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Comparison of quality characteristics of Japanese Tomato varieties

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Abstract
Tomato, the most consumed fruit worldwide, has several varieties. In Japan, Momotaro is the most commonly consumed fresh tomato variety. Although several tomato varieties have been developed in recent years, studies comparing these varieties based on their characteristics are limited. The aim of this study was to compare and evaluate the quality characteristics of five tomato varieties, namely, Hope, Reika, Saturn, Rinka 409, and Animo. Seven quality characteristics of the tomato varieties were evaluated using relevant parameters: sugar level determining sweetness (Brix); acidity (pH); vitamin C level reflecting the level of ascorbic acid; lycopene and β-carotene levels determining the color; glutamate level determining umami; and bacterial count. The Brix values were high in Reika and Saturn; lycopene, β-carotene, and ascorbic acid levels were high in Momotaro Hope; and glutamate level was high in Rinka 409, indicating that Reika and Saturn are superior in sweetness, Momotaro Hope in color, Rinka 409 in flavor. The results of this study will help clarify the characteristics of different tomato varieties and determine superior varieties of tomatoes, promoting their application in the food, agriculture, and allied industries.

Keywords: Tomato, umami, lycopene, β-carotene, glutamate, ascorbic acid

Introduction

Tomatoes (*Solanum lycopersicum* L.) are native to the highlands of northwestern South Africa. In 2019, the global production of tomatoes was 180 million tons [1]. Approximately 20% of the produce is processed to tomato soup, tomato juice, pizza sauce, tomato puree, canned whole tomatoes, and ketchup, whereas 80% is consumed raw [2]. Although Momotaro is the most common tomato variety in Japan, several other varieties have been developed in recent years.

Tomato quality is assessed by sweetness, acidity, umami, color, nutritional components, and general viable bacterial count. The color of tomatoes can be evaluated by measuring the lycopene and β-carotene levels (the orange and red pigments, respectively), whereas the sweetness and acidity can be evaluated by measuring the sugar level and acidic components, respectively. The balance between the sugar level and acidity determines the sweetness of fruits, including tomatoes [3].

Glutamate (Glu) is the main contributor to the umami flavor in tomatoes, influencing the eating quality of fruits [4]. Ascorbic acid (AsA), which easily oxidizes over time after harvest, can be used as a parameter for evaluating freshness in tomatoes [5]. Quantifying the general bacteria is crucial to evaluating the safety of tomatoes. The Ministry of Health, Labour and Welfare of Japan stipulates that the general bacterial count should be less than 1.0×10^6 CFU g^{-1} for vegetables and fruits to avoid the risk of food poisoning [6]. However, to the best of my knowledge, no previous study has compared these factors in different tomato varieties. The aim of this study was to investigate and compare the quality characteristics of different Japanese tomato varieties. Seven quality parameters of five tomato varieties were evaluated, namely, sugar level; acidity; vitamin C (AsA), lycopene, β-carotene, and Glu levels; and bacterial count. The results of this study could clarify the characteristics of different tomato varieties and help determine superior varieties of tomatoes. Thus, the findings could be applied in the food, agriculture, and allied industries.

Materials and Methods

Materials

The following five frozen tomato varieties were used in this study: Momotaro Hope (TAKII & CO., LTD., Kyoto, Japan), Reika (Sakata Seed Corporation, Kanagawa, Japan), Saturn (Sakata Seed Corporation), Rinka 409 (Sakata Seed Corporation), and Animo (Asahi AGRIA Co., Ltd., Tokyo, Japan and Musashino Seed Co., Ltd., Tokyo, Japan).

Measurement of sweetness

Tomato sweetness was assessed by measuring sugar level [7]. Approximately, 20 g of tomato was homogenized, and the filtrate was passed through circular Qualitative Filter Paper No. 1 (150 mm; ADVANTEC). Sugar level was measured using a sugar meter (Atago Co., Ltd., Tokyo, Japan).

Measurement of acidity

Acidity was measured as previously described [8, 9]. A total of 2.5 g of sample was dissolved in 10 ml of Milli-Q water, and the pH was measured using a pH meter (HORIBA, Ltd. Kyoto, Japan).

Measurement of color

Tomato color was assessed by measuring lycopene and beta-carotene levels [10]. From the prepared sample, 1.0 g was added to 10 ml of acetone/hexane solution (9:1) and allowed to stand at 25 °C for 15 min to extract the pigments. The extract was analyzed using a spectrophotometer (Shimadzu Corporation, Kyoto, Japan), and absorbance was used to calculate lycopene and β-carotene levels in tomato fruits using a previously reported formula [11].

