

## Review

# Recent progress in sweetpotato breeding and cultivars for diverse applications in Japan

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Sweetpotato (*Ipomoea batatas* (L.) Lam.) is an outcrossing hexaploid that is cultivated in the tropics and warm-temperate regions of the world. Sweetpotato has played an important role as a famine-relief crop during its long history and has recently been reevaluated as a health-promoting food. In Japan, sweetpotato is used for a wide range of applications, such as table use, processed foods, and alcohol and starch production, and two groups at National Agriculture Research Organization (NARO) undertake the breeding of cultivars for these applications. Sweetpotato breeders utilize breeding processes such as grafting for flower induction and the identification of incompatibility groups before crossing to conquer problems peculiar to sweetpotato. For table use, new cultivars with high sugar content were released recently and have become popular among Japanese consumers. New cultivars with high anthocyanin or  $\beta$ -carotene content were released for processed foods and use as colorants. As raw materials, new cultivars with high alcohol yield were released for the production of *shochu* spirits. In addition, new cultivars with high starch yield and a cultivar containing starch with excellent cold-storage ability were released for starch production. This review deals with recent progress in sweetpotato breeding and cultivars for diverse applications in Japan.

**Key Words:** sweetpotato, breeding, hexaploid, cultivar, production, utilization.

## Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is a vegetative propagation crop that belongs to the family Convolvulaceae. This crop is an autohexaploid ( $2n = 6x = 90$ ) (Shiotani and Kawase 1989). *Ipomoea trifida* (H. B. K.) G. Don ( $2n = 2x = 30$ ) is the most likely diploid ancestor of cultivated sweetpotato, and it forms a polyploid complex with a series from diploid to hexaploid (Nishiyama *et al.* 1975). Most varieties of sweetpotato show self- and cross-incompatibility, low natural flowering ability, and low seed fertility (Fujise 1964, Martin 1965). This outcrossing, polyploidy, and vegetative propagation in sweetpotato, causes high heterozygosity and variability in the genetic background of this crop.

It has been suggested that sweetpotato originated in the tropical lowlands of Central or South America (Austin 1988, Yen 1974). After Columbus arrived at the Caribbean in 1492, this crop spread widely from America to other tropical and warm-temperate regions worldwide. The Spanish

introduced the sweetpotato into Europe, and from here it was taken to Africa, India, and China. Sweetpotato was brought from China to Japan between 1597 and 1609, and it spread to various parts of Japan as a famine-relief crop over the 17th and 18th centuries.

Farmers can cultivate the sweetpotato twice a year in tropical regions, but in temperate regions sweetpotato can grow in only summer seasons that have at least 5 months of frost-free conditions. Cultivation of sweetpotato does not require much input from farmers except for occasional weeding. The vines grow rapidly and cover the field to prevent soil erosion (Loebenstein and Thottappilly 2009). Endophytic  $N_2$  fixation organisms have been isolated from the aerial parts of sweetpotato (Asis and Adachi 2003, Paula *et al.* 1991), and Yoneyama *et al.* (1998) reported the occurrence of  $N_2$  fixation in sweetpotato plants based on  $^{15}N$  natural abundance data. Sweetpotato can grow well in infertile soils with a little N fertilizer and is tolerant to severe weather conditions such as typhoons and drought. This crop shows higher productivity per unit area than other food crops such as cereals and has played an important role as a famine-relief crop during its long history (Loebenstein and Thottappilly 2009, Woolfe 1992).

In addition, sweetpotato roots contain high levels of

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nutrients such as carbohydrates, dietary fiber, vitamins A and C, and minerals, contained in both cereals and vegetables. Sweetpotato roots can be boiled, steamed, baked, or fried and can be used for diverse applications, such as table use, processed foods, alcohol and starch production, and animal feed. In developed countries, sweetpotato has recently been reevaluated as a health-promoting food, because of its high content of nutrients in balance and functional components such as anthocyanins, carotenoids, and phenolic compounds, which have anti-oxidant and other activities (Tanaka *et al.* 2017).

Sweetpotato is the fourteenth most important food crop worldwide from viewpoint of production, with approximately 103 million tons, produced from an area of about 8 million ha and an average yield of about 12.6 tons/ha (FAOSTAT 2013). Among the root and tuber crops of the world, sweetpotato ranks third after potato and cassava in terms of production. Sweetpotato is mainly grown in developing countries in the tropics and warm-temperate regions. China is the largest sweetpotato producer, and its annual production is about 70 million tons, accounting for 68.6% of total production in the world. The rest of Asia accounts for 7.5%, Africa for 19.5%, America for 3.5%, Oceania for 0.8%, and Europe for 0.1% of total production.

Japan is the fourteenth largest sweetpotato producer, and its production is approximately 942 thousand tons, from a production area of about 38 thousand ha and the average yield is about 24.4 tons /ha (FAOSTAT 2013). In Japan, the production of sweetpotato increased greatly in the period of food shortages immediately after World War II and reached a peak of about 7 million tons in 1955. After that, production declined sharply as the Japanese diet stabilized, and recent production remains around 1 million tons (Fig. 1). Sweetpotato in Japan was a subsistence crop before World War II and it was used mainly as a raw material for starch after the war. Recently, it has mainly been consumed for

table use, which accounts for about 45% of total consumption (Fig. 1). Starch use has continued to decrease in the face of competition from inexpensive imported corn and cassava. There was more consumption of alcohol (*shochu* spirits) produced from sweetpotato than starch in 2005. Food processing use has increased gradually and accounts for around 10% of current total consumption. Sweetpotato breeding in Japan is mainly carried out by two breeding groups at the National Agriculture Research Organization (NARO) for these diverse applications.

Previous reviews have reported production and consumption, cultivation and utilization, and breeding and varieties of sweetpotato in Japan up to about 2000 (Komaki 1997, Kumagai 2001, Nakatani 2001, Yamakawa 2000). This review deals with recent approaches to sweetpotato breeding in Japan. In addition, we introduce the cultivars released for diverse applications since 2000.

### Breeding procedure in Japan

Sweetpotato breeding at NARO is conducted in two groups: the Institute of Crop Science, NARO (NICS) and Kyushu Okinawa Agricultural Research Center, NARO (KARC/NARO). The laboratory for NICS is located in Tsukuba in the Kanto region, which is the northern limit of commercial production in Japan, and the laboratory for KARC/NARO is located in Miyakonojo in the Kyushu region, which is a southern warm-temperate area in Japan. The group at NICS mainly undertakes the breeding of cultivars for table use, and the group at KARC/NARO predominantly breeds cultivars for processing and raw materials.

