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# Current Progress of Sweet Potato Breeding in Japan

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**Abstract**
In Japan, sweet potato is grown annually with the acreage of approximately 65,000 ha as of 1989. It is utilized mostly for starch production and table use through the market. Recent cultivars released from the breeding center have a wide range of utilizations not only in conventional use but also in food processing industry for high content of vitamins, low-amylase activity and extremely high starch content. Germplasm collections at the breeding center include Japanese old local cultivars, breeding lines and introductions from China, Fuji, Indonesia, New Zealand, Papua New Guinea, the Philippines, Solomon Islands and U.S.A. Total accessions of 1,200 were characterized and evaluated with their yielding abilities and degrees of resistance against pests and diseases. Wild relatives of sweet potato were also introduced from Latin America. The breeding program generally employs a usual crossing method, including combining ability tests. Biotechnology works have recently been initiated, aiming at improvement of breeding efficacy. Objectives of the breeding program are to raise productivity with a high starch content, pest and disease resistance, high quality for table use with better marketability and to develop new characteristics which facilitate greater utilization in food processing industry with a large scale.

**Discipline:** Crop production
**Additional key words:** cultivars, germplasm, Ipomoea, batatas, LAM., starch content

Since sweet potato (*Ipomoea batatas* (L.) LAM.) was introduced to Japan in 1597, it has been grown throughout the country except for Hokkaido, a northernmost island, and become one of the most important upland crops in the country. Sweet potato can tolerate fairly well natural disasters such as typhoon and drought. It has played an important role as a source of carbohydrates in Japanese agriculture. Despite its favorable growth habits, there are a few instrinsics unsuitable for modernized farming, such as a high water content in the final product and difficulties in mechanized cultivation. Sweet potato breeding has been carried out in Japan for more than 70 years, starting in 1914 when the method of cross breeding for practical purposes was initiated. During that period, a number of new cultivars have been released to meet various types of the current needs. Approximately 90% of the acreage under sweet potato is covered by modern cultivars released in the national breeding program, whereas only 55% of Irish potato.

The present paper reviews the recent progress of sweet potato breeding in Japan, including objectives, methods, germplasms and newly released cultivars.

## Sweet potato in Japan

Total planted area of sweet potato is approximately 65,000 ha as of 1989, although it was once grown annually with the acreage of more than 440,000 ha during the period of food shortage in the late 1940s. National average yield has increased by 1.7 times since then. Total annual production is approximately 1.5 million t, comprising 400,000 t for table use through the market, 540,000 t for starch production, and 556,000 t for other uses.

Almost all of the starch extracted from sweet potato is converted to thick malt syrup, which is consumed in food industry. Other uses relate to raw materials for alcohol production, feeds and home use of farmers. The ratio of table use through market has greatly increased during the last three

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decades. Use for food processing has gradually increased, though its amount is still limited. These changes have been caused by imported agricultural products, a huge amount of which has flowed in after the trade liberalization. Improvement of food situation in Japan achieved after the Second World War has also contributed to those changes.

Production of sweet potato has been considerably stabilized for the last 20 years under the policy instrument for tie-in sale of imported corn starch with domestic sweet potato starch. However, if such an administrative action has been repealed, about half of the sweet potato acreage is likely to be lost within a short period. Such a loss will accompany the decline of upland farming in Kyushu and Kanto districts, where sweet potato is one of the most important and suited crops under low soil fertility with a limited water supply. Development of new demand for sweet potato is needed most urgently in Japan.

## Breeding

*1) Institutions for breeding*

Breeding research on sweet potato in Japan has been undertaken at two institutions; one is under the Kyushu National Agricultural Experiment Station in Miyakonojyo and the other is under the National Agriculture Research Center in Tsukuba. Evaluation on adaptability of breeding materials is carried out at several prefectural agricultural experiment stations, which locate in the major producing areas.