Measurement of AsA level

Nutritional components of tomato were measured by AsA level [12]. AsA was extracted by placing 2.5 g of tissue from each tomato variety in 25 ml of 5% trichloroacetic acid and shaking the mixture vigorously. The mixture was centrifuged (11,509 × *g*, 5 min, 25 °C), and the supernatant was passed through a 0.2-µm filter. The filtrate was used as a sample.

High performance liquid chromatography (HPLC) analysis conditions were as follows: pump, LC-10AD (Shimadzu Corporation, Kyoto, Japan); column, COSMOSIL(R) 5C18-MS-II Packed Column 4.6 mm I.D. × 150 mm (NACALAI TESQUE, INC., Kyoto, Japan); mobile phase, 2% NaH_2PO_4 (pH 2.8); flow rate, 0.7 ml min^{-1}; temperature, 40 °C; detector, Shimadzu SPD-10A; wavelength, 250 nm.

Quantification of general viable bacteria

Microorganisms in tomato were measured by assessing general viable bacterial count [13]. A total of 2.5 g of tomato was finely chopped and placed in a 50-ml centrifuge tube. Sterile NaCl solution (0.9%; The Salt Industry Center of Japan) was added to adjust the final volume to 25 ml. The supernatant was diluted with 0.9% sterile NaCl solution, and 100 µl of the diluted sample was poured onto standard agar medium (5.0 g peptone, 2.5 g yeast extract, 1.0 g glucose, and 15 g agar 1.0 l^{-1} pure water; Eiken Chemical Co., Ltd., Tokyo, Japan) to determine the number of viable bacteria. The inoculated medium was incubated at 35 °C for 48 h.

Measurement of Glu level

Umami in tomato can be measured by glutamic acid level [14]. Glutamic acid from tomato was extracted by placing 2.5 g of tomato in a 15-ml centrifuge tube and adding 4 ml of 10% perchloric acid (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan). The solids were removed using centrifugation (11,000 × *g*, 10 min, 5 °C) (MX 201; Tomy Seiko Co., Ltd., Tokyo, Japan), and the supernatant volume was adjusted to 10 ml with 10% perchloric acid. Furthermore, 1 ml of this solution was neutralized with potassium hydroxide (Kanto Chemical Co., Inc., Tokyo, Japan). The precipitate was removed after centrifugation (12,000 × *g*, 5 min, 5 °C), and the volume of the supernatant was adjusted to 5 ml with purified water.

Glu in the sample solution was labeled by mixing 40 µl of the sample solution with 70 µl of ethanol, 20 µl of triethylamine (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan), and 20 µl of phenyl isothiocyanate (Kanto Chemical Co., Inc., Tokyo, Japan). The mixture was allowed to react at 25 °C for 30 min. Subsequently, 500 µl of acetate-sodium acetate (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan) buffer (50 mM, pH 6.0) and acetonitrile (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan) (97:3 v/v) were added to the sample mixture. The mixture was passed through a 0.22-µm filter, and Glu level was measured using HPLC. The HPLC column (Cosmosil Packed Column 5C18-MS-II, 4.6 mm I.D. × 150 mm) was injected with 20 µl of the sample at 1.0 ml min^{-1} flow rate. The HPLC detection parameters were as follows: wavelength, 254 nm; temperature, 40 °C. The mobile phase conditions were as follows: eluent A was composed of 50 mm acetate-sodium acetate buffer (pH 6.0):acetonitrile (97:3); eluent B was composed of acetonitrile: water (6:4); gradient: eluent B was increased from 5 to 100% from 0 to 16 min, decreased from 100 to 5% for the next 4 min, and was kept steady for another 5 min. Glutamic acid level was calculated using the standard curve of glutamic acid (Fujifilm Wako Pure Chemical Corporation, Osaka, Japan).

Statistical analysis

Data were obtained based on Fisher's three principles with nine replicates of the same sample. Tomatoes are considered to be prone to type 1 errors because of large individual differences. Therefore, Bonferroni correction was used in this study to avoid type 1 errors. Bonferroni correction was used for 10 repetitions of the *t*-test, with a significance level of 0.5% to correct the risk rate according to the number of comparisons (0.05/test). The *t*-test was performed using Microsoft Excel.

