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Sweet Potato Breeding

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The sweet potato *Ipomoea batatas* (L.) Lam. is an asexually propagated vegetable grown in commercial quantities along the East Coast, in New Jersey, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida; in the Gulf states of Alabama, Mississippi, Louisiana, and Texas; in other southern and western states including Tennessee, Oklahoma, Arkansas, New Mexico, and California; and on the islands of Hawaii and Puerto Rico. Currently about 35% of the U.S. crop is produced in North Carolina, followed by 19% in Louisiana, 10% in California, and 8% in Texas (*89*). Thus, over half of the U.S. production is concentrated in two states, North Carolina and Louisiana. The area devoted to sweet potato production declined drastically from 1949 to 1970 but appears to have stabilized during the 1970s at about 119,000 acres (48,000 ha) (Table 1.1). Total production and per capita consumption followed the same trend, although the declines were not as severe due to increasing yields per acre.

The sweet potato is grown in most of the tropical and subtropical regions of the earth, where it is an important staple of subsistence farmers. The vines as well as the roots are eaten or fed to livestock (*92*). It is an important source of industrial starch in Japan, and its potential for fuel alcohol conversion is under study in many countries. In the United States, its cultivation is extended to its temperate limits. Sweet potato can be planted about 4 weeks after the average date of the last killing frost and generally requires a frost-free growing season of 4 or 5 months. Some cultivars will produce edible-sized roots in as

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TABLE 1.1. Trends in Area under Production, Yields, and Per Capita Consumption of Sweet Potatoes in the United States, 1940–1979[a]

Years	Production: Area (×1000 acres)	Production: Av. yield (tons/acre)	Production: Total (×1000 tons)	Per capita consumption (lb)
1940–1944	731	2.4	1754	19.4
1945–1949	551	2.6	1429	15.2
1950–1954	361	2.6	954	9.5
1955–1959	282	3.3	934	8.6
1960–1964	180	4.1	737	7.1
1965–1969	146	4.8	701	6.0
1970–1974	116	5.4	623	5.3
1975–1979	119	5.7	678	5.5

[a]Adapted from Walsh and Johnson (*89*).

little as 100 days, but if night temperatures are too cool they may not grow normally even though they survive. Although U.S. yields have increased in recent years to 5.4 or 5.7 tons/acre (12–13 MT/ha) (Table 1.1), yields in more tropical countries frequently reach 15.6–17.8 tons/acre (35–40 MT/ha). The lower U.S. yields are primarily due to a cooler climate and to the fact that markets require rather small roots, which results in harvesting prior to maximum yield.

ORIGIN AND GENERAL BOTANY

The exact origin of the sweet potato is not known, but an American origin is generally accepted. Available evidence suggests southern Mexico through Central America and northern South America as the probable area of origin. Until more extensive collections are made, especially in Central America and northern South America, the exact center cannot be specified. The sweet potato is obviously better adapted to seasonal variations characterized by wet and dry seasons than by warm and cold seasons. It is a perennial but is handled as an annual in the temperate United States, where its hardiness and drought tolerance are well recognized.

A member of the Convolvulaceae, the sweet potato has 90 chromosomes (Fig. 1.1) and is the only known natural hexaploid morning glory (*3,32*). Most of the wild species collected have proven to be diploid ($2n = 30$) (*35*), although some have been tetraploid (*62,63*) and occasional collections have been triploid (*77*). There is considerable uncertainty regarding the phylogenetic relationships of the wild species. Austin's (*4*) recent taxonomic study provides a good start toward clarification of the sweet potato complex, but clear understanding awaits more complete collections and cytotaxonomic studies (*93*).

Although hybridization with other species of the genus has been demonstrated by Japanese workers (*53,78*), the technique is very difficult. Generally hybridization is restricted to crosses within the species. Because it is hexaploid, there is extensive variability within the species available for exploitation by plant breeders (*34,92*). Each seedling is genetically different from all others and is potentially a new cultivar (Fig. 1.2).

In the United States, the sweet potato is sometimes referred to commercially as a "yam." The designation is technically incorrect and is quite confusing to those who have

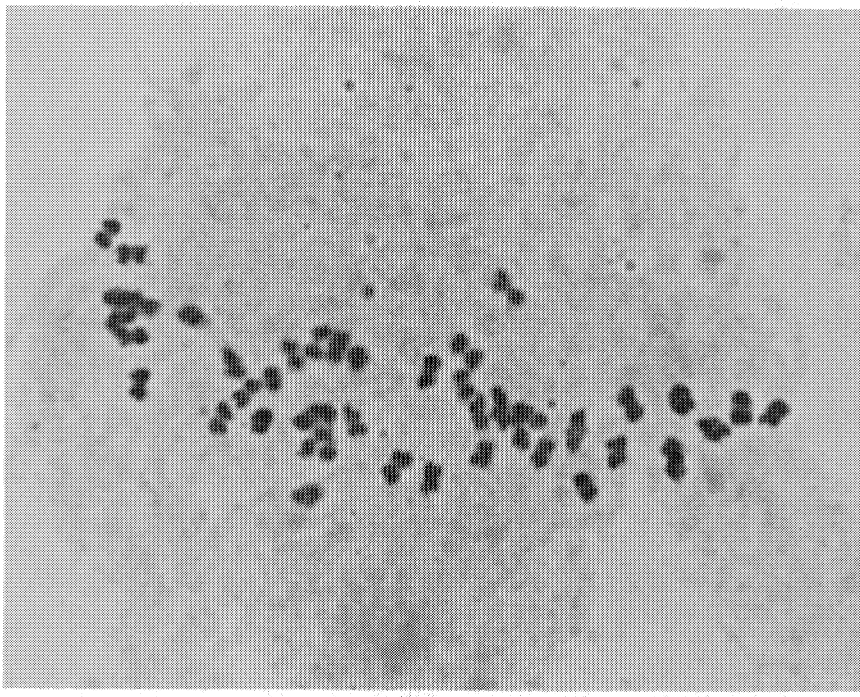

FIGURE 1.1. Chromosome pairing at metaphase I of a sweet potato pollen mother cell, illustrating that bivalent pairing is the rule and involves an average of 87.6 of the 90 chromosomes.
After Jones (*32*).

lived in tropical areas where yams are an important food. The 50 or more species of edible yams in the tropics belonging to the genus *Dioscorea* (*59*) are not even distantly related to the sweet potato. Frequently the edible sweet potato is wrongly referred to as a "tuber." Since a tuber is a fleshy subterranean stem or shoot, the sweet potato, which is a root, cannot be a tuber. Reference to the sweet potato as a tuber leads to another common error, which is to refer to a "mature" tuber or root. The sweet potato is perennial, and the storage root is capable of continued enlargement and does not mature in the sense of reaching some final size or stage of development. From the standpoint of function, the sweet potato root system consists of absorbing roots and fleshy or storage roots (*20*).

FLORAL BIOLOGY AND CONTROLLED POLLINATION

Sweet potato flowers are similar to those of other morning glories and occur in axillary inflorescences of 1–22 buds (Figs. 1.3 and 1.4) (*34*). They open in groups of two or more soon after daybreak and generally fade by noon. Colors of the floral parts vary from white through degrees of lavender to complete lavender. The tube depth varies from 28 to 63 mm and the limb width (corolla diameter) from 26 to 56 mm. The five petals are fused and have stamens attached at their bases with anthers that are normally white but may be light or dark lavender. Filaments vary in length from 5 to 21 mm, and this affects the position of anthers in relation to the stigma. Any number of anthers may be below, equal to, or above the stigma position as a result, and this pattern differs with cultivars. The stigma is

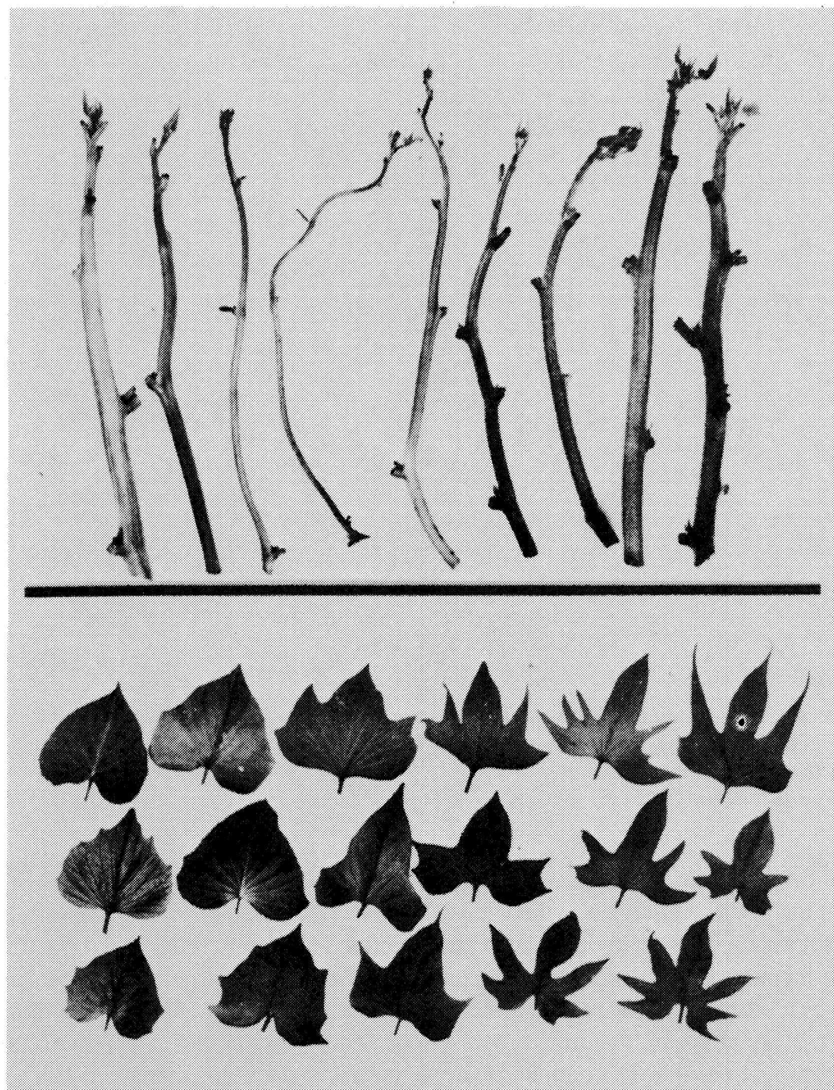

FIGURE 1.2. Every sweet potato seedling is different from all the others; thus the diversity of types is vast as illustrated by leaf and stem variations.
After Jones (33).

generally white and bilobed, but may be light or dark lavender. Styles may be from 8 to 29 mm long. There are two ovaries in the pistil, each containing two ovules. Sepals are leaflike and persistent and may be glabrous or pubescent. At the base of the corolla there are conspicuous yellow glands that contain insect-attracting nectar (*4,62*). Capsules contain one to four seeds and may be glabrous or pubescent (Fig. 1.5). Mature seeds are flat on two sides and round on the other with diameters of 3–5 mm (*60*). At maturity they are about half or less of their maximum green size, are usually dark brown or black (although some may be tan and others speckled), and weigh about 2 g per 100 seeds, which varies with parental type from about 1.3 to 3.0 g (*22,42*).

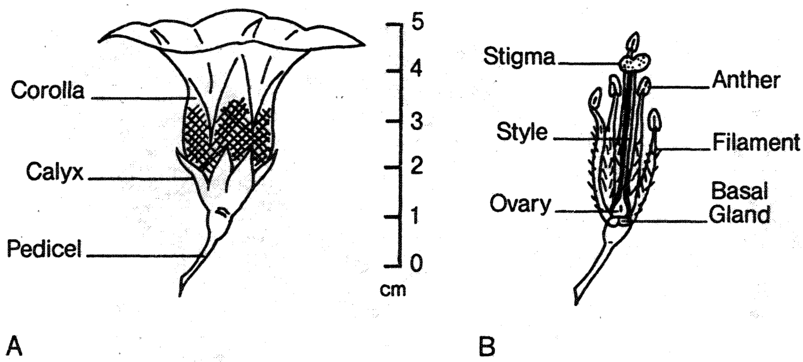

FIGURE 1.3. Parts of the sweet potato flower: (A) side view; (B) with calyx and corolla removed.

The seeds are hard and may retain viability for 20 years or more. Germination is consequently very irregular unless some means of seed scarification is used. The seed can be soaked in concentrated sulfuric acid for 20–60 min, washed in water or neutralized with a solution containing bicarbonate of soda, and rinsed in clear water (*85*). Also, seeds can be scarified by hand with a sharp needle or with a mechanical scarifier before sowing. Seeds are subject to infestation by the seed weevil *Megacerus impiger* Horn. in the field or in storage (*41*). A small (5 × 5 cm) segment of a household pest strip (20% 2,2-dichlorovinyl dimethyl phosphate) enclosed in a plastic bag with the seed has given satisfactory control.

A rather extensive literature cites the difficulty of obtaining flowering in sweet potato and includes studies of the causes of that condition (*20,57,58*). More recent work indicates that this condition was probably due to chance associations in the original plants used in U.S. breeding programs interested in dark orange flesh types. There are wide

FIGURE 1.4. (A) Sweet potato flowers and the subsequent seed capsules occur in axillary inflorescences called cymes. (B) A cyme with an unusually large number of seed capsules.