Previous studies indicated that sweetpotato is an auto-hexaploid, and its inheritance mode is hexasomic (Kumagai *et al.* 1990, Shiotani and Kawase *et al.* 1989). Frequently, a trait controlled by a single gene can be quantitatively scored by phenotype owing to the specificity of its segregation in

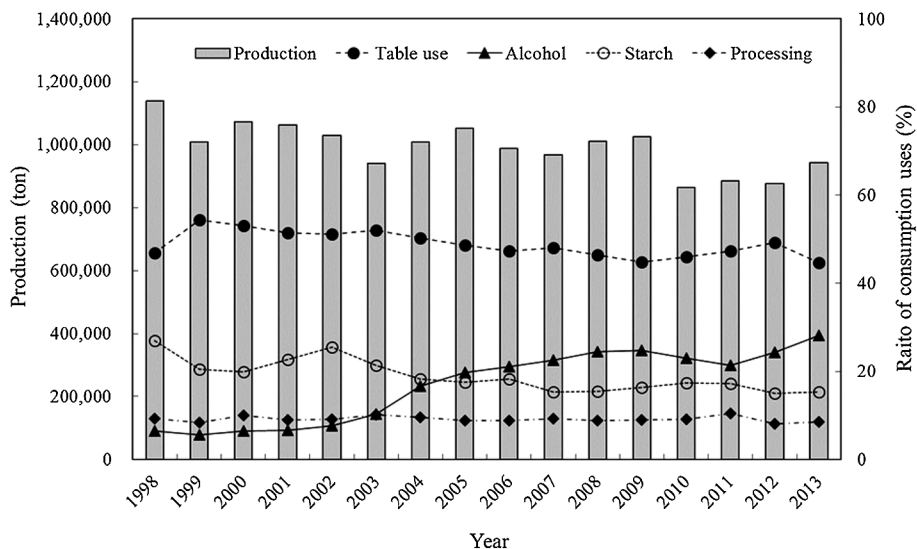


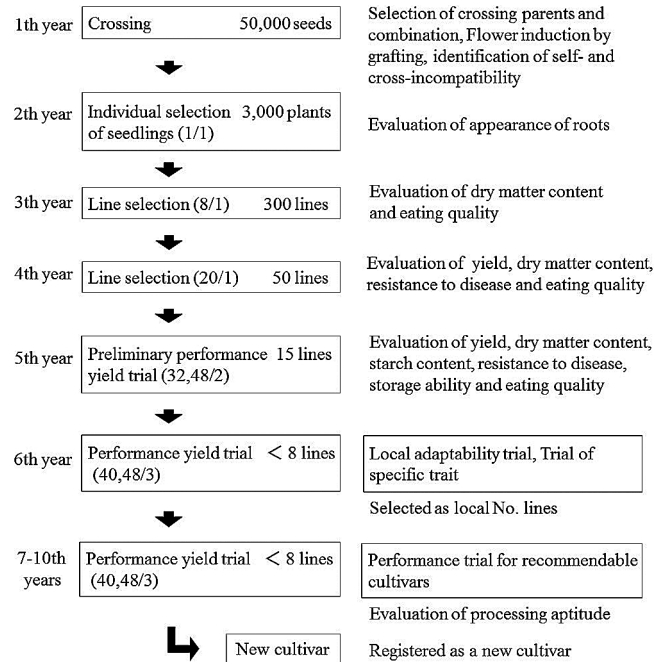
Fig. 1. Change in sweetpotato production and the ratio of consumption uses in Japan.

autopolyploids (Watanabe 2015). The highly heterozygous, outcrossing polyploidy in sweetpotato complicates its genetic analysis, but theoretical prediction of segregation is very important in sweetpotato breeding.

The two breeding groups at NARO maintain approximately 3,000 accessions of wild species and sweetpotato, which consist of registered cultivars, breeding lines, local varieties from Japan, and introductions from North and South America, Asia, and Oceania (Komaki 1995). About one-third of accessions are duplicated and conserved by both groups. Over 80% of the accessions are maintained using storage roots harvested from the experimental fields. The plants of accessions that produce no storage roots are maintained in pots of greenhouses. Morphological characteristics such as the shapes of leaves and roots, and agricultural characteristics such as disease and pest resistance and quality are evaluated for over 50 accessions every year.

The initiation of sweetpotato breeding involves the selection of crossing parents from the genetic resources and cross combinations. Most varieties of sweetpotato can produce few or no flower in temperate regions and they show the self- and cross-incompatibility. Therefore, sweetpotato breeders utilize breeding processes such as grafting for flower induction and the identification of incompatibility groups before crossing to overcome these problems. The top grafting method using morning glory stocks is adopted to induce flowering (Reynoso *et al.* 1999a). A dwarf type of Japanese morning glory, *Ipomoea nil* (L.) Roth cv. “Kidachi-asagao” is used as a rootstock for two reasons: one has a thick stem, which makes grafting manipulations easier, and it also has a long flowering period that increases the total number of flowers (Kobayashi and Nakanishi 1982). The sweetpotato scions form flower buds in 3 weeks after grafting and continue to flower for more than 2 months. The flowers of sweetpotato and *I. trifida* possess a strong sporophytic type of self-incompatibility (Kowyama *et al.* 2000) and 16 cross-incompatibility groups (A–P) have been classified in sweetpotato (Nakanishi and Kobayashi 1979). This is the main barrier to seed production after self-pollination and crossing within the same cross-incompatibility groups. Representative varieties from each group have been identified as “incompatibility testers”, and they are used in crossing between varieties whose incompatibility groups are unknown. Incompatibility is determined by observing the development of pollen tubes stained with aniline blue using a fluorescence microscope (Reynoso *et al.* 1999b). This approach allows unknown varieties to be identified according to five groups (A, B, C, D, and E) and the other groups. Recently, the laboratory at KARC/NARO has handled 200–300 cross combinations in total twice a year in spring and fall for the two breeding groups of NARO and they harvest approximately 50,000–70,000 seeds each year.

The breeding scheme of sweetpotato at NARO is shown in Fig. 2. These seeds are sown in nursery beds, and each seedling is transplanted into the field. Storage roots of selected plants with a good appearance are harvested and



**Fig. 2.** Breeding scheme for sweetpotato at the National Agriculture Research Organization (NARO) in Japan. The numbers in parentheses of each square indicate the number of plants and replicates in each trial in NARO. The right column indicates the evaluated traits in each trial and the trials conducted at agricultural experimental stations in some prefectures.

stored over winter. After the second year, they are investigated in various tests for line selection. Breeders decrease the number of selected lines and increase the amount of storage roots of the selected lines every year. In the sixth year, the local number lines are selected in performance yield trials and they are investigated for resistance to diseases and pests, local adaptability, trials of specific traits or performance trials for recommendable cultivars in several prefectures. The laboratory at NICS conducts resistance tests for major diseases and pests, including black rot (*Ceratocystis fimbriata*), stem rot (*Fusarium oxysporum* f. sp. *batatas*), soil rot (*Streptomyces ipomoea*), and southern root-knot nematodes (RKN, *Meloidogyne incognita*) (Okada *et al.* 2017). The laboratory at KARC/NARO investigates resistance to RKN and coffee root-lesion nematodes (RLN, *Pratylenchus coffeaceae*). Completing a new cultivar takes over 8 years after crossing.

