops and fruits dried in a combined mode solar dehydrator. The objectives of the study were to conserve conventional energy, to improve the quality and economics of solar dried foods, and to advance solar dehydration technology.

EXPERIMENTAL

Solar dehydrator - design and construction

A combined mode, or mixed mode, solar dehydrator was designed and built. Solar-heated air from a detachable solar collector supplies the thermal energy for drying in the indirect mode. In the direct mode, it functions with solar radiant energy absorbed in the drying chamber. Thus this solar dehydrator can function in three modes of drying: direct, indirect and combined direct and indirect. Figure 1 shows the side view and dimensions of the dryer while Figure 2 shows the cutaway view of the drying chamber.

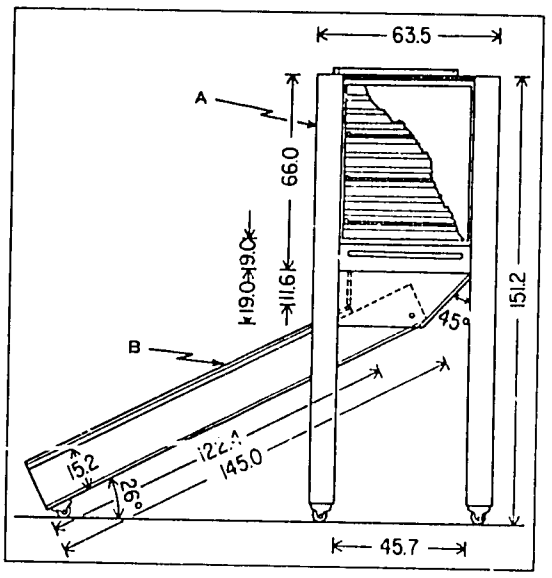

Figure 1. Side view of the combined mode solar dehydrator with dimensions in centimeters. A is the dehydrator and B the solar collector

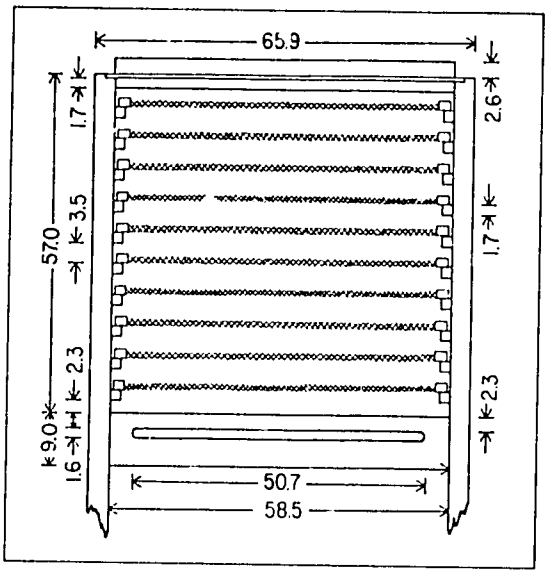

Figure 2. Cutaway view of the drying chamber of the combined mode solar dehydrator with dimensions in centimeters

The basic materials of construction are plywood and wood. The drying chamber features sliding panels on its four sides providing for selection of different construction materials for drying rate comparison and for different modes of operations. Panels of aluminum screening, aluminum sheeting painted black and clear plastic (acrylic) were used for direct, indirect and combined mode respectively. The top of the chamber is equipped with a detachable panel similar to the side panels with about a 3 cm wide space on the back side (opposite to the collector entrance) for air movement when the indirect or combined mode is used. Air movement is by natural convection.

A duplicate combined mode solar dehydrator was built to allow direct comparisons of different modes of drying operation under the same solar and weather conditions.

Solar dehydration of sweet potato

Sample preparations: Samples of sweet potato (Hawaii No. 1 Grade) were prepared by washing, boiling, peeling, trimming and slicing into 6 x 80 x 20 mm pieces. The slices were dipped in a 2% sodium metabisulfite solution for two minutes to minimize discoloration

Weather conditions, temperature and solar radiation measurements: In solar drying and other solar applications, the most variable and unpredictable factor is the weather. A completely clear and sunny day would provide ideal conditions for solar dehydration. More often than not, however, non-ideal conditions prevail. The availability of solar energy in a given location on a given day could change by the hour.

The weather in Hawaii changes less than that in many other parts of the world, but it still changes. The campus of the University of Hawaii, where our experiments were conducted, is situated in the Manoa Valley (Honolulu), where cloud, rain and sunshine fluctuate. Fortunately, the samples inside the dryer were protected from sudden rain because of the design of the dehydrator.

A hygrothermograph was used to monitor ambient air temperature and relative humidity (Bendix Corp, Baltimore, MD, USA). Temperatures at various points of the dryer system were measured with copper-constatan thermocouples and recorded on a 12-point potentiometric recorder (Honeywell, Philadelphia, PA, USA). On-site direct solar insolation was measured with an Eppley black and white pyranometer and recorder (Eppley, Newport, Rhode Island, USA).

Drying rate measurements: Drying rates of different samples dried in different modes of solar dehydration were measured by the gravimetric method. A single layer of sweet potato slices was placed on the drying screen which resulted in a loading density of 6.4 ± 0.4 kg/m^2.

Use of dehumidified air in solar dehydration

It is generally recognized that lowering the relative humidity of the air used in a dryer should help increase the drying rate by allowing a larger vapor pressure gradient between the water in the food and the water vapor in the air and therefore a larger driving force for vapor transfer. This part of the experiment explored the use of dehumidified air in the solar dehydrator.

Sample preparations: Samples of sweet potato (Hawaii No. 1 Grade) were prepared by washing, blanching in boiling water for 30 minutes and slicing into 5 x 5 x 30 mm pieces. Blanching is another accepted practice to minimize darkening of the sweet potato.

Drying system with or without dehumidified air: When the solar dehydrator described above was operating in the combined mode, it served as the control run for comparing solar drying rates and determining the benefits of using dehumidified air in solar dehydration.

Modification was made to the solar drying system to accomodate compressed air being dehumidified in a silica gel column before being admitted to the solar collector for drying of sweet potato samples. The air was forced through the silica gel column by a 1.5 hp air compressor. Air velocities in the two drying chambers were measured with a hot wire anemometer (Alnor, Niles, Il, USA).

Drying rate measurements: Solar drying rates of sweet potato samples in the two systems were measured by the gravimetric method. The loading density was about 3.5 + 0.3 kg/m^2.

The 'Osmosol' process for drying sweet potato

Osmosol process: This is a two-step process involving the removal of water from a food in a concentrated syrup (usually about 60-65° Brix) for 4 to 6 hr; then transferring the food to a solar dehydrator to complete the drying. It is a variation from the 'osmovac' process (Ponting *et al* 1966; Farkas and Lazar 1969; Moy *et al* 1977a, 1979) where the second step is carried out *in vacuo*. Preliminary experiments showed that the vacuum drying step was not necessary, and quality of the osmosol dried samples was quite good. A schematic diagram of the process is shown in Figure 3.

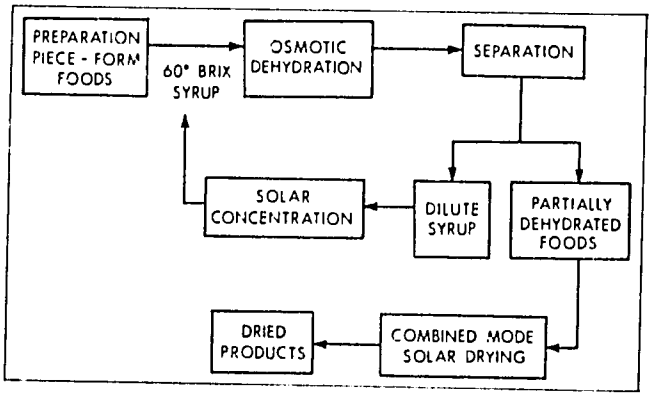

Figure 3. A schematic diagram of the osmosol process

Figure 4. A combined mode solar dehydrator used in solar drying experiments

Osmosol drying experiments: Samples of sweet potato (Hawaii No. 1 Grade) were prepared in the same way as for the direct, indirect or combined mode solar drying except that the samples were first placed in four osmotic vessels with recirculating 65° Brix syrup for 4 hr. The samples were then removed from the syrup, given a quick rinse of cold water, dipped in a 2% sodium metabisulfite solution for 2 min, drained and then loaded on screen trays at about 6.0 ± 0.4 kg/m^2 for combined mode solar drying.