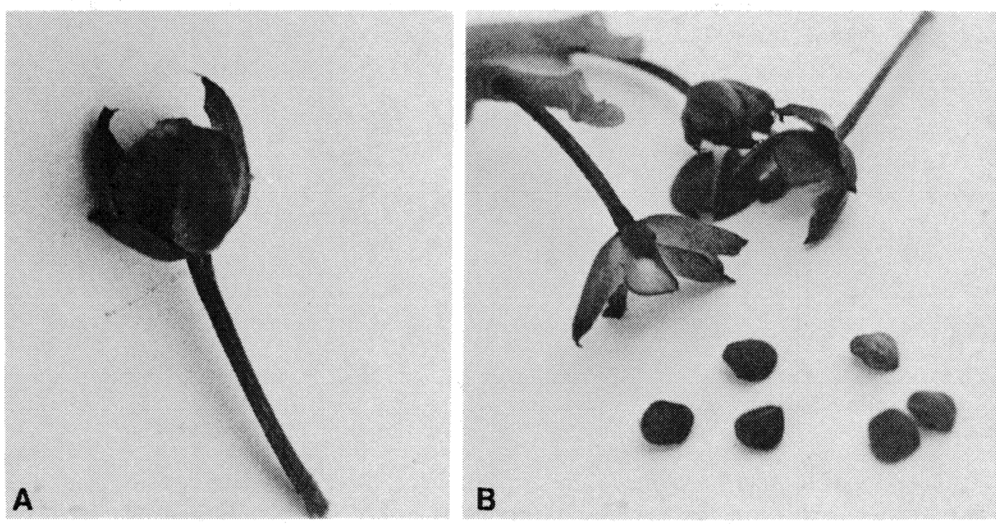

FIGURE 1.5. Seed capsules may be (A) glabrous or pubescent and (B) contain from 1 to 4 seeds, which are usually dark brown to black, sometimes speckled or tan.
After Jones (*40*).

genetic differences in flowering incidence, as well as strong environmental influences (Table 1.2) (*32, 92*). Many breeding programs routinely induced non-flowering plants to flower by grafting or by various physiological shocks, perpetuating the non-flowering trait in subsequent generations. The best solution to non-flowering has been genetic: selection for good flowering. After about three generations of selection virtually every plant will flower sometime during the season (*61*). Further, no undesirable traits have been associated with good flowering (*42,45,84*). It may be necessary or desirable to use poorly flowering plants as parents in special situations, but in general it is best to use profusely flowering types if they can be found with the desired traits. In cases where poorly

TABLE 1.2. Genetic Flowering Differences[a]

Flowering stage score[b]	Flowering stage percentages, 1965				
	6/24	7/16	8/6	9/16	11/1
0	26.2	15.7	12.3	20.5	6.4
1	6.0	7.2	3.3	1.9	3.9
2	20.0	6.6	4.5	11.1	3.9
3	7.4	3.3	4.1	4.3	9.1
4	14.2	3.3	1.6	4.5	16.9
5	26.2	63.9	74.2	57.7	59.8

[a]After three cycles of mass selection most plants will flower sometime during the season, but flowering incidence will change as the season progresses, as demonstrated in this population of 485 plants, where 92% flowered sometime during the season (*34*).

[b]0, no evidence of flower buds; 1, buds initiating; 2, 3 internodes have buds; 3, few buds, most mature; 4, abundance of buds, but no flowers; 5, flowering.

flowering parental types are used, the complex compatibility and sterility systems may be an important consideration. Techniques of making controlled crosses have been outlined recently by one of the authors (*40*). Since the use of polycross and mass selection techniques appears to be the most efficient way to breed sweet potatoes, techniques for controlled crossing will not be repeated here.

Trellises to facilitate open pollination by naturally occurring insects can be constructed of metal reinforcing rods, stakes, or bamboo canes placed alongside each plant and tied together near the top by a single cord anchored at the ends of the row (Fig. 1.6). A string tied at the base of the support is then twined around the vines and secured near the top of the support. During wet periods good air movement is important to control capsule rots and assure high seed quality. Ground mulches and/or herbicides may be used to hold weed growth to a minimum, and the trellises may be spaced sufficiently far apart to allow cultivation between rows. Insects and diseases can reduce seed set, and pesticide treatments can help alleviate the problem (*31,46,50*). Infestations of corn earworm [*Heliothis zea* (Boddie)] or fall armyworm [*Spodoptera frugiperda* (Smith)] can be very severe in the flowers. Chemical treatments should be made in the evenings when bee activity is reduced, and contact sprays or baits should be favored over those with residual activity to avoid killing insect pollinators.

The field layout is not especially critical except that long, narrow nurseries should be avoided to better assure random crossing. Seed mature in about 1 month, and seed harvest occurs over an extended time since flowering occurs over an extended period. Some plants will drop their capsules or shatter the seed if not harvested promptly after maturing. Care must be taken not to overfertilize, and especially high nitrogen should be avoided in the nursery because luxuriant growth is not necessary for good seed set. In fact, best seed

FIGURE 1.6. Elaborate trellises are not necessary for good sweet potato seed production, but they facilitate open pollination by insects.

set occurs on fairly small plants, and excessive foliage contributes to increased disease problems and lower seed quality.

Natural pollination is accomplished by insects during the morning hours when many species, chiefly Hymenoptera, can be observed visiting the flowers. Undoubtedly pollen transfers are made by many of these visitors, but honey bees and bumble bees are thought

TABLE 1.3. Some Diseases of Sweet Potato in the United States

Scientific name	Common name
Fungal diseases	
Fusarium oxysporum f. sp. *batatas* (Wr). Snyd. & Hans.	Fusarium wilt or stem rot
Fusarium oxysporum Schlect.	Surface rot
Fusarium solani (Mart.) Appel & Wr.	Fusarium root rot
Sclerotium rolfsii Sacc.	Southern blight: sclerotial blight and circular spot
Ceratocystis fimbriata Ell. & Halst	Black rot
Monilochaetes infuscans Ell. & Halst ex. Harter	Scurf
Rhizopus stolonifer (Ehr. ex. Fr.) Lind., and other *Rhizopus* spp.	Soft rot; ring rot
Diplodia tubericola (Ell. & Ev.) Taub.	Java black rot
Diaporthe batatatis Harter & Field	Diaporthe dry rot; stem rot
Phyllosticta batatas (Thuem.) Cbe.	Phyllosticta leaf blight
Cercospora batatae Zimm., and other *Cercospora* spp.	Cercospora leaf spot
Albugo ipomoeae-panduratae (Schw.) Swing.	White rust
Plenodomus destruens Harter	Foot rot
Macrophomina phaseoli (Maubl.) Ashby	Charcoal rot
Septoria bataticola Taub.	Septoria leaf spot
Bacterial diseases	
Streptomyces ipomoea (Person & W. J. Martin) Waks. & Henrici	Pox or soil rot
Erwinia chrysanathemi Dupes	Bacterial stem and root rot
Viral diseases	Feathery mottle: common strain, russet crack strain, internal cork strain
	Mild mottle
	Vein mottle
	Sweet potato mosaic viral complex
Diseases caused by nematodes	
Meloidogyne incognita (Kofoid & White) Chitwood	Southern root-knot nematode
Meloidogyne javanica (Treub.) Chitwood	Javanese (tropical) root-knot nematode
Meloidogyne hapla Chitwood	Northern root-knot nematode
Rotylenchulus reniformis Linford & Oliveira	Reniform nematode
Belonolaimus longicaudatus Rau	Sting nematode
Belonolaimus gracilis Steiner	Sting nematode
Ditylenchus dipsaci (Kuhn) Filipjev	Brown ring rot
Pratylenchus coffee (Zimmermann) Goodey	Root lesion nematode

to be the most important. Beehives placed near trellis areas can assure adequate numbers of pollinators.

DISEASES AND INSECT PESTS OF SWEET POTATO IN THE UNITED STATES

A number of diseases occur on sweet potatoes in the plant bed, during field production, or in storage (Table 1.3) (*7,27,71,86,87*). These diseases are a major concern of the plant breeder as resistances to some are now or soon will be necessary in any new cultivar (*67*). The only practical control of fusarium wilt is resistance. Resistance to root knot is readily available and new cultivars should contain at least an intermediate level (*72*). The release of a cultivar susceptible to internal cork would cause a serious problem to the trade; therefore, breeders must evaluate for resistance or tolerance to it (*64,76*). Soil rot (pox) is an increasingly important problem, and resistance to it has been found (*75*). There are obvious differences in degrees of susceptibility or levels of resistances to most of the other diseases, and breeders should take advantage of these.

At least 19 species of insects feed on sweet potato roots (Table 1.4) (*12*). Injury by a number of these is difficult to distinguish at harvest after the insects have left and damage has been altered by subsequent growth of the roots. Resistances to four types of insect injury have been identified. For convenience, damage by seven species that cause similar injury can be considered together as the WDS complex (wireworm–*Diabrotica–Systena*)

TABLE 1.4. Soil Insects of Sweet Potato in the United States

Scientific name	Common name
WDS complex (selection for resistance on basis of similar injury)	
Conoderus falli Lane	Southern potato wireworm
Conoderus vespertinus Fabricius	Tobacco wireworm
Diabrotica balteata LeConte	Banded cucumber beetle
Diabrotica undecimpunctata howardi Barber	Spotted cucumber beetle
Systena blanda Melsheimer	Pale-striped flea beetle
Systena elongata Fabricius	Elongate flea beetle
Systena frontalis Fabricius	A flea beetle
Grubs (selection for resistance on basis of similar injury)	
Phyllophaga ephilida Say	A white grub
Plectris aliena Chaplin	A white grub
Sweet potato flea beetle (selection for resistance on basis of typical injury)	
Chaetoncnema 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
Euzophers semifuneralis Walker	American plum borer
Melanotus communis Gyllenhal	A wireworm
Metriona spp.	Tortoise beetles
Noxtoxus calcaratus Horn	A flower beetle
Peridroma saucia Hubner	Variegated cutworm
Scolytid	Ambrosia beetle
Typophorus nigritus viridicyaneus Crotch	Sweet potato leaf beetle

as developed by Cuthbert and Davis (Fig. 1.7) (*13*). Grub injury is easily recognized as they gouge broad, usually shallow, areas in the roots (Fig. 1.8). Feeding by sweet potato flea beetle larvae leaves narrow channels or grooves just under the root skin (Fig. 1.9). Sweet potato weevils can be found in the root and identified directly (Fig. 1.10). No matter which insect species may be causing injury problems, genetic resistance should be considered as a possible solution. Even intermediate levels of resistance can be of significant economic importance (*16,81*). Little is known regarding the physiological mechanisms involved in soil insect resistances except that some factor seems associated with the root skin (*14*).

Some cultivars are more susceptible to flooding damage than others, a condition that is generally worsened by cool temperatures (10°C). Jewel is quite susceptible to this kind of damage (*1,88*). Chilling of roots during storage, shipping, or marketing below 5°C can cause a physiological disorder known as hardcore (*6*). Some cultivars are more tolerant to low-temperature exposure than others (*25*).

MAJOR BREEDING ACHIEVEMENTS OF THE RECENT PAST

Cultivars released since 1970 demonstrate the success breeders have had in development of multiple-pest resistance in combination with high yield and good culinary qualities

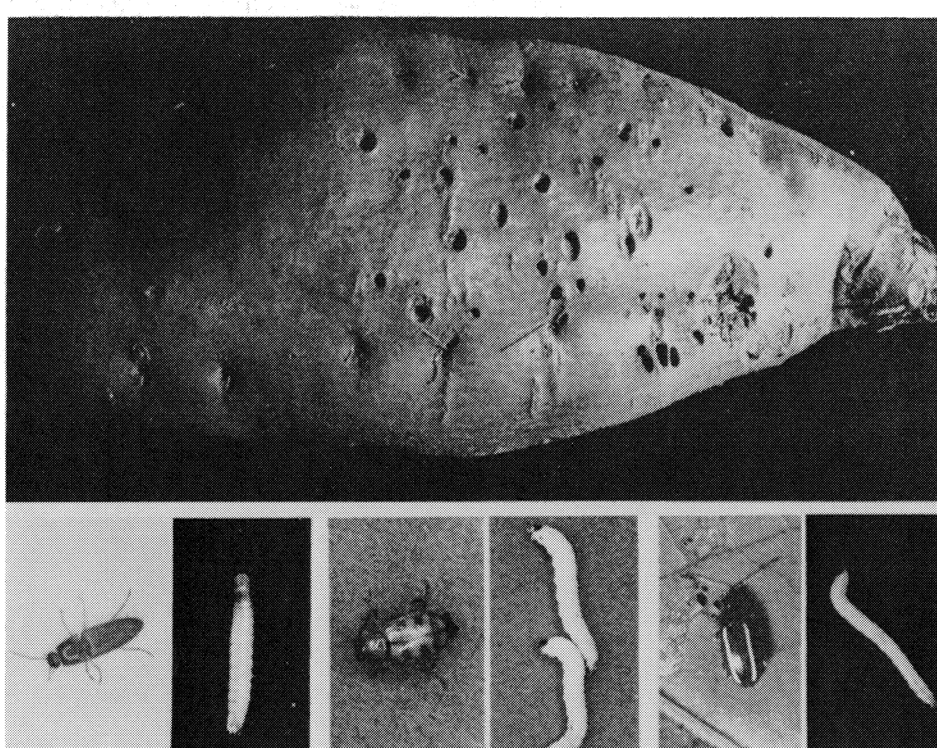

FIGURE 1.7. Soil insects of the WDS complex cause similar kinds of injury to sweet potato roots. Pictured here from left to right are adults and larvae representative of the wireworm, *Diabrotica*, and *Systena*.
After Cuthbert (*12*).

