Sweet Potato Breeding Using Wild Related Species

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A sweet potato variety and various breeding materials that include germ plasm of wild *Ipomoea* suggest that the wild species have much to offer sweet potato breeders. The wild relatives that can be crossed with cultivated sweet potato include diploids, triploids, tetraploids, and hexaploids. All of them resemble the sweet potato in two respects: they have similar floral morphologies and incompatibility systems. These characters may be useful in future searches for wild plants.

Our experience in the practical use of wild species in sweet potato breeding, a flower induction technique, self- and cross-compatibility test, and species hybridization with sweet potato suggests that useful genes can be expected from wild species. Some principles necessary for an effective gene introduction system have been identified.

The improvement of yield and quality proceeds quite rapidly during the initial phase of plant breeding; however, additional genetic gains become increasingly difficult to attain. This is especially true if the gene pools are limited and breeding procedures remain unchanged. Sweet potato breeding in Japan reached this stage. About 95% of the total area planted in sweet potato were local varieties in 1940, but over 80% were replaced in the next 10 years by improved varieties bred through a systematic breeding program. This replacement of the local varieties with improved varieties indicates that the breeding efficacy in the initial phase was considerably higher. The gene sources that were used were mainly popular local varieties. The second improvement resulted from the development of "Koganesengan" in 1966, which included exotic breeding materials introduced from the USA after 1956. Introduced varieties had performed an important role in the genetic progress that had been made prior to this, especially increasing the yield of tuberous roots and the starch content beyond the plateau achieved by domestic materials. Another plateau developed, however, and it seemed impossible to develop new varieties exceeding the yield level of "Koganesengan." A third increase in yield levels was marked by the development of "Minamiyutaka" in 1975. This variety, with one eighth of its germ plasm from the wild plant K123, topped the yield levels achieved by "Koganesengan" and other cultivars at several locations.

In 1955, many wild plants related to sweet potato were collected by Nishiyama in Mexico and the United States (Nishiyama 1959). This

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collection was used to study sweet potato phylogeny and the utilization of wild plants in sweet potato breeding. Progress in both fields accelerated and additional collections increased the number of wild plants that were available.

Nishiyama et al. (1975) reviewed phylogenetic studies, and Sakamoto (1970) summarized studies using wild relatives before 1970. These wild species appear to have much to offer sweet potato breeders, and the present paper is an attempt to demonstrate a practical method for using these relatives in breeding.

Species Crossed with Cultivated Sweet Potatoes

More than 200 accessions of *Ipomoea* species have been introduced from Mexico and other countries in Central America and the northern part of South America by several researchers since 1956. Our interest was directed toward wild plants that could be hybridized with the sweet potato directly or indirectly. So little research had been done from a breeding viewpoint on *Ipomoea*, that we did not know which species could be crossed with cultivated sweet potatoes. In addition, species identification was almost impossible because species of the section *Batatas* had not been well defined taxonomically. (Hopefully, reclassification of *Ipomoea* will be done soon.)

After hundreds of crosses between wild relatives and sweet potatoes, we concluded that *Ipomoea* species that can be hybridized with sweet potatoes have the following characters: (1) the flower is similar to that of sweet potato; the corolla is bell-shaped and not funnel-form, the colour of the interior of the tube is invariably darker than that of the limb, and the glands at the base of the corolla are prominent; and (2) the plants are self-incompatible, and there are several incompatibility groups among them. We could find no common characteristics other than these two. These characters may be useful when collectors search for wild plants for sweet potato improvement.

Wild *Ipomoea* that showed the above characteristics and could be crossed with cultivated sweet potatoes were as follows:

K221: Ten seeds of this plant were collected at Acapulco, Mexico by M. Kobayashi, Kagoshima Agricultural Experiment Station, in 1960. This diploid ($2n = 30$) plant was called *I. leucantha* Jacq. by Teramura (Teramura et al. 1967). For a long time, we believed that K221 would not hybridize with sweet potato without bridge plants, but in 1975 we obtained many seeds between K221 and sweet potato. It was also found that the autotetraploid of K221 induced by using colchicine crossed well with sweet potatoes.