These were exploratory experiments in that drying rates determination was not replicated, and quality was evaluated by an informal taste panel only.

RESULTS AND DISCUSSION

Performance of the solar dehydrator

There are ten shelves in the solar drying chamber each measuring 42 x 44 cm. The total area available for solar dehydration is 1.85 m^2. With the loading densities used in various experiments, the capacity of the dehydrator is 6.5 to 12 kg per load. This was not used in actual experiments because it would involve a large amount of material for each experiment and time and logistics made this impractical. The experimental results reported here represented only partial loading of the solar dehydrator.

With natural convection, ambient air entered the solar collector and was heated twice - in the collector and again in the drying chamber when operating in the combined mode. It was quite obvious that the air received more heat in the combined mode than in either the direct or indirect mode. Temperature measurements in the geometric center of the drying chamber in the combined mode on a typical day showed the air heated to 40°C at 10 AM, and to a maximum of 54°C between 12 noon and 1 PM, and then decreased to 44°C by 4 PM. This was in comparison to ambient air temperatures of 29°C, 32°C, and 30°C at the same times. Solar insolation varied from day to day and from month to month. The highest average was in September, 632 cal/cm^2/day; the lowest was in December-January, 320-370 cal/cm^2/day. These readings obtained during the period of May-September were comparable to those measured in other locales in the US such as Miami, Florida and Charleston, South Carolina, but not as high as those in Albuquerque, New Mexico and El Paso, Texas (Löf *et al* 1966).

Figure 4 shows the combined mode solar dehydrator as constructed. The mid-plane of the solar collector was a piece of corrugated copper plate painted black serving as the solar heat absorber. Other metals such as galvanized iron could also be used, but copper has a thermal conductivity two to seven times higher than other metals commonly available for industrial applications. The efficiency of the collector could also be increased by adding a triangular-shaped collector to each side, or by adding fins to the copper plate.

A common problem in solar drying is the interruption of drying caused by cloud, rain and nightfall. An electrical heater could be installed to supply the thermal energy needed to continue drying. This is not always practical and is not in line with the idea of conserving conventional energy. A good substitute for an electrical heater in this situation would be to use biogas to augment solar drying, especially by generating biogas from fruit and vegetable wastes.

Solar dehydration of sweet potato

Results of drying 6 mm thick cooked sweet potato slices in three modes of solar dehydration are shown in Figure 5. Represented in a composite of 2-3 days' drying rate data, the indirect mode of solar dehydration was the least efficient of the three. This was because the thermal energy for drying came mainly from the heated air through the solar collector. The combined mode solar dehydrator was the most efficient of the three modes. It utilized both direct solar radiant energy in the drying chamber and solar-heated air from the collector to the food samples. The efficiency of the direct mode solar drying was between that of the indirect mode and that of the combined mode.

These findings agree with earlier solar drying studies of raw taro and raw sweet potato slices in terms of the drying rates in the three modes of drying (Moy *et al* 1977b, 1980a). The drying rates of raw taro and sweet potato slices were higher than those of cooked sweet potato slices. This was due to the changes in the chemical structure of the two forms of the root, uncooked and cooked. The starch in the cooked slices gelatinizes during cooking, and water has to be removed from a more tightly bound structure.

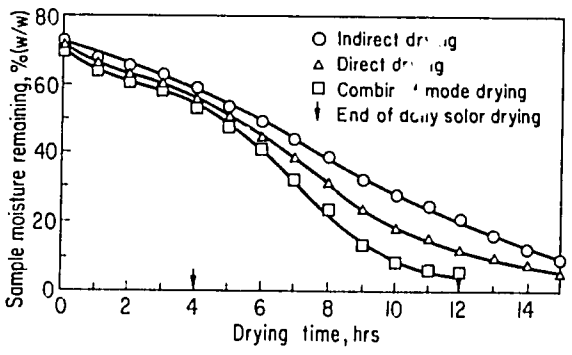

Figure 5. Drying rates of 6 mm thick, cooked sweet potato slices in three modes of solar drying at a loading density of 6.4 kg/sq m

It is logical (but not always compatible with techniques available), that forms of sweet potato to be dehydrated should have some relationship to the forms people prefer to consume. If served as table sweet potato, it should probably be in chunk form. While this is available as a canned or frozen product, it is not practical to dehydrate in this form because of the thickness involved. Another commercial form involves the preparation by drum drying of sweet potato flakes. When rehydrated, this becomes mashed sweet potato. But this form probably has only limited appeal.

This leaves the slices, dices or shreds as suitable forms for drying. The raw slices or shreds can easily be solar dried, and can be ground into a flour. This flour can be still further processed into forms resembling rice, noodle and macaroni. No work has been done in this area except on taro in Papau New Guinea mentioned earlier (Moy *et al* 1980b). The potential of this form of sweet potato product should be explored.

The form of solar dried, cooked sweet potato slices prepared in this study can be used as a snack and marketed in the same category as dried fruit. Some of the experimental samples were quite acceptable based on an informal taste panel evaluation. The color and texture of the solar dried sweet potato could be further improved to minimize darkening and case harden-

ing. Studies of the chemical and organoleptic qualities and storage stability of solar dehydrated sweet potatoes are under way.

Dehumidified air in solar dehydration

Drying rates of sweet potatoes in the combined mode solar dehydrator were compared with or without using dehumidified air. Figure 6 shows that in terms of sample moisture remaining compared to drying time, the use of dehumidified air increased the drying rates by about 6-8%. The higher drying rate began after the first hour until the moisture contents of the blanched samples dropped to about 20%. A small difference in drying rates was observed in the latter period of drying at the end of which the final moisture fell to about 10%. Results also showed that it took about the same length of time to remove the next 10% of moisture as the first 55% of the moisture from the samples. This occurs in a number of drying processes including vacuum drying and freeze drying. The use of dehumidified air is not considered sufficiently efficient. In the case of solar drying of sweet potatoes, the variables were the amount of heat transfer from solar radiation to the dryer system, size and shape of the samples, loading densities, and the relative humidity of the air as a result of being heated.

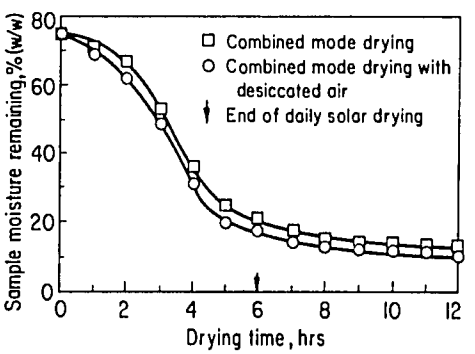

Figure 6. Drying rates of blanched sweet potato (5 x 5 x 30 mm) at a loading density of 6.0 kg/sq m in the combined mode solar drying with and without using dehumidified air

In these experimental runs, the percentage relative humidity difference between using and not using dehumidified air was about 10 to 12% during most of the drying period. The temperature in the system using dehumidified air was 5 to 7°C higher than the one without dehumidified air. This phenomenon can probably be attributed to the lower air velocity in the dryer with dehumidified air, 3.8 m/sec as against 5.0 m/sec in the system without dehumidified air. Thus, the contribution to drying rate increase made by lowering relative humidity by using dehumidified air was considered not significant.

Qualities of the sweet potato samples solar dried with and without dehumidified air were quite acceptable. However, during six months of storage in glass containers, the samples gradually turned dark.

Adding dehumidified air to the solar dehydration system requires using a quantity of desiccant such as silica gel, and expending a certain amount of thermal energy to regenerate it frequently. While regeneration of the desiccant using solar energy is feasible, the technology is not economically so as yet. In view of the added cost involved in using dehumidified air, it is not considered cost-effective at present.

Results of the osmosol process

Sweet potato samples of the same size as used in the combined mode solar dehydration (6 x 80 x 20 mm) were first dehydrated for 4 hr in recirculating syrup of 65° Brix, then placed in the combined mode solar dehydator for the second phase of drying until the final moisture was about 8-10% of wet weight.

