Watermelon [*Citrullus lanatus* (Thunb.) Matsum. et Nakai] Cultivation in Japan: Current State, Problems and Prospects

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Summary

Watermelon is an ancient horticultural crop that is considered to have originated in northeastern or western Africa and has been cultivated for over 4000 years. This crop was introduced into Japan between the 16th and 17th centuries, and nowadays, it is almost exclusively used as fresh dessert fruit in the country. The fruit flesh of watermelon contains vital health-benefit compounds including lycopene, citrulline, arginine, and so forth. Despite having much value, watermelon cultivation has shown declining trends in the past several decades. Watermelon breeding in Japan has focused primarily on improving fruit quality traits such as sugar content, flesh texture and color, and rind color or pattern. Moreover, a recent trend has been to develop small-fruited cultivars with high market acceptability. In this paper, we review literature to provide an overview of commercial production, cultivation history, and farming practices of watermelon in Japan. The paper also describes the agronomic characteristics of representative cultivars.

Key words

breeding, commercial production, fruit quality, genomics, small-fruited cultivars

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Introduction

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. et Nakai] is one of the most popular and economically important horticultural crops worldwide. It belongs to the Cucurbitaceae family and is cultivated in temperate and tropical regions of the world (Levi et al., 2017). Total global production reached 100.4 million metric tons in 2019 (FAO, 2020). China is the largest producer with 60.7 million tons (60.4 % of the world production), followed by Turkey, India, Brazil, Algeria, Iran, Russia and the United States (FAO, 2020).

Watermelon cultivation has over 400 years of history in Japan (Hagiwara, 2000). Nowadays, watermelon is almost exclusively used as fresh dessert fruit in the country, though the crop is pickled in some areas (Hagiwara, 2000). Watermelon has gradually attracted the attention of Japanese consumers, because its flesh is known to contain several important health-related compounds including lycopene, citrulline, arginine, and glutathione (Reddy et al., 2015; Hashizume, 2019). More than 350 cultivars have been released in Japan after World War II, but there is an ongoing need to improve watermelon, particularly with respect to development of new cultivars with earlier maturity, higher fruit quality, and other characteristics that enhance acceptability by end users (Hagiwara, 2000; Tsubaki, 2019).

The objective of this paper is to review the information about the commercial production and cultivation history of Japanese watermelons as well as agronomic characteristics of representative cultivars. The expectation is that the synthesized information from this review will aid in understanding the problems and prospects of watermelon cultivation in Japan.

Origin and Dispersal into Japan

Until recently, watermelon was widely believed to have originated in southern Africa (Levi et al., 2013), but this was based on the erroneous synonymization of a wild South African *Citrullus* species with the cultivated dessert watermelon (Chomicki and Renner, 2015; Renner et al., 2017). The latest molecular-phylogenetic evidence seems to be in favor of northeastern or western Africa as the region of the crop's origin (Guo et al., 2013; Chomicki and Renner, 2015; Chomicki et al., 2020).

The earliest archaeological evidence of cultivated watermelon consists of seeds dated to ca. 5000 BP in Libya (Dane and Liu, 2007; Chomicki et al., 2020). In addition, ancient Egypt has long been recognized as an early site of watermelon cultivation (Paris, 2015; Sousa and Raizada, 2020). Watermelon may have entered the Iberian Peninsula around 512 AD (Reddy et al., 2015), but its spread to northern Europe was relatively slow due to the generally unfavorable growing climate (Dane and Liu, 2007). The crop was also brought to the New World in the 1500s (Dane and Liu, 2007; Nimmakayala et al., 2014). From Africa, watermelon was dispersed to India by at least 800 AD and to China by 1100 AD (Reddy et al., 2015).

From India and China, cultivation spread to Southeast Asia in the 15th century, and reached Japan between the 16th and 17th centuries (Hagiwara, 2000; Dane and Liu, 2007). In Japan, several local watermelon cultivars were already recognized by the early 1700s (Hagiwara, 2000). It is also worth mentioning that a painting of red-fleshed watermelons sold in slices appears on the 180-year-old wooden tablet of a Shinto Shrine located in Nara district of west central Japan (Hagiwara, 2000; Hashizume, 2019).