Results and Discussion

Table 1 lists the measurements of the quality endpoints for each tomato plant. In terms of acidity, the pH of Momotaro Hope, Rinka 409, Reika, Saturn, and Animo was 4.4, 4.4, 4.3, 4.6, and 4.3, respectively, with Saturn showing high values compared to Momotaro Hope, Reika, and Animo ($p > 0.005$). Saturn also showed slightly higher values than Rinka 409 ($p > 0.005$). The pH of Reika was lower than that of Momotaro Hope, Rinka 409, and Saturn ($p > 0.005$) and similar to that of Animo ($p > 0.005$). The order of sugar level among the varieties was as follows: Saturn (7.8.%) > Reika (7.3%) > Momotaro Hope (6.4%) > Rinka 409 (5.%) > Animo (5.0%) ($p < 0.005$). The order of lycopene level among the varieties was as follows: Momotaro Hope (1.2 mg 100 g^{-1}) > Reika (0.95 mg 100 g^{-1}) > Saturn (0.93 mg 100 g^{-1}) > Rinka 409 (0.69 mg 100 g^{-1}) > Animo (0.22 mg 100 g^{-1}). Animo showed values lower than those of all the other cultivars examined ($p < 0.005$). The order of β-carotene level among the varieties was as follows: Rinka 409 (0.59 mg 100 g^{-1}) > Momotaro Hope (0.54 mg 100 g^{-1}) > Saturn (0.51 mg 100 g^{-1}) > Reika (0.43 mg 100 g^{-1}) > Animo (0.20 mg 100 g^{-1}) ($p > 0.005$). The order of AsA level among the varieties was as follows: Momotaro Hope (15 mg 100 g^{-1}) > in Reika (11 mg 100 g^{-1}) > Rinka 409 (9.4 mg 100 g^{-1}) > Saturn (9.2 mg 100 g^{-1}) > Animo (5.8 mg 100 g^{-1}). Momotaro Hope showed values higher than those of all the other cultivars studied ($p < 0.005$). The order of Glu level among the varieties was as follows: Rinka 409 (4.4 mg g^{-1}) > Reika (3.7 mg g^{-1}) > Saturn (3.7 mg g^{-1}) > Animo (2.0 mg g^{-1}) > Momotaro Hope (1.5 mg g^{-1}) ($p > 0.005$). The order of bacterial count among the varieties was as follows: Saturn (2.0×10^3 CFU g^{-1}) > Animo (1.2×10^3 CFU g^{-1}) > in Momotaro Hope (1.2×10^2 CFU g^{-1}) > Reika (1.1×10^2 CFU g^{-1}) > Rinka 409 (5.8×10 CFU g^{-1}) ($p > 0.005$).

The acidity (pH) of the tested tomatoes ranged from 4.3 to 4.6. The pH values of cherry tomatoes and Italian acid tomatoes are 4.59-4.65 [15] and 4.23-4.36, respectively [16]. All varieties examined in this study showed similar values, and no varietal differences were observed.

The Brix values of the tomatoes tested in this study ranged from 5.0 to 7.8%. The Brix values of several Japanese and Italian tomato varieties have been reported to be 6-8% [17] and 6.4-7.6% [16], respectively. All varieties examined in this study showed similar values, except Animo, which had a low Brix value of 5.0%; mini tomatoes have Brix values of 4-12% [18].

In this study, the lycopene and β-carotene levels across all varieties ranged from 0.22 to 1.2 and 0.20 to 0.59 mg 100 g^{-1}, respectively. Their levels in Hungarian tomatoes are 5.2-8.5 and 0.28 0.62 mg 100 g^{-1}, respectively [19]. The lycopene and β-carotene levels in tomatoes in the present study were lower than these values. Momotaro Hope had higher lycopene and β-carotene levels than the other varieties. The lycopene level in Momotaro was lower than that in a previous study (2.0-3.0 mg 100 g^{-1}) [20]. The lycopene level in tomatoes decreases during frozen storage [21, 22], and the use of frozen tomatoes in this study may have resulted in lower lycopene levels. Additionally, in House Momotaro; a variety close to Momotaro Hope, the lycopene level is 1.05 mg 100 g^{-1} in fall crops and 4.36 mg 100 g^{-1} in spring crops the lycopene level varies with the season [14]. Therefore, the harvest time may have influenced the results of this study. The β-carotene level in House Momotaro is 0.75-1.09 mg 100 g^{-1} [14], which is higher than the levels recorded in this study. The β-carotene level decreases over time due to freezing [21]. Hence, the level of β-carotene may have decreased in this study due to freezing. Although fading of pigmentation due to freezing was observed, Momotaro Hope still had superior color among all varieties examined in this study.