Flavor, color and texture of osmosol-dried samples were quite good as judged by an informal taste panel. Except for the slight increase in sweetness, the overall quality and acceptability were as good as or better than those by the combined mode solar drying.

The problems with this process are the additional time, labor and expense required in the osmotic dehydration step. But compared with the conventional method of preparing glazed fruit, which takes many hours of cooking the fruit in syrup, the 4 hr osmotic step used in this experiment seems quite practical. In a study of the economic feasibility of making osmovac dried tropical fruits, Moy and Spielmann (1980) found it to be economically feasible and can compete with other conventional nonglazed, dried fruits such as dried peach, prune, apricot, and so on.

Since the osmosol process will be more economical than the osmovac process because solar dehydration is less expensive than vacuum drying, the potential of the osmosol process is worthy of further study.

CONCLUSIONS

Experimental results of several methods of solar dehydration of sweet potatoes led to the following conclusions:

1. The combined mode solar dehydrator is efficient and economical in producing quality dehydrated sweet potato slices and other root crops. 2. Dehumidifying the air prior to solar dehydration does not contribute to a significant increase in drying rate and is tentatively judged not economically practical. 3. The osmosol dehydration process can produce sweet potato slices of good quality. Its potential application warrants further study. 4. Studies of chemical, organoleptic and storage qualities of several promising forms of solar dehydrated sweet potato should be encouraged and supported.

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AVRDC flood tolerance screenings at the seedling stage.

Sweet Potatoes (*Ipomoea batatas* (L) Lam) for Beef Production: Agronomic and Conservation Aspects and Animal Responses

M. E. RUIZ

Tropical Agricultural Research and Training Center (CATIE), Turrialba, Costa Rica

INTRODUCTION

Traditionally, the sweet potato (*Ipomoea batatas* (L) Lam) has been cultivated for its root production, its aerial part being considered as a residue. The value of the root rests on its high energy content (2.6 Mcal of metabolizable energy/kg of dry matter (DM), according to McDowell *et al* (1974); but its crude protein content is only 3.4% (Backer 1976). The aerial part is usually left in the field. It is known that animals can consume the aerial part, but little information on its nutritional characteristics has been produced.

One idea that is being explored by researchers in tropical America is the development of new animal feeding systems for the small farmer, utilizing crop residues and even whole crop biomass as the basis for the system. Due to the popularity of sweet potatoes among Central American farmers, this is one of the main crops that is being studied in this context.

This paper deals with variations in agronomic management, taking into account the need to produce foliage as a source of roughage and protein for ruminants. Also, the silage characteristics of the foliage and roots are examined, since a whole crop is usually harvested at once and the use of its residues over a prolonged period of time will require conservation measures. Finally, digestion, consumption and input/product data and an animal production model based on these aspects will be presented to provide an idea of the potential of sweet potato as a dual-purpose crop: as a direct provider of food to man and of feed for cattle whose product, milk or beef, is used by man as a major source of high quality protein.

AGRONOMIC ASPECTS

Planting density

The production potential of sweet potato roots, under Costa Rican conditions, and with certain varieties, can reach up to 25 t/ha/harvest (Zumbado 1967; Mora-Vargas 1969; Pinchinat 1974). Usually, the planting distance has been 50 cm between plants and 1 m between rows (Pinchinat 1974). Very few studies have been conducted with regard to planting density and these have shown that as the distance between plants is reduced the root yield will decrease (Mandal *et al* 1971) and the foliage yield will increase (Gamboa 1962).

To examine the effects of varying the planting density on foliage and root production, and on chemical composition and digestibility of the foliage, Ruiz *et al* (1980) compared four distances of planting: 10, 20, 30 and 40 cm between plants (maintaining 50 cm between rows constant) in two varieties of sweet potato, C-15, commonly used in Costa Rica, and C-1 Asbana which was

introduced to Costa Rica from Taiwan and is characterized by a shorter vegetative cycle (Personal communication with Roger Meneses, CATIE).

In Table 1, the results on foliage production, at the end of the growth cycle (165 days for variety C-15 and 131 days for variety C-1) are shown.

From Table 1, it is clear that the total foliage yield is 39% greater from C-15 than from C-1. However, this comparison is distorted since the C-1 has a much shorter growth cycle; therefore, the rate of growth of the aerial part is a more appropriate basis for comparison. In this respect, although the C-15 still shows some superiority (10%), the difference between the two varieties is not significant.

Table 1. Total yield and rate of growth of sweet potato foliage (Ruiz *et al* 1980)

Variable	Avg density plants/ha	Yield kg DM/ha/crop	Growth rate kg/DM/ha/day
Variety			
C-15	104,000	5,979	36.2
C-1	104,000	4,305	32.9
Distance between plants			
10 cm	200,000	4,779	32.3
20 cm	100,000	5,090	34.5
30 cm	67,000	5.254	35.5
40 cm	50,000	5,222	35.3

Distance between plants did not cause significant differences in the yield of foliage. The yield from plots where the distance between plants was more in accordance with commercial planting (40 cm), was as high or even higher than the yields from plots with more dense planting. The dry matter (DM) content of the foliage at harvest was, on the average, 14.6% with very little variation; this means that the yield on fresh basis was approximately 36 t/ha/crop. It is interesting to note that the rate of growth of the aerial part (32.3 to 35.5 kg DM/ha/day) is superior to that observed in natural swards (González 1979), similar to grass-legume associations (Coimbra 1979) but slightly inferior to fertilized pastures (Rocha 1978), all comparisons made among results obtained from CATIE's experiment stations in Costa Rica.

With respect to root yield no significant differences are caused by varying the distance between plants (Ruiz *et al* 1980), the average production being 3409 kg DM/ha/crop. The average DM content in roots is 30.1% (Backer *et al* 1980).

It would seem, then, that planting density has no significant effect on either foliage or root yield, thus contrasting with the results found by Mandal *et al* (1971) and Gamboa (1962). It is remarkable that foliage is produced at the level mentioned; this implies that in certain areas of the tropics, where two crops of sweet potatoes can be obtained per year, as much as

70 t/ha of fresh material can be harvested. With respect to the root production, yield is not high (11 t/ha/crop) when compared to other experimental results, for example that of Mora-Vargas (1969) who obtained 34 t/ha of fresh roots.

Frequency and intensity of pruning

The work by Ruiz *et al* (1980) included the study of the effects of cutting off the sweet potato vines on yields of aerial parts and roots. In Table 2, it can be seen that cutting off most of the vines (leaving one or two per plant) will significantly increase the yield and rate of growth of the aerial part. Also it seems unimportant whether one vine or two are left since the foliage yields were not different between these two treatments.

Table 2. Effect of frequency and intensity of pruning on the yield of foliage and roots (Ruiz *et al* 1980)

Variable	Foliage[a]		Root[a]
	yield kg DM/ha/crop	growth rate kg DM/ha/day	Yield kg DM/ha/crop
Number of prunings			
One (only at harvest)	4,136 a	27.9 a	5,634 a
Two (two months after planting and at harvest)	5,212 b	35.2 b	3,706 b
Three (three months after planting and at harvest)	4,845 b	32.7 b	3,409 b
Intensity of pruning			
Leaving one vine	5,035 a	34.0 a	3,416 a
Leaving two vines	5,250 a	35.5 a	3,699 a

[a]Figures with different superscripts are significantly different ($P \leq 0.05$)

On the other hand, pruning had a negative effect ($P \leq 0.05$) on root yield. That is, the greater foliage production induced by pruning resulted at the expense of root yield, probably because a reduction of leaf area results in a poorer solar energy utilization for root development (Lizarraga 1976) or because regeneration of the aerial part will draw on the energy stored in the roots. In any case, the results described offer the possibility of managing the crop to increase leaf (protein) yield at the expense of roots (energy) or vice versa, depending on the objectives set.

Meyreles and Preston (1979) initially pruned at three months after planting and afterwards compared cutting every 4, 6, 8 or 10 weeks. All cuttings were complete; that is, no vines were left on the ground. They found that the yields were 88, 121, 108 and 122 t of fresh material/ha on a yearly basis, respectively; however, the proportion of leaf in the cut material declined as the cutting interval increased, and the authors concluded that an interval of six weeks between cuttings was optimum. Unfortunately, no data on root production were provided.