### Breeding objectives and cultivars for table use

Recently, table use has accounts for about 45% of total consumption in Japan. Important breeding objectives for table use are good eating quality, good appearance, resistance to diseases and pests, and yield. Eating quality is affected by two main factors, namely sweetness and texture. Sweetpotato has a mechanism whereby  $\beta$ -amylase saccharifies the starches gelatinized by heating to maltose and the sweetness, sugar content, increases with cooking. The maltose content

**Table 1.** Characteristics of leading varieties and current cultivars for table use in Japan

Cultivars	Released year	Ratio for yield of the standard cultivar <sup>a</sup>	Resistance to diseases/pests	Quality of steamed roots and other characteristics
Kokei No.14	1945	—	—	Leading variety in west Japan, moderate texture, moderate brix%, moderate taste
Beniazuma	1984	104% of Kokei No.14	Soil rot	Leading variety in east Japan, dry texture, slightly high brix%, slightly good taste
Benimasari	2002	115% of Kokei No.14	Black rot	Slightly moist texture, slightly high brix%, good taste
Quick Sweet	2002	107% of Beniazuma	RKN	Slightly moist texture, high brix%, slightly good taste, low pasting temperature starch
Purple Sweet Lord	2002	157% of Beniazuma	—	Slightly dry texture, slightly low brix%, moderate taste, anthocyanin-rich
Beniharuka	2008	114% of Kokei No.14	RKN	Slightly moist texture, high brix%, good taste, wide regional adaptability
Himeayaka	2009	78% of Beniazuma	—	Slightly moist texture, slightly high brix%, good taste, compact size storage roots
Aikomachi	2012	101% of Beniazuma	RKN, black rot	Slightly dry texture, high brix%, slightly good taste, suitable for confectioneries

<sup>a</sup> Values under standard cultivation conditions.

is influenced by  $\beta$ -amylase activity and starch gelatinization temperature (Kitahara *et al.* 2017). In Japan, the monoculture of sweetpotato for table use has increased rapidly in commercial cultivation, and the continuous cropping of sweetpotato causes an increase in soil-borne diseases, such as soil rot and RKN. Resistance to these diseases is an important breeding objective for table use, too. In this chapter, we review the sweetpotato cultivars bred recently for table use (Table 1).

The leading varieties for table use in Japan are ‘Beniazuma’ and ‘Kokei No.14’. ‘Beniazuma’ was released by the National Agricultural Research Center (now known as NICS) in 1984 and is the progeny of a cross between ‘Kanto No.85’ and ‘Koganesengan’ (Shiga *et al.* 1985). The storage root is long fusiform with a dark red-purple skin and yellow flesh. This cultivar shows higher yields than ‘Kokei No.14’ and exhibits a better taste and higher brix% than ‘Kokei No.14’ and a dry texture to the steamed root flesh. ‘Beniazuma’ is slightly resistant to soil rot and has high sprouting ability but low storage ability. This cultivar is mainly cultivated in eastern Japan and its cultivation area in 2013 was about 4,800 ha. ‘Kokei No.14’ was released by Kochi prefecture in 1945 and was derived from a cross between ‘Nancy Hall’ and ‘Siam’. The storage root is fusiform with a red-purple skin and yellowish-white flesh. This cultivar exhibits wide regional adaptability, is multipurpose, and shows moderate brix% and texture of the steamed root flesh. However, it is susceptible to soil rot and RKN and has moderate sprouting ability and slightly high storage ability. This cultivar contains some derivative lines, and these lines are mainly cultivated in western Japan. The total cultivation area in 2013 was about 5,200 ha.

During the last two decades, consumers’ preferences for sweetpotato have changed in Japan. Japanese consumers currently prefer sweetpotato cultivars that exhibit strong

sweetness and a slightly moist texture to the cooked root flesh. Therefore, the cultivation of new cultivars with high sugar content has increased recently. Baked sweetpotato, called ‘*yaki-imo*’ in Japanese, which is very sweet, gained in popularity with current Japanese consumers. In addition, Japanese sweetpotato is increasing the volume of exports to Asian countries.

The trendy beginning of high-sugar cultivars was ‘Annou-imo’, such as ‘Annou-beni’ and ‘Annou-kogane’. These cultivars were bred from some landraces on Tanegashima Island by Kagoshima Prefectural Agricultural Experiment Station, Kumage Branch, in 1998 (Kouzuma *et al.* 2003). The storage root of ‘Annou-beni’ is fusiform with a brown skin and yellow flesh, and the taste is very sweet and smooth with a moist texture. The storage root of ‘Annou-kogane’ is cylindrical with a light-yellow skin and yellow flesh, and the taste is very sweet and smooth with a moist texture. These cultivars are cultivated on Tanegashima Island and their cultivation area is about 500 ha.

‘Benimasari’ is a cultivar for table use, developed at KARC/NARO and released in 2001 (Ishiguro *et al.* 2004). It is the progeny of a cross between ‘Kyushu No.104’ and ‘Kyukei 87010-21’. The storage root is uniformly fusiform with a red skin and yellow flesh. The yield of ‘Benimasari’ is considerably higher than that of ‘Kokei No.14’. The texture of the steamed root is slightly moist and its taste is better than that of ‘Kokei No.14’. The brix% of the steamed root is slightly higher than that of ‘Kokei No.14’. This cultivar is also resistant to black rot. Its sprouting and storage abilities are slightly high. The total cultivation area in 2013 was 195 ha in Ibaraki prefecture.

‘Quick Sweet’ was released by the NICS in 2002 and is the progeny of a cross between ‘Beniazuma’ and ‘Kyushu No.30’ (Katayama *et al.* 2003). The storage root is fusiform with a dark red-purple skin and yellowish-white flesh. The

