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Review Article

Japanese Sweetpotatoes: Production, Cultivars, and Possible Ancestry

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Abstract

Sweetpotato has recently received much attention due to its many agricultural advantages such as its adaptability to different environmental conditions and its nutritional value. It has been grown in Japan for more than 400 years, and the bulk of the Japanese harvest is presently destined for fresh market consumption as well as for the food and beverage processing industry. This review begins by providing an overview of the commercial production and agronomic characteristics of sweetpotato cultivars in Japan. The paper deals with the possible ancestry of Japanese sweetpotatoes, and finally describes several orange- or purple-fleshed genotypes that are adapted well to cold northern climates and considered as valuable sources for enhancing the physiological functionality of this crop.

Keywords: adaptability, breeding, genetic resources, horticultural characteristics, *Ipomoea batatas* (L.) Lam.

Introduction

Sweetpotato [*Ipomoea batatas* (L.) Lam.], a member of the morning glory family Convolvulaceae, ranks as seventh among the most important food crops in the world (Çalişkan *et al.*, 2007; Rossel *et al.*, 2008; Troung *et al.*, 2011; Rodrigues-Bonilla *et al.*, 2014). It is an obligatorily outcrossing crop, but rarely flowers when the daylight is longer than 11 hours, as is normal outside of the tropics (Gurmu *et al.*, 2013; http://schoolswikipedia.org/2006/wp/s/Sweet_potato.htm). The crop is generally propagated either by vine cuttings or by sprouts called “slips” that are removed from the tuberous roots (George *et al.*, 2011). The outcrossing nature, combined with clonal propagation has created a vast number of cultivated genotypes around the world (Zhang *et al.*, 1998; Huamán *et al.*, 1999; Elameen *et al.*, 2011; Thiyagu *et al.*, 2013).

It is believed that sweetpotato was first introduced into Japan as early as the beginning of the 17 th century (http://www.nodai.ac.jp/journal/research/suzki_s/0803_01.html). Thereafter the crop became popular in this country because it was a reliable crop in cases of crop failure of other staple foods. While cultivars grown in Japan before the 1920s were mostly direct introductions and landraces, modern cultivars are either the products of controlled crosses or somatic selections of mutants (MAFF, 2015). More than 100 sweetpotato cultivars have been developed by Japanese breeders, but currently sweetpotato culture in the country is dominated by only a few cultivars (MAFF, 2015).

Breeding efforts have been made to develop new sweetpotato cultivars with high yield, resistance to biotic and abiotic stresses, and other characteristics that enhance acceptability by end users (Katayama *et al.*, 2006; Oki *et al.*, 2006; Ishiguro *et al.*, 2010). Having a collection of information about the Japanese sweetpotato germplasm accessions is valuable to researchers and other stakeholders interested in understanding sweetpotato production in Japan. However, the information of interest is scattered among individual scientific reports. This review outlines the current status of Japanese sweetpotato production and the horticultural characteristics of leading cultivars. The paper also focuses on the ancestry of Japanese sweetpotatoes, and the genetic resources potentially useful for enhancing the adaptability and physiological functionality of this crop.

Commercial Production

Sweetpotato is cultivated throughout tropical and warm temperate regions wherever there is sufficient water to support its growth. According to the FAO statistics, world production in 2013 exceeded 103 million metric tons (FAO, 2015). The majority came from China, with a production of 70 million tons from 3,358,000 ha. The average sweetpotato production per year during 2010-2014 was ca. 890,000 tons in Japan (Table 1). Almost all of the Japanese harvest is destined for human consumption, in contrast with China where 40% of the sweetpotatoes harvested is used as animal feed to support an increasing domestic demand for animal protein (Adam, 2005; Statistics of Agriculture, Forestry and Fisheries, 2016). In Japan, the fresh tuberous roots are commonly boiled, steamed, baked or fried to eat them at home. They are also processed to make industrial products such as starch, liquor, flour and food dyes (Katayama *et al.*, 2006). In recent years, the market for sweetpotato as a source of Japanese traditional spirits is growing (MAFF, 2015).

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Table 1. Harvest area and production of sweet potato in Japan

Parameters	2010	2011	2012	2013	2014
Harvest area (ha)	39,700	38,900	38,800	38,600	38,000
Production (t)	863,600	885,900	875,900	942,300	886,500

Source: Statistics of Agriculture, Forestry and Fisheries (2016)

Leading cultivars

In 2012, Japan's sweetpotato growing land area (38,800 ha, see Table 1) consisted mostly of the following cultivars: 'Koganesengan', 22.1% of total acreage; 'Beniazuma', 19.0%; 'Kokei 14' and its mutants, 11.4%; 'Shiroyutaka', 11.0%; 'Beniharuka', 5.3%; and 'Benimasari', 2.1% (MAFF, 2015). Horticultural characteristics of these cultivars are described below.