K222: This accession was collected together with K221 by M. Kobayashi. All eight plants of this accession were found to be triploid ($2n = 3X = 45$) by S. Shiotani, Mie University (Teramura et al. 1967). Teramura's tentative identification was *Ipomoea* (*trifida* 3X).

K233: The seeds of this accession were collected at Veracruz, Mexico, by M. Muramatsu, Okayama University, in 1962. This tetraploid ($2n = 4X = 60$) has been called *I. littoralis* Blume by Teramura, but K233 is the same plant that Jones called *I. gracilis* R. Br. (Jones 1970; Martin and Jones 1972).

K300: The seeds of this accession were supplied in 1972 by F. W. Martin, USDA, Mayaguez, Puerto Rico. According to him this tetraploid ($2n = 4X = 60$) species occurs in Ecuador and Colombia. This plant could be hybridized with sweet potatoes only when K300 was used as the male parent.

K400: This collection was made in Mexico by S. Shiotani, Mie University, in 1973. The plants are self-incompatible and there are several incompatibility groups among them. Whether this plant will cross with sweet potatoes is not yet certain, but we expect that it will hybridize with sweet potato directly. K400 is a tetraploid ($2n = 4X = 60$).

K123: This accession was collected in Fortin, Mexico by Nishiyama in 1955 and was designated *I. trifida* (H.B.K.) G. Don. K123 is hexaploid ($2n = 6X = 90$) and has been considered as the direct progenitor of sweet potato by Nishiyama (Nishiyama 1961; Nishiyama et al. 1975). Some researchers, however, consider K123 to be a wild form of sweet potato rather than a different species (Jones 1967; Martin and Jones 1972; Yen 1973).

Apart from the species nomenclature, K123 has been recognized to be very important as a gene source for sweet potato improvement. It was used in the development of the registered variety "Minamiyutaka," which has high yield and high resistance to some diseases and insects. Many strains with K123 germ plasm are being used in our breeding program.

Table 1. Effect of grafting on flowering of wild plant, K300 (1974) planted on 7 July and grafted on 5 September.

	Natural condition		Grafted on morning glory	
Plant	Date first flowers opened	Number of flowers[a]	Date first flowers opened	Number of flowers[a]
K300-1	1 Nov	215	11 Oct	750
K300-2	3 Dec	32	11 Oct	432
K300-3	15 Oct	53	20 Oct	312
K300-4	—	0	26 Oct	303
K300-5	10 Dec	13	20 Oct	565
K300-6	—	0	13 Oct	331
K300-7	8 Nov	47	11 Oct	364

[a]Counting started when the first flowers opened and ended 31 Dec 1974, while the flowering continued.

Flower Induction Technique

Under natural conditions flowering of the wild relatives available for sweet potato breeding is generally encouraged by short days. Most flower in October or November whether they are planted as seeds or vines in April through July.

An effective means of inducing flowering in these materials would greatly facilitate the utilization of the wild plants for sweet potato breeding. An effective technique for inducing flowering in these plants was found in our laboratory. During any season, plants treated with this technique begin to flower within one month, even under long day conditions. The flower induction procedure consists of the following steps: (1) Treat seeds of the dwarf type morning glory, *I. nil* (L.) Roth cv. Kidachi-asagao, with sulfuric acid for 1 hour, rinse with water overnight, and then plant in 15 cm pots; (2) After germination, keep the pots under all-day lighting conditions for about 1 month; (3) When seedlings are about 40 cm high and have 8–10 leaves, cut off the stem tips and split the stem for insertion of the scion. The stem of the wild plants used as scions should be about 20 cm long and have cuts 5–8 cm long on both sides of the stem; (4) Hold the grafts in place with grafting clips until the scion is established, and keep the grafted plants in a humid and sheltered place for about 1 week; and (5) Transplant the grafted plants to 24-cm pots and place under favourable growing conditions. The effectiveness of this procedure is indicated by Table 1.