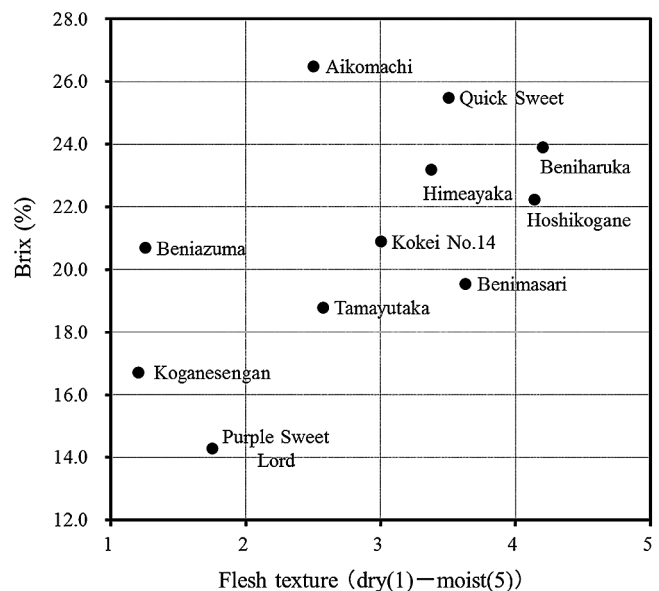
yield of this cultivar is similar to that of ‘Beniazuma’. The taste is equivalent to ‘Beniazuma’, the brix% is higher than ‘Beniazuma’, and the steamed root flesh has a slightly moist texture. This cultivar is slightly resistant to stem rot and RKN, but its sprouting ability and storage ability are low. The starch of ‘Quick Sweet’ has approximately 20°C lower gelatinization and pasting temperatures, slower retrogradation and higher digestibility of raw starch than ordinary cultivars, and this starch is qualitatively different from those of ordinary cultivars in terms of the chain-length distribution of amylopectin molecules (Katayama *et al.* 2002, Kitahara *et al.* 2005). It was reported that inhibition of expression of the starch synthase II gene led to low pasting temperature of sweetpotato starch (Takahata *et al.* 2010). This trait is a qualitative character controlled by one recessive allele, which is inherited in a hexasomic manner (Katayama *et al.* 2015). The storage roots of ‘Quick Sweet’ can be cooked quickly and taste good even when cooked rapidly in a microwave oven, because of its low pasting temperature. This cultivar is mainly cultivated in eastern Japan and its cultivation area in 2013 was about 10 ha.

‘Purple Sweet Lord’ was released by the NICS in 2002 and is derived from cross-pollinating ‘Kyushu No.119’ with a mixture of pollen from five lines: ‘Kanto No.85’, ‘Kanto No.99’, ‘Kanto No.103’, ‘Kyushu No.105’, and ‘Beniotome’ (Tamiya *et al.* 2003). Monden *et al.* (2013) reported that the pollen parent was ‘Kanto No.99’ as a result of DNA marker analysis. ‘Kyushu No.119’ is an anthocyanin-rich line, and ‘Purple Sweet Lord’ contains anthocyanin. The storage root is fusiform and uniform with a dark red-purple skin and purple flesh. The yield of this cultivar is higher than that of ‘Beniazuma’. The taste is equivalent to ‘Kokei No.14’, the brix% is lower than ‘Beniazuma’, and the steamed root flesh shows a slightly dry texture. This cultivar is slightly resistant to stem rot, and its sprouting ability and storage ability are slightly high. ‘Purple Sweet Lord’ is also used for side dishes, confectioneries, and *shochu* spirits. This cultivar is grown in various part of Japan and its cultivation area in 2013 was about 30 ha.

‘Beniharuka’ is a cultivar for table use, developed at KARC/NARO and released in 2007 (Kai *et al.* 2010). It is the progeny of a cross between ‘Kyushu No.121’ and ‘Harukogane’. The storage root is uniformly fusiform with a reddish-purple skin and yellowish-white flesh. The yield of ‘Beniharuka’ is higher than that of ‘Kokei No.14’. The dry matter content is higher than that of ‘Kokei No.14’ and the brix% of steamed root is higher than ‘Kokei No.14’. The steamed root texture is slightly dry soon after harvesting but it becomes slightly moister after about 1 month in storage, and its taste becomes sweeter. ‘Beniharuka’ is typical of the high-sugar cultivar and exhibits wide regional adaptability. It is slightly resistant to RLN, and is resistant to RKN. ‘Beniharuka’ exhibits moderate sprouting ability and high storage ability. Total cultivation area in 2013 was 2,012 ha, mainly in Ibaraki, Chiba, Kumamoto, Oita, and Kagoshima prefectures.

‘Himeayaka’ was released by the NICS in 2009 and is derived from a cross between ‘Kyushu No.127’ and ‘Kanto No.115’ (Ohara-Takada *et al.* 2011). ‘Himeayaka’ has compact size roots suitable for consumption in a single meal and the storage root is average weight about 140 g, which is 60% of that of ‘Beniazuma’ or ‘Kokei No.14’. The storage roots are short fusiform with a red-purple skin and yellow flesh. The yield of this cultivar is lower than those of ‘Beniazuma’ or ‘Kokei No.14’, but this has higher yield than both cultivars with roots less than 200 g. The taste is good and brix% is higher than both cultivars. In addition, the steamed root flesh shows a slightly moist texture and is bright yellow, and the incidence of blackening after cooking is low. This cultivar is slightly resistant to soil rot, stem rot, and black rot, and its sprouting ability is slightly high and storage ability is moderate. ‘Himeayaka’ is suitable for *yaki-imo* and is mainly cultivated in parts of the Kanto region.

‘Aikomachi’ was released by the NICS in 2012 and is derived from a cross between ‘Quick Sweet’ and ‘Kankei 107’ (Ohara-Takada *et al.* 2016). The storage root has a good appearance and is fusiform with a dark red-purple skin and light-yellow flesh. The average weight of storage roots is slightly lower than that of ‘Beniazuma’, but the yield is similar. The taste is good, its brix% is higher than ‘Beniazuma’, and the steamed root flesh shows a slightly dry texture. Because this cultivar shows little blackening after cooking and high dry matter content, it is suitable for processing for *imo-yokan*, solidified sweetpotato paste, and *daigaku-imo*, sugar-glazed fried sweetpotato, which are traditional Japanese confectioneries. This cultivar is resistant to RKN and black rot, and although its sprouting ability is slightly low, its storage ability is moderate. ‘Aikomachi’ is



**Fig. 3.** Classification of Japanese cultivars according to the relationship between brix% and flesh texture of steamed roots. Average value in 2006–2013 of cultivars that were cultivated at the Institute of Crop Science, NARO (NICS).

mainly expected to be cultivated in parts of the Kanto region.

**Fig. 3** shows the classification of Japanese cultivars according to the relationship between brix% and the flesh texture of the steamed roots. Most of new cultivars bred recently in Japan have high brix% and a slightly moist texture of the steamed roots (Katayama *et al.* 2014). In addition, these cultivars with high sugar content exhibit higher  $\beta$ -amylase activity and/or lower starch pasting temperature than those of ordinary cultivars. These results suggest that  $\beta$ -amylase activity and starch pasting temperature are important characteristics for breeding the cultivars with high sugar content.

### Breeding objectives and cultivars for processed foods

Since the latter half of the 1980s, breeders have actively promoted programs for developing cultivars adaptable for food processing in order to replace cultivars for starch production, which was decreased gradually in their area of cultivation in southern Kyushu. As a result, breeders have developed cultivars that have a high content of  $\beta$ -carotene and anthocyanin, which are suitable as natural food colorants, pastes, flours, juices, and precooked foods.