'Koganesengan'

This cultivar was derived from a cross between 'Kakei 7-120' and 'L-4-5 (Pelican Processor)', and has been predominantly grown in warmer western Japan. The maternal parent of 'Kakei 7-120' is an Indonesian landrace, whereas 'Pelican Processor' is a cultivar bred in Louisiana Agricultural Experiment Station, USA. Storage roots of 'Koganesengan' are mostly fusiform and are characterized by their cream-coloured skins and white to light yellow flesh. Mature leaves are cordate and slightly lobed. The release of 'Koganesengan' in 1966 provided consumers and growers with high-yielding and high-starch-content sweetpotato. The cultivar also exhibits moderate resistance to the coffee root-lesion nematode, *Pratylenchus coffeae* (Zimmermann) Filipjev & Schuurmans Steckhoven. For many years, it was primarily used as a source of industrial starch. At this present time, however, demand for higher-starch sweetpotatoes declines with the wide availability of inexpensive corn (maize) and cassava starch. 'Koganesengan' is currently the most commonly grown cultivar for the production of Japanese spirits. It is also used for fresh market consumption thanks to its good taste.

'Beniazuma'

'Beniazuma' was produced by crossing 'Kanto 85' as the seed parent with 'Koganesengan' as the pollen parent, and approved for release in 1984. This cultivar has green and cordate leaves, some with slight teeth on the margin. The vines are purple in colour and vigorous, forming a dense canopy. Storage roots are fusiform, lightly grooved, with an attractive purple-red skin and yellow flesh (Fig. 1A). Sprouting of bedded roots is mostly satisfactory. 'Beniazuma' has a dry texture with a sweet taste when cooked, and has been almost exclusively used for fresh market consumption. It is generally favoured in the markets of eastern Japan. 'Beniazuma' is resistant to soil rot caused by *Streptomyces ipomoeae* (Person & W.J. Martin) Waksman & Henrici. The cultivar has also moderate resistance to the southern root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood.

'Kokei 14'

The cultivar originated from a cross 'Nancy Hall' × 'Sium', and was officially released in 1945. 'Nancy Hall' is a U.S. cultivar, while the origin of 'Sium' is uncertain. Vine growth is relatively vigorous with green, cordate leaves. Plants form long, fusiform storage roots with a purple-red skin colour and light-yellow flesh colour. 'Kokei 14' and its mutants (*e.g.* 'Miyazakibeni', 'Narutokintoki' and 'Tosabeni'), all of which are mainly utilised for fresh market consumption, have a slightly dry texture and sweet taste upon cooking. These quality attributes are generally preferred by the consumers of western Japan. 'Kokei 14' exhibits early thickening growth of storage roots, making it possible to harvest the crop early. Harvested roots also keep well under long-term storage. 'Kokei 14' has intermediate or relatively high level of resistance to the coffee root-lesion nematode.

'Shiroyutaka'

'Shiroyutaka' is a cultivar for starch production, and has moderate to high level of field resistance to insect pest and disease as well as high storage root yield. It generally yields more than 'Koganesengan'. 'Shiroyutaka' originated from a 1975 cross between 'Kyukei 708-13' and 'S684-6', and was released in 1985. 'Kyukei 708-13' was a source of resistance to the southern root-knot nematode, while 'S684-6' provided resistance to black rot caused by the ascomycete fungus, *Ceratocystis fimbriata* and coffee root-lesion nematode. This cultivar has spreading vines and vigorous growth. Storage roots are fusiform, and skin colour is pale yellow with pink at both proximal and distal ends. Flesh colour is white to cream.

