Quality Evaluation of Strawberries Grown in Various Regions by Singaporeans and Japanese

Atsushi Ikegaya\textsuperscript{a,b,c}, Seiji Ohba\textsuperscript{b}, Tomoyasu Toyoizumi\textsuperscript{b}, and Eiko Arai\textsuperscript{c,d}

\textsuperscript{a}Department of Agricultural Production, Shizuoka Professional University Junior College of Agriculture, Iwata, Japan; \textsuperscript{b}Shizuoka Prefectural Research Institute of Agriculture and Forestry, Iwata, Japan; \textsuperscript{c}Graduate School of Integrated Pharmaceutical and Nutritional Sciences, University of Shizuoka, Yada, Japan; \textsuperscript{d}School of Food and Nutritional Sciences, University of Shizuoka, Yada, Japan

ABSTRACT
The objective of this study was to evaluate the quality of strawberries distributed in global markets. We obtained strawberries from Egypt, Mexico, the Republic of Korea, Spain, and the United States of America (US) being sold in Singapore, and compared them with Japanese strawberries (cv. Benihoppe) using instrumental analysis and sensory evaluation. Sensory evaluation was conducted by Singaporean and Japanese assessors. The results showed that the quality of strawberries in Mexico, Spain, and Egypt were relatively close, but the others were significantly different. The strawberries from the US and Japan had high total soluble solids (TSS) content, while those from Egypt, Mexico, Spain, and the US were firmer and had higher titratable acidity (TA). In the sensory evaluation, the assessors preferred strawberries with high total soluble solids (TSS) and low titratable acidity (TA). These findings suggest that varieties with high TSS and low TA are desirable for the global market. In addition, compared with the Japanese assessors, the Singaporean assessors tended to prefer strawberries with lower TA. These preferences may change depending on the eating habits of the region.

KEYWORDS
Instrumental analysis; palatability; sensory evaluation; strawberry; taste

Introduction

The strawberry (\textit{Fragaria × ananassa} Duchesne) is one of the world’s most popular fruits. Most of the strawberries currently cultivated are the descendants of Dutch strawberries crossbred on Dutch farms in the eighteenth century (Darrow, 1966). However, the cultivars, cultivation methods, distribution systems, and consumption trends vary greatly by region (Angelini, 2010). Therefore, the quality of fresh strawberries is expected to vary greatly depending on the production area.

Strawberries have an extremely thin fruit skin and soft flesh; thus, their shelf life is around 7 days, even when stored at a typical storage temperature of about 5°C (Ayala-Zavala et al., 2004). Consequently, fresh strawberries have conventionally been consumed in regions relatively close to the area of production. Research on strawberries has been conducted in countries with high production, which import relatively small quantities of strawberries. Therefore, to our knowledge, no studies have compared the quality of strawberries produced in different regions at the same time. However, improvements in agricultural distribution technology have extended the shelf life of fresh strawberries, increasing global exports (Ikegaya et al., 2020).

Various studies have been conducted on the export of strawberries, mainly focusing on shock during transportation (Kitazawa et al., 2010) from temperature, humidity, and packaging (Hikawa-
Endo and Sone, 2017), as well as pest control that complies with the pesticide regulations of the import nations (Ministry of Agriculture, Forestry and Fisheries Japan, 2015). However, the taste and palatability of exported strawberries have not been studied. Under these circumstances, expanding the export market requires knowledge of strawberries distributed around the world and customer preferences.

Singapore is a country with a low food self-sufficiency rate that imports food from many different countries. Therefore, we obtained fresh strawberries from the market in Singapore to survey the quality of strawberries from as many different countries as possible. The quality of the strawberries was evaluated by instrumental analysis and sensory evaluation. We also transported major brands of Japanese strawberries to Singapore for quality comparisons because we were interested in whether ordinary consumers could distinguish slight differences in the quality of strawberries from the same country.

Based on the results of the instrumental analyses and sensory evaluations of these two sets of strawberries, we evaluated what kinds of strawberries are preferred by customers, mainly in terms of taste.