Commercial Production

In Japan, the average watermelon production per year during 2014-2019 was 336,000 tons which were harvested from approximately 10,300 ha (Table 1). The crop is grown throughout the country. Southern production areas (e.g., Kumamoto district, 32°N-33°N) begin shipping in early March and the harvest continues until October by moving to more northern areas (e.g., Hokkaido Island, 41°N-46°N). The current production is ca. 50 % of what it was in the 1980s, for example, watermelon was grown in 26,400 ha with a total yield of 680,000 tons in 1985 (Watanabe, 2013). Watermelon cultivation has been in decline throughout the country, though the total yield of this crop has remained fairly steady in the recent past (see Table 1).

One of the reasons why watermelon acreage has decreased is the demographic change in the major watermelon producing areas (Watanabe, 2013). The population in these areas has continued to decrease mainly due to the migration of young people to urban areas. The leftover workforce is aging, and thus there are not sufficient hands to work in the farm. The cultivation practices of watermelon, particularly vine-pruning, fruit-thinning, and harvesting are considered as labor-intensive, causing the farmers to reduce watermelon planting (Watanabe, 2013).

Another reason is the change in Japanese dietary habits. The appreciation of Japanese yen, as well as improvement in the liberalization of imports beginning in the 1970s, brought about a rapid increase of food imports. As for imports of fruit, banana has led the trade (ca. 1,045,000 tons in 2019), far ahead of pineapple (ca. 153,000 tons in 2019) in second position (MOF, 2020). Kiwifruit, oranges, avocado, and grapefruit represent other major import products (MOF, 2020). These imports are now marketed throughout the year and the variety of fruit is substantially increasing, which results in the decrease in the gross amount of consumption of watermelon (Watanabe, 2013). Meanwhile, watermelon production in Japan has traditionally centered around cultivation of large-fruit types. The decline in watermelon consumption is also considered to be attributed to an increase in smaller families and inconvenience with handling large-fruited watermelons.

Cultivation Practices

In Japan, watermelon is exclusively transplanted. Commercial watermelon seedlings are mostly grafted onto bottle gourd (*Lagenaria siceraria* Standley var. *hispida* Hara) rootstock, with the aim of improving tolerance to soil-borne diseases such as fusarium wilt (caused by *Fusarium oxysporum* f. sp. *niveum* (Fom)) and black root rot (caused by *Phomopsis sclerotioides* Kesteren) (Zaaroor et al., 2016; Devi et al., 2020). Grafted seedlings are then transplanted to either open-field or field in a plastic greenhouse. Transplants are generally cultivated on black polyethylene mulch. In addition to promoting earlier maturity, the use of black plastic mulch retains soil moisture and aids in weed control (Perković et al., 2018). Vine pruning is carried out when five to seven foliage leaves are expanded on the primary vine and four vigorous lateral vines are retained.

Table 1. Production and cultivation area of watermelon in Japan

	2014	2015	2016	2017	2018	2019
Cropping acreage (ha)	10,800	10,600	10,400	10,200	9,970	9,640
Total yield (t)	357,500	339,800	344,800	331,100	320,600	324,200

Source: MAFF (2020)

Watermelon produces imperfect female and male flowers on the same plant and requires insects for proper pollination and fruit growth (Boyhan et al., 2000). Hand pollination is recommended to ensure adequate fruit set. Fruit thinning should begin when fruits are approximately 3-4 cm in diameter, because this practice is expected to improve fruit size and quality by enhancing the partitioning of photoassimilates to the remaining fruit (Zaaroor-Presman et al., 2020). Watermelons are hand-harvested when fully ripe: the crop reaches harvest maturity five to seven weeks after pollination, depending upon cultivar and growing season.

Major Cultivars

Planned watermelon improvement by public research institutions began in the early 1900s in Japan (Hagiware, 2000). By the 1930s, the most successful open-pollinated cultivars were 'Yamato-suika' and its descendants 'Yamato 2', 'Yamato 3', and 'Yamato 4'. 'Yamato-suika' is thought to be a natural hybrid between 'Gonji-suika' and 'Ice Cream' (Hagiwara, 2000). 'Gonji-suika' was a landrace mainly grown in Nara district, whereas an ancient landrace 'Ice Cream' was introduced from the United States in 1901 (Hagiwara, 2000).