It was reported that  $\beta$ -carotene, which is the origin of orange flesh color, can change into vitamin A in the human body, so it has antioxidative functions and immunomodulating effects (Tanaka *et al.* 2017). Breeders have used a landrace, ‘Hayatoimo’, which has a lower  $\beta$ -carotene content, and American cultivars ‘Centennial’ or ‘86J-6’, which have higher  $\beta$ -carotene content as crossing parents, and have developed ‘Benihayato’ for processed foods and ‘J-Red’ for juices. In recent years, to focus on higher  $\beta$ -carotene content and taste, ‘Ayakomachi’ with its good taste and ‘Tama-akane’ with higher than 50 mg/100 g dry weight (DW) of  $\beta$ -carotene content have been developed (Kai *et al.* 2004, Sakai *et al.* 2011).

Sweetpotato cultivars with purple flesh color containing anthocyanin for processed foods are recognized broadly as the health-promoting foods. At the same time, it was also supported widely as a foodstuff. It is well-known that ‘Bise’ from Okinawa prefecture and ‘Tanegashimamurasaki’ from Kagoshima prefecture are landraces that contain anthocyanin. However, because of their low anthocyanin content, they cannot be used as the natural food colorant materials, which needs the factors of high anthocyanin content, sufficient supply and high stability during processing, storing and displaying. In the middle of the 1980s, ‘Yamagawamurasaki’ was found in Kagoshima prefecture and shown to contain higher anthocyanin than the other landraces. This cultivar mainly contains eight anthocyanins, identified as acylated glycosides of cyanidin and peonidin (Goda *et al.* 1997, Terahara *et al.* 1999), so that it has stability of a similar level to red cabbage in response to stimulation of light and heat (Otake *et al.* 1994). The expression of anthocyanin is a dominant trait (Mano *et al.* 2007), and its content has a high arithmetic effect, so that it is easy to select offspring lines con-

taining higher anthocyanin levels than the parents. In fact, the anthocyanin production per unit area of ‘Ayamurasaki’, which is a second-generation offspring of ‘Yamagawamurasaki’, can be ten-times higher than ‘Yamagawamurasaki’, and there is no unpleasant odor unlike with other anthocyanin-rich crop, red cabbage. This market scale is estimated as being the same as or somewhat higher than that of red cabbage colorants. Except for applications as a natural food colorant, it is widely used in confectionary, juices, jams, vinegars, and bread. In addition, a lot of physiological functions have been clarified, for example, radical-scavenging activity, reduction of liver injury, anti-hyperglycemic effect, and blood fluidity improving effects (Tanaka *et al.* 2017).

Nowadays, breeders are focusing on processing aptitude, increasing pigment content, and high competitiveness by adding high value in the colorants. New lines with high anthocyanin and low dry matter content were selected for reduction in the production cost. Manufacturers seek improvements of the stability for light and heat stimulation. The color is mainly dependent upon the structure (Hong and Ronald 1990), existence ratio (Yoshinaga *et al.* 1999), and/or coexisting substances (Takeda 1988) of each anthocyanin. Therefore, breeders have tried to make the line mass with various anthocyanin components. The mechanism of anthocyanin synthesis has been clarified in the gene level (Mano *et al.* 2007). It can be expected that efficient selection techniques will lead to the development of anthocyanin-rich lines in the future.

Steamed and dried sweetpotato cakes, called ‘*hoshi-imo*’ in Japanese, are an important local agricultural product in Japan. Recently, *shirota*, which is a white-opaque defect that occurs frequently in *hoshi-imo* as a result of hot summer, has become a more frequent problem. This defect greatly reduces the commodity value of *hoshi-imo*, and the breeding of cultivars with lower occurrence rates of *shirota* is becoming important aim. Moreover, expanding the variety of colors has been requested by farmers and consumers. It is also important to breed new cultivars with excellent taste for *hoshi-imo*. In this chapter, we review the sweetpotato cultivars bred recently for processed foods (**Table 2**).

‘Tamayutaka’ was bred by the Kanto-Tosan agriculture experiment station in 1960 and is the progeny of a cross between ‘Kanto No.33’ and ‘Kuroshirazu’ (Onoda *et al.* 1970). ‘Tamayutaka’ is suitable for *hoshi-imo*. The storage roots are short fusiform with a light-yellow-white with partially light crimson skin and white-yellow flesh. The yield of this cultivar is high, and the mean weight of a root is more than 300 g. *Shirota* defects occur frequently in *hoshi-imo* made from ‘Tamayutaka’. This cultivar is resistant to black rot and its sprouting ability and storage ability are slightly high. This cultivar has been a leading variety for *hoshi-imo* processing for a long time, and the total cultivation area in 2013 was 127 ha in the Kanto region.

‘Ayamurasaki’ is a cultivar for processed foods with high anthocyanin content, developed at KARC/NARO and released in 1995 (Yamakawa *et al.* 1997). It is derived from a

**Table 2.** Characteristics of leading varieties and current cultivars for processed foods in Japan

Cultivars	Released year	Ratio for yield of the standard cultivar <sup>a</sup>	Resistance to diseases/pests	Quality of processed foods and other characteristics
Tamayutaka	1960	—	Black rot	Leading variety until recently for <i>hoshi-imo</i> , high yield, slightly good taste
Ayamurasaki	1995	—	—	Leading variety for purple food colorant, high anthocyanin content
Murasakimasari	2001	107% of Ayamurasaki	RKN, RLN	High anthocyanin content, <i>shochu</i> with a sweet and wine-like flavor
Ayakomachi	2003	100% of Sunny Red	RKN	High $\beta$ -carotene content, suitable for cooking materials
Okikogane	2004	112% of Koganesengan	—	The steamed root is not sweet, high yield, suitable for cooking materials
Akemurasaki	2005	105% of Ayamurasaki	RKN, RLN	High anthocyanin content, suitable for food colorant
Tamaakane	2009	92% of J-Red	RKN, RLN	High $\beta$ -carotene content, <i>shochu</i> with a tropical fruit flavor
Hoshikogane	2012	90% of Tamayutaka	RKN	<i>Hoshi-imo</i> with high quality, high yield

<sup>a</sup> Values under standard cultivation conditions.

cross between ‘Kyushu No.109’ and ‘Satsumahikari’. The storage root is elongated fusiform with deep-purple skin and flesh. The yield of ‘Ayamurasaki’ is higher than that of ‘Kokei No.14’. The anthocyanin content in storage roots is very high. The color value, which is based on the absorption coefficient and is an indication of anthocyanin content, is about five times that of ‘Yamagawamurasaki’. Anthocyanin-rich extracts from storage roots are used in various foods and beverages. This cultivar is slightly resistant to RKN. ‘Ayamurasaki’ exhibits moderate sprouting ability and slightly high storage ability. The total cultivation area in 2015 was about 100 ha in southern Kyushu.