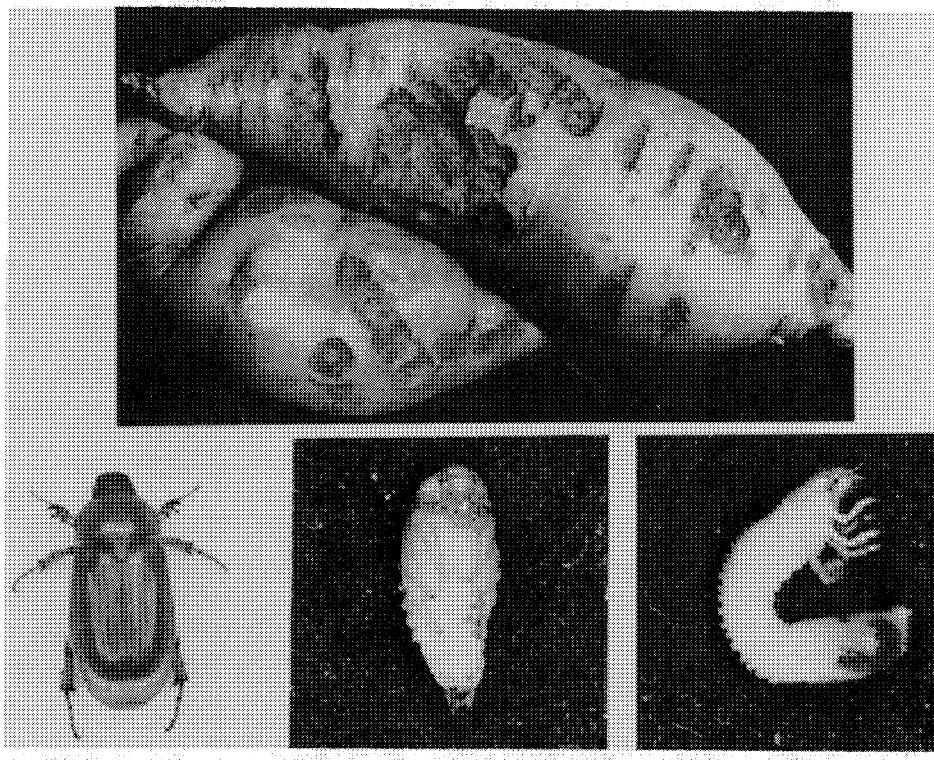

FIGURE 1.8. Grubs tend to feed on the underside of roots, causing this type of injury. Pictured are adult, pupae, and larva of the white grub *Plectris aliena* Chapin.
After Cuthbert (*12*).

(Table 1.5). Jewel, released by the North Carolina Agricultural Experiment Station (AES) in 1971 (*79*), is currently the most popular and widely grown cultivar in the United States and accounts for more than 75% of the commercial plantings. It has a very wide adaptability, high quality, consistently dependable yields, and good storage characteristics and sprouts well. One reason for its success is its high levels of resistances to fusarium wilt and southern root knot. Certainly this cultivar is one of the main reasons for the increased yields recorded for 1970–1979 (Table 1.1). All of the other releases since 1970 except Georgia Jet (*26*) have sufficient resistance to fusarium wilt for effective control under field conditions, and most have at least a moderate level of root-knot resistance. Those cultivars developed by the Louisiana AES in recent years generally have at least some resistance to soil rot, a disease of increasing importance. Most new cultivars have resistance to the internal cork virus, a potentially serious storage disease.

There has been a trend toward higher yielding types with excellent processing and baking traits. Travis (*28*) has averaged 35–40% higher marketable yields than Jewel in most recent regional trials. Eureka (*83*) and Vardaman (*2*) have been rated higher than Jewel in baking and canning trials. The other lines (Table 1.5) were developed to meet special needs; and although their general adaptability may not be as good as that of Jewel, they do represent major accomplishments in meeting those special needs. Jasper (*29*) was released for use in soil rot infested areas; Rojo Blanco (*90*), to meet the limited but important white flesh market; Painter (*23*), for its potential in the Maryland–Virginia area;

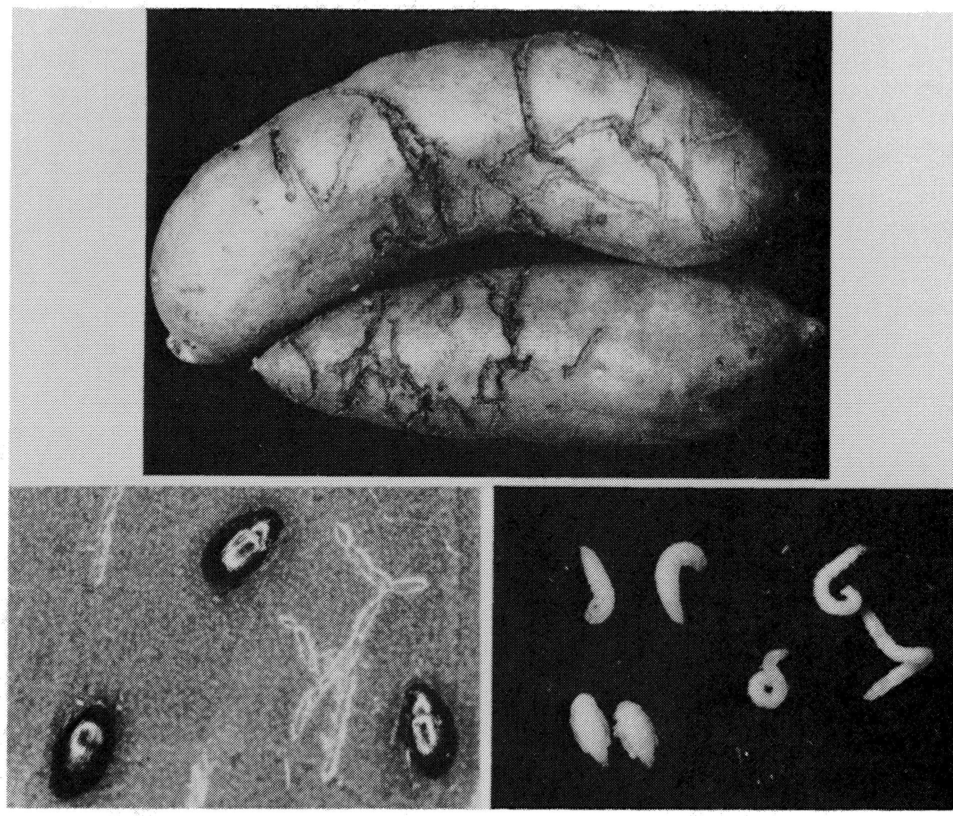

FIGURE 1.9. Narrow channels of the sweet potato flea beetle larvae can ruin the appearance of the susceptible cultivars. Pictured are adults, pupae, and larvae (from left to right).
After Cuthbert (*12*).

Georgia Jet, as an early sizing cultivar for use in South Georgia; Oklamex Red (*30*) and Caromex (*11*), to meet the unique environmental requirements for production in New Mexico; Pope (*10*), for use in areas subject to flooding; Eureka, because it appears to do well in California soil rot infested areas; and Vardaman, for its adaptation to Mississippi conditions.

New sources of resistances to many of the disease and insect pests have resulted through use of mass selection techniques (*15,43,45*). The U.S. Vegetable Laboratory in Charleston, South Carolina, has released nine breeding lines in recent years with unique combinations of high-level resistances (Table 1.6). All have orange flesh and the five most recent releases (W-115, W-119, W-125, W-149, and W-154) have generally acceptable baking and canning quality. As a group they tend to be more susceptible than current cultivars to sclerotial blight in plant beds. One line, W-51, was released because of its resistance to a resistance-breaking race of southern root-knot nematode first reported in 1973 (*65*).

The success in finding resistance to the resistance-breaking race of southern root knot demonstrates the value of a wider gene base, in this case provided through use of mass selection techniques. The degree of control provided by host plant resistance to insects has been demonstrated in sweet potato to be as good or better than that obtained with chemical

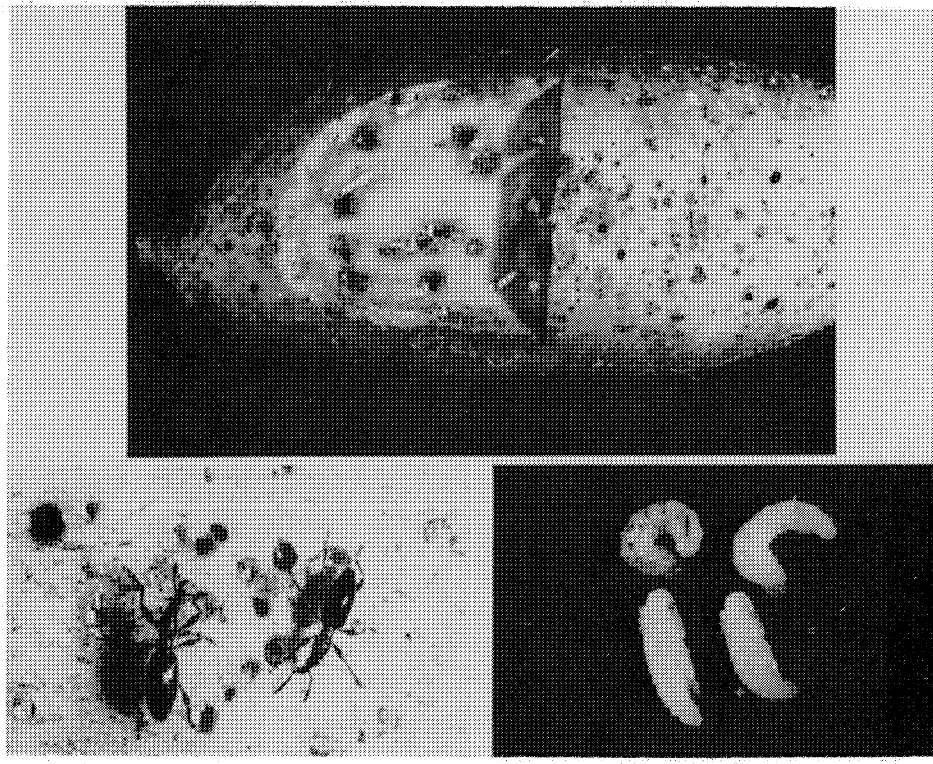

FIGURE 1.10. Worldwide, the most serious insect pest of sweet potato is the sweet potato weevil, which damages the roots during field production and continues to do so during storage. Pictured here are adults, pupae, and larvae of the weevil that occurs in the United States.
After Cuthbert (*12*).

TABLE 1.5. Disease and Insect Reactions of U.S. Sweet Potato Cultivar Releases, 1971–1981[a]

		Disease reactions				Insect reactions		
Cultivar	Previous designations	Internal cork	Fusarium wilt	Southern root knot	Soil rot	WDS	Flea beetle	White grub
Jewel (*79*)	NC-240	R	R	R	S	S	R	S
Redmar (*68*)								
(Goldmar) (69)	Md-2416		I–S	I–R		I–S	S	S
Georgia Jet (*26*)	GA-41		S	S		S	S	S
Jasper (*29*)	L9-190	R	R	I–R	R	I–S	I–R	S
Painter (*23*)	VP9-51	S	R	I–R		I–S	S	S
Carver (*91*)	TI-1885		R	I		I	R	S
Rojo Blanco (*90*)	CL-22-72		I	S		I	I	S
Oklamex Red (*30*)	OK-64-59		R	I				
Caromex (*11*)	NC-320		R	I		I–S	I	S
Pope (*10*)	NC-345	I–R	R	R		I–S	I	I
Travis (*28*)	L4-62	R	I–R	I	I–R	S	R	S
Eureka (*83*)	L4-131	R	R	I	I–R	S	R	I
Vardaman (*2*)	M3-702	R	R	S	I–S	S	S	S

[a]R, resistant; I, intermediately resistant; S, susceptible.

TABLE 1.6. Disease and Insect Reactions of Recent Sweet Potato Breeding Line Releases by the U.S. Vegetable Laboratory, Charleston, South Carolina[a]

Line number	Disease			Insect			
	Internal cork	Fusarium wilt	Southern root knot	WDS	Flea beetle	White grub	Sweet potato weevil
W-13 (*44*)	R	R	R	R	R	R	I–R
W-51 (*18*)	R	HR	HR	S	S		
W-71 (*48*)	R	HR	R	HR	R	I	R
W-115 (*48*)	R	R	R	R	HR	I–R	R
W-119 (*48*)	R	HR	HR	HR	R	R	R
W-125 (*48*)	R	R	R	R	HR	R	R
W-149 (*48*)	I	HR	HR	R	R	I–R	I–R
W-154 (*48*)	R	R	HR	R	R	R	I–R
W-178 (*44*)	R	R	R	R	S	R	

[a]HR, highly resistant; R, resistant; I, intermediately resistant; S, susceptible.