The cultivar 'Shin Yamato', with its striped rind and red flesh, was the first major F1 hybrid developed from a cross of 'Yamato 3' x 'Kanro (a US introduction)' in 1928 (Hagiwara, 2000). This F1 cultivar gained popularity as high-quality watermelon, and later became the progenitor of modern cultivars grown in the country. After World War II, much attention was drawn to the research reported by Kihara (1951) concerning a technique of creating triploid F1 hybrids that produced seedless fruit. However, seedless watermelons failed to achieve popularity in Japan, because of low fruit quality, poor seed germination, and relatively high production costs (Hagiwara, 2000). This contrasts with the situation in the United States where a great number of triploid seedless cultivars with high fruit quality have been produced and are now the primary type grown commercially (Levi et al., 2017). In Japan, commercial watermelon production has mostly used diploid F1 hybrid cultivars developed by private seed companies since the 1950s (Hagiwara, 2000). High fruit quality, high yield, early maturation, and long shelf life are the main objectives for today's watermelon breeding. F1 hybrids have advantages over open-pollinated cultivars in their uniformity in many important horticultural traits between plants. It should also be emphasized that the development of hybrid cultivars offers the protection of intellectual property for private seed companies (Gusmini and Wehner, 2005).

Watermelons vary in shape from round to oblong, depending on the cultivar. Flesh colors can be dark red, red, pink, orange or yellow. Watermelons have also a green rind, ranging from light to dark and from solid to striped. Although round-shaped watermelons with red flesh and striped green rind are most commonly marketed in Japan, cultivars having yellow flesh and/or solid dark green rind are gaining popularity to some extent. Table 2 shows the agronomic characteristics of representative cultivars currently grown in Japan.

Small-Fruited Cultivars

Most of the present-day Japanese cultivars produce fruits in the range of 5–10 kg (see Table 2). Besides whole watermelons, it is popular to sell watermelons in pre-cut halves, quarters, slices, and chunks in supermarkets throughout the country. An emerging trend has been to develop smaller-fruited cultivars with high market acceptability, because small fruit size is ideal for small families and for storage in home refrigerators (Risse et al., 1990; Tsubaki, 2019). Although small watermelon cultivars have been available for many years, their marketable yield and quality have not been as good as those of the large watermelon cultivars (Sugiyama et al., 2003). However, several small-fruited cultivars such as 'Himekansen' and 'Hitorijime' gain a good reputation for their fruit taste and appearance (Table 2). A newly released cultivar 'Pino Girl' is characterized by small fruit (1.8-2.0 kg), micro seeds (or edible seeds), and excellent eating quality: the flesh of its fruit is pinkish-red, sweet (sugar content is around 13 %), and very crisp, and the seed length is 5 mm or less (Okuno, 2019).

Concluding Remarks

Watermelon has been improved by domestication and various conventional breeding approaches from the wild plant with small fruits having hard, pale-colored flesh and bland or bitter taste, into the crop plant with large fruits having edible, sweet flesh and a thin rind (Wehner, 2008). Over the past few decades, watermelon breeding in Japan has focused primarily on fruit quality traits such as sugar content, flesh texture and color, and rind color or pattern (Hagiwara, 2000; Tsubaki, 2019). Most of the fruit quality traits are inherited in a complex manner and vulnerable to environmental influence (Mohr, 1986). Genomics approaches are particularly useful when dealing with such complex traits (Pérez-de-Castro et al., 2012). Moreover, we would like to add that watermelon cultivars are constantly being changed and market trends are also changing (Boyhan et al., 2000). In order to meet consumer requirements in coming years, there is a need to enhance watermelon breeding programs through the integrated use of genomic tools (Ren et al., 2014; Reddy et al., 2015; Subburaj et al., 2019).

The development of advanced genomic resources (e.g., large collections of molecular markers, mapping populations, and high-density linkage maps) allows the elucidation of the genetic architecture of economically important traits and the improvement of breeding efficiency via marker-assisted selection.