CHEMICAL COMPOSITION AND DIGESTIBILITY

Differences in crude protein content can be expected between varieties, judging from the results shown in Table 3 (Ruiz *et al* 1980). The superiority of C-1 over C-15 is very evident although both varieties received the same amount of nutrients (125, 130 and 48 kg of NPK/ha). Other than the effect on crude protein, no other differences are found due to variety.

In Table 3, it can also be seen that when the aerial part is cut, either at two or three months after planting, the protein content of the foliage is always higher, nearing the value of 20% on a dry basis, as compared to the values found at the end of growing period.

Distance of planting and intensity of pruning do not alter the content of crude protein either at the time of pruning or at the end of the growing period. As expected, when the material is cut at three months, its protein content is lower than when it is cut at two months ($P \leq 0.05$).

A striking result in Table 3 is that which refers to the *in vitro* digestibility data. The procedure used for determining this is the two-stage technique of Tilley and Terry (1963), which simulates rumen and gastric digestion. All figures indicate that the sweet potato tops are highly digestible and, furthermore, that their digestibility does not change with age: the aerial part at normal harvest age is similar in digestibility to the aerial part at two or three months after planting.

Table 3. Content of crude protein (CP), cell wall constituents (CWC) and *in vitro* dry matter digestibility (IVDMD) of sweet potato foliage at pruning (A) and harvest (B) (Ruiz *et al* 1980)

Variable	% CP[a]		% CWC[a]		% IVDMD[a]	
Variety	A	B	A	B	A	B
C-15	17.5	12.2 a	28.2	29.7	74.0	72.3
C-1	20.2	17.3	29.3	33.6	80.2	77.2
Distance between plants						
10 cm	18.2	13.6	28.6	31.8	75.3	75.5
20 cm	18.9	15.6	29.1	31.3	75.3	71.7
30 cm	18.5	15.6	28.9	31.5	71.4	77.4
40 cm	19.9	15.7	29.5	31.5	77.8	75.4
Number of prunings						
One (only at harvest)	20.3 a	14.5	26.0 a	32.0	77.6	74.7
Two (at two months and at harvest)	17.4 b	15.0	32.0 b	31.0	76.6	75.0
Two (at three months and at harvest)	-	13.7	-	29.5	-	75.1
Intensity of pruning						
Leaving one vine	18.7	14.6	29.0	31.2	78.2	71.5
Leaving two vines	19.0	14.9	29.1	31.8	76.1	74.4

[a]Within a factor and column, different superscript indicate significant differences ($P \leq 0.05$)
Dry matter at pruning time was 11.7 and at harvest 14.6 with minimum due to factors

SILAGE CHARACTERISTICS OF SWEET POTATO FOLIAGE

After harvesting sweet potatoes, a large volume of foliage, constituted by stems and leaves, and a variable amount of non-commercial roots are left in the field. Some varieties may be used to produce two or three crops per year, which could represent up to 125 t/year of fresh material of which 64% would be the aerial part (Pinchinat 1974). Chemical analyses of the aerial part indicate values of 12% to 17% crude protein, less than 18% crude fiber and a DM digestibility of over 70% (Ffoulkes *et al* 1978; Ruiz *et al* 1980). However, a major constraint in the use of the sweet potato residues as animal feeds is the fact that they are produced once or at most twice a year, usually at a time when pastures are in any case abundant. Therefore, there is a need to conserve these materials or to plant the crop in strips at appropriate time intervals.

The information that follows is derived from the work of Ruiz *et al* (1981) which was carried out using microsilos consisting of double plastic bags where chopped sweet potato foliage dried for one day was introduced and packed together with various additions of urea and roots. The addition of urea to ensiling material is to promote the formation of lactic acid which is desirable (Lara y Lara 1977) although it may also cause an increase in butyric acid (Barnett 1957), an acid that imparts a foul smell to silages and causes animals to reject them. The use of a source of rapidly fermenting carbohydrates, such as molasses, cereal grains or roots is to promote a rapid fermentation which will lower the pH to a point where bacterial action will cease (Cherry 1970).

Dry matter content and losses by putrefaction

Dry matter content of sweet potato foliage silages does not change by adding roots (up to 1.2%) or urea (up to 1.6%). The average DM content is 20.4 in these silages, which is higher than the content in fresh material (14.6), the difference being due to the wilting for 24 hours prior to ensiling.

Losses of DM by putrefaction are not altered by additions of roots, and average 21.6 loss when the level of urea is kept constant at 0.8%. This implies that the sweet potato top silage does not require any rapidly fermenting carbohydrate additive and that the forage is sufficiently fermentable. Other results shown later give support to this statement.

In contrast to the effect of adding roots, the addition of urea increases the proportion of silage lost by decay or mold invasion (Figure 1). When no urea was added less than 10 of the silages were lost, but the losses increased exponentially to 28 with additions of urea.

Such a deleterious effect of urea clearly eliminates it from consideration as an additive for sweet potato foliage silage. Although there is a dearth of information relating to the causes of this effect, it may be speculated that the microbial activity in the silage was stimulated due to the alkaline effect of urea which would promote an undesirable fermentation by clostridia and mold (Britt and Huber 1975).

Acidity

The implication of an alkaline effect of urea is clearly demonstrated in Figure 2.

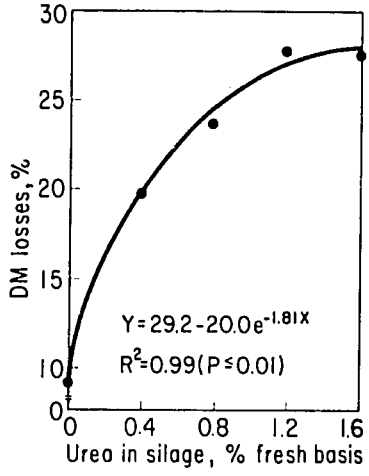

Figure 1. Effect of the addition of urea (X) to sweet potato foliage silage on the losses by putrefaction (Ruiz *et al* 1981)

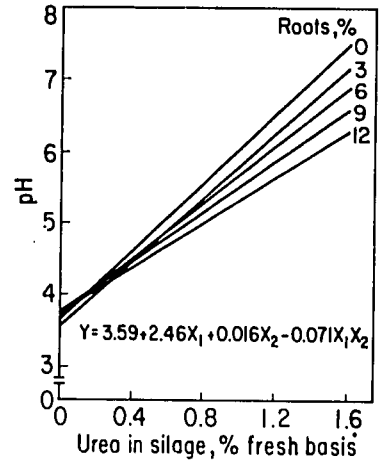

Figure 2. Effect of the addition of urea (X) and roots (X_2) on the pH of sweet potato foliage silage (Ruiz *et al* 1981)

In Figure 2, it is clear that urea has a definite effect on pH, and raises it to values between 6.2 and 7.5, depending on the amount of roots added to the ensiled material. Figure 2 also serves to illustrate that if no additives (neither urea nor sweet potato roots) are added, a silage made of sweet potato foliage is sufficiently acid (pH 3.6) to show excellent conservation characteristics, according to Wilkinson *et al* (1976). When no urea is used, or if low levels are used, adding roots to the silage does not seem to affect the pH.

Organic acids: acetate, butyrate and lactate

Lactic acid content in the silages was highly variable and no definite trends could be detected as a function of level of urea or roots. The average lactic acid content was 2.01 ± 2.27% on dry basis.

Urea did not cause definite changes in either acetic or butyric acid; however the addition of roots tended to increase linearly the concentration of these acids (Figure 3).