TABLE 1.7. Estimates of Genetic and Insecticide Control of Soil Insects[a]

Selection or cultivar	Roots damaged (%)			Control by source (%)[b]		
	Untreated	Treated	Mean	Genetic	Insecticide	Both
	WDS at Charleston, South Carolina, 1975					
W-13	35	19	27	61	18	79
W-3	65	34	50	28	34	62
Goldrush	90	57	74	—	37	—
	Sweet potato flea beetle at Charleston, South Carolina, 1975					
W-13	3	2	3	89	4	93
W-3	4	3	4	85	4	89
Goldrush	27	17	22	—	37	—
	All insects including white grub (*P. aliena*) at Charleston, south Carolina, 1975					
W-13	27	20	24	70	8	78
W-3	65	39	52	29	29	58
Goldrush	91	66	79	—	27	—
	White grub (*P. ephilida*) at Sunset, Louisiana, 1978					
L3-64	8	0	4	87	12	100
W-94	12	3	7	81	14	96
W-99	16	5	11	75	17	92
L4-89	31	10	20	52	32	84
SC 1149-19	46	23	34	28	36	64
Centennial	64	46	55	—	28	—

[a]Adapted from Cuthbert and Jones (*16*) and from Rolston *et al.* (*81*).
[b]Control estimates based on injury to the untreated susceptible cultivar.

treatment of susceptible cultivars (Table 1.7) (*16,81*). These recent breeding achievements suggest promise for even greater progress in the near future.

CURRENT GOALS OF BREEDING PROGRAM

The primary breeding goals for sweet potato are much as they always have been: to develop cultivars with the highest possible quality that can be produced at the lowest possible cost (Fig. 1.11). This implies high yield, good culinary qualities, and the many necessary traits for efficient production and marketing. These include good storage characteristics and resistances to storage diseases, high sprout production and resistances to plant bed diseases, and good field performance and resistances to field pests in types suitable for continued improvement efforts (plants that, therefore, flower and set seed without special treatments).

Breeders continue to seek higher levels of resistances to fusarium wilt and root knot, which are important diseases throughout the sweet potato production areas of the country.

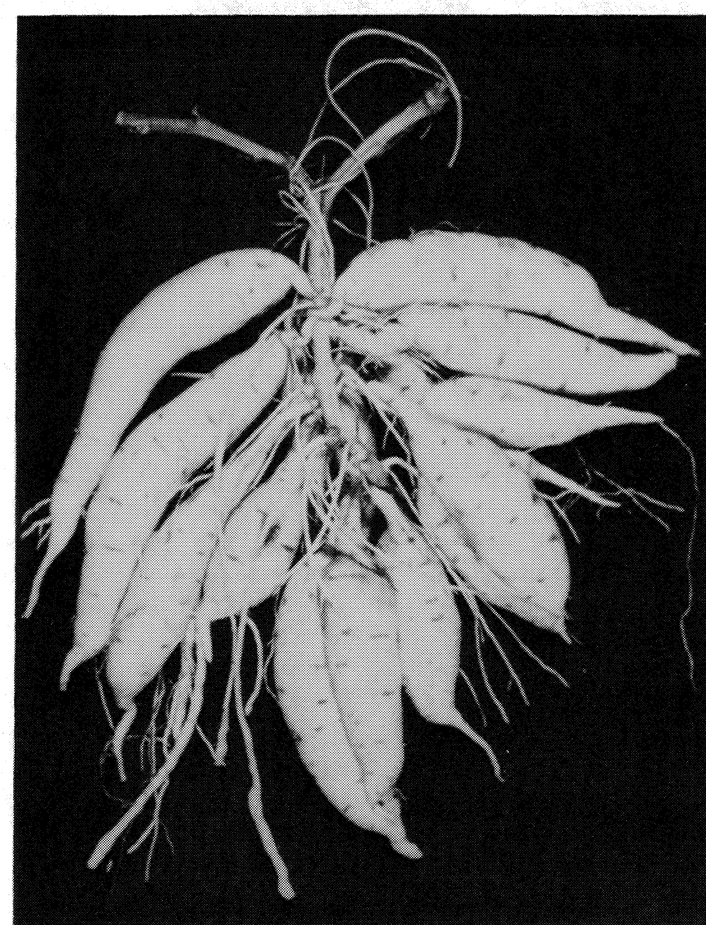

FIGURE 1.11. Selection for a large number of well-shaped roots is one way to achieve high marketable yields.

Resistances to soil insects are receiving more emphasis especially for the lower parishes of Louisiana, where severe infestations in recent years have contributed to significant reductions in sweet potato production (*81*). Because sweet potatoes are increasingly grown in rotation with other crops requiring liming of soil and consequent increases in soil pH, soil rot has become a more severe problem especially in the major production areas of California, Louisiana, and North Carolina (*66*). Resistance offers the only practical solution to the soil rot problem and is therefore receiving major attention in the three states mentioned. Studies suggesting the possibility of resistance to sweet potato weevil (*24,48,73,74,81*), and the fact that it is of primary importance throughout the tropical growing areas of the world, have spurred greater interest and increased effort in breeding for weevil resistance. Virus diseases are a special concern, but there is little current

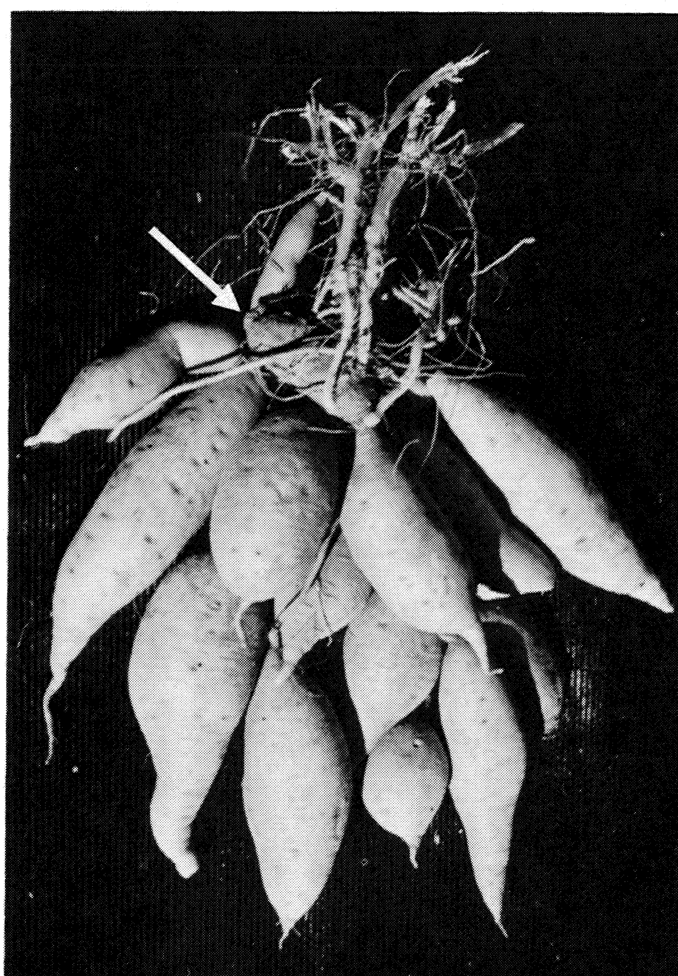

FIGURE 1.12. Suitability for planting with cut root pieces is under genetic control. The planted piece (arrow) either decays or fails to enlarge and the new hill consists of marketable shaped roots. By the elimination of beds for plant production this trait may contribute to reduced labor requirements.

TABLE 1.8. Correlation of Flesh Color with Root Specific Gravity[a]

Root specific gravity[b]	Number of plants, flesh color:[c]						
	W	CR	VLO	LO	O	DO	Total
1.00	0	1	1	3	4	3	12
1.02	2	3	2	3	9	9	28
1.04	2	9	3	10	15	13	52
1.06	6	19	10	7	10	2	54
1.08	3	11	7	7	4	4	36
Total	13	43	23	30	42	31	182

[a]Although a number of studies have demonstrated significant correlations of white or light flesh and high dry matter, orange and dark orange types do occur with high specific gravity or dry matter as demonstrated in the fifth generation of mass selection population I. [After Jones *et al.* (*45*).]
[b]Determined by flotation, Cherokee and Goldrush = 1.00.
[c]Subjective scores: W, white; CR, cream or yellow; VLO, very light orange; O, orange; LO, light orange; DO, dark orange.

breeding activity for resistances except to discard those types obviously susceptible to internal cork or russet crack. Only modest efforts are being made to find and incorporate resistances to reniform nematodes (*8*), sclerotial blight (*19*), scurf, and the various storage diseases.

Secondary breeding goals involve special-purpose types such as direct planting cultivars that can be planted with cut root pieces (Fig. 1.12), short vining or dwarf types for small-farm or garden cultivars, white-flesh types for cooking, and high-yielding cultivars for liquid-fuel production (biomass types). It remains a possibility to breed other special-purpose kinds if new developments provide sufficient demand. For instance, a high dry matter, orange-flesh sweet potato especially suited for making chips and french fries is possible (*39,45*) (Table 1.8, Fig. 1.13). Vine tips can be eaten and selection for high quality in that respect is possible as well as selection for forage value.

The sweet potato offers considerable promise for biomass production because of its adaptation to dry environments and its perennial growth. Many crops mature and cease growing after a relatively short growth period. In contrast, sweet potatoes continue growth as long as temperatures are not too cool, thus making use of available sunlight until harvested. The statistics on U.S. sweet potato yields (Table 1.1) are not applicable when considering biomass production because harvests are begun when prices are favorable for U.S. #1 size roots. Therefore, relatively small-sized roots are harvested prior to maximum root development, which would result in maximum bulk yields. Good data for biomass yield estimates are not yet available, but 18–22 tons/acre (40–50 MT/ha) is a reasonable expectation and as much as 40 tons/acre (90 MT/ha) may be possible.

SELECTION TECHNIQUES FOR SPECIFIC CHARACTERS

In sweet potato breeding one must remember while making selections for specific characters that the ultimate goal is to find unique combinations of favorable characteristics. One must resist the temptation to approach breeding as a gamble, to keep a plant for further testing on the slim chance that it will be outstanding. For instance, it does little good to select for root-knot resistance and then to keep those plants with deep orange flesh

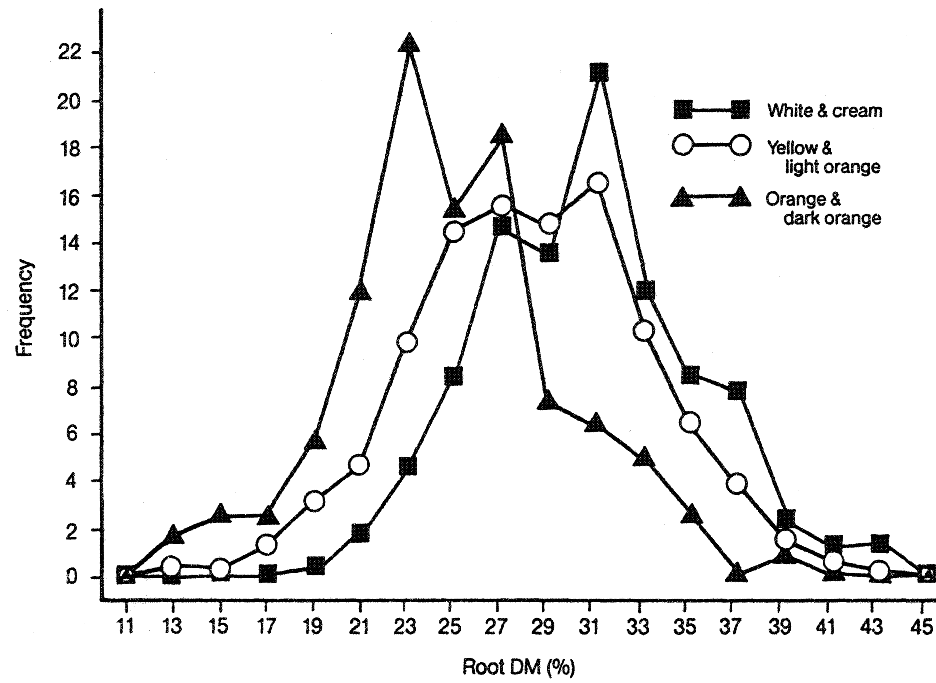

FIGURE 1.13. Frequency polygons for dry matter (DM) of three flesh-color groups of sweet potato, suggesting two genetic systems for DM, one associated with orange flesh and the other with white flesh. Although the lighter flesh colors are correlated with high DM (.61, significant at 1% level), dark orange selections with high DM are available in sufficient frequency for effective selection progress. From mass selection population H/3: white and cream (*n* = 222), yellow and light orange (*n* = 567), and orange and dark orange (*n* = 127).
After Jones (39).

whether they have resistance or not. For selection to be effective, plants that otherwise would have been saved must be discarded because of a particular unfavorable trait. Efficient breeding procedures and firmly set selection priorities remove most of the gamble and assure positive progress. The following procedures are taken from those of the authors and may not necessarily conform to procedures used in other breeding programs.

Preliminary Selections

The cost involved in testing each plant increases during the selection process. Efficiency demands that undesirable plants be discarded as early in the program as possible. Therefore, efficient systems follow sequential screening procedures that evaluate as many plants for as many traits as possible in the seedling stage.

