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JAPANESE BULB ONION: PRODUCTION, CONSUMPTION, AND CULTIVARS

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ABSTRACT

Bulb onion is an ancient vegetable crop that has been cultivated for at least 5,000 years. In Japan, this cultivation has only 150 years of history, but nowadays, it ranks fourth in total production, fourth in cropping acreage, and second in consumption among vegetables grown domestically. Until the 1970s, open-pollinated onion cultivars were predominantly cultivated throughout the country; they were selected mainly from old US cultivars. Over the past three decades, these open-pollinated cultivars have been replaced with F1 hybrid cultivars that offer higher yield, better disease resistance, uniformity at maturity, and high bulb quality. In this review, an attempt is made to characterize the commercial production and consumption of Japanese bulb onion as well as agronomic characteristics of representative cultivars.

Key words: breeding, cultivation history, disease resistance, F1 hybrids, food safety, marker-assisted selection

INTRODUCTION

Bulb onion (*Allium cepa* L.) has been valued as a food and a medicinal plant since ancient times (McCallum et al. 2006; Pareek et al. 2018). Although the exact place of origin and domestication of bulb onion is uncertain, the crop has been variously described as having originated in Central Asia, Iran, and western Indian subcontinent (Havey 1997; Valenzuela et al. 1999; Boyhan & Torrance 2002). From its center of origin, onion was introduced into the Mediterranean region. Bulb onion cultivation spread throughout Europe with subsequent dispersal to North and South America, Australia, sub-Saharan Africa, Japan, and eastern Asia (Havey & Ghavami 2018). This crop is currently cultivated in more than 240 countries, with an estimated annual production of almost 98 million metric tons in 2017 (FAO 2019). China and India are the primary bulb onion-growing countries, followed by the United States, Iran, Egypt, Russia, and Turkey (FAO 2019).

In Japan, bulb onion is one of the most popular and economically important vegetables. Breeding efforts have been made to develop new cultivars with high yield, storability, processing quality, and other characteristics that enhance acceptability by end users (Kojima 2010; Ariyanti et al. 2018). Information regarding the Japanese bulb onion germplasm accessions as well as the current state of onion culture in the country is, however, scattered among individual scientific reports. With this in mind, we herein present an overview of commercial production, uses, and consumption of bulb onion in Japan. The paper also reviews the agronomic characteristics of major Japanese cultivars.

Commercial production

In a 5-year average from 2014 to 2018, bulb onion was harvested from 25,720 ha with a total yield of 1,212,000 tons annually in Japan (Table 1). The top three bulb onion-producing areas are Hokkaido (the northernmost island), Hyogo (a district of west central Japan), and Saga (a district in southwestern Japan). In 2018, bulb onion production in Hokkaido accounted for 62.1% of national output, followed by Saga (10.2%) and Hyogo (8.3%) (MAFF 2019a). Bulb onion is the second most consumed vegetable in Japan, behind cabbage (ALIC 2019). The annual per capita consumption of bulb onion was 5,375 g in 2018 (ALIC 2019). Insufficient quantities of bulb onion are grown domestically, so approximately 20% of the supply is imported from China, the United States, and New Zealand; for example, in 2018, 301,700 tons were imported to supplement domestic production (ALIC 2019).

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Table 1. Production and cultivation area of bulb onion in Japan

	2014	2015	2016	2017	2018
Cropping acreage (ha)	25,300	25,700	25,800	25,600	26,200
Total harvest (t)	1,169,000	1,265,000	1,243,000	1,228,000	1,155,000

Uses

Domestically grown bulb onion is primarily used to enhance the flavor of other foods, and both mild and pungent onions are in demand for both, as ingredients of popular Japanese dishes and in the manufacture of sauces, paste, canned soups, pickles, extracts, and dehydrated products. Onion bulbs come in three different colors: yellow, white, and red. Although yellow onion cultivars are most commonly grown in Japan, there is an increasing demand for mild-flavored, white or red onions suitable for serving raw. It is also worth mentioning that red onions with high quercetin-glycoside content have recently attracted the attention of consumers (Muro et al. 2015).