Self- and Cross-Incompatibility

The wild *Ipomoea* that would hybridize with the sweet potato were all self-incompatible and several intra-incompatible, inter-compatible groups were recognized. Self- and cross-incompatibilities of the wild relatives were determined using the following staining technique.

Crosses were made under greenhouse conditions. Flowers pollinated before 10:00 with pollen from appropriate plants were collected 3 or more hours after pollination. Stigmas, with styles attached, were placed on glass slides and stained with 0.5% cotton blue in lactol phenol. A cover-glass was placed on the stigma and pressed. The prepared slides were kept at room temperature for microscopic observation the following day. Usually five flowers per cross were used for this purpose. This schedule generally gave satisfactory results (Table 2). Compatibilities of the wild relatives and sweet potato are presented in Table 3.

No new principles have been used, but we believe that this technique will be useful for research workers interested in the utilization of wild *Ipomoea* for sweet potato improvement.

Hybridization Results

Pollen reaction on the stigma suggests whether two plants will cross. In most cases involving the wild species and the sweet potato, however, we did not obtain seeds even when the pollen germinated on the stigma. Therefore, it is necessary to check whether seeds can be produced by actual hybridization. For this pur-

Table 2. Pollen germination[a] on stigma in K300, indicating self-incompatibility and three incompatibility groups (1974).

Stigma	Pollen: K300-6	K300-7	K300-1	K300-2	K300-5	K300-3	K300-4
K300-6	—	—	+++	++	++	+	+
K300-7	—	—	+++	++	+++	±	+
K300-1	—	—	—	—	+++	±	+
K300-2	—	—	—	—	+++	+	++
K300-5	+++	+++	—	—	—	—	—
K300-3	+++	+++	+++	+++	—	—	—
K300-4	+++	+++	+++	+++	—	—	—

[a]Five stigmas per one crossing were observed. Over 50 pollen grains were put on each stigma. Symbols in the table: +++ more than 10 pollen grains germinated per stigma with four or five stigmas; ++ 6–9 pollen grains germinated; + 1–5 pollen grains; ± very rarely 1–3 pollen grains; — no pollen germinated.

Table 3. Relationship of incompatibility groups of sweet potato and wild relatives (1958–1975).[a]

Accession	Plants tested	Determined groups in sweet potato[b]: A	B	C	D	E	F	G	H	I	J	K	L	M	N	Undetermined groups in sweet potato: 1	2	3	4	5	6	7	8	9	Number of groups
Sweet potato	>1000	O	O	O	O	O	O	O	O	O	O	O	O	O	O										14
K123	20	O	O	O	X	O	O	O	O							O	O	O							10
K233	7	X	X	O	X	X	O				O					X			O	O					5
K300	7	X	X	X						O	O					X									2[c]
K222	8	X	X	O	X	X															O	O			3
K221	5	X	X	O	X	X										X							O	O	3

[a]Incompatibility was determined by pollen germination on stigma.
[b]O = incompatible to sweet potatoes in each group; X = compatible.
[c]Three incompatibility groups were classified in K300 (see Table 2), but two groups merged when tested with sweet potatoes.

pose, we crossed at least 25 flowers for each mating combination. Apomixis and seed abortion are other problems. It is necessary to measure F_1 plants morphologically to confirm hybrid identities. Maximum seed set percentages obtained between wild *Ipomoea* and sweet potato are given in Fig. 1. With the exception of K123, higher seed set (%) was obtained when the wild plants were used as male parents.

Useful Genes in Wild Species

We do not know how many genetic factors control yield in sweet potatoes, but the development of "Minamiyutaka" indicates that we can use genes from wild plants for yield improvement.