Seedlings can be started in seed trays filled with horticultural-grade vermiculite or Jiffy mix (Fig. 1.14). We use commercially made plastic trays (11 × 22 × 2 in.) with drainage holes placed on black plastic to prevent contamination by microflora of the greenhouse benches and to help control moisture. Scarified seed are planted in holes made in the medium with a plywood template containing 20 × 10 rows of ¼-in. round pegs that are 1 in. long (200 per tray). When the majority of the seedlings have about four leaves they are transplanted to steam-sterilized greenhouse bench medium on 3- to 4-in. centers in holes

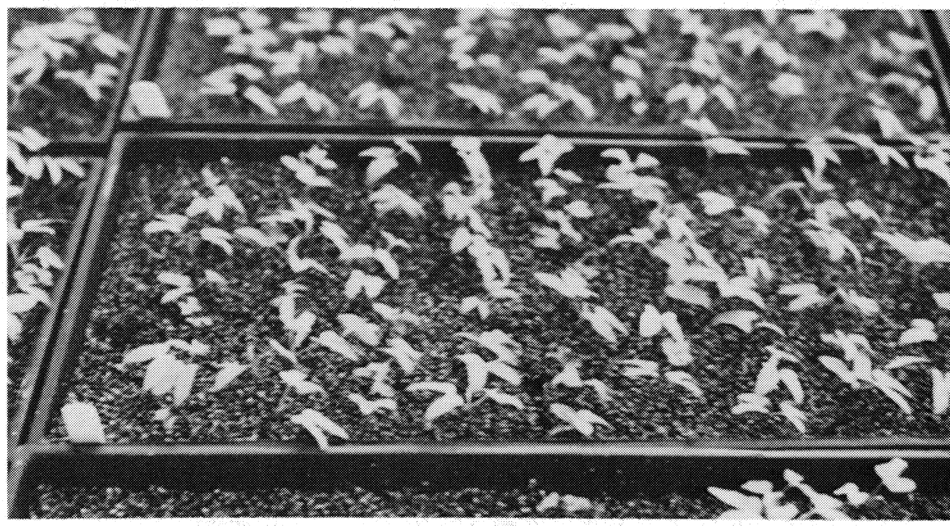

FIGURE 1.14. **Seedlings started in trays filled with horticultural-grade vermiculite.**

made with a long template (length determined by width of the bench) containing ¾-in. round pegs that are 2½ in. long. We have rather high sides (10 in.) on our benches to allow a deep medium for good root formation. Through the years we have found that many soil mixtures work well but that high proportions of coarse sand allow better moisture control. At the time the seedlings are transplanted, they are inoculated with a water suspension of composite inoculum containing about 2000 root-knot nematode eggs and 50,000 propagules of fusarium wilt organism per plant (*17*). The inoculum is poured around the seedlings before the holes are closed and then the soil mixture is firmed around the seedlings with two fingers. Temperatures must be carefully maintained at 24°C or above (30°C optimum) and the soil kept moist (near field capacity) to favor good nematode development. Plants are fertilized periodically with nutrient solution approximating a 1–2–3 (N–P–K) nutrient ratio. After 35–45 days of growth in the inoculated soil, soil moisture can be reduced until plants begin wilting, which favors expression of fusarium wilt and promotes storage root formation. Many of the plants suceptible to fusarium wilt will die and others will show typical symptoms such as yellowing, stunting, wilting, discoloration of the vascular system, and/or stem splitting. About 60 days after transplanting, the seedlings should be carefully lifted from the soil, their roots rinsed in water and examined with 2.75× magnifiers. At that time plants with fusarium wilt symptoms or evidence of root-knot susceptibility are discarded. Most plants should have small storage roots forming that can be cut to evaluate flesh color, and only those with dark orange flesh are saved for further testing. The authors save 10–15% of the seedlings at this stage. The total number of seedlings evaluated depends on availability of greenhouse space and plot land for subsequent field evaluations.

The selected seedlings are transplanted to black-plastic-covered field beds previously prepared with a complete fertilizer relatively high in nitrogen to force rapid vine growth. The black plastic helps maintain a warm soil, which encourages fusarium wilt development as well as good plant growth and provides effective identification of escapes from the greenhouse wilt screening. Each spring is slightly different; but as soon as weather permits and plant growth is sufficient, five vine cuttings about 12 in. long from each seedling are planted in five-plant field plots conforming as nearly as possible to commercial practices (Fig. 1.15). Plants are spaced 12 in. apart in the row with skips of 5 ft between plots to reduce root mixtures during harvest. In general, sweet potatoes are grown on ridges 8–10 in. high, depending on soil type, soil drainage, row width, and farming equipment in use. Row widths usually are 42–48 in. but may be less (36 in.) on sandy soils where ridges can be low. Vine growth of sweet potatoes is rapid providing good weed competition and some farmers use no herbicides. In experimental tests where vine types vary and in most farming operations, locally recommended herbicides are generally used.

After about 110 days of growth the seedlings are dug and judgments made whether or not to test them further. Those with obviously poor yield, poor shape, lobing, veining, cracking, or otherwise unacceptable root appearance are discarded immediately. The use of frequent plots of check cultivars, such as Jewel, assists greatly in these judgments. Roots from promising-looking plants are examined more closely for signs of insect or disease injury and lines discarded if they appear susceptible. Roots from selected plants are picked up in wet-strength paper bags, labeled with appropriate identity, cured, and stored. Curing roots immediately after harvest for 4–7 days at 27°–30°C and from 85 to 90% relative humidity promotes rapid healing of injuries through the formation of new cork layers and reduces decay. After the curing period, temperatures are lowered to 13°–16°C, but a high relative humidity is maintained. During the curing and storage periods,

FIGURE 1.15. Orange fleshed seedlings with resistance to fusarium wilt and root-knot nematode are tested in five-plant plots during the first year. The five plants in each plot are propagated from vine cuttings from resistant seedlings.

starch is converted to sugars and dextrins, a process that occurs at different rates and to different degrees in each selection. These differences are recognized in the trade and cultivars are classed as moist-flesh ("yam") or dry-flesh types. Soon after harvest, sample roots of the seedling selections are cut and acceptable flesh color confirmed. Those that appear mottled or very light orange are discarded, as are those that are pithy or float in water.

At a convenient time after harvests, roots of each line are baked at 176°C for 2 hr and rated for culinary acceptability. We use two replicates of two roots each in these first baking tests. Since there will be more lines than can be baked at one time, an acceptable cultivar, such as Jewel, should be included as a control with each lot of samples baked. We rate five traits subjectively after cutting the roots from end to end. A scale of 1 to 5 is used for each trait, where 1 is excellent, 2 is good, 3 is questionable but worth retesting, 4 is probably not acceptable, and 5 is definitely unacceptable. The five traits rated are (1) color, (2) fiber, (3) discoloration or darkening, (4) general appearance or eye appeal, and (5) taste. Separate notes are made about any unusual quality or specific trait such as bland, too dry, very moist, grainy, very sweet, or pithy. When the average rating of the four roots is 3.0 or more for any one of the five baking traits, that line is discarded. This is a critical stage in the selection process and very vulnerable to individual bias, which must be carefully avoided. Judges must be objective and highly experienced. Sometimes it may be best to skip the taste test at this point and to use only the other four traits. Fiber is a particularly difficult trait to rate (*47*). One must remember that sweet potatoes are roots and must have some fiber even in those with excellent quality. It helps to think in terms of rating degrees of "objectionable" fiber. We rate fiber visually and by feel using a standard table fork in these early tests.

Sweet potatoes are propagated vegetatively with sprouts from roots placed in various kinds of plant beds (*86*). In the colder regions of production, plant beds must be heated to prevent chilling of the roots or sprouts; in more moderate temperature zones, a simple plastic cover is all that is required; while in much of the south a soil cover of 2–3 in. is sufficient. Vine cuttings from early plantings are also used for later plantings.

As roots are taken out of storage for bedding in early spring those selections with excessive shrivelling or storage rots can be discarded. Those that sprout poorly or have severe sclerotial blight when grown in plant beds covered with black plastic need not be tested further (Fig. 1.16). Those selections remaining make up the second-year seedlings and are subjected to more critical evaluations.

Second-Year Seedlings

In the second year, seedlings are yield tested in 25-plant plots replicated four times. Two replications are harvested after about 100 days to identify short-season types and the other two replications after about 120 days. We use four controls in these tests: Jewel and Centennial for yield comparisons, W-13 as an insect-resistant check, and SC 1149-19 as an insect-susceptible check. At harvest all entries are rated for insect injury, shape, freedom from cracking, veining or lobing, and good general appearance. The weights of each of four grades of roots are recorded: U.S. #1, roots with 2- to 3.5-in. diameters and 3- to 9-in. lengths, free of defects, and well shaped; Canner, roots with 1- to 2-in. diameters and 2- to 7-in. lengths; Jumbo or Oversize, roots that exceed the diameter and length requirements of U.S. #1 but are of marketable quality; and Cull, roots with 1-in. or larger diameters and so misshappen, cracked, or unattractive that they do not fit as

FIGURE 1.16. The use of black plastic on plant beds increases sclerotial blight incidence and aids in selection for resistance in seedlings entering the second year of testing.

marketable in any of the other grades. Grading boards with three holes of 1-, 2-, and 3.5-in. diameters assure uniform grading standards. After curing, baking quality is tested as outlined earlier.

Insect damage ratings are obtained from 10-plant plots replicated four times with the same four control cultivars as above and grown in an area where natural insect infestations are generally high. The numbers of holes or scars caused by each of the three groups of insects outlined in Table 1.4 under WDS complex, grubs, and sweet potato flea beetle are recorded for each root of all entries. With high natural infestation levels, the percentages of roots injured by larvae of the WDS complex or the sweet potato flea beetle may be adequate and are much less tedious to obtain (*51*). Where insect-rearing facilities are available, artificial infestations may be used to supplement natural insect populations (*82*).

The root-knot and fusarium wilt resistances of selections should be confirmed during this second year of testing in carefully controlled greenhouse tests. Uniform vine cuttings of the selections can be obtained from plant beds or field plots. This work is best done during the warm growing season because a supply of healthy, vigorous terminal cuttings are available and conditions are generally best for disease evaluations.

The fusarial inoculum should consist of a composite of virulent isolates (six or more isolates, if possible) of the wilt pathogen (*Fusarium oxysporum* f. sp. *batatas*) selected from widely separated production areas in the United States. The inoculum is produced and standardized to approximately 50,000 propagules per milliliter (*17*). This inoculum density should result in complete mortality of the standard susceptible cultivars Porto Rico and Nemagold within 2 weeks after inoculation. The fresh terminal cuttings with their expanded leaves removed are dip-inoculated and immediately placed in a greenhouse bench-bed containing a soil–sand mixture. Standard control cultivars with intermediate and high resistance are always included for comparative purposes. Optimum conditions for disease development are maintained. Disease readings are started at the first indication of wilt (stem rot) symptoms, which usually occur 5–7 days after inoculation. These readings are continued every other day for a total of eight times. After 21 days the remaining live plants are removed and their stems sliced to determine the number and extent of vascular infection. A disease index is computed from the disease data, and each selection is compared to the resistant standard cultivars. Only those selections with wilt resistance equal to or better than the intermediate-resistant cultivar Centennial are retained in the program.

Highly virulent isolates of the root-knot nematode species are maintained on susceptible host plants until eggs are needed for inoculations. Eggs of the nematodes are extracted from the fresh roots using the sodium hypochlorite procedure (*43*). About 2000 eggs are used to inoculate each cutting of each line. Standard resistant and susceptible cultivars are always used in these tests. Inoculation is accomplished by simply pouring an aqueous suspension of eggs into and around the holes in the soil of the bench in which the cuttings have been placed. The plants are grown under optimum conditions for growth and disease development for 50 to 60 days. They are then gently uprooted and their roots washed carefully and examined under magnification to obtain gall and egg mass indices for each plant. Plants are evaluated using a scale of 1 to 5 where 1 equals high resistance (no galls or egg masses) and 5 equals high susceptibility (severely galled or massive egg masses). In some special cases root samples are taken from some outstanding lines and the eggs extracted to determine the actual amount of reproduction. This is perhaps the ultimate method for evaluating for resistance, since this will show the amount of reproduction that has occurred. This is, however, a very time-consuming and tedious procedure. The root-knot indices are compared to the standard cultivars in the tests, and only those lines with a high level of resistance are retained. Since all of our seedlings are routinely evaluated in the preliminary testing procedure, a very high percentage of these lines (>90%) have high levels of resistance to both diseases. Promising selections still retained after these second-year trials are tested in the advanced trials the third year.

Trials of Advanced Lines

The advanced lines represent the best selections from two or more years of evaluation. These are handled in very much the same way as the second-year seedlings. As data are collected from increasing numbers of trials, better judgments regarding the cultivar potential of the selections can be made. Some idea of yield stability can be obtained from results of several years, and more data are available on sprouting, storage, and baking quality. During this period, canned roots are subjected to quality ratings, and root-knot nematode resistances are tested under field conditions in a uniformly infested nursery.

There has been an increasing interest in sweet potato weevil resistance and techniques for screening have been developed (*24,74,80*). Reliance on natural infestations has not been successful for us. Rearing of weevils is relatively easy, but quarantine regulations restrict doing so in certain areas of the country. The specific techniques are still in a period of refinement but some general comments are in order. By using laboratory screening techniques during winter months the frequencies of resistant lines in field tests can be increased, and the numbers of lines decreased, allowing more replications to be grown in a test of the same size. We find 10-plant plots to be sufficiently large and try to have at least eight replications. The mechanisms of resistance are not known at this time, but we suspect that effective field resistance may involve more than one mechanism. The levels of resistance attained (Table 1.6) do not approach immunity but probably are sufficient to be economically important.

Techniques for evaluation of soil rot resistance in the laboratory or greenhouse have not been developed to the extent that it can be done routinely in a large breeding program. However, field screening in infested soils can be very effective as demonstrated by recent releases from Louisiana (Table 1.5).