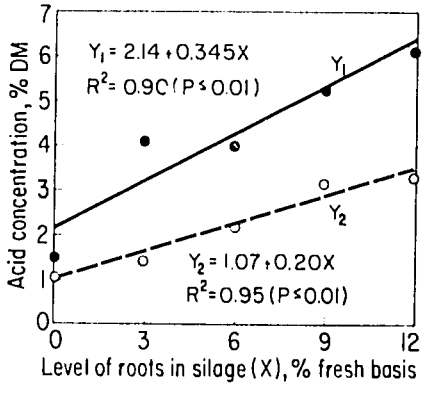

Figure 3. Changes in acetic acid (——) and butyric acid (---), concentration in sweet potato foliage silage as a function of the amount of roots added (Ruiz *et al* 1981)

The plotted points in Figure 3 correspond to silages where an average of 0.8% urea was present. Although not shown here, Ruiz *et al* (1981) reported that the silages which did not receive any additives contained 0.68% butyric acid, 3.49% acetic acid and 5.21% lactic acid, on a dry basis, which indicates excellent silage characteristics according to Barnett (1957). Thus, the data shown lead to the conclusion that excellent quality silages can be obtained from sweet potato foliage when no additives are used. It remains to be seen if such indication is valid for practical, in-field condition silages; according to Moreno (1977), there exists a positive correlation between laboratory and field silages with respect to qualitative parameters.

ANIMAL RESPONSES

Given the information on the quantitative and qualitative characteristics of the sweet potato foliage, its utilization for animal feeding presents possibilities exceeding in value other tropical plant materials that have recently been considered. Nevertheless, to decide whether the sweet potato plant can play a role in some improved animal production systems, it is essential to study its acceptability by cattle and their efficiency in converting the foliage and roots into milk or beef.

Because of the convenience in handling the animals and in measuring biological responses, nearly all the research on the use of sweet potatoes for cattle feeding has used beef steers.

Voluntary intake

Despite the high digestibility (70%) of sugarcane (*Saccharum officinarum*, L), cattle do not consume it at levels that will support high rates of production. Given this situation, Ffoulkes *et al* (1978) reported that by substituting sweet potato forage for whole chopped sugarcane a significant increase in total DM intake occurred (Figure 4).

Given the similar values in DM digestibility for both sugarcane and sweet potato forage, the intake of digestible DM follows the same pattern as the intake of DM (Figure 4). Also, the higher intake means an increase in true protein supplied by the sweet potato forage (Table 4) and a reduction in the non-protein nitrogen provided by urea (Table 4).

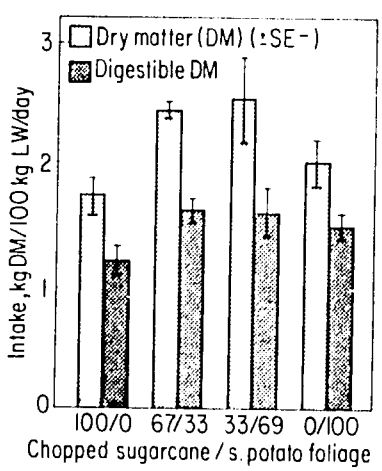

Figure 4. Dry matter and digestible dry matter intake of steers fed diets including different proportions of chopped sugar cane and sweet potato foliage (Ffoulkes *et al* 1978)

Table 4. Intake of the diet components and sources of N in diets with different proportions of whole cane/sweet potato foliage (Ffoulkes *et al* 1978)

	Sugarcane : sweet potato foliage (dry basis)			
	100:0	67:33	33:67	0:100
DM intake, kg/day				
Total	3.88	5.41	5.70	4.51
Sugarcane	3.88	3.62	1.88	-
Sweet potato	-	1.79	3.82	4.51
Protein provided by sweet potato, g/day	-	370	784	900
Nitrogen provided by urea, g/day	136	124	68	-

In view of such changes in the composition of the dietary nitrogen, Ffoulkes *et al* (1978) suggested that perhaps part of the sweet potato was escaping rumen fermentation and thus more true protein was being made available at the intestinal level. This could be the factor responsible for stimulating feed consumption (Kempton and Leng 1978). An alternative hypothesis was that perhaps the sweet potato forage promoted a higher intake through a stimulation of rumen function and an increase in the efficiency of microbial fermentation. That the second idea was the most probable one was shown by Meña *et al* (1979) and Gill *et al* (1980) who found that sweet potato foliage is extensively degraded in the rumen and that its half-life digestion rate was as low as 13.3 ± 7.7 hours as compared to 40.8 ± 24 hours for sugarcane. At such a fast rate of rumen degradation, it was not surprising to find that the rate of ruminal outflow was increased from 40 to 120 liters/day when derinded sugarcane was supplemented with sweet potato forage (Gill *et al* 1980). It would then appear that the increased voluntary intake observed, when sweet potato forage is used as a supplement of sugarcane, is due to a rumen function stimulation and not to an increase in dietary protein flow to the duodenum.

Rate of growth in beef animals

In terms of the nutritive value of sweet potato foliage for beef animals, Ffoulkes and Preston (1978) reported that young bulls with an initial weight of 216 kg and fed a molasses/urea - based diet showed a rate of 0.570 kg/day when the roughage source was sweet potato forage. This response was further improved by 38 when soybean meal was added to the diet (Table 5).

In light of the results shown in Table 5, Ffoulkes and Preston (1978) reasoned that in the diet where no soybean meal was used, the major limiting factor was not just that the amount of protein provided by the diet was insufficient (the sweet potato forage was offered at only 5 of the body weight) but that it contained very little, if any, protein insoluble in the rumen. This limitation was remedied by the use of soybean meal which contains a large proportion of protein that escapes rumen fermentation.

On diets based on derinded sugarcane, the supplementation with fresh

sweet potato forage (offered at 5% of the body weight) dramatically improves feed intake and weight gain of young bulls weighing between 174 and 194 kg (Meyreles *et al* 1979). The main results of the experiment of Meyreles *et al* (1979) are illustrated in Figure 5.

Table 5. Weight gain, feed intake and feed conversion in young bulls fed molasses/urea plus sweet potato forage and soybean meal (Ffoulkes and Preston 1978)

Parameters	Soybean meal, g/day	
	0	400
Live weight, kg		
Initial	217	218
Final	287	316
Daily gain	0.57	0.78
Feed intake (fresh basis), kg/day		
Sweet potato forage	10.58	11.16
Sugarcane molasses (2.5% urea)	5.82	4.83
Soybean meal	0	0.40
Feed intake (dry basis), kg/day		
Sweet potato forage	1.45	1.51
Total	4.72	5.28
Voluntary intake index[a]	1.87	1.98
Feed conversion[b]	8.28	6.74

[a]kg DM intake/100 kg LW/day
[b]kg DM intake/kg weight gained

In Figure 5, it can be seen that when derinded sugarcane is fed, whether with a low level of urea (6 g/kg fresh sugarcane) or a high level of urea (25 g/kg fresh sugarcane), the DM intake is rather limited. However, when sweet potato foliage or cottonseed meal (750 g/day) or both together are used as supplements a significant increase ($P \leq 0.002$) in intake occurs. Weight gain response follows the same pattern except that the improvement imparted by the supplements is more impressive since sugarcane/urea fed animals can only maintain their weight. Meyreles *et al* (1979) argue that the results shown are due to a stimulus of rumen motility (and therefore, of rumen turnover rate) by the sweet potato forage which would result in greater flow of protein to the duodenum. In the case of the cottonseed effect, this would have been caused indirectly by the stimulus that rumen by-pass protein has on voluntary intake (Kempton *et al* 1977) which in turn would increase the rumen turnover rate.

That voluntary intake and weight gain are intimately related has been shown by a number of workers; for example, Meyreles *et al* (1979) who related weight gain (WG) to feed intake index (FI) by the linear function

$$WG = -0.875 + 0.691\ FI\ (\pm\ 0.069)$$

$$R^2 = 0.94\ (S_{yx} = \pm\ 0.088)$$

where WG is given in kg/day and FI in kg DM/100 kg live weight.