Wild plants can provide genetic resources for disease resistance and insect tolerance. For instance, K123 is resistant to the root lesion nematode and the root knot nematode, which were introduced into "Minamiyutaka." We might also be able to use the characteristics from wild relatives that enable them to tolerate physiological stress. The breeding of sweet potatoes using wild relatives has begun, but we must now learn more about the genes or genetic complexes of value for sweet potato improvement.

Gene Introducing System

The genetic resources of sweet potato include all materials available through hybridization, but we do not yet know the most effective way to obtain useful gene(s) from wild plants. In any system, back crossing would be effective in the later part of the breeding program; the recurrent parents in back crossing should be different varieties of sweet potatoes. From our experience, the following methods are practical.

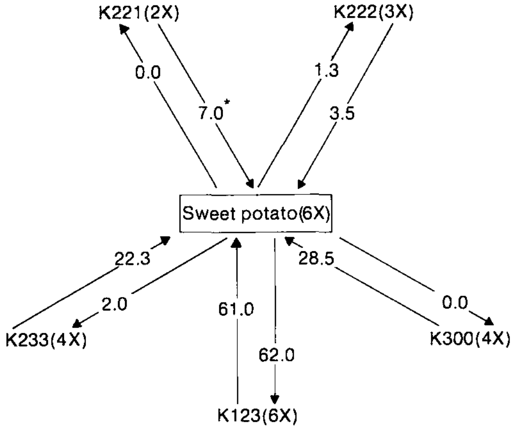

Fig. 1. Maximum seed set (%), from figures obtained between 1958 and 1975, in crossing of wild species and sweet potatoes. Arrows point from male to female in crosses. Asterisk indicates that female was Kyushu 58, which includes one fourth germ plasm of K123.

Direct Use of Wild Plants

Plants with 90 chromosomes like K123 can be used directly as a donor in crossing procedures. F_1's must be back crossed to sweet potato cultivar(s) at least two times. "Minamiyutaka" was bred by this method. Some F_1's between K222 ($2n = 45$) and sweet potato ($2n = 90$) were found to be hexaploids ($2n = 90$). Thus, it is possible to obtain F_1's with 90 chromosomes from crosses with wild relatives even when they are diploids or tetraploids. Therefore, we can use wild plants directly, although seed set percentages are extremely low in some cases.

Use of Synthesized Hexaploids

Some theoretical ways of synthesizing hexaploids ($2n = 90$), some of which we have actually used for sweet potato improvement, are:

(1) Diploid $\xrightarrow{c}$ Tetraploid, Tetraploid × Diploid $\xrightarrow{c}$ Hexaploid
(2) Tetraploid $\xrightarrow{c}$ Octaploid × Tetraploid ⟶ Hexaploid
(3) Diploid × Tetraploid $\xrightarrow{c}$ Hexaploid
(4) Triploid × Triploid ⇢ Hexaploid (in the case of outcrossing of K222)

$\xrightarrow{c}$: Doubled chromosome using colchicine solutions.
⇢ : Doubled chromosome by natural unreduced gametes.

In our crossing experiments, seed set percentages from crosses between wild plants and sweet potatoes were higher when the synthesized hexaploids were used as female parents.

Use of Heteroploidy

Because the sweet potato or hybrids with it can be propagated vegetatively, it is practical to use heteroploids with desirable agronomic characteristics. It is also possible to back cross heteroploids with the sweet potatoes to obtain other heteroploids possibly having more desirable characteristics. The problem with heteroploidy is that seed set percentages from back crossing are extremely low.

Use of Lower Ploidy

Tetraploids with some economical characteristics are being bred in our laboratory using K221, K222, and cultivated sweet potatoes. We have obtained tetraploids with enlarged storage roots. Thus, it seems quite possible to develop tetraploid sweet potatoes. By taking advantage of the wild relatives of the sweet potato it may also be possible to develop diploids producing tuberous roots like hexaploid sweet potatoes.

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