'Beniharuka'

'Beniharuka', a cultivar for fresh market consumption, is an attractive purple-red-skinned, cream-fleshed sweetpotato released in 2007. It resulted from hybridization of 'Kyushu 121' with

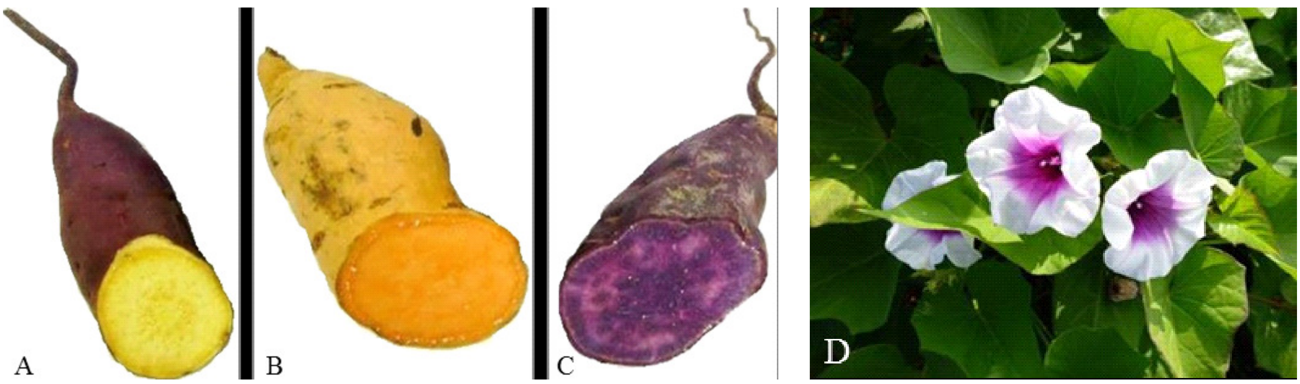

Fig. 1. Root skin and flesh colour of cv. 'Beniazuma' (A), 'Umekei 13' (B) and 'Umekei 15' (C), and the sweetpotato plant in flower (D) (Photo: S. Tsutsui)

'Harukogane', and demonstrates resistance to the southern root-knot nematode. The cultivar has a somewhat dry texture with a sweet taste when cooked, and is also characterized by good storage quality.

'Benimasari'

This cultivar originated from a cross of 'Kyushu 104' × 'Kyukei 87010-21', and is mainly utilized for fresh market consumption. The release of 'Benimasari' in 2001 provided consumers and growers with a pale-yellow-fleshed, attractive red skinned sweetpotato. Mature leaves are cordate and dark green. 'Benimasari' roots store well and have a somewhat moist texture and sweet taste upon cooking. In addition, the cultivar is resistant to black rot and moderately resistant to the coffee root-lesion nematode.

Ancestry of Japanese sweetpotatoes

The question then arises as to from where and how sweetpotatoes reached Japan. Molecular markers have been extensively used for analysing the genetic diversity and phylogenetic relationships among a wide array of sweetpotato genotypes (Prakash *et al*., 1996; Zhang *et al*., 1998, 2004; Dhillon and Ishiki, 1999; Tseng *et al*., 2002; Elameen *et al*., 2008). Intriguingly, RAPD (Randam Amplified Polymorphic DNA) analysis of sweetpotato accessions originating from different geographical regions led Gichuki *et al*. (2003) to conclude that sweetpotato was domesticated in Mesoamerica and then spread to South America (the Peruvian-Ecuadorian region). They also suggested the existence of two distinct genepools (the South-American and Central American/Caribbean genepools) in the primary centre of diversity.

This theory has subsequently been challenged by Roullier *et al*. (2011, 2013a, 2013b) who, using both nuclear and chloroplast microsatellite markers, indicated that sweetpotato was domesticated twice, once in Mesoamerica and the other in the northwestern part of South America. According to linguistic and archaeological studies, sweetpotato could have spread to the Pacific *via* three different main routes (*viz*. Kumara, Batata, and Camote lines) (Barrau, 1957; Yen, 1974). The Kumara line represents the transfer of South American sweetpotatoes by Polynesian travelers or chance spread of seeds *via* ocean currents, from the western coast of South America to Polynesia, between 1000 and 1100 AD. The second route (Batata line) is based upon the assumption that the Portuguese explorers of the 16th century introduced sweetpotatoes from the Caribbean and Central America to eastern Indonesia.