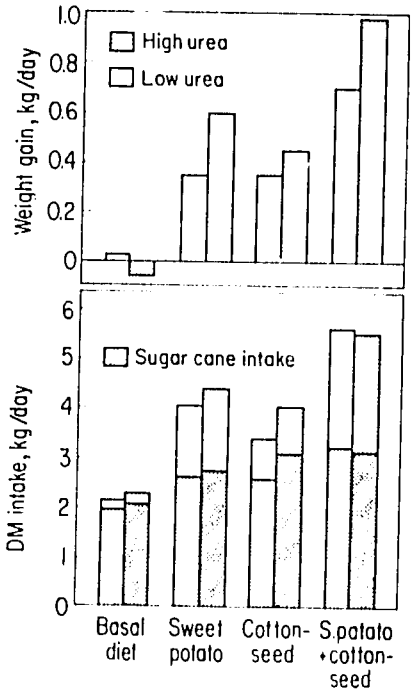

Figure 5. Weight gain and feed intake of diets based on derinded sugar cane stalks, supplemented with sweet potato foliage, cottonseed meal and two levels of urea (adapted from Meyreles *et al.* 1979)

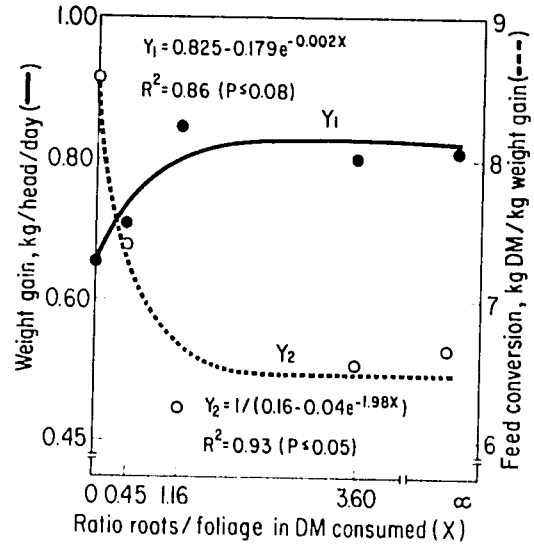

Figure 6. Weight gain and feed conversion of animals fed different root/foliage ratios of sweet potato (adapted from Backer *et al.* 1980)

Integral use of sweet potato plant components in animal feeding

Backer (1980) used an approach which differs from the ones reviewed above, in that the whole diet of beef steers was based on various combinations of sweet potato forage and culled roots; urea was used to keep all rations isonitrogenous. Table 6 shows the nutrient intake data, while Figure 6 shows the weight gain and feed conversion results.

Obviously, roots, being rich in highly digestible starch and sugars, had a positive effect on the metabolizable energy intake, although the total DM intake was rather constant across treatments and at a level considered adequate.

Weight gain response (Figure 6) was best described by an exponential function from which it can be estimated that a nearly asymptotic value was obtained when roots and aerial parts were in nearly equal proportions in the ration.

As is commonly known, not all the roots harvested can be marketed; for Costa Rica a minimum value of 12 of the crop does not qualify as commercial. With this figure in mind and with the results obtained by Backer *et al.*

Table 6. Consumption data for rations based on sweet potato plant components fed to young steers (Backer *et al* 1980)

Dietary proportion of roots: aerial part	Intake, units/100 kg LW/day		
	dry matter kg	crude protein (N x 6.25) kg	metabolizable[a] energy Mcal
0:100	2.45	0.30	5.05
25: 75	2.32	0.27	5.19
50: 50	2.34	0.29	5.53
75: 25	2.39	0.27	5.74
100: 0	2.41	0.30	6.34

[a]Calculated from McDowell *et al* (1974)

al (1980), it is possible to consider a situation where the sweet potato is grown primarily for its traditional purpose but its residues, tops and culled roots are fed to cattle properly supplemented with urea, minerals and vitamins. All this information has been integrated into a model using Costa Rican economic indexes (Table 7).

The data shown clearly indicate that it is possible to derive economic gains from the use of the sweet potato residues which, in nearly all cases in tropical America, are lost. In fact, and perhaps more important than the economic considerations, these 'wastes' can be transformed efficiently into high quality food for humans.

Table 7. A model for the integral utilization of one hectare of sweet potatoes (Backer *et al* 1980)

Agronomic component		Beef production component	
Variety	C-15	Foliage production (16.8% DM), t	13
Growth period, days	150	Non-commercial roots (30.1% DM), t	1.8
Root production, t	15	Urea (100 days), kg	14.8
Commercial roots, t	13.2	Minerals and vitamins, kg	26.0
Farm labor, US dollars		Number of animals	5.2
Soil preparation	60.4	Initial weight of animals, kg	184
Planting	71.7	Days in feeding	100
Fertilization, weed control	23.6	Ratio roots/foliage	0.25
Hand weeding	63.4	Intake, kg DM/head/day	5.2
Harvesting	85.6	Weight gain, kg/head/day	0.71
Costs of materials, US dollars		Farm labor, US dollars	50.0
Seed	39.0	Cost of urea, minerals, etc, US$	11.3
Fertilizer	17.6		
Herbicide	45.9	Other costs, US dollars	
Insecticide	3.1	Feed	78.0
Other costs, US dollars		Administration (10% of income)	36.9
Land rent	58.6	Interest (8%)	90.6
Administration (10% of income)	335.3		
Interest on investment (8%)	63.6	Gross income, US dollars	369
Gross income, US dollars	3,353	Profitability, %	38
Profitability, %	290		

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Symposium delegates inspecting improved breeding lines at the Taiwan Agricultural Research Institute.

General Discussion

(Session VI)

VILLORENTE: Regarding your gasohol production program, may we know which is more expensive now in Indonesia, a liter of alcohol or a liter of gasoline? If alcohol is more expensive, what measures are being taken to reduce the price of alcohol production so as to be more competitive with gasoline?

WINARNO: I don't exactly know the price of alcohol in Indonesia, but the cost of gasoline is still below US$0.25 per liter. We are concerned about the future. I hope the future of alcohol production is very good and that it can supplement our oil production so that our supply of oil will not deplete very fast. It will be economically good for farmers since there will be another incentive to grow sweet potatoes.

URITANI: Are there changes that occur during sun-drying of flour?

WINARNO: Yes, β-carotene is destroyed by prolonged sun-drying. Pretreatments such as lye peeling, blanching and storage of raw material also reduce β-carotene content. The browning reaction is commonly observed too.

URITANI: Please explain in detail the method of manufacture of sweet potato flour. Is the flour manufactured without heat treatment?

WINARNO: There are several ways to produce sweet potato flour; two of them are through direct sun-drying and dehydration. Traditionally sweet potato flour is produced by slicing unpeeled roots (3 mm thick) and drying them until brittle (easy to break, usually with 6-8% moisture). Then the dried potatoes are ground and screened to get flour. The color of the flour is usually dark. This is used as bread extender and in baking cakes.

WILSON: Has it been determined whether alcohol production from sweet potatoes will be economical in Indonesia considering conversion costs? Will alcohol be produced from existing varieties? Are they high dry matter types?

WILSON: Has it been determed whether alcohol production from sweet potatoes will be conomical in Indonesia considering conversion costs? Will alcohol be produced from existing varieties? Are they high dry matter types?

WINARNO: According to calculations, yes. More important, however, is that the alcohol factory will give additional income to people participating in the transmigration. Alcohol is produced from the most suitable variety. I expect the high-starch varieties are better.

CHEN: Apart from the price, is the texture of canned sweet potato a problem in its acceptability?

WINARNO: In canning sweet potato only selected varieties with good texture that can stand sterilizing temperatures are used. For example in the US, Centennial, Goldrush, Julian, and Nuggett varieties have been used because they have acceptable textures. They have also the desired root size that can fit into the cans that are generally used.

VILLAREAL: What is the cause of diarrhoea in hogs fed with uncooked sweet potato?

YEH: Trypsin inhibitor contained in raw sweet potato roots is higher than in sun-dried or cooked (heat-processing) roots. This inhibitor may indirectly cause indigestion of protein in diets which in turn causes diarrhoea in hogs fed with uncooked sweet potato.

CHEN: What is the definition of starch availability? What is the difference between starch availability and starch digestibility?

YEH: In our experiment, starch availability is expressed by applying diazyme solution (ml CO_2/g DM/hr). Starch digestibility should be measured by animal test. Starch availability is usually positively correlated with starch digestibility.

ANONYMOUS: How would you explain your data on the daily gain of pigs using sweet potato diet. It is lower compared to a corn diet and the feed/gain is high.

YEH: Superior daily gain of pigs fed corn diets usually results in lower feed/gain. The higher feed/gain means lower feed efficiency.

ANONYMOUS: Does wounding or fungus infection induce IAA oxidase activity too? Will submersion of wounded or fungus-infected sweet potato slices in a solution, such as NaCl solution, prevent the series of enzyme reactions?