History of bulb onion cultivation in Japan

In Japan, bunching onion (*Allium fistulosum* L.), a close relative of bulb onion, is one of the most popular flavoring vegetables and economically important; approximately 22,400 ha of bunching onion were harvested in 2018 with a total yield of 452,900 tons (MAFF 2019a). This crop presumably has its origin in north-western China and had been introduced into Japan by the 7th century (Tsukazaki et al. 2010; Fujime 2012).

On the contrary, the cultivation of bulb onion in this country is fairly recent, with the first attempt to grow it being in Hokkaido in 1871 (Abe et al. 1955; Satoh et al. 1993). The commercial production commenced in the end of the 19th century, after the successful growing of a well-known ancient cultivar ‘Yellow Globe Danvers’ introduced from the United States (Satoh et al. 1993; Kojima 2010). An open-pollinated cultivar ‘Sapporo-ki’, a selection from ‘Yellow Globe Danvers’, dominated almost all bulb onion-growing areas in Hokkaido until the beginning of 1970s (Komochi 2015). Likewise, in Osaka district of west central Japan, a local cultivar ‘Senshu-ki’ was selected from a US introduction ‘Yellow Danvers’ in the late 19th century and later became the progenitor of modern cultivars grown in western Japan (Kojima 2010).

In 1973, a serious onion disease Fusarium basal rot, caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cepae*, broke out in Hokkaido (Komochi 2015). The epidemic caused substantial losses in bulb yield and quality. Unfortunately, ‘Sapporo-ki’ lacked resistance against the disease. Thereupon, efforts were concentrated on developing F1 hybrid onion cultivars with resistance to Fusarium basal rot in Hokkaido (Kojima 2010).

Now, F1 cultivars characterized with hybrid vigor for various traits of economic importance as well as uniformity in agronomic characteristics, including maturity, and color, shape and size of bulbs are preferred (Khosa et al. 2016; Colombo & Galmarini 2017). Although bulb onion is considered an outcrossing crop, it is self-fertile (Currah & Ockendon 1978). The onion umbel consists of hundreds of small, perfect flowers, making emasculation impractical (Currah & Ockendon 1978). The production of hybrid onion seed became economically feasible with the discovery of cytoplasmic male sterility by Jones and Clarke (1943).

A Fusarium basal rot-resistant cultivar ‘Furanui’ was produced by crossing cytoplasmic male sterile line ‘W202A’ with a pollen parent line ‘F316’ originated from ‘Sapporo-ki’, and approved for release in 1979 (Komochi 2015). The line ‘W202A’, which exhibited resistance to the disease in question, was bred in the University of Wisconsin, USA (Komochi 2015). What is important, in this context, is that onion hybrid cultivars offer a great benefit to private seed companies, because the identity of the parental inbred lines utilized to develop the hybrid is protected. The hybrid cannot be reproduced without the original inbred parents. Nowadays, F1 hybrid cultivars developed by private seed companies occupy large onion-growing areas in Japan, though the accurate numerical data for acreage and production under hybrid bulb onions are not available (Komochi 2015).

Japanese cultivars

Bulb onion may be direct-seeded or transplanted. In Japan, bulb onion is commonly grown in nursery beds and 1- to 2-month-old seedlings are then transplanted into the production field, which ensures earlier maturity, higher yield, and better control of weeds.

The onion plant forms bulb in response to the amount of daylength in the region where it is being grown. Japanese bulb onion cultivars are typically classified into long-day (14 or more h long), short-day (11–12 h daylengths), and intermediate-day types (Kojima 2010).

For bulb production, long-day genotypes are mostly cultivated in a high-latitude region, Hokkaido (41°N – 46°N) where seeds are sown on the nursery beds from mid-February to early March, and the resultant seedlings usually become ready for transplanting to the ground in about 60 days after sowing. Harvesting takes place from early August to September. Most of the Hokkaido bulb onions are relatively pungent, with hard bulbs that store well.