‘Murasakimasari’ is a cultivar with high anthocyanin content used for *shochu* spirits and processed foods. It was developed at KARC/NARO and released in 2001 (Kumagai *et al.* 2002a) and is the progeny of a cross between ‘Ayamurasaki’ and ‘Siroyutaka’. The storage root is uniformly fusiform with a good shape and deep purple skin. The flesh color is deep purple, and the color value is the same as that of ‘Ayamurasaki’. The yield, dry matter content, and starch content of ‘Murasakimasari’ are higher than those of ‘Ayamurasaki’. ‘Murasakimasari’ is suitable for direct-planting methods, which reduces labor and production costs for management of nurseries and transplanting. The alcohol yield is similar to that of ‘Koganesengan’ in the brewing of *shochu*, and spirits made from ‘Murasakimasari’ have a slightly sweet, wine-like flavor. This cultivar is resistant to RLN and RKN, and it is slightly resistant to black rot. ‘Murasakimasari’ exhibits moderate sprouting ability and high storage ability. The total cultivation area in 2015 was about 300 ha in southern Kyushu.

‘Ayakomachi’ is a cultivar for cooking materials and table use that was developed at KARC/NARO and released in 2003 (Kai *et al.* 2004). It is derived from a cross between ‘Sunny Red’ and ‘Hamakomachi’. The storage root is uniformly fusiform with a red skin and orange flesh. The yield of ‘Ayakomachi’ is similar to that of ‘Sunny Red’ and slightly less than that of ‘Kokei No.14’. The dry matter con-

tent is less than that of ‘Sunny Red’ and ‘Kokei No.14’, and the  $\beta$ -carotene content is 30 mg/100 g DW. This cultivar is slightly resistant to RLN and is resistant to RKN. ‘Ayakomachi’ exhibits moderate sprouting ability and high storage ability, and is cultivated in Chiba prefecture.

‘Okikogane’, a cultivar for cooking materials and food processing, was developed at KARC/NARO and released in 2004 (Kai *et al.* 2005). It is the progeny of a cross between ‘Beniwase’ and ‘Satsumahikari’. ‘Satsumahikari’ is a non-sweet cultivar lacking  $\beta$ -amylase activity for food processing. The storage root is uniformly short fusiform with a pale-yellowish-brown skin and pale-yellowish-white flesh. Although the yield of ‘Okikogane’ is higher than that of ‘Koganesengan’, its starch content is lower. The steamed root texture is slightly dry with a slightly unpleasant taste because it is not sweet. ‘Okikogane’ is suitable for wide variety of dishes, such as croquettes or French-fries like an Irish potato. This cultivar is slightly resistant to RLN, and it exhibits moderate sprouting ability and high storage ability. ‘Okikogane’ is mainly cultivated in Kyushu and Okinawa region.

‘Akemurasaki’ is a cultivar for processed foods with high anthocyanin content that was developed at KARC/NARO and released in 2005 (Sakai *et al.* 2010). It is derived from a cross between ‘Ayamurasaki’ and ‘Kyukei 174’. The storage root is elongated fusiform with a deep red-purple skin and deep purple flesh. The yield, dry matter content, and starch content of ‘Akemurasaki’ are all similar to those of ‘Ayamurasaki’. The anthocyanin content of ‘Akemurasaki’ is 15–30% higher than that of ‘Ayamurasaki’, and the ratio of cyanidin-based anthocyanins is higher than that of ‘Ayamurasaki’, and thus the paste and powder colors of ‘Akemurasaki’ are a slightly strong shade of blue. This cultivar is resistant to RLN and RKN. ‘Akemurasaki’ exhibits moderate sprouting ability and slightly high storage ability, and it is cultivated in southern Kyushu.

‘Tamaakane’ is a cultivar with high  $\beta$ -carotene content used for *shochu* spirits, and it was developed at KARC/

NARO and released in 2009 (Sakai *et al.* 2011). It is the progeny of a cross between ‘Resisto’ and ‘Kyukei 179’. The storage root is uniformly short fusiform with a light-brown skin and bright-orange flesh. The yield of ‘Tamaakane’ is higher than that of ‘Koganesengan’, but the dry matter and starch contents are lower. The alcohol yield is less than that of ‘Koganesengan’ in the brewing of *shochu*, and spirits made from ‘Tamaakane’ have a tropical fruit-like flavor derived from  $\beta$ -ionone, which is a decomposition product of  $\beta$ -carotene during the distillation process. ‘Tamaakane’ can be adapted for direct-planting methods because the ‘seed’ storage root of this cultivar disappears during the growth process, as is the case with the Irish potato. This cultivar is resistant to RLN and RKN. ‘Tamaakane’ exhibits slightly low sprouting ability and high storage ability. The total cultivation area in 2015 was about 40 ha in southern Kyushu.

‘Hoshikogane’ was released by NICS in 2012 and is derived from a cross between ‘Kanto No.120’ and ‘Quick Sweet’ (Kuranouchi *et al.* 2015). ‘Hoshikogane’ is suitable for *hoshi-imo* processing. The storage roots are short fusiform with a red-purple skin and light-yellow flesh. The yield of this cultivar is about 90% of that of ‘Tamayutaka’, and the mean weight of a storage root is slightly lower than that of ‘Tamayutaka’. *Shirota* hardly occurs in this cultivar. The brix% of *hoshi-imo* made from this cultivar exceeds that of ‘Tamayutaka’ from early winter, and the taste of ‘Hoshikogane’ is almost the same or slightly exceeds that of ‘Tamayutaka’. This cultivar is resistant to RKN and is slightly resistant to stem rot and black rot. Its sprouting ability is slightly high, but its storage ability is low. ‘Hoshikogane’ is cultivated in Ibaraki prefecture.

### Breeding objectives and cultivars for raw materials of alcohol and starch

*Imo-shochu* is a traditional spirit made from the sweetpotato and is popular with consumers in Japan. The leading variety used as a raw material of alcohol production is ‘Koganesengan’ (Sakai *et al.* 1967). This cultivar exhibits high yield, wide regional adaptability, and is multipurpose. In addition, *shochu* made from ‘Koganesengan’ has a good flavor and sweetness. Thus ‘Koganesengan’ has gained a strong reputation from users as a raw material for *shochu*. However, ‘Koganesengan’ has some disadvantages including limitations in disease resistance, storage ability, and shape of the storage root. Therefore, the breeding objectives for alcohol are to provide not only high yield and high brewing aptitude but also disease resistance, high storage ability, and superior shape of the storage root. Moreover, to expand the consumption of *shochu*, there is a desire to develop new products more-favored by young people and woman, who are currently not major consumers of *shochu*. It is thought that the characteristic flavor of conventional *shochu* comes from monoterpene alcohols, especially linalool, and  $\beta$ -damascenone as the main flavor ingredients (Kamiwatari *et al.* 2006, Kamiwatari and Setoguchi 2011). Currently,

many characteristic *shochu* products have been developed such as that made from purple-fleshed cultivars, which have wine- or yogurt-like flavors characterized by diacetyl and orange-fleshed cultivars with fruity tastes characterized by  $\beta$ -ionone. These *shochu* products contribute to the development of the *shochu* industry, thus breeding of cultivars corresponding to the diversification of flavors is also desirable.