URITANI: Wounding and infection induce IAA oxidase. However, IAA is synthesized by wounding. Thus, IAA seems to be separated from IAA oxidase by the membrane system. Generally speaking, anaerbiosis stops the induction.

ANONYMOUS: Do coumarins or furanoterpene compounds found in wounded or diseased roots pose a threat to man or animal if eaten?

URITANI: Yes, because they are toxic.

MOYER: Colonization by *Fusarium oxysporum*, causal agent of surface rot *M. infuscans*, causal agent of scurf, is limited to the periderm. Hyphae are seldom found in the cortex. What resistance factor or factors do you think responsible for this phenomenon?

URITANI: Sweet potato has a primary and a secondary defense mechanism. The former involves lectin-type components, which may be related to the defense against surface rot and scurf. The latter may be related to the defense, possibly because of the strong antibiotic activity to those pathogens.

WILSON: Can you explain the fungus-induced synthesis of enzymes in sweet potato tubers?

URITANI: The fungus seems to have two kinds of components. The first one is to recognize the penetrating fungus, leading to synthesis of some of the enzymes. The other is to induce other enzymes specially related to furanoterpene biosynthesis.

ANONYMOUS: How can you use solar dehydration in the rainy and cloudy weather?

What is the cost of equipment? How long can you keep the dried sweet potato products?

MOY: By coupling the solar dehydrator with a source of electrically-heated or biogas-heated air, and activating the heat source by a thermostat when it is rainy or cloudy, drying can be continued, and into the night also. The latter system using methane is preferred. The solar dehydrator that we built cost less than US$200 in Hawaii. The main expense is the acrylic plastic. Solar dried sweet potato can be kept for at least 12 to 18 months without change in quality of slices or flour if packaged in plastic bags or glass jars.

ANONYMOUS: Do you think that it is possible to use your solar dryer with other starchy root crops?

MOY: Yes, it is possible to use our solar dryer to dry other starchy root crops such as taro and cassava.

ANONYMOUS: Would you compare electrical and solar dryers on the basis of practicality, economy and quality of dried materials?

MOY: With the high cost of oil and electricity, a solar dryer is definitely more economical than an air dryer with electrical heat. The only impracticality is that it depends on the sun and the weather. So a good method will be to add biogas (methane) as another source of heat for drying. Qualities of solar dried products are at least as good as air dried products. In some cases, solar dried products are preferred over hot-air dried products.

ANONYMOUS: In comparing the efficiencies of direct solar dehydration, indirect solar dehydration and a combination of the two, did you consider the space each type would occupy?

MOY: The space occupied by the three modes of solar dehydrators is not too much different. The direct mode solar dehydrator does take a little less room because no collector is involved.

RASHID: Have you studied the effect of atmospheric humidity on the rate of dehydration by solar drier? If yes, what are the findings?

MOY: Not systematically as yet, but the relative humidity (RH) of the air decreases when the air is heated through the solar collector. As long as the RH is not as high as 90-100%, solar drying should be quite efficient. The air temperature in our solar dryer ranges between 45-55°C.

YANG: How about the exit humidity? How do you dry silica gel for repeat use?

MOY: While accurate measurements are not simple, we estimate the exit humidity in our solar dryer to vary between 65 to 85% relative humidity. The factors influencing the exit RH would be the initial RH of the air entering the solar dryer, the temperature to which the air is heated for solar drying, the velocity of the air going through the solar dryer and the amount of moisture being removed from the food products in a given time interval. To dry the silica gel, electrical heat can be used. It would take about 10

really that profitable in Taiwan now. Farmers grow the crop for other reasons, like the need for an intercrop or as feed for backyard hogs.

WARGIONO: The price of rice is always higher than sweet potato but in fact farmers grow sweet potato over a large area. Do you think that sweet potato is more profitable compared to rice?

CHEN: I don't think profitability of rice and sweet potato should be compared because they are not competing crops. In fact, their incomes supplement one another. Also sweet potato is grown especially if irrigation water is not sufficient to grow a rice crop.

hrs at 130°C or higher. With today' ·ost of electricity, it seems not economical to regenerate a batch of ica gel with electric heat. If a solar concentrator can be used to dry the silica gel, then it would be practical to use silica gel to dehumidify the air to improve solar drying rates.

HAMMETT: Would it be feasible economically to intensify heat production by using a series of lenses and mirrors?

MOY: Yes, mirrors and lenses would intensity solar radiation, but they increase the cost of solar drying which may become uneconomical.

CHEN: People have said that if the sliced sweet potato is sun-dried before cooking with rice, its texture will be poor when compared with using freshly sliced sweet potato. Please comment on this.

MOY: This is a problem that has not been methodically studied, and one should should look into it if one were to make solar dried sweet potato rice.

ANONYMOUS: In some regions in the Philippines, there is a distinct dry season and wet season during the year. Therefore, if sweet potato harvesting falls during rainy months where sunlight is expectedly minimal, you think solar dryers will work under such conditions?

MOY: Please see my answer on adding biogas (methane) to the solar drying system.

VILLAREAL: How much is the cost of a solar dehydrator (unit) that you described for small scale industry or for family use? Where can you buy the unit?

MOY: The size that we built costs less than US$200 in Hawaii. It should cost less elsewhere. It is suitable for family use. One can build several units for small scale industry operations. Instead of buying the unit, the best way is to build one yourself. We can furnish you with a sketch and dimensions. The dimensions are not important since you can vary the size to suit your needs.

ANONYMOUS: What is the moisture content of the sweet potato dehydrated by solar drier? How many hours would it require to dry 100 kgs of sweet potato when a solar dryer is used?

MOY: Usually about 6-10 , but it is better not to dry the sweet potato slices to too low a moisture content because the texture may become hard and unacceptable. Our dryer has a capacity of about 9 kg per batch at 12 hrs per batch. So for 100 kg, it would take 132 hrs of drying using our solar dryer.

WARGIONO: In your marketing system + 60 of sweet potato production is bought by shipper. Do you have a floor price for sweet potato? How profitable is it for farmers to grow?

CHEN: In general we don't have a floor price for sweet potato in Taiwan. However, some farmers' associations have established a floor price only of one variety of sweet potato - Tainung 57. Growing sweet potato is not

PARTICIPANTS

Waichi Agata, Faculty of Agriculture, Kyushu Univ., Fukuoka, Japan.

Will Lungat Akus, Dept. of Primary Industry, Highlands Agric. Expt. Sta., Aiyura, P.O. Box 384, Kainantu, E.H.P., Papua New Guinea.

Merle M. Anders, SHRDP, Papua New Guinea.

Anthony Baah, Dormaa Secondary School, P.O. Box 39, Dormaa Ahenkro, Ghana.

Emelita Baldonado, Ministry of Human Settlement, Technology Resource Center, Buendia Ave. Ext. , Makati, Metro Manila, Philippines.

Perfecto U. Bartolini, Philippine Root Crop Research & Training Center, Visayas State College of Agric., Baybay, Leyte 7127, Philippines.

Luis Bonilla, Plan Sierra, P.O. Box 1152, Santiago, the Dominican Republic.

John C. Bouwkamp, Dept. of Horticulture, Univ. of Maryland, College Park, Maryland 20742, USA.

Diosdado V. Castro, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Yung-Sing Chang, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

Chih-Kang Chao, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

Chao-Yih Chen, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Hsing-Yiu Chen, Agricultural Marketing Division, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

Fa-Shiang Chiu, Hsinchu DAIS, 9 Nan-Yah St., Hsinchu, Taiwan.

Ren-Jong Chiu, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

Su-Chin L. Chiu, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Liang-Yih Chou, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Tsai-Yi Chow, Taiwan Livestock Res. Inst., Hsinhua, Tainan, Taiwan.

Wanda W. Collins, North Carolina State Univ., 210 Kilgore Hall NCSU, Raleigh, NC 27650, USA.

Romeo Dongallo, Ministry of Human Settlement Buendia Ave. Ext., Makati, Metro Manila, Philippines.

Somporn Drabyasara, Dept. of Horticulture, Kasetsart University, Bangkok, Thailand.

Dennis Eusebio, POP, Economic Garden, Los Baños, Laguna, Philippines.