The AsA level in this study was 5.8-15 mg 100 g^{-1}, as shown in Table 1. The AsA level in Japanese, Indian, and Hungarian tomatoes is 8.4-32.7 [23], 16.4-22.41 [24], and 15-21 mg 100 g^{-1} [19], respectively. The AsA level increases until ripeness and decreases after ripening [8] and during frozen storage [21]. Overall, the tomatoes examined in this study showed a relatively low AsA level, which may be due to freezing. In this study, the AsA and lycopene levels were significantly low in Animo compared with those in the other varieties. As tomatoes turn red only on ripening and do not change color after ripening [25], the low levels of lycopene, β-carotene, and AsA indicate that the tomatoes were harvested before ripening.

In this study, the Glu level was 1.5-4.4 mg g^{-1}. The Glu level in different tomato varieties is as follows: 3.2 mg g^{-1} in Momotaro, 2.5 mg g^{-1} in Tokimeki No. 2 [10], and 4.0 mg 100 g^{-1} in German tomatoes [26]. Although the Glu level increases during maturation [10], no change in Glu level was observed when the tomatoes were retained on the vine after ripening [27]. In this study, low Glu levels were recorded in Animo and Momotaro Hope. This may have been due to the harvesting of Animo during the maturation process and that of Momotaro Hope after maturity, based on the color and AsA level.

In this study, the overall microbial count was 10^2 CFU g^{-1}. The microbial count in Brazilian tomatoes stored at 22 °C for 16 days was reportedly < 1.5×10^3 CFU g^{-1} up to day 12 [28], which is similar to the values recorded in this study.

Although, the quality of several tomato varieties were compared this study, they were all Japanese varieties. Hence, the values obtained in this study could be treated as reference values, which are highly dependent on the growth conditions and environment. Further studies are required to elucidate the effects of various environmental factors on these parameters.

In this study, the quality of five tomato varieties was compared. The Brix values were high in Reika and Saturn; lycopene, β-carotene, and AsA levels were high in Momotaro Hope; and Glu level was high in Rinka 409, indicating that Reika and Saturn are superior in sweetness, Momotaro Hope is superior in color, and Rinka 409 is superior in flavor. Although Momotaro is the main edible variety currently distributed in Japan, other varieties are also edible, as there is no significant difference in quality between Momotaro and other varieties. However, as the sugar level varies considerably among the varieties, the sweeter varieties can be consumed raw, whereas the less sweet ones can be used for cooking, thus broadening their application. Since Rinka 409, Reika, Saturn and Animo varieties still have a limited cultivation in Japan and its procurement is challenging, it is difficult to increase the sample size of these varieties. Moreover, the cultivation method also influences the quality of the sample to some extent.

Table 1: Measurement of quality assessment parameters of each tomato variety

	Acidity (pH)	Sugar level (Brix %)	Lycopene (mg 100 g^{-1})	β-Carotene (mg 100 g^{-1})	Ascorbic acid (mg 100 g^{-1})	Glutamic acid (mg g^{-1})	Number of viable bacteria (CFU g^{-1})
Momotaro Hope	4.4 (0.041)	6.4* (0.045)	1.2 (0.38)	0.54 (0.18)	15* (0.85)	1.5 (0.26)	1.2×10^2 (0.96)
Rinka 409	4.4 (0.051)	5.7* (0.055)	0.69 (0.17)	0.59 (0.14)	9.4 (1.1)	4.4 (0.35)	5.8×10 (0.50)
Reika	4.3 (0.016)	7.3* (0.045)	0.95 (0.27)	0.43 (0.27)	11 (0.67)	3.7 (0.54)	1.1×10^2 (0.50)
Saturn	4.6	7.8*	0.93	0.51	9.2	3.7	2.0×10^3

	(0.14)	(0.071)	(0.13)	(0.14)	(0.63)	(0.078)	(0.96)
Animo	4.3 (0.047)	5.0* (0.084)	0.22* (0.075)	0.20 (0.020)	5.8 (0.52)	2.0 (0.21)	1.2×10^3 (0.82)

n = 9. The numbers in parentheses indicate standard deviation. *Significant difference compared to all varieties evaluated ($p < 0.005$)

Conclusion

The varieties of tomatoes differ in their quality characteristics, which makes some varieties superior to others. In this study, the quality characteristics of various tomato varieties were compared, which can aid in producing superior processed tomato products and can aid the food and agriculture industries. Although Momotaro is the main edible variety currently distributed in Japan, the other varieties hold equal promise for consumption, owing to a minimal difference in their quality characteristics.

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