On the other hand, the cultivars grown in low-latitude regions such as Saga (33°N – 34°N) and Hyogo (34°N – 36°N) are short-day or intermediate-day type. In these regions, seeds are generally sown during mid-September through early October, and the onion crop is harvested during late March through mid-June. Bulb onions from Saga and Hyogo are mainly marketed from April through August, whereas Hokkaido bulb onions are sold from late August to May of the following year. Although more than 100 bulb onion cultivars are available for cultivation in Japan, commercial onion production is currently dominated by a small number of cultivars. The agronomic characteristics of major bulb onion cultivars are given in Table 2. The average bulb weight indicated is from Nakayama (2009).

Table 2. List of representative bulb onion cultivars (yellow onions) grown in Japan

Cultivar	Agronomic characteristics
Long-day type	
'Kitamomiji 2000'	A high-yielding cultivar with high market acceptability. Bulbs are round in shape, firm, and store well. Resistant to Fusarium basal rot and mainly cultivated in Hokkaido.
'Okhotsk 222'	An early-maturing cultivar* that produces uniform globe-shaped bulbs with excellent keeping quality and good market acceptability. Bulbs are less pungent, and sweet in taste when cooked. Mainly cultivated in Hokkaido.
'Kitahayate 2 go'	Characterized by early maturity and high yield. Bulbs are less pungent and soft in texture upon cooking. Mainly cultivated in Hokkaido.
Short-day or intermediate-day type	
'Tarzan'	The cultivar forms globular bulbs (average bulb weight: ca. 250 g) with glossy, copper-colored skin. Resistant to bacterial soft rot and high in keeping quality.
'Momiji 3 go'	A late-maturing cultivar** producing somewhat oblong bulbs with good storage quality. Resistant to bacterial soft rot and mainly cultivated in Hyogo.
'Takanishiki'	A very early-maturing cultivar with good taste and high market acceptability. It forms slightly oval bulbs with glossy, dark yellow-colored skin. Mainly cultivated in Saga.
'Shippo wase 7 go'	Bulbs (average bulb weight: ca. 260 g) are slightly oblong in shape. An early-maturing and high-yielding genotype.
'Advance'	An early-maturing cultivar characterized by the bulbs that are large in size (average bulb weight: ca. 300 g) and somewhat oblong in shape. Mainly cultivated in Saga and unsuitable for long-term storage.

* In Hokkaido, harvesting of early-maturing cultivars generally takes place from early August to early September, while harvesting of late-maturing cultivars starts in mid-September

** In Saga and Hyogo, harvesting of early-maturing cultivars generally takes place from late March to mid-May, while bulbs of late-maturing cultivars are harvested from early June

Disease and pest problems

Bulb onion is subject to a wide range of diseases and pests in Japan. Among the diseases, downy mildew caused by the oomycete *Peronospora destructor* is of great concern. This soil-borne disease inflicts substantial damage when relatively cool moist weather prevails (Scholten et al. 2007). In 2016, severe epidemic of downy mildew occurred in Saga and Hyogo districts (Zen & Shobu 2017), which caused a reduction in bulb growth and quality, with yield losses of 20–40% being reported (Saga Prefecture 2019).

Several cultural and chemical methods are recommended for the control of downy mildew: soil solarization of the nursery beds as a means of reducing the population size of the pathogen in question; removal of all infected plants from the field; good soil drainage; and timely application of fungicides (e.g., at the first sign of the disease or when conditions become favorable for disease development) (Saga Prefecture 2019). Other bulb onion diseases include Fusarium basal rot, bacterial soft rot (caused by *Pectobacterium carotovorum*), gray-mold neck rot (caused by *Botrytis aclada*), gray mold (caused by *Botrytis cinerea*), onion rust (caused by *Puccinia allii*), and pink root rot (caused by *Pyrenochaeta terrestris*) (Kodama et al. 1976; Kodama & Saito 1981; Tanaka 1983; Akutsu 1995; Iketani-Saito et al. 2016). Potential diseases of concern during storage of onion bulbs are gray-mold neck rot and bacterial soft rot.