Furthermore, Spanish "Acapulco-Manila" galleons are supposed to have introduced the Mesoamerican sweetpotatoes to the Philippines in the 16th century (Camote line), with subsequent dispersal to Japan and China. Actually, the analysis of nuclear and chloroplast microsatellite loci confirmed that the Japanese landraces examined are principally derived from the Central American/Caribbean genepool (Roullier *et al*., 2013a). In Japan, there have been multiple introductions of breeding materials from different sources (see the description of cvs. 'Koganesengan' and 'Kokei 14') after the initial transmission, which suggests the broadening of genetic diversity. On the basis of DNA marker [RAPD, SAMPL (Selective Amplification of Microsatellite Polymorphic Loci) or ISSR (Inter-Simple Sequence Repeat)] analyses, however, most of modern Japanese cultivars exhibited limited genetic diversity (Komaki *et al*., 1998; Dhillon and Ishiki, 1999; Tseng *et al*., 2002; Hu *et al*., 2003). This may be partly a consequence of selection for the attributes favoured by Japanese consumers and growers as well as of adaptation to the local environment within Japan. In addition, the possibility cannot be ruled out that the sweetpotato genotypes chosen as parents in hybrid breeding so far belong to the same genepool.

Genetic resources and breeding

Sweetpotato normally grows best at ambient day and night temperatures from 20 to 30 °C and requires a minimum of five months of frost-free growing conditions (Rossel *et al*., 2008). It is also noted that the storage roots may sustain chilling injury if they are subjected to temperatures below 10 °C for even a few hours (Stoddard *et al*., 2013). In Japan, commercial sweetpotato production is indeed confined to the temperate central and southwestern areas. New sweetpotato cultivars with enhanced tolerance to low temperature would enable this crop species to be cultivated under normally unfavorable culture conditions. Interestingly, some sweetpotato genotypes have recently proven adaptable to colder regions (Tsutsui *et al*., 2008). As shown in Table 2, five breeding lines were grown in the experimental fields (maximum and minimum air temperatures in the growing season and frost-free period, in 2005 and 2006, were 33.4 °C, 2.2 °C, and 143 days, respectively) situated in Hokkaido, the northernmost district of Japan, and data were collected for storage root yield and other agronomic traits. These lines produced yields comparable to or exceeding the average national root yield of 2,300 kg/10a (Tables 1 and 2).

Vine cuttings were planted in a row with a between-row distance of 120 cm and a between-plant distance within the row of 40 cm, giving a population density of 2,083 plants per 10 ares. The ridges were covered with polyethylene film mulch. The plots received 5-10-10 (N-P_2O_5-K_2O) kg/10a fertilizer. The harvest time was the beginning or middle of October.

Table 2. Storage root yield and horticultural characteristics of five sweetpotato breeding lines ('Umekei 09' through 'Umekei 15') and cv. 'Beniazuma' when tested at Urausu-chou (43°26′N, 141°49′E, *ca*. 100 m a.s.l.) in Hokkaido, in 2005 and 2006

Genotype	Mean for root yield (kg/10a)	Skin colour	Flesh colour	Flowering habit
'Umekei 09'	2,852	Pale red	Dark orange	Profuse
'Umekei 10'	4,100	Purple-red	Orange	Moderate
'Umekei 12'	4,579	Red	Orange	Moderate
'Umekei 13'	3,518	Orange	Dark orange	Profuse
'Umekei 15'	4,198	Dark purple	Dark purple	Moderate
'Beniazuma'	2,745	Purple-red	Yellow	Failure of flowering

Source: S. Tsutsui *et al*. (2008)

The lines have also orange or purple flesh colour (Tsutsui *et al*., 2008, Table 2, Fig. 1B, C). There has been increasing emphasis in recent years upon the physiological functionality of sweetpotatoes. Breeding efforts do exist to improve the content of functional components such as anthocyanins, ß-carotene, polyphenols, dietary fibres, vitamins and minerals (Katayama *et al*., 2006; Oki *et al*., 2006; Ishiguro *et al*., 2010). It is certain that sweetpotatoes with orange and purple flesh are rich in ß-carotene and anthocyanins, respectively (Oki *et al*., 2006; Ishiguro *et al*., 2010; Montilla *et al*., 2011; Saraswati *et al*., 2013). Hence, the lines in question are surely valuable as raw materials for developing new sweetpotato cultivars with enhanced functionality as well as with the adaptability to cold climates.

An additional feature of these breeding lines merits comment. Most Japanese sweetpotato cultivars normally fail to flower under the conditions in their main growing regions, and some treatments has been used to induce flowering , including grafting, vine girdling, day-length control and so forth (Lardizabal and Thompson, 1988, 1990). By contrast, the five lines flowered well without grafting and other treatments (Tsutsui *et al*., 2008, Table 2, Fig. 1D), making them good parents for a sweetpotato breeding programme. In conclusion, a variety of sweetpotato genetic resources should be properly collected and efficiently phenotyped to identify the genotypes necessary for genetic improvement of the crop.

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