Sweetpotato starch does not have excellent characteristics as a food material, thus approximately 70–80% of starch obtained from sweetpotato is used as a raw material for saccharification, and the starch is competing with cheaper imported corn and tapioca starches. Therefore, a reduction in production costs is a key requirement, and the most important breeding objectives for starch production are high yielding ability and high starch content. Moreover, to extend use as a food raw material, improvement of the quality of the starch becomes an important object. For adding value to sweetpotato starch, a new cultivar ‘Konamizuki’ has been developed, which provides starch with an extremely low degree of retrogradation compared with conventional starch (Katayama *et al.* 2012). In this chapter, we review the sweetpotato cultivars bred recently as raw materials of alcohol and starch (Table 3).

‘Koganesengan’ was developed at Kyushu National Agricultural Experiment Station (now known as KARC/NARO) and released in 1966 for starch production (Sakai *et al.* 1967). It is the progeny of a cross between ‘Kakei 7-120’ and ‘L-4-5 (Pelican Processor, cultivar from the USA)’. The storage root is short and fusiform with yellowish-white skin and flesh. The yield of ‘Koganesengan’ is higher than that of ‘Norin No.2’, a predecessor cultivar of starch production. The starch content shows a range of 24–26% and the starch yield is higher than that of ‘Norin No.2’, but ‘Koganesengan’ is inferior in resistance to RLN and RKN. This cultivar exhibits slightly high sprouting ability but slightly low storage ability. The steamed roots have a favorable taste. ‘Koganesengan’ is a main cultivar grown in southern Kyushu and used for *shochu*, table use, and processing. *Shochu* made from this cultivar has a strong flavor of sweetpotato and is superior in terms of the balance between flavor and sweetness. Therefore, ‘Koganesengan’ is regarded as the most suitable cultivar for *shochu*. The total cultivation area in 2013 was about 8,300 ha in southern Kyushu.

‘Shiroyutaka’ was developed at Kyushu National Agricultural Experiment Station (now KARC/NARO) and released in 1985 for starch production (Sakamoto *et al.* 1987). It is derived from a cross between ‘Kyukei 708-13’ and ‘S684-6’. The storage root is fusiform with a white skin, faintly red colored at the top and tail and white flesh. The yield of ‘Shiroyutaka’ is 124% of that of ‘Koganesengan’ under standard cultivation conditions. The starch content is 24.0%, which is similar to that of ‘Koganesengan’, but starch yield is 120% of that of ‘Koganesengan’. ‘Shiroyutaka’ exhibits resistance to RKN and black rot and slight resistance to RLN. This cultivar exhibits high sprouting ability but slightly low storage ability. ‘Shiroyutaka’ is a



**Table 3.** Characteristics of leading varieties and current cultivars for raw materials in Japan

Cultivars	Released year	Ratio for yield of the standard cultivar <sup>a</sup>	Resistance to diseases/pests	Quality of products and other characteristics
Koganesengan	1966	—	—	Leading variety for <i>shochu</i> spirits, good flavor and taste
Siroyutaka	1985	124% of Koganesengan	RKN, black rot	Leading variety for starch production, high yield
Konahomare	2000	106% of Shiroyutaka	—	Starch production, high yield, high starch content, high starch yield
Daichinoyume	2003	109% of Shiroyutaka	RKN	Starch production, high yield, high starch content, high starch yield
Tokimasari	2008	99% of Koganesengan	—	<i>Shochu</i> with full-bodied and rich flavor, high alcohol yield
Satsumamasari	2010	108% of Koganesengan	RKN	<i>Shochu</i> with sweet and fruity flavor, and refreshing taste, high alcohol yield
Konamizuki	2010	99% of Shiroyutaka	RKN	Starch production, low pasting temperature starch, cold storage stability
Koganemasari	2012	102% of Koganesengan	RKN, RLN	<i>Shochu</i> with flavor similar to Koganesengan, high alcohol yield

<sup>a</sup> Values under standard cultivation conditions.

leading variety for starch production in southern Kyushu and the total cultivation area in 2013 was about 4,100 ha.

‘Konahomare’ is a cultivar for starch production, developed at KARC/NARO and released in 2000 (Kumagai *et al.* 2002b). It is the progeny of a cross between ‘Hi-Starch’ and ‘Kyukei 82124-1’. The storage root is short and fusiform with light brown skin and light-yellowish-white flesh. The yield of ‘Konahomare’ is 106% of that of ‘Shiroyutaka’ under standard cultivation conditions. The starch content is 27.3%, which is 2.2% higher than that of ‘Shiroyutaka’. Depending on the cultivation conditions, the starch yield of ‘Konahomare’ is 15–29% higher than that of ‘Shiroyutaka’. This cultivar is slightly resistant to RKN, and it exhibits moderate sprouting ability but slightly low storage ability. The total cultivation area in 2013 was 92 ha in southern Kyushu.

‘Daichinoyume’ is a cultivar for starch production, developed at KARC/NARO and released in 2003 (Katayama *et al.* 2004). It is derived from a cross between ‘Kyukei 117’ and ‘Hi-starch’. The storage root is uniformly fusiform with white skin and light yellowish-white flesh. The yield of ‘Daichinoyume’ is 109% of that of ‘Shiroyutaka’ under standard cultivation conditions. The starch content is 26.9%, which is 1.9% higher than that of ‘Shiroyutaka’, and the starch yield is 17–31% higher depending on the cultivation conditions. This cultivar is resistant to RKN and slightly resistant to RLN. ‘Daichinoyume’ exhibits slightly high sprouting and storage abilities, which are superior to those of ‘Shiroyutaka’. The total cultivation area in 2013 was 371 ha in southern Kyushu.

‘Tokimasari’ is a cultivar for *shochu* spirits, developed at KARC/NARO and released in 2008 (Katayama *et al.* 2009). It is the progeny of a cross between ‘Starch Queen’ and ‘Konahomare’. The storage root is short and fusiform with light-pink skin and light-yellowish-white flesh. The yield of ‘Tokimasari’ is similar to that of ‘Koganesengan’ under standard cultivation conditions. The starch content is 25.5%, which is 1.5% higher than that of ‘Koganesengan’, and the

starch yield is 106%. The alcohol yield is higher than that of ‘Koganesengan’ in the brewing process. *Shochu* made from ‘Tokimasari’ is full-bodied with light sweetness and characterized by a rich flavor of steamed storage roots. The monoterpene alcohol concentration in ‘Tokimasari’ *shochu* is four times higher than that made from ‘Koganesengan’. This cultivar is slightly resistant to RKN. Its sprouting ability and storage ability are slightly high. The total cultivation area in 2013 was 5 ha in southern Kyushu.