*2) Objectives and relevant breeding methods*

(1) Yield improvement

It is reported that storage root yield of sweet potato is controlled by non-additive gene effects. It is also reported that the increased variation of root yields is associated with selection of the parents with great non-additive gene effects in the course of breeding works of high yielding varieties. To alleviate such an increased variation, it is proposed that the breeding program more utilize additive gene effects, which might be possessed by new varieties, inbred lines and interspecific hybrids between wild species[17]. It is generally recommended to employ parents that indicate lower values of inbreeding coefficients[23]. Modern cultivars in Japan have high root yields, i.e. 30–40 t/ha under usual cultivation practices in farmers' fields and occasionally 70 t/ha in the high yielding trials of the experiment stations. Urgent objective of the breeding program is to release new varieties which can produce higher yields, i.e. 50 t/ha at the farmers' level.

(2) Starch content

The cultivars for starch production in southern Kyushu usually contain 22–26% crude starch. Considering that the starch content of sweet potato is controlled by additive effects of genes, it may be effective to accumulate high starch genes to increase a starch content. For the purpose of producing $F_1$ progenies with a high starch content, it is required to use parents having a high starch content[17]. A cultivar of 30% starch content has already been available, thus the next target is to attain 35%. In selecting materials with a high starch content, dry matter contents are used as a criterion since these two factors have a high correlation, i.e. $r = 0.85$[16]. Specific gravity of roots, however, is not applied to differentiate starch content due to a low correlation between these two elements[16].

Quality of starch grains is also relevant. There exist distinctive varietal differences in whiteness and size of starch grains. From the industrial viewpoint, more white and larger size of grains are preferred.

(3) Pest and disease resistance

Some sweet potato is cultivated in the early cropping season without any crop rotation. It is grown under a structure such as plastic houses or tunnels with mulching. This environment causes occasionally very serious damages by pests and diseases.

Damages by root-knot nematode (*Meloidogyne incognita*) and root-lesion nematode (*Pratylenchus coffeaeae*) have rapidly increased in Japan. Source plants with resistance to the nematodes are available among the cultivated sweet potato as well as among the wild relatives such as *Ipomoea trifida*[19]. A number of resistant clones to root-knot nematode are also available among the germplasms introduced from Papua New Guinea[21]. Although it is reported that the inheritance of resistance to nematode is controlled by a polygenic system[4], there might be a possibility to obtain nematode resistance controlled by less number of genes[12]. The resistance is likely to be a dominant character under either monogenic or oligogenic inheritance, as reported in barley, tobacco, potato and grape[15].

Among the fungal diseases of sweet potato in Japan, serious damages are caused by: black rot

(*Ceratocystis fimbriata*), soil rot (*Streptomyces ipomoea*), and stem rot (*Fusarium* rot, *Fusarium oxysporium* f. sp.*batatas*). In the breeding program, screening for resistance to black rot is carried out with the inoculation of conidia suspension to shoot tips in the fourth clonal generation. No screening methods, with an exception of selection based on natural infection, are available for the latter two diseases.

Since a decade ago, russet crack-like symptoms, discoloration of root skin, russet and bumpy roots have been prevailing in Kyushu. They seriously reduce their market value of roots for table use[22]. Three types of virus particles were isolated from those plants; i.e. M, Mo and C types showing some differences in length of particles (personal communication with Shinkai). Further studies are required to identify which type of particles is pathogenic and whether any complex of those types is responsible for such symptoms. No information are now available in regard to the sources to resistance, though there are some varietal differences in the symptoms.

Table 1 shows a list of characteristics which should

**Table 1. Important characteristics in sweet potato breeding**

| Item | Characteristic |
|---|---|
| Yield | Storage root number, size of storage root, storage tolerance |
| Growth defect free | Gemmation, growth crack |
| Quality | Starch use: Starch content, whiteness and size of starch grains<br>Table and processing use: Dry matter content, flavor, texture, after-cooking blackening (polyphenol content and polyphenol oxidase activity) |
| Appearance | Storage root shape, uniformity, skin color, flesh color, smoothness of root skin |
| Pest and disease resistance | Nematode, black rot, soil rot, stem rot, rasset crack |
| Adaptability | Drought, high soil moisture, early cropping |