Parental Selection

Probably the most important aspect of selection from a breeding standpoint is that of parent plants because it determines the direction of the breeding program and, ultimately, its success or failure. The selection of a parent plant is based on two things: its phenotypic expression and that of its offspring, i.e., its ability to transmit desired traits to the next generation. Heritability estimates give us a general idea of what can be expected in regard to transmission of a desirable trait, but each parent will perform differently because of the complex hexaploid inheritance of sweet potato. Thus, progeny testing is a valuable tool in determining the breeding value of a particular selection.

Quantitative Genetic Considerations

Because inheritance in sweet potato is best described in quantitative genetic terms, it is very important for sweet potato breeders to develop a working concept of what heritability estimates are and how to interpret them. Heritability is the degree of correspondence between phenotypic values and breeding values (*21*). Heritabilities are not measures of desirability. They have nothing directly to do with frequency of good versus poor types, and they say nothing about means or distributions. A high estimate says nothing about how good our materials are, only that the better parents should tend to give the best progeny and, on the other hand, the poor parents can be counted on to have poor progeny on average. They merely estimate how well we can evaluate the parents and predict what the offspring will be like with the particular breeding materials and techniques of evaluation being used. If those breeding materials are from a wide gene base, the estimates will probably have wider application than if they were from a narrow gene base.

Heritability estimates can be obtained through a number of statistical procedures (*21*). For purposes of this discussion it is sufficient to consider two general narrow-sense heritability (h^2) estimation methods, one from variance–covariance techniques (*36,52*) and the other from twice the regression of offspring means on parent means (*39,43,51*). A considerable number of h^2 estimates has accumulated in recent years, and this body of knowledge can assist us in the interpretation of new estimates and can provide guidance in planning breeding programs (Table 1.9). By comparing estimates obtained by regression with those obtained by variance–covariance, we can see that the regression results are more conservative. It is apparent that the variance–covariance technique tends to yield overestimates. This illustrates the importance of knowing how an estimate was obtained in order to interpret it properly.

The size of the h^2 estimate provides guidance for planning selection sequences and

TABLE 1.9. Partial List of Narrow-Sense Heritability (h^2) Estimates

Trait	h^2 estimate (%)	Statistical technique	Reference
Root weight (yield)	41	Variance–covariance	*52*
	41 ± 4	Regression	*49*
	44	Variance–covariance	*55*
	25 ± 13	Regression (after two cycles of selection)	*39*
Growth cracks	51	Variance–covariance	*52*
	37 ± 4	Regression	*49*
Flesh color	66	Variance–covariance	*52*
	53 ± 14	Regression	*39*
Flesh oxidation	64	Variance–covariance	*52*
Dry matter	65 ± 12	Regression	*39*
Crude protein	57	Variance–covariance	*56*
Fiber	47 ± 4	Regression	*49*
Skin color	81	Variance–covariance	*52*
Sprouting	39 ± 14	Regression	*39*
	37 ± 2	Regression	*49*
Vine length	60	Variance–covariance	*37*
Leaf type	59	Variance–covariance	*37*
Flower buds/cyme	50	Variance–covariance	*37*
Fusarium wilt reaction	86	Variance–covariance	*36*
	89	Variance	*9*
	50	Regression	*9*
Nematode egg mass index (*M. incognita*)	75 ± 23	Regression	*43*
	57 ± 37	Regression	*43*
(*M. javanica*)	69 ± 18	Regression	*43*
WDS root injury (%)	45 ± 12	Regression	*51*
Sweet potato flea beetle root injury (%)	40 ± 7	Regression	*51*
Weevil resistance (*C. puncticollis* Boh)	84	Variance–covariance	*24*

techniques. When the estimate is high we can rely on the parental phenotype and not worry so much about progeny testing. We should be able to increase frequencies of desirable types rather quickly with the selection methods used to make the estimate. If the estimate is low, we may want to evaluate parental candidates by progeny tests. Since the h^2 estimate is basically a ratio of the additive genetic variance over the phenotypic variance, a low estimate may indicate a need for greater precision in techniques. Maybe one should consider more replications, more locations, artificial infestations, greenhouse tests, or laboratory techniques in order to reduce the phenotypic variance. Of course, if the estimate is low because of a small genetic component, reducing the phenotypic component may not be of much help.

What size h^2 estimate can be considered favorable in sweet potato breeding? An exact answer is difficult, but comparison of some actual selection advances with h^2 estimates from materials of similar genetic makeup does give some clues. Both frequencies and levels of resistance to the WDS complex of soil insects were increased considerably by recurrent selection (*15*) (Fig. 1.17). The h^2 of WDS resistance was later estimated as 0.37 ± 0.11 by regression of offspring means on parent means in somewhat similar materials

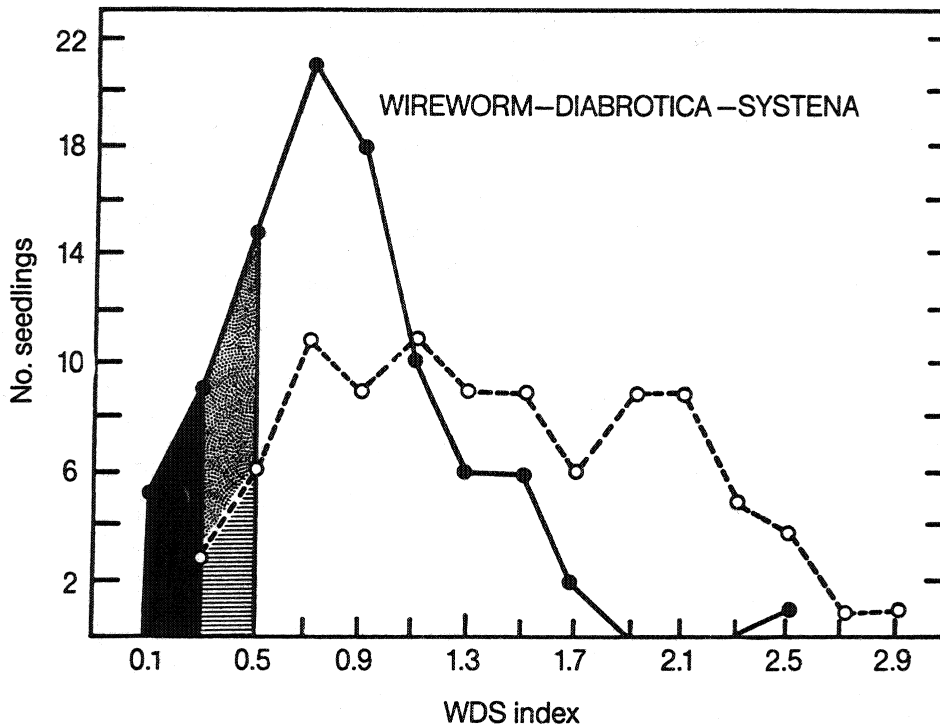

FIGURE 1.17. Frequency polygon for WDS injury to selected (solid line) and unselected (broken line) sweet potato populations. The cross-hatched area shows the portion of the unselected population with an acceptable level of resistance; the lightly shaded area shows the increased frequency of the same level of resistance in the selected population; and the heavily shaded area shows the portion of the selected population with higher levels of resistance than found in the unselected population. Thus, through four cycles of mass selection, both frequency and level of resistance were increased.
After Cuthbert and Jones (*15*).

(*51*). The h^2 of root flesh oxidation after treatment with catechol was estimated as 0.64 by variance–covariance methods (*52*), and subsequent selection experiments for low oxidation demonstrated rapid improvement (*38*) (Table 1.10). Obviously estimates over 0.60 are quite adequate for good selection advance. Probably estimates as low as 0.30 by regression and 0.40 by variance–covariance could be considered favorable provided that the selection techniques have enough precision.

Mass selection in sweet potato has been shown to be an effective way of combining favorable characters in parental types (*45*). In general, traits are sufficiently independent to allow effective selection with independent culling levels. It is important to note that mass selection not only provides for improvement in the mean performance of successive generations but also for higher levels of performance than occurred in the base population (Fig. 1.17). It is quite likely that we can develop higher levels of sweet potato weevil resistance than we now have.

DESIGN OF THE COMPLETE BREEDING PROGRAM

The philosophy of sweet potato breeding is slowly changing, with a gradual acceptance of mass selection methods based on quantitative genetic principles (*33*). Rapid generation

TABLE 1.10. Selection Advance for Low Root Flesh Oxidation Following Two Selection Schemes[a]

Population/generation	Root flesh oxidation classes (%)[b] 1	2	3	4	5	Mean[c] score	No. plants scored
C/4[d]	3	38	23	14	22	3.1a	153
A/6[e]	17	53	22	6	2	2.2c	157
D/7[f]	7	46	24	13	10	2.7b	150

[a]After Jones (*38*).
[b]Increasing darkening of flesh 10 min after dipping in 0.25 *M* catechol solution.
[c]Means not followed by same letter are different at .01 significance level.
[d]C/4: initiating mass selection population with plants in classes 1 and 2 selected (30%) to begin the selection advance study. These results are from remnant seed grown and evaluated at the same time as A/6 and D/7.
[e]A/6: the selected clones from C/4 were polycrossed in isolation and seedlings of A/5 were evaluated as they were removed from the greenhouse bench. The selected plants were polycrossed to produce seed for A/6. Therefore, this population represents results from two cycles of selection in the seedling or first year of growth followed by crossing of the selected plants.
[f]D/7: seed from the same selections as used in population A were used to start a mass selection scheme with evaluations made at harvest and seed from low-oxidizing plants used to start the next cycle of selection. Therefore, this population represents results of three cycles of mass selection.

advance can be achieved by high selection pressures in open-pollinated populations by using flowering plant types. The concept that profuse flowering would be negatively associated with other favorable traits, such as high yield, has been shown to be unfounded (*45,84*). These techniques provide a sound basis for sweet potato improvement quite different from the classic pedigree breeding procedures, which were based on qualitative genetic principles.

As with other crops, sweet potato breeders are faced with long- and short-range breeding goals (Table 1.11). Long-range goals might encompass the search for new sources of resistances and their introduction into plants acceptable or almost acceptable to the trade, usually in combination with many other traits already considered essential. The new sources may come from plant exploration, genetic engineering, related species, increases or decreases in ploidy levels, somatic hybridization, or use of some other novel genetic technique. This may require looking ahead 15 to 20 years or more. Short-term goals encompass the development of new cultivars with as many of the known desirable traits as possible or some combination of them suitable for special environmental uses or purposes. Often, meeting short-term goals requires looking ahead 5 to 10 years. More breeding programs concentrate on short-term goals than long-term goals, which is proba-

TABLE 1.11. Short and Long-Term Breeding Goals

Short-term goals	Long-term goals
Cultivars	Parents
Individual plant value	Average line value
Small numbers of plants	Large numbers of plants
Precise evaluation	Less precise evaluations
Quick improvement	Gradual continuous improvement
Adaptive research	Fundamental research
Expression	Transmission
Backcross procedures	Mass selection procedures

bly as it should be. Both objectives are important to maintain long-term stability in crop production and to meet increasing global food needs.

Mass Selection Populations

A comprehensive sweet potato breeding program addressing both long- and short-term goals should contain one or more mass selection populations to provide new parental types and to assure the necessary wide gene base for continuous selection advance in future years (Fig. 1.18). In early cycles of mass selection one complete sexual generation can be

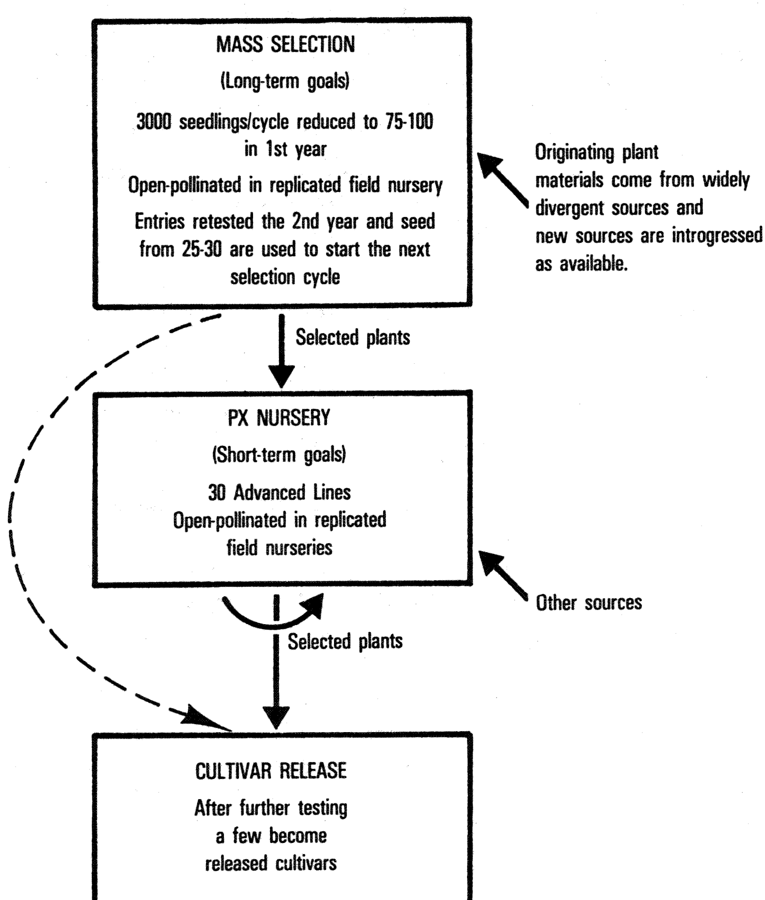

FIGURE 1.18. A comprehensive breeding program addressing both long- and short-term goals should contain mass-selected populations to provide new parental types and to assure the wide gene base necessary for continued selection advances in future years. The authors use two mass selection populations to provide new selections for the PX nursery, each with 2 years per cycle and grown on seed increase trellises in alternate years. Seedling selections from the PX nursery also provide materials for the next PX nursery. Selections from the mass selection population could become cultivars, but the probability is lower than for those from the PX.

completed each year by advancing from true seed to true seed each year. In the mass selection procedure, selected plants are not used in the next cycle, only seed from them. In the beginning cycles it is important to keep records on sources of each plant in order to be sure that the various sources remain represented for about three generations. After that time there is no need to keep records of origins, and seed from selected plants can be bulked to begin subsequent cycles of selection. Our experience indicates that light selection can begin in these early generations. For instance, progeny rows of seedlings from individual selections can be inoculated with root-knot nematodes in the greenhouse and the best resistance within each progeny selected. In some sources it may be necessary to keep low levels of resistances or even some susceptible plants to maintain that source in the population. If orange flesh occurs in low frequency, one can begin some light selection for that trait to assure its presence in later stages of the program. Field tests can be limited to nonreplicated five-plant plots. Controls consisting of the best cultivars should be included for yield comparison.