Onion thrips (*Thrips tabaci*) is a widespread pest of bulb onion in Japan. Thrips feeding impacts photosynthetic potential, resulting in bulb yield reduction (Hamasaki 1999). Other insect pests which may infest the bulb onion plants include onion fly (*Delia antiqua*) and *Liriomyza chinensis*. In recent years, the bulb onion fields attacked by *L. chinensis* have gradually increased in Hokkaido (Hokkaido Plant Protection Office 2019). This pest does damage to onion bulbs as well as leaves, which reduces the eventual marketable yield. Pesticide use is the primary method to control the pests in bulb onion, though the chemical control is, for most situations, neither economically sustainable nor environmentally suitable and leads to pesticide resistance (Hamasaki 1999).

Consumer concerns: food safety and quality

With regard to agricultural produce, Japanese consumers tend to be highly demanding, laying great emphasis upon its quality and safety. To meet such demands, major Japanese retailers are now focusing their attention on customer satisfaction as well as providing competitive price. In particular, retailers need significant effort to attract consumers by quality and safety assurance from on-farm production to consumption: the production and selling of safe food are essential for protecting consumers from the hazards such as microbial contamination and pesticide residues. Japanese supermarket chains are increasingly requiring their fresh-produce suppliers (including bulb onion growers) to provide evidence of compliance with on-farm food safety standards, known as Good Agricultural Practices (GAPs).

Global GAP is a pioneering private food safety standard established by a consortium of European retailers (Amekawa 2009; Tallontire et al. 2011). It sets stringent criteria for compliance with a set of control points relating to food safety, hygiene, labor conditions, animal welfare, and environmental management on the farmland (Amekawa 2009). Global GAP seeks to ensure transparency, accountability, and social trust by means of an elaborate traceability system and third-party certification (Amekawa 2009).

In Japan, a private voluntary standard named JGAP was developed in 2007 by the Japan GAP Foundation (a non-profit organization) with due regard to the specific features of Japan's agriculture, in terms of the scale of farming, environmental and legal issues, and institutions (Nabeshima et al. 2015; Japan GAP Foundation 2019). ASIAGAP was subsequently created based on the JGAP standard. This certification program was recognized to conform to the benchmarks of Global Food Safety Initiative (GFSI) and became GFSI approved in 2018 (Japan GAP Foundation 2019). As shown in Table 3, GAP-certified farms increased in number from 1,891 in 2013 to 4,845 in 2018. However, the dissemination of GAP approaches in Japan is still limited to a fraction of growers. Actually, only 2% of onion bulbs marketed had the GAP certification in 2018 (MAFF 2019b). The same holds true for other representative vegetables such as cabbage, lettuce, and tomato (MAFF 2019b).

One of the reasons having direct implication in the limited dissemination is that stringent compliance with GAP standards demands costly investments for growers. These investments relate to various inputs, including safer yet more costly pesticides, structures such as pesticide storage units and packhouse, and periodical certification and accreditation (Amekawa 2009). Another reason is that Japanese consumers generally regard domestically grown agricultural produce as safe and quality (Jonker 2000; Nabeshima et al. 2015). Hence, awareness of the significance of GAP approaches seemingly remains insufficient among growers in Japan. In addition, a lot of farmers think that GAP certification does not lead to an increase in their income (Japan Finance Corporation 2018), which may prevent the dissemination of GAP approaches. Meanwhile, an increase in the acquisition of GAP certification is important for strengthening the competitiveness of Japan's agriculture via the export expansion of Japanese agricultural produce (MAFF 2019c). Importers and retailers in overseas markets increasingly demand certification of compliance with Global GAP standard or an equivalent standard. Nevertheless, the amount of export of most vegetable crops harvested in the country still remains small; for instance, Japan exported 11,465 tons (only ca. 1% of national output) of bulb onion, primarily to South Korea and Taiwan in 2015 (Hakodate Customs 2016).