Table 2. List of representative watermelon cultivars currently grown in Japan

Cultivar	Agronomic characteristics	Reference
Large- or medium-fruited type		
Fujihikari	Round-shaped fruit (6-7 kg in weight) with medium-green rind and dark green stripes Flesh is bright red with a sweet flavor (sugar content is 12-13 %) and crisp texture.	Umemoto (1981)
Asahikari	It is adaptable to low temperature season and bears fruit well. Fruit is globular, weighing 4-7 kg. Scarlet red flesh is sweet, non-fibrous, and crisp. Rind is dark green with dark stripes; it is thin but tough, making the fruit withstand transportation.	Okada (1985)
Shimaou 3404	The cultivar bears fruit well, with high marketable yield. Globular fruit weighs between 6 and 7 kg. Flesh is pinkish-red and tastes nice; sugar content is around 11-12 %.	Tsubaki (1988)
Koudai	A cultivar producing somewhat oblong fruit (7-10 kg in weight) with good transportability and long shelf life. Flesh is bright pinkish-red, sweet and tastes delicious. Rind is deep green with broad dark green stripes.	Morimoto (1991)
Matsuribayashi	Good female-flower formation even under low temperature. Fruit is round, weighing 5-8 kg; its heart is scarcely hollow. Rind is dark green with dark stripes. Scarlet red flesh is sweet, firm, and crisp.	Okada (1997)
Ajikirara	Good pollen production and stable fruit set. Fruit is somewhat oblong in shape, 6-8 kg in weight, and has a deep green rind with wide stripes. Flesh is bright pinkish-red, sweet (sugar content is around 13 %), and the tastes is delicious.	Ohira (2003)
Harunodanran	Good pollen production and stable fruit set under low-temperature condition. Round-shaped fruit (6-8 kg in weight) with scarcely hollow heart. Pinkish-red flesh is firm, dense, crisp, and sweet (sugar content is around 13 %). This cultivar is suited to be sold as pre-cut watermelons.	Yoshimura (2006)
Kogane Special	Characterized by bright lemon-yellow flesh with sweet flavor, and firm and crisp texture. It is good to be sold as pre-cut watermelons. Fruit is globular and has hardly hollow heart; it weighs around 8-11 kg. Rind is dark green with fine stripes.	Uno (2019)
Small-fruited type		
Himekansen	Fruit is globular, weighing around 2-2.5 kg. Rind is dark green with wide stripes; it is thin but tough, enhancing fruit-cracking resistance. Flesh is bright red and crisp with excellent eating quality.	Miyata (2000)
Hitorijime	It bears fruit well. Fruit (1.5-2.5 kg in weight) is round with a dark green rind and sweet pinkish-red flesh. Its flesh quality is as high as that of large-sized watermelons. Rind is thin but tough, which makes the fruit a good shipper. This cultivar has less hollow heart.	Kawaguchi (2000)

Several genetic linkage maps have been constructed for watermelon using various molecular marker systems including randomly amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), simple sequence repeat (SSR), sequence tagged sites (STS), and single nucleotide polymorphism (SNP) (Hashizume et al., 2003; Levi et al., 2006; Ren et al., 2016; Cheng et al., 2016). Based on the next-generation sequencing technology, the genomes of many watermelons germplasm accessions have been successfully sequenced, thus facilitating the development of DNA markers, the construction of linkage maps, and the mapping of quantitative trait loci (QTLs) associated with horticultural traits (Subburaj et al., 2019). Actually, the major gene(s) or QTLs responsible for the traits such as sugar content, flesh color, and rind color and pattern were identified and mapped (Ren et al., 2014; Guo et al., 2019; Li et al., 2019; Subburaj et al., 2019).

Many years of selection for desirable fruit qualities resulted in a genetic bottleneck and a narrow genetic base among watermelon cultivars (Levi et al., 2001, 2013), hindering progress of watermelon breeding efforts. The molecular diversity of watermelon cultivars is reflected in the low number of SNPs between the US heirloom cultivar 'Charleston Gray' and the Chinese accession '97103', which show an average of 1 SNP every 1,430 bp (Guo et al., 2013; Reddy et al., 2015). It has been shown that the low genetic diversity in this crop can be averted with the use of wild or exotic genotypes (Levi et al., 2013; Zhang et al., 2016). For example, two wild relatives, *Citrullus amarus* Schrad. and *C. mucosospermus* (Fursa) Fursa are considered to be useful sources of genes that would confer resistance to major diseases including Fusarium wilt and Zucchini Yellow Mosaic Virus, though they do not have desirable fruit qualities (Levi et al., 2017). As it is well known, the fruit rind plays a vital role in fruit cracking and water loss, and thus has an impact on fruit transportability, storability and shelf-life quality (Sugiyama et al., 1999, 2003; Liao et al., 2020). Sugiyama (2001) reported that some wild watermelon accessions introduced from Africa and India had a harder rind when compared with Japanese cultivars, and such wild accessions might be valuable as breeding materials for cracking resistance. Further efforts are required to expand the collection of wild or exotic watermelon germplasm accessions and to evaluate the accessions via morphological, physiological, and molecular characterization.

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