An exact number of cultivars necessary to start a mass selection program cannot be defined, but there are some general guidelines. For long-term objectives with flexibility to include selection for as yet unknown traits (such as resistance to future disease or insect pests), one should strive for as wide a gene base as possible. For instance, our most recent mass selection population (population J) was started with 350 collections from Taiwan, Japan, New Guinea, Hawaii, Nigeria, Thailand, Peru, Cuba, Philippines, Puerto Rico, New Zealand, Guatemala, Uruguay, Cook islands, Marquesas islands, Spain, Canada, and one of our previous wide gene base populations (population F). These were open-pollinated and about 3000 seedlings started in the greenhouse with 700 representing as near as possible all the various sources moved to a trellis area. Seed from about 200 were used to start the next cycle. In the third cycle the number selected as seed parents was reduced to about 100 among 700 trellised plants. For more limited short-term goals, one might start with as few as six plants, with the realization that a narrow gene base might provide better chances for rapid advance to meet some pressing need.

After about three cycles of intercrossing with light selection, it probably will be necessary to change to 2-year cycles in order better to evaluate yield, sprouting, and storage traits (*45*). Seedlings can be evaluated for flesh color and resistances to fusarium wilt and root knot in the greenhouse; and vine cuttings can be transplanted to the field for evaluation of yield, insect resistances (by including insect-resistant and -susceptible controls), lack of defects (cracking, veining, and lobing), acceptable shape, and general appearance using five-plant nonreplicated plots. About 150 of the best selections can be stored and evaluated for keeping quality in storage and for culinary qualities. In the spring the remaining selections can be rated for sprouting and other bedding traits, such as resistance to sclerotial blight. The best 75–100 selections are then planted on trellises in four or five replications. These are intercrossed by naturally occurring insects and seed collected with appropriate source labels. During the same season, vine cuttings or sprouts from the plant bed are used to plant replicated field trials. Data are collected on yield, insect resistances, and other traits of interest, and the best 25 or 30 selections identified. Seed from these are used to start the next cycle of selection.

This procedure should provide for rather rapid selection advance and concomitant narrowing of the gene base. Thus, it may be necessary to begin a second mass selection population that can be timed to alternate with the original mass selection population. In this way the breeder can have two mass selection populations with only one trellised seed increase nursery each year. New plant collections can be introgressed into the mass selection populations by inclusion in the seed increase nursery. In some cases it will be necessary to induce flowering by grafting or some other means (*20,40,70*). The identity of seedlings from these sources probably should be kept for about three generations, and it may be necessary to make some compromises and reduce selection pressure when evaluating them.

Selections from the mass selection populations can be tested directly for cultivar potential but are more likely to provide a source of parental material for a more restricted polycross nursery. Samples of seed from each cycle can be stored for later use in comparative studies of actual progress attained (*15,45*).

The Polycross Nursery

Technically, "polycross" refers to natural intercrossing of a group of plants in an isolated crossing block and would be applicable to the mass selection nursery, but for our purposes we define the polycross nursery in a more restricted manner. We use the term to refer to a limited number of parents (30 or less) randomly crossed in isolation by naturally occurring insects for the purpose of deriving new cultivars or advanced breeding lines. In our breeding strategy this refers to that group of plants intercrossed to meet our most pressing immediate or short-term goals (Fig. 1.18).

The authors grow a polycross nursery of about 30 advanced lines replicated four times in each of two locations each year. Generally sufficient seeds are produced in one location, but the second provides assurance against adverse environmental conditions that might lower seed set in one location. These nurseries are only about 200 ft each way when 30 plants are set 4–6 ft apart on four rows spaced sufficiently wide to allow for tractor cultivation between rows.

It is important to place some inflexible limits on the number of entries in the polycross to avoid the temptation to add just a few more parental selections. When too many parents are used, the average effect of each parent is diluted; and the hard decisions of which lines to drop are avoided, resulting in reduced selection progress. Each time a new line is added to the polycross, one of the previous entries must be dropped. If one assumes effective selection, the limitation on the number of parents in the polycross assures gradual and continuous improvement. In 5 or 10 years, the breeder will not still be crossing the same set of parents and their immediate progeny, but instead will be crossing an entirely new set of parents, each selected because of some superiority over previous entries. Some of the new entries should come from the mass selection populations and from other sources to prevent too much inbreeding and narrowing of the gene base.

By determining the average values of the important traits of parents in the polycross each year the breeder can visualize how much progress has been made and where selection pressures need increasing to obtain the favorable combinations required. At the same time, progeny tests can and should be used further to evaluate each parent. Where time or facilities prevent formal progeny tests, good notes taken during the selection process can be very valuable. For instance, the percentages of progeny discarded because of poor flesh color or susceptibilities to fusarium wilt and root knot will give a good idea of whether the seedlings from a particular parent will survive even the initial greenhouse screening procedures. If the proportion of seedlings kept is very small, more seed may need to be started from that parent, or it should be considered a candidate for replacement. If the seed set of some plant is very low, it can be entered twice in each replication or grafted to induce better flowering and eventually replaced.

Seedlings from the polycross provide a major source of potential cultivars and are screened for the many essential traits as detailed in previous sections. Selections made in the first year are tested in the second-year seedling trials and in the advanced line trials for 2 years or more. The most promising selections may then be vegetatively increased for submission to the national trials. Although the breeding program makes use of seed-propagated plants, the final hexaploid genotypes must be multiplied exclusively and indefinitely by vegetative means. A cultivar such as Jewel is actually one seedling multiplied clonally.

PERFORMANCE TRIALS OF ADVANCED LINES

National sweet potato trials are conducted annually by members of the National Sweet Potato Collaborators Group, which includes personnel of AES in Alabama, Arizona, Arkansas, California, Georgia, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Missouri, New Jersey, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia and of the USDA, Agricultural Research Service. This group, organized in 1939 (*5*), has contributed greatly to sweet potato improvement through the cooperative efforts of its members. Current data on all phases of sweet potato research are assembled annually, distributed to the members, and discussed at meetings held each year in early February.

Breeders are free to enter any new selection they consider worthy of consideration to the group for testing at 20–24 locations. Not all locations provide yield tests, but they may supply information on other aspects such as disease and insect resistances or baking and canning qualities. Generally yield trials are conducted at about 18 locations. New entries are grown in the Observational Trials the first year of submission. These trials consist of 25-plant plots that are not replicated because of the limited number of bedding roots usually available. The Observational Trials typically contain about 6–10 selections plus Jewel and Centennial as controls. At the annual meeting the members vote whether to retain an entry in the Observational Trials, test it in the Advanced Trials, or drop it from further consideration. An entry may remain in the Observational Trials more than 1 year, but usually a recommendation either to advance it or drop it is made after 2 years.

Advanced Trials are usually conducted at the same locations as the Observational Trials but have four replications of 25 plants. Typically these trials contain only three to six selections and Jewel and Centennial. Harvested roots are weighed by grades, and the percentage of U.S. #1 is calculated by dividing the weight of U.S. #1 by the total marketable weight (culls and cracks not included). Comments made at harvest are made available to other members to assist in line evaluations. Also, any unusual conditions encountered are noted, which provides valuable information on performance under such stress conditions as prolonged periods of drought, cool wet weather during harvest, or severe disease or insect infestations. Notes are also provided on storage qualities, sprouting characteristics, culinary qualities, and production factors such as disease and insect reactions. About six or seven stations present results from taste panels for both baked and canned samples. Baked roots are rated on a scale of 1 to 10 for eye appeal, color intensity, color uniformity, freedom from discoloration, smoothness, moistness, lack of fiber, and flavor. Weighted baking and canning scores based on all subsidiary traits using a scale of 1 to 100 are then computed for each entry and the controls. Data from each location and summaries of all locations are included in the annual progress reports.

The members of the national group vote whether to drop a selection from further consideration by the group, to retain it for testing the next year, or to recommend that the originator name and release it for commercial production. Recommendations from the group are not binding on the breeder, who may release a selection the group has dropped from further consideration without a recommendation for release. There are many instances where such deviations from the national group evaluation are well justified. There may be a pressing need for a new cultivar with resistance to some specific pest in a limited production area, or a selection may appear very well suited to special environmental conditions or market needs of a particular area.

The national trials provide much more information on potential cultivars than an individual AES could obtain otherwise. A reasonably good estimate of yield stability can be made because of the many environments sampled in the 2 or 3 years of trials. Comments by other scientists about performances of the selections under various growing conditions are of immense value in decisions about release of new cultivars. This is especially true when extreme stress conditions have been encountered. The trials also give workers in cooperating states an opportunity to observe the performances of selections prior to release. Thus grower questions about new cultivars can be answered and informed recommendations made.

REFERENCES

1. Ahn, J. K., Collins, W. W., and Pharr, D. M. 1980. Influence of preharvest temperature and flooding on sweet potato roots in storage. HortScience *15*, 261–263.
2. Allison, M. L., Ammerman, G. R., Garner, J. W., Hammett, H. L., Singleton, C., Withers, F. T., and Palmertree, H. D. 1981. Vardaman, a new early maturing sweet potato variety for Mississippi. Miss. Agric. For. Exp. Stn., Inf. Sheet *1305*.
3. Austin, D. F. 1977. Hybrid polyploids in *Ipomoea* section *batatas*. J. Hered. *68*, 259–260.
4. Austin, D. F. 1978. The *Ipomoea batatas* complex. I. Taxonomy. Bull. Torrey Bot. Club *105*, 114–129.
5. Bowers, J. L., Harmon, S. A., and Dempsey, A. H. 1970. History of group and early research. South. Coop. Ser. Bull. *159*, 1–7.
6. Ceponis, M. J., Daines, R. H., and Hammond, D. F. 1974. Hardcore in Centennial sweet potatoes. N.J., Agric. Exp. Stn., Circ. *610*.
7. Chupp, C., and Sherf, A. F. 1960. Vegetable Diseases and Their Control. Ronald Press, New York.
8. Clark, C. A., Wright, V. L., and Miller, R. L. 1980. Reaction of some sweet potato selections to the reniform nematode, *Rotylenchulus reniformis*. J. Nematol. *12*, 218.
9. Collins, W. W. 1977. Diallel analysis of sweet potatoes for resistance to fusarium wilt. J. Am. Soc. Hortic. Sci. *102*, 109–111.
10. Collins, W. W. 1982. 'Pope' sweet potato. HortScience *17*, 265.
11. Collins, W. W., Pope, D. T., and Hsi, D. C. H. 1979. 'Caromex' sweet potato. HortScience *14*, 646.
12. Cuthbert, F. P., Jr. 1967. Insects affecting sweet potatoes. U.S., Dep. Agric., Agric. Handb. *329*.
13. Cuthbert, F. P., Jr., and Davis, B. W. 1970. Resistance in sweet potatoes to damage by soil insects. J. Econ. Entomol. *63*, 360–363.
14. Cuthbert, F. P., Jr., and Davis, B. W. 1971. Factors associated with insect resistance in sweet potatoes. J. Econ. Entomol. *64*, 713–717.
15. Cuthbert, F. P., Jr., and Jones, A. 1972. Resistance in sweet potatoes to *Coleoptera* increased by recurrent selection. J. Econ. Entomol. *65*, 1655–1658.
16. Cuthbert, F. P., Jr., and Jones, A. 1978. Insect resistance as an adjunct or alternative to insecticides for control of sweet potato soil insects. J. Am. Soc. Hortic. Sci. *103*, 443–445.