Table 3. Number of GAP-certified farms in Japan since 2013

	2013	2014	2015	2016	2017	2018
Global GAP-certified farms	142	251	309	386	480	632
ASIAGAP/JGAP-certified farms	1,749	1,817	2,529	3,954	4,113	4,213

Source: Sasaki (2018)

CONCLUDING REMARKS

Ever since bulb onion was domesticated, conventional breeding approaches have been used to improve productivity, bulb quality, and resistance against biotic and abiotic stresses (Khosa et al. 2016). Over the last three decades, a number of cultivars have been developed and released in Japan. However, there is still enough scope to increase the onion genotypes available commercially, viz., earlier maturing genotypes, genotypes with higher storability, better disease resistance, and milder flavor, genotypes suitable for direct sowing to achieve labor saving and cost reduction, genotypes containing higher amount of health benefit compounds, and so forth (Muro et al. 2015; Usuki et al. 2019; Ariyanti et al. 2018). Japanese breeders indeed developed two early maturing cultivars ('Shutaro' and 'Soujiro') for spring planting, of which the bulbs can be marketed in early August, the off-crop season of major onion-producing areas (Yanagida et al. 2012). Attempts have also been made to breed the genotypes for processing purpose (Muro et al. 2011).

In these breeding approaches, evaluation and identification of genetic variants of interest have exclusively relied upon phenotypic traits. Nevertheless, characterization based on phenotype is affected by environmental conditions (Chinnappareddy et al. 2013). Recent advances in genomics are providing breeders with new tools and methodologies that facilitate the direct study of the genotype and its relationship with the phenotype (Pérez-de-Castro et al. 2012; Khosa et al. 2016). Genomic approaches are of great use when dealing with complex traits such as bulb yield and quality, because these traits usually have a multi-genic nature and are vulnerable to environmental influence (Pérez-de-Castro et al. 2012).

The development of advanced genomic resources (e.g., molecular markers, mapping populations, and saturated linkage maps) has been hampered in bulb onion by its unusually large genome size (16.3 Gb per 1C nucleus: Arumuganathan & Earle 1991; Taylor et al. 2019), biennial life cycle, and outbreeding nature, compared to most other major crops (Baldwin et al. 2012; Khosa et al. 2016; Taylor et al. 2019). In bulb onion, molecular markers have been developed through restriction fragment length polymorphisms (RFLPs), amplified fragment length polymorphisms (AFLPs), simple sequence repeats (SSRs), and single nucleotide polymorphisms (SNPs) (van Heusden et al. 2000; Martin et al. 2005; Baldwin et al. 2012; Chinnappareddy et al. 2013; Havey & Ghavami 2018).

SNPs are particularly useful for marker-assisted selection (MAS) in bulb onion because of co-dominant inheritance, common occurrence among a wide range of germplasm (Duangjit et al. 2013; Havey & Ghavami 2018), and the suitability for automated genotyping assays. The use of high-throughput genotyping technologies and availability of doubled haploid lines have allowed SNPs to be readily identified in this crop (McCallum et al. 2008; Duangjit et al. 2013). Bulb onion SNPs were located on existing linkage maps (Duangjit et al. 2013).

MAS is an indirect process where selection is carried out on the basis of markers instead of the trait itself. Adoption of MAS approaches will enhance selection efficiency and shorten the breeding process. The successful application of MAS relies upon the tight association between the marker and the major gene or quantitative trait loci (QTL) responsible for the trait. Although different traits have been mapped on bulb onion genetic maps (Duangjit et al. 2013; Khosa et al. 2016), a large number of more tightly linked markers are still required to significantly improve MAS approaches.

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