**Table 2. Sweet potato breeding scheme at the Kyushu Nat. Agr. Exp. Sta.**

| Year | No. of clones | Procedures taken | Note |
|---|---|---|---|
| 0 | | Production of trueseed by artificial crossing and polycrossing | Carried out at the Lab. of Sweet Potato Seed Production |
| 1 | 50,000–60,000 | Nursery seedlings, screening for root-knot nematode resistance, root skin color and plant type (discarding twining type) | |
| 2 | 1,000–1,500 | 8-plant plots (1 site), dry matter %, cooking quality, nematode resistance | |
| 3 | 100–150 | 20-plant plots (1 site), aggregate evaluation of clones, routine disease tests, storage tolerance, cooking quality | |
| 4 | 50–80 | Semi-final yield trial, 48-plant plots, 2 replicates/(1 site), starch content and quality, preliminary regional trials (6 sites), disease tests (3 sites) | |
| 5–7 | 30–40 | Final yield trials, 48-plant plots, 3 replicates (5 sites), regional tests (10 sites) | Some promising clones are distributed to prefec. agr. exp. sta. for adaptability test. |
| 6–8 | 5 | Yielding ability tests in the farmers' fields (more than 8 sites) | |
| 7–10 | (Naming) | Commercialization under approval of MAFF* | Norin number given |

* MAFF: Ministry of Agriculture, Forestry and Fisheries.

receive careful attention in the sweet potato breeding in Japan.

*3) Breeding program*

A usual cross-breeding scheme is employed in Japan as shown in Table 2. In breeding for high starch cultivars, parents are selected on the basis of the results of combining ability tests regarding root yields and starch contents[16].

## New cultivars

Since the national research institutes initiated a sweet potato breeding program in 1935, 43 cultivars have been released. Some of the new cultivars are briefly explained hereafter.

(1) Benihayato (Norin 37, released in 1985)

Selected from a cross in 1976 between Centennial (U.S. cultivar, high carotene content) and Kyushu 66 (high yielding line, nematode resistant). The storage roots are fusiform, and uniformly good-shaped with bright red skin and bright orange flesh of a moist texture. Extremely high carotene content (12 mg%) in the storage root, which exceeds Centennial by more than 50%. Recommended for cooking pie, icecream and cakes. Suitable for processing dried granules and dried mash which are used for snack food production[10].

(2) Shiroyutaka (Norin 38, 1985)

Selected from a cross in 1975 between Kyukei 708-13 (breeding line, high starch content, root-knot nematode resistant) and S684-6 (breeding line, resistant to black rot and root-lesion nematode). Skin color of storage roots is yellowish white with a faintly reddish top and tail. Very high yielding, exceeding Koganesengan, a leading cultivar for starch production, by 12-15%. Starch content is more than 24%. Starch quality is very fine due to large size and bright whiteness of starch grains. Rapidly spreading in southern Kyushu, covering 5,000 ha in the third year after release[10].

(3) Shirosatsuma (Norin 39, 1986)

Selected from a cross between CS69136-2 (breeding line, resistant to nematode and high starch content) and Tamayutaka (high yielding, starch type). Storage roots contain 24-26% starch. Tolerant for a long storage[2].

(4) Satsumahikari (Norin 40, 1987)

Selected from a cross between Kyushu 84 and Kyushu 88, both of which are high yielding breeding lines with early maturity and nematode resistance. The storage roots are fusiform and uniformly good-shaped with a deep-red skin, and a bright yellowish-white flesh of powdery texture. Lacking in ß-amylase activity in the storage roots. Due to the low activity of this enzyme resulting in very limited hydrolysis of starch to maltose, roots have no sweet taste after cooking. Activity of ß-amylase in Satsumahikari is 0.11 I.U./m*l*, and maltose content in the cooked roots is only 0.6%, while that in Koukei 14, a popular cultivar for table use, is 950 I.U./m*l* and 11.5%, respectively.

Snack foods such as fried chips, crisps and bread mixed with the flour from Satsumahikari are presently subjected to evaluation in processing and market. Liquors distilled from this variety receive a good reputation of consumers. Food manufacturing industry in Japan is keenly interested in Satsumahikari because of its unique characteristics as stated above[9].