‘Satsumamasari’ is a cultivar for *shochu* spirits, developed at KARC/NARO and released in 2010 (Katayama *et al.* 2013). It is derived from a cross between ‘Tokimasari’ and ‘Kyushu No.102’. The storage root is short and fusiform with yellowish-white skin and flesh. The yield of ‘Satsumamasari’ is 108% of that of ‘Koganesengan’ under standard cultivation conditions, and the starch content is 25.2%, which is 1.6% higher than that of ‘Koganesengan’. The starch yield is 114% of that of ‘Koganesengan’, and the alcohol yield is higher. *Shochu* made from ‘Satsumamasari’ has a sweet and fruity flavor, and a refreshing taste. This cultivar is resistant to RKN. Its sprouting and storage abilities are slightly high. The total cultivation area in 2014 was 12 ha in Kagoshima prefecture.

‘Konamizuki’ is a cultivar for starch production, developed at KARC/NARO and released in 2010 (Katayama *et al.* 2012). It is the progeny of a cross between ‘99L04-3’ and ‘Kyukei 236’. The storage root is long and fusiform with white skin and flesh. The yield of ‘Konamizuki’ is similar to that of ‘Shiroyutaka’ under standard cultivation conditions. On the other hand, the yield was 79% of that of ‘Shiroyutaka’ in long-term mulching conditions. The starch content was 24.5–24.6%, which is 0.1–1.0% higher than that of ‘Shiroyutaka’. The starch yield is similar to that of ‘Shiroyutaka’ under standard cultivation conditions but 21% lower in long-term mulching cultivation conditions. The chain-length distribution of the amylopectin molecules shows that ‘Konamizuki’ starch has a higher proportion of

short chains (DP 6–10) than the starch of ordinary cultivars (Kitahara *et al.* 2014). The starch pasting temperature is approximately 20°C lower than that of ‘Shiroyutaka’. The percentage of leaked water and hardness of starch gel after cold storage revealed that the starch of ‘Konamizuki’ retrogrades extremely slowly compared with that of ‘Shiroyutaka’ and has excellent cold storage stability. The raw starch of ‘Konamizuki’ has higher digestibility than ‘Shiroyutaka’, and ‘Konamizuki’ starch is of naturally high quality and is beneficial in keeping the texture of processed products soft. This cultivar is slightly resistant to black rot and RLN and resistant to RKN. ‘Konamizuki’ exhibits slightly high sprouting ability and moderate storage ability. The total cultivation area in 2015 was 36 ha in Kagoshima prefecture.

‘Koganemasari’ is a cultivar for *shochu* spirits, developed at KARC/NARO and released in 2012 (Sakai *et al.* 2013). It is derived from a cross between ‘Starch Queen’ and ‘Kyukei 236’. The storage root is short and fusiform with a yellowish-white skin and white flesh. The yield of ‘Koganemasari’ is similar to that of ‘Koganesengan’ under standard cultivation conditions. The starch content is 26.9%, which is 4.1% higher than that of ‘Koganesengan’, and the starch yield is 120% of that of ‘Koganesengan’. The alcohol yield is higher than that of ‘Koganesengan’ in the brewing of *shochu*. The flavor of *shochu* made from ‘Koganemasari’ is similar to that of ‘Koganesengan’. This cultivar is resistant to RLN and RKN. ‘Koganemasari’ exhibits slightly high sprouting ability and high storage ability, and is mainly cultivated in Miyazaki prefecture.

### Future prospects

There are many remaining problems to be resolved thorough future sweetpotato breeding programs. The major problems focus on the reduction of production costs, stable production and supply, climate change measures, high added value, and developments to meet new demands. The mechanization of sweetpotato cultivation has not advanced greatly, and working hours for management of nurseries and transplanting are higher than those of other crops. In order to reduce the working hours and production costs, it is important to improve seedling plant types that are suitable for transplanting and cultivating using machinery (Kuranouchi *et al.* 2016). In addition, direct planting methods of ‘seed’ storage roots are considered to remove the need for transplanting work, and new cultivars with high direct planting suitability are expected for raw materials of starch and alcohol, following ‘Tamaakane’ and ‘Murasakimasari’ for processing use. In order to secure stable production and supply, it is also necessary to improve yields, resistance to diseases, and storage ability. The production of sweetpotato is gradually decreasing year by year in Japan, and new cultivars with high yield and multiple disease resistances are being sought by the sweetpotato farmers. Sweetpotato storage roots do not exhibit dormancy and are not suitable for a long-term storage, such as for more than 6 or 7 months. In

Japan, the storage roots are harvested in autumn and are stored until the next summer. The storage roots saccharify during storage and their quality is easy to change during long-term storage. The farmers use a curing technic (4–7 days at 30–33°C and 90–100% relative humidity) to aid in wound healing and reduce loss due to disease during storage. Because the supply shows a slight lack in summer, new cultivars with high storage ability or early thickening ability are desired to improve the annual supply.

The influence of climate change and global warming is of concern. The invasion of tropical pests, such as sweetpotato weevils, may become a new threat, but the northernmost limit of sweetpotato cultivation area is advancing. Sweetpotato weevils are already endemic to the South-West Islands and Ogasawara Islands in Japan. Research on resistance to these new pests is considered important and is already being undertaken at KARC/NARO (Okada *et al.* 2017). On the other hand, sweetpotato cultivation has recently spread to colder climate areas that were not suitable for production in the past. Therefore, it is also necessary to breed new cultivars suitable for cultivation in colder areas, and NICS is developing new lines with better low soil temperature tolerance.

Japanese consumers are highly discerning with regard to food quality, and Japanese sweetpotato cultivars for table use have the highest quality levels in the world. Consumers are also very conscious of health functionality as well as high quality for future sweetpotato production. In order to enhance the health functionality for consumers and increase consumption, it is important to improve eating quality and the levels of constituents related to health function, such as anthocyanins,  $\beta$ -carotenes, and dietary fibers (Tanaka *et al.* 2017). In addition, the manufacturers of processed foods, *Shochu* spirits, or starch are keen to achieve reduced costs and to develop new demand for sweetpotato products. We evaluate the quality and processing aptitude of new lines, in which the manufactures collaborate. It is necessary to breed new cultivars containing specific pigments or starches with new properties in order to meet these new demands (Kitahara *et al.* 2017, Tanaka *et al.* 2017).

Because sweetpotato is a highly heterozygous, outcrossing hexaploid with 90 chromosomes, this complicates genetic and linkage analysis, and the accumulation of genome sequence information for this crop had been slower than in selfing diploid crops. However, whole genome sequencing in the diploid ancestor, *Ipomoea trifida* (H. B. K.) Don was reported recently (Hirakawa *et al.* 2015). Additionally, whole genome sequencing and genetic linkage mapping in hexaploid sweetpotato is progressing now (Isobe *et al.* 2017, Monden and Tahara 2017). In the near future, DNA makers for sweetpotato will be developed, and the DNA maker selection will be possible in sweetpotato breeding programs. Marker-assisted breeding may also offer new targets through the modification of pigments or starches by accumulating recessive alleles.

Sweetpotato has played various important roles as a

famine-relief crop, biomass crop, commercial crop, and health promoting crop in its long history. These diverse applications will also support the cultivation and use of this crop in various regions and situations. It will be necessary to continue to improve sweetpotato for a wide range of applications in the future.

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