Jack Gershon, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Sylvia K. Green, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Previous Page Blank

S. K. Hahn, IITA, P.M.B. 5320, Ibadan, Nigeria.

Harrell L. Hammett, LSU Sweet Potato Research Center, P.O. Box 120, Chase, Louisiana 71324, USA.

Leonard Ho, Asian Vegetable Research and Development Center. P.O. Box 42, Shanhua, Tainan, Taiwan.

Eun Hi Hong, Upland Crops Division, Crop Expt. Sta., Office of Rural Development, Suweon 170, Korea.

Yoshio Hozyo, National Inst. of Agric. Sciences, Kannondai, Yatabe, Tsukuba, Ibaraki, Japan.

Ko-Chang Hsieh, National Science Council, 2 Kuang Chow St., Taipei, Taiwan.

Sung-Ching Hsieh, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Ching-Sheng Hsu, Dept. of Crop Improvement, Tainan DAIS, Tainan, Taiwan.

Cheng-Rung Hu, Agric. Prod. Section, Provincial Dept. of Agric. and Forestry, Chung-Hsing Village, Taiwan.

Po-Chao Huang, Dept. of Biochemistry, College of Medicine, National Taiwan Univ., Taipei, Taiwan.

R. K. Jana, Faculty of Agriculture, Univ. of Dar Es Salaam, P.O. Box 643, Morogoro, Tanzania.

Alfred Jones, Vegetable Laboratory, P.O. Box 3348, Charleston, South Carolina Carolina 29407, USA.

Ching-Huei Kao, Dept. of Agronomy, National Taiwan Univ. Taipei, Taiwan.

Stanley J. Kays, Univ. of Georgia, College of Agriculture, Athens, Georgia 30602, USA.

Te-Yeh Ku, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

George, C. Kuo, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Chin-Tian Lee, College of Agriculture & Life Sciences, Univ. of Guam, UOG Station, Mangilao, Guam 96913.

Liang Li, Chiayi Agric. Expt. Sta., Chiayi, Taiwan.

Chem-Kun Lien, National Science Council, 1 Kuang Chow St., Taipei, Taiwan.

Cheng-Yi Lii, Inst. of Chemistry, Academia Sinica, Nankang, Taipei, Taiwan.

Yaw-Huei Lin, Inst. of Botany, Academia Sinica, Nankang, Taipei, Taiwan.

Yi-Sheng Lin, Dept. of Plant Pathology, Taiwan, Agric. Res. Inst., Taichung, Taiwan.

Dan-Jiang Liu. Taiwan Agric. Res. Inst., Taichung, Taiwan.

Hsiao-Feng Lo, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Marcia Lo, Dept. of Botany, National Chung Hsing Univ., Taichung, Taiwan.

Chih-Lin Luh, Advisory Group, Executive Yuan, Taipei, Taiwan.

Franklin W. Martin, Mayaguez Inst. of Trop. Agric., P.O. Tox 70, Mayaguez, Puerto Rico 00709

J. T. Mey..hardt, Hort. Res. Inst., Private Bag X293, Pretoria 0001, Republic of South Africa.

Yun-Ho Moon, Crop Expt. Sta. Office of Rural Development, Suweon 170, Korea.

Raul A. Moreno, Annual Crops Program, CATIE, Turrialba, Costa Rica.

James H. Moy, Dept. of Food Science & Human Nutrition, Univ. of Hawaii, Honolulu, Hawaii 96822, USA.

James W. Moyer, Dept. of Plant Pathology, North Carolina State Univ., Box 5397, Raleigh, NC 27650, USA.

Ichizo Nishiyama, Kyoto Univ., Kitashirakawa-Oikake-cho, Sakyo-ku, Kyoto 606, Japan.

Hiko-Ichi Oka, Food Drops Res. Inst., National Chung Hsing Univ., Taichung, Taiwan.

Shih-Huang Ou, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Rohan Rajapakse, Dept. of Entomology, Faculty of Agriculture, Mapalana Kamburupitiya, Sri Lanka.

M. M. Rashid, Bangladesh Agric. Res. Inst., Joydelpur, Dacca, Bangladesh.

Yu-Chi Roan, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Adisak Sajjapongse, Asian Vegetable Research and Development Denter, P.O. Box 42, Shanhua, Tainan, Taiwan.

Ramon S. Salire, Bicol State Univ., Legaspi Cit., Philippines.

Lina M. Sanque, Ministry of Human Settlement, Buendia Ave, Ext., Makati, Metro Manila, Philippines.

Mallik A. As-Saqui, Central Agric. Res. Inst., Ministry of Agric., P.O. Box 32, Gharnga, Bong County, Liberia.

George W. Selleck, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua. Tainan, Taiwan.

Webster H. Sill, Jr., Dept. of Plant Pathology, National Chung Hsing Univ., Taichung, Taiwan.

Kuang-Chi Su, Taichung DAIS, Taichung, Taiwan.

Paul M. H. Sun, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Tomohisa Takemata, Sweet Potato Breeding Center, Central Agric. Expt. Sta., Kuriyama 1055, Kotsukaido, Chiba 284, Japan.

N. S. Talekar, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Ichiro Tanabe, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

John M. Taylor, Field Agro Industries Inc., Peter Go Bldg, Mango Ave, Cebu City, Philippines.

Jawahir L. Tickoo, Div. of Genetics. Indian Agric. Res. Inst., New Delhi 110012, India.

Shi-Shun Tsai, National Taiwan Univ., Taipei, Taiwan.

Wen-Fu Tsai, Dept. of Agronomy, National Taiwan Univ., Taipei, Taiwan.

Hsin-Sheng Tsay, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Samson C. S. Tsou, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Chin-Chyu Tu, Tainan DAIS, Tainan, Taiwan.

Hsun Tu, Council for Agricultural Planning and Development, 37 Nanhai Road, Taipei, Taiwan.

H. R. von Uexkull, Inter. Potash Inst./Potash & Phosphate Inst. of N. America 126 Watten Estate Road, Singapore 1128.

Ikuzo Uritani, Faculty of Agriculture, Nagoya University, Chikusa, Nogoya 464 Japan.

Ruben L. Villareal, Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua, Tainan, Taiwan.

Ambrosio R. Villorente, Bureau of Agric. Ext., Ministry of Agric., Diliman, Quezon City 3008, Philippines.

Van H. Waddill, Agric. Res. Educ. Center, Univ. of Florida, 18905 S. W. 280 St., Homestead, Florida 33031, USA.

Hsiung Wan, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Shui-Chen Chiu Wan, Taiwan Agric. Res. Inst., Taichung, Taiwan.

Hsia Wang, Chiayi Agric. Expt. Sta., Chiayi, Taiwan.

J. Wargiono, Root & Tuber Crops, Central Res. Inst. for Agric., Jl. Merdeka 99, Bogor, Indonesia.

Bantoone Warrit, Dept. of Horticulture, Chiangmai University, Chiangmai, Thailand.

L George Wilson, North Carolina State Univ., Raleigh, NC 27607, USA.

Laurence A. Wilson, Dept. of Crop Science, Univ. of the West Indies, St. Augustine, Trinidad, W.I.

F. G. Winarno, Food Tech. Dev. Center, Inst , Pertanian Bogor, P.O. Box 61, Bogor, Indonesia.

Hong-Pang Wu, Inst. of Botany, Academia Sinica, Nankang, Taipei, Taiwan.

James S. Wu, National Taiwan Univ., Taipei, Taiwan.

Yu-Long Wu, Kaohsiung DAIS, Pingtung City, Taiwan.

Romke Wustman, Bangladesh Agric. Res. Inst., P.O. Box 166, Gulshan, Dacca, Bangladesh.

Chia-Wenn Yang, Hsinchu DAIS, Hsinchu, Taiwan.

Tsu-Hsing Yang, Dept. of Agric. Chem., National Taiwan Univ., Taipei, Taiwan.

Tsa-Pou Yeh, Animal Ind. Res. Inst., Taiwan Sugar Corporation, Chunan, Taiwan.

Douglas E. Yen, The Australian National Univ. P.O. Box 4, Canberra ACT 2600, Australia.

Muhammad Yusuf, CRIA, Bandar, Buat, P.O. Box 34, Padang, West Sumatra, Indonesia.

Dominador Zara, Dept. of Horticulture, U. P. at Los Baños, Laguna, Philippines.

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