(5) Hi-starch (Norin 41, 1988)

Selected from a cross between CS7279-19G and CS69136-33; both are breeding lines with a high starch content. Hi-starch has an extremely high starch content, ranging from 28 to 32% (personal communication with Tarumoto). Its outstandingly high content of starch is expected to contribute to reducing the cost of domestic starch production.

(6) Beniotome (Norin 43, 1990)

Selected from a cross between Kyushu 88 and Kyukei 7674-2; both are breeding lines with a desirable root-shape, a high yielding ability and resistance to nematodes. Beniotome has a high yielding ability in storage roots with a desirable shape and a bright-red skin color. Torelant for a long storage, maintaining long-lasting good eating quality. This new cultivar is expected to replace Koukei 14, which is presently a leading variety of sweet potato for table use.

## Germplasm collections and preservation

Germplasm collections at the Kyushu National Agricultural Experiment Station contain approximately 1,200 accessions as shown in Table 3. Characterization of each accession has been completed, and evaluation of important agronomic traits, such as yielding ability, dry matter content, eating quality and nematode resistance are presently under way. Some of these genetic resources are infected

Table 3. Germplasm of sweet potato at the Kyushu Nat. Agr. Exp. Sta. (1987)

| Group of germplasm | No. of accessions | Remarks |
|---|---|---|
| Japanese local cultivars and germplasms from other countries | 288 | Including introductions from China, Fiji, North and South America, the Philippines, Papua New Guinea, Solomon Island and Taiwan |
| National registrations (Norin number) | 39 | Approved by MAFF* for recommendation |
| Breeding lines (Kyushu number) | 79 | Promising clones bred by Kyushu Nat. Agr. Exp. Sta., but not included in national recommendations. |
| Breeding lines (Kanto number) | 59 | Promising clones bred by Nat. Agr. Res. Center, but not included in national recommendations. |
| Breeding lines (Chugoku number) | 22 | Promising clones bred by Chugoku Nat. Agr. Exp. Sta., but not included in national recommendations. |
| Yen's collections | 202 | Introduced from New Zealand in 1969 |
| Experimental lines | 492 | Lines for breeding works |
| Total | 1,181 | |

* MAFF: Same with Table 2.

by virus diseases, resulting in poor storage root formation, less flowering and deformed plant growth. Preservation *in vitro* is adopted for such materials: approximately 250 genotypes are now kept in test tubes. Recent introductions include 15 accessions from China and 143 accessions from Papua New Guinea, all of which were subjected to plant quarantine examination.

## Non-conventional approaches

(1) Use of wild relatives

A wild relative, *Ipomoea trifida* (H.B.K.) DON. was first introduced from Mexico in 1956[14]. Breeding works initiated in 1957 released in 1975 a new cultivar Minamiyutaka which contains 1/8 kinship of *trifida* in its pedigree[20]. Minamiyutaka was planted to 5,500 ha in 1982 in the southern part of Kyushu. In 1978, another cultivar, Okiyutaka, was released from interspecific hybridization at the Okinawa Prefectural Agricultural Experiment Station. Breeding lines selected show kinship of *trifida* to some extent[6].

(2) Mutation breeding

Mutation works in sweet potato were reviewed by Broertjes and van Harten (1978)[1], and recently by Kukimura (1988)[7].

Although a number of useful characters produced by various mutagens have been reported[6,7,10], no cultivars have been developed from the mutation works. Less attempts of mutation breeding have been made in sweet potato than in other major legume and cereal crops.

(3) *In vitro* works

It is very difficult to regenerate plants of sweet potato from either calluse or protoplast, though not impossible[3,13]. The authors successfully induced an embryoid which developed into plants from calluse of sweet potato[5]. From protoplast, only calluse could be obtained so far. This type of studies might lead to the utilization of somaclonal variations and gene recombinations among the cross-incompatibility groups in future as well as to the basic works for utilization of DNA-recombinations in the practical breeding program.

## Conclusion

The prospects of breeding of this crop are closely related to the future of sweet potato itself. Sweet potato as a source of starch might decline in the face of competition with maize, cassava and Irish potato. However, it will still remain to be a high potential crop for biomas production as well as a traditional staple food in various countries. Diversification of utilization will have to be exploited extensively in order to hand down such a highly domesticated plant.

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