17. Dukes, P. D., Jones, A., and Cuthbert, F. P., Jr. 1975. Mass evaluation of sweet potato seedlings for reaction to fusarium wilt and root knot nematodes. Proc. Am. Phytopathol. Soc. *2,* 133.
18. Dukes, P. D., Jones, A., Cuthbert, F. P., Jr., and Hamilton, M. G. 1978. W-51 root knot resistant sweet potato germplasm. HortScience *13,* 201–202.
19. Dukes, P. D., Jones, A., and Schalk, J. M. 1979. Evaluating sweet potato for reaction to sclerotial blight caused by *Sclerotium rolfsii.* HortScience *14,* 123.
20. Edmond, J. B., and Ammerman, G. R. 1971. Sweet Potatoes: Production, Processing, Marketing. AVI Publishing Co., Westport, CT.
21. Falconer, D. S. 1960. Introduction to Quantitative Genetics. Ronald Press, New York.
22. Fujise, K., Yunoue, T., and Chishiki, T. 1955. Studies on the habits of flowering and seed-setting in varieties of sweet potatoes (*Ipomoea batatas* Lam.). Bull. Kyushu Agric. Exp. Stn. *3,* 109–142 (in Japanese, English summary).
23. Graves, B. 1976. Painter—a new sweet potato variety. Veg. Grow. News *30* (11), 1.
24. Hahn, S. K., and Leuschner, K. 1982. Breeding sweet potato for weevil resistance. *In* Sweet Potato. R. L. Villareal and T. D. Griggs (Editors), pp. 331–336 AVRDC, Tarnan, Taiwan.
25. Hammett, H. L., Alberton, R. C., and Withers, F. T. 1978 Hardcore in some sweet potato cultivars and lines. J. Am. Soc. Hortic. Sci. *103,* 239–241.
26. Harmon, S. A. 1974. 'Georgia Jet,' an early, high yielding high quality sweet potato cultivar for Georgia. Ga., Agric. Exp. Stn., Res. Rep. *193.*
27. Harter, L. L., and Weimer, J. L. 1929. A monographic study of sweet potato diseases and their control. U.S., Dep. Agric., Tech. Bull. *99.*
28. Hernandez, T. P., Constantin, R. J., Hammett, H., Martin, W. J., Clark, C., and Rolston, L. H. 1981. 'Travis' sweet potato. HortScience *16,* 574.
29. Hernandez, T. P., Hernandez, Travis P., Constantin, R. J., and Martin, W. J. 1974. Jasper, a soil rot-resistant sweet potato variety. La., Agric. Exp. Stn., Circ. *100.*
30. Hsi, D. C. H., and Corgan, J. N. 1979. 'Oklamex Red' sweet potato. HortScience *14,* 79–80.
31. Jones, A. 1964. A disease of pollen mother cells of sweet potato associated with *Fusarium moniliforme.* Phytopathology *54,* 1494–1495.
32. Jones, A. 1965. Cytological observations and fertility measurements of sweet potato (*Ipomoea batatas* (L.) Lam.). Proc. Am. Soc. Hortic. Sci. *86,* 527–537.
33. Jones, A. 1965. A proposed breeding procedure for sweet potato. Crop Sci. *5,* 191–192.
34. Jones, A. 1966. Morphological variability in early generations of a randomly intermating population of sweet potatoes, *Ipomoea batatas* (L.) Lam. Ga., Agric. Exp. Stn., Tech. Bull. [N.S.] *56.*
35. Jones, A. 1968. Chromosome numbers in *Ipomoea* and related genera. J. Hered. *59,* 99–102.
36. Jones, A. 1969. Quantitative inheritance of fusarium wilt resistance in sweet potatoes. J. Am. Soc. Hortic. Sci. *94,* 207–209.
37. Jones, A. 1969. Quantitative inheritance of ten vine traits in sweet potatoes. J. Am. Soc. Hortic. Sci. *94,* 408–411.
38. Jones, A. 1972. Mass selection for low oxidation in sweet potato. J. Am. Soc. Hortic. Sci. *97,* 714–718.
39. Jones, A. 1977. Heritabilities of seven sweet potato root traits. J. Am. Soc. Hortic. Sci. *102,* 440–442.
40. Jones, A. 1980. Sweet potato. *In* Hybridization of Crop Plants. W. R. Fehr and H. H. Hadley (Editors), pp. 645–655. Am. Soc. Agron. Inc., Madison, WI.
41. Jones, A., and Cuthbert, F. P., Jr. 1971. Unpublished data. U.S. Vegetable Laboratory, U.S. Department of Agriculture, Charleston, SC.
42. Jones, A., and Dukes, P. D. 1976. Some seed, seedling and maternal characters as estimates of commercial performance in sweet potato breeding. J. Am. Soc. Hortic. Sci. *101,* 385–388.
43. Jones, A., and Dukes, P. D. 1980. Heritabilities of sweet potato resistances to root knot caused by *Meloidogyne incognita* and *M. javanica.* J. Am. Soc. Hortic. Sci. *105,* 154–156.

44. Jones, A., Dukes, P. D., and Cuthbert, F. P., Jr. 1975. W-13 and W-178 sweet potato germplasm. HortScience *10,* 533.
45. Jones, A., Dukes, P. D., and Cuthbert, F. P., Jr. 1976. Mass selection in sweet potato: Breeding for resistance to insects and diseases and for horticultural characteristics. J. Am. Soc. Hortic. Sci. *101,* 701–704.
46. Jones, A., Dukes, P. D., and Cuthbert, F. P., Jr. 1977. Pesticides increase true seed production of sweet potato. Hort Science *12,* 165–167.
47. Jones, A., Dukes, P. D., Hamilton, M. G., and Baumgardner, R. A. 1980. Selection for low fiber content in sweet potato. HortScience *15,* 797–798.
48. Jones, A., Dukes, P. D., Schalk, J. M., Mullen, M. A., Hamilton, M. G., Patterson, D. R., and Boswell, T. E. 1980. W-71, W-115, W-119, W-125, W-149, and W-154 sweet potato germplasm with multiple insect and disease resistances. HortScience *15,* 835–836.
49. Jones, A., Hamilton, M. G., and Dukes, P. D. 1978. Heritability estimates for fiber content, root weight, shape, cracking and sprouting in sweet potato. J. Am. Soc. Hortic. Sci. *103,* 374–376.
50. Jones, A., and Jackson, C. R. 1968. Fungi from floral parts of sweet potato. HortScience *3,* 76–77.
51. Jones, A., Schalk, J. M., and Dukes, P. D. 1979. Heritability estimates for resistances in sweet potato to soil insects. J. Am. Soc. Hortic. Sci. *104,* 424–426.
52. Jones, A., Steinbauer, C. E., and Pope, D. T. 1969. Quantitative inheritance of ten root traits in sweet potatoes. J. Am. Soc. Hortic. Sci. *94,* 271–275.
53. Kobayashi, M., and Miyazaki, T. 1977. Sweet potato breeding using wild related species. *In* Tropical Root Crops. J. Cock, R. MacIntyre, and M. Graham (Editors), No. 1, pp. 53–57. Int. Development Res. Center, Ottawa, Canada.
54. Li, L. 1967. Study on the combining ability in crosses among five varieties of sweet potato. J. Agric. Assoc. China [N.S.] *58,* 33–45.
55. Li, L. 1975. The inheritance of quantitative characters in a randomly intermating population of sweet potatoes (*Ipomoea batatas* (L.) Lam.). J. Taiwan Agric. Res. *24,* 32–42 (in Chinese, English summary).
56. Li, L. 1977. The inheritance of crude protein content and its correlation with root yield in sweet potatoes. J. Agric. Assoc. China *100,* 78–87 (in Chinese, English summary).
57. Martin, F. W. 1965. Incompatibility in the sweet potato. A review. Econ. Bot. *19,* 406–415.
58. Martin, F. W. 1970. Sterility in some species related to the sweet potato. Euphytica *19,* 459–464.
59. Martin, F. W. 1977. Selected yam varieties for the tropics. *In* Tropical Root Crops. J. Cock, R. MacIntyre, and M. Graham (Editors), No. 1, pp. 44–49. Int. Development Res. Center, Ottawa, Canada.
60. Martin, F. W., and Cabanillas, E. 1966. Post-pollen-germination barriers to seed set in sweet potato. Euphytica *15,* 404–411.
61. Martin, F. W., and Jones, A. 1971. Flowering and fertility changes in six generations of open pollinated sweet potatoes. J. Am. Soc. Hortic. Sci. *96,* 493–495.
62. Martin, F. W., and Jones, A. 1973. The species of *Ipomoea* closely related to the sweet potato. Econ. Bot. *26,* 201–215.
63. Martin, F. W., Jones, A., and Ruberte, R. M. 1974. A wild *Ipomoea* species closely related to the sweet potato. Econ. Bot. *28,* 287–292.
64. Martin, W. J. 1970. Virus diseases. South. Coop. Ser. Bull. *159.*
65. Martin, W. J., and Birchfield, W. 1973. Further observations of variability in *Meloidogyne incognita* on sweet potato. Plant Dis. Rep. *57,* 199.
66. Martin, W. J., Jones, L. G., and Hernandez, T. P. 1967. Sweet potato soil rot development in olivier silt loam soil as affected by annual applications of lime or sulfur over a seven year period. Plant Dis. Rep. *51,* 271–275.
67. Martin, W. J., Nielsen, L. W., and Morrison, L. S. 1970. Diseases. South Coop. Bull. *159.*

68. Maryland AES 1971. Mimeo Rel. Notice (unnumbered). Jan. 19. Redmar.
69. Maryland AES 1972. Mimeo Rel. Notice (unnumbered). Jan. 17. Goldmar.
70. Miller, J. C. 1939. Further studies and technic used in sweet potato breeding in Louisiana. J. Hered. *30,* 485–492.
71. Miller, P. R. 1960. Plant pests of importance to North American agriculture—index of plant diseases in the United States, U.S. Dep. Agric., Agric. Handb. *165.*
72. Morrison, L. S. 1970. Nematode diseases. South. Coop. Ser. Bull. *159.*
73. Mullen, M. A., Jones, A., Davis, R., and Pearman, G. C. 1980. Rapid selection of sweet potato lines resistant to the sweet potato weevil. HortScience *15,* 70–71.
74. Mullen, M. A., Jones, A., Arbogast, R. T., Schalk, J. M., Patterson, D. R., Boswell, T. E., and Earhart, D. R. 1980. Field selection of sweet potato lines and cultivars for resistance to the sweet potato weevil. J. Econ. Entomol. *73,* 288–290.
75. Nielson, L. W. 1970. Fungus and miscellaneous diseases. South. Coop. Ser. Bull. *159.*
76. Nielson, L. W., and Terry, E. R. 1977. Sweet potato (*Ipomoea batatas* L.). *In* Plant Health and Quarantine in International Transfer of Genetic Resources. W. B. Hewiet and L. Chiarappa (Editors), pp. 271–276. CRC Press, Inc., Cleveland, OH.
77. Nishiyama, I. 1971. Evolution and domestication of the sweet potato. Bot. Mag. *84,* 377–387.
78. Nishiyama, I., Miyazaki, T., and Sakamoto, S. 1975. Evolutionary autoploidy in the sweet potato (*Ipomoea batatas* (L.) Lam.) and its progenitors. Euphytica *24,* 197–208.
79. Pope, D. T., Nielsen, L. W., and Miller, N. C. 1971. Jewel, a new sweet potato variety for North Carolina. N.C., Agric. Exp. Stn., Bull. *442.*
80. Rolston, L. H., Barlow, T., Hernandez, T. P., Nilakhe, S. S., and Jones, A. 1979. Field evaluation of breeding lines and cultivars of sweet potato for resistance to the sweet potato weevil. HortScience *14,* 634–635.
81. Rolston, L. H., Barlow, T., Jones, A., and Hernandez, T. 1981. Potential of host plant resistance in sweet potato for control of a white grub, *Phyllophaga ephilida* Say (Coleoptera:Scarabaeidae). J. Kans. Entomol. Soc. *54,* 378–380.
82. Schalk, J. M., and Jones, A. 1982. Methods to evaluate sweet potato for resistance to the banded cucumber beetle in the field. J. Econ. Entomol. *75,* 76–79.
83. Scheuerman, R. W., Hernandez, T. P., Martin, W. J., Clark, C., Constantin, R. J., and Hammett, H. 1981. 'Eureka' sweet potato. HortScience *16,* 689.
84. Shikata, S. 1980. Utilization of random mating population in sweet potato breeding. Bull. Chugoku Natl. Agric. Exp. Stn., Ser. A *26* (in Japanese, English summary).
85. Steinbauer, C. E. 1937. Methods of scarifying sweet potato seed. Proc. Am. Soc. Hortic. Sci. *35,* 606–608.
86. Steinbauer, C. E., and Kushman, L. J. 1971. Sweet potato culture and diseases. U.S. Dep. Agric., Agric. Handb. *388.*
87. Thornberry, H. H. 1966. Plant pest of importance to north american agriculture-index of plant virus diseases. U.S. Dep. Agric., Agric. Handb. *307.*
88. Ton, C.-S., and Hernandez, T. P. 1978. Wet soil stress effects on sweet potatoes. J. Am. Soc. Hortic. Sci. *103,* 600–603.
89. Walsh, P. A., and Johnson, E. 1980. Agricultural Statistics. U.S. Government Printing Office. Washington, D.C.
90. Whatley, B. T., and Phills, B. R. 1977. 'Rojo Blanco' sweet potato. HortScience *12,* 265.
91. Whatley, B. T., and Phills, B. R. 1977. 'Carver' sweet potato. HortScience *12,* 266.
92. Yen, D. E. 1974. The sweet potato and Oceania. B. P. Bishop Mus. Bull. *236,* 1–389.
93. Yen, D. E. 1976. Sweet potato. *In* Evolution of Crop Plants. N. W. Simmonds (Editor), pp. 42–45. Longmans, Green, New York.