**Materials and Methods**

**Procurement of Strawberries Distributed in the Singapore Market**

Five different brands of strawberries were purchased from the market in Singapore on February 7, 2017 (Figure 1). The strawberries were from Egypt (Cairo 3A, New Cairo, Egypt), Mexico (Driscoll Strawberry Associates, Inc., Watsonville, CA), the Republic of Korea (ROK; producer unknown as this information was not provided on the packaging), Spain (Onubafruit, Huelva, Spain), and the United States of America (US; Orange County Produce, LLC, Irvine, CA). No information regarding the cultivars was included on any of the packaging labels. Following purchase, the strawberries were stored in a refrigerator at 4°C at the Mitsui Chemicals Singapore R&D Center (R&D Center). The instrumental analyses and sensory evaluations were conducted the following day (February 8, 2017).

**Transport of Japanese Strawberries**

Five brands of Japanese strawberries, Amaoh (Japan Agricultural Cooperatives [JA] Fukuoka-Yame, Yame, Fukuoka, Japan), Benihoppe (JA Shimizu, Shizuoka, Japan), Hinoshizuku (JA Kamoto, Yamaga, Kumamoto, Japan), Kirapika (JA Shimizu), and Tochiotome (JA Oyama, Oyama, Tochigi,

| Country of origin | Egypt | Mexico | Republic of Korea | Spain | United States of America |
|-------------------|-------|--------|--------------------|-------|--------------------------|
| Packaging         | ![Egypt image] | ![Mexico image] | ![Republic of Korea image] | ![Spain image] | ![United States of America image] |

| Appearance       | ![Egypt image] | ![Mexico image] | ![Republic of Korea image] | ![Spain image] | ![United States of America image] |

| Purchase site  | Supermarket | Department store | Retail market | Department store | Department store |
|----------------|-------------|-----------------|--------------|-----------------|-----------------|
| Weight per pack (g) | 350 | 454 | 350 | 350 | 454 |
| Price (Singapore dollars/kg) | 7.0 | 63.9 | 22.0 | 19.7 | 32.8 |

**Figure 1.** Strawberries distributed in Singapore.
Japan) were shipped from each production area in Japan on February 5, 2017, and arrived at Shizuoka Airport the next morning (Figure 2). The strawberries were loaded onto an air-shipping container and transported from Shizuoka to Changi Airport via Naha Airport, where they arrived on the morning of February 7. The strawberries were transported in a refrigerated truck to the R&D Center and stored at 4°C. The strawberries were handled the same way as other regular export cargo without any special treatment. The quality analysis and sensory evaluations were conducted the following day (February 8, 2017).

**Instrumental Analyses**

The strawberries purchased from the Singapore market and transported from Japan were returned to room temperature (25°C) and weighed, and the color of the fruit skin at the center of the surface of the fruit was measured using a colorimeter (CR-13; Konica Minolta Japan, Inc., Tokyo, Japan). The colors were expressed using the L*a*b* color system formulated by the International Commission on Illumination (CIE 1976, CIELAB). The firmness of the fruit skin at the center of each surface was measured using a fruit firmness meter (KM-1; Fujiwara Factory, Tokyo, Japan) equipped with a conical plunger 1 cm in diameter. Color and firmness were measured for 10 strawberries from each variety. The measurement was performed three times for each fruit, and the average value was used.

Next, the calyxes were removed from all strawberries, which were then individually wrapped in gauze and subsequently processed in a juicer (Hand Juicer; Ito Seisakusho Co. Ltd., Mie, Japan). The total soluble solids (TSS) content and titratable acidity (TA) in the resulting juice were measured using a Brix-Acidity Meter (PAL-BX ACID F5; Atago Co. Ltd., Tokyo, Japan). TSS/TA ratios were calculated by dividing the value of TSS by that of TA.

**Sensory Evaluations**

**Evaluation of Strawberries Distributed in the Singapore Market (Sensory Evaluation A)**

Sensory evaluation A was conducted with 14 assessors (seven Singaporeans and seven Japanese). All Japanese assessors were expatriate employees of a Japanese-affiliated company who had been living in Singapore for less than 5 years. The assessors (9 females, 5 males) ranged in age from 24 to 49 years (2 in their 20s, 5 in their 30s, and 7 in their 40s). None of the assessors had any specialized training in food assessment. The assessors evaluated the strawberries from Egypt, Mexico, the ROK, Spain, and the US purchased from the market in Singapore. The ‘Benihoppe’ variety produced in Japan was added as a control. This variety is produced in large quantities and cultivated throughout Japan. Therefore, this variety was considered easy to compare.

The strawberries were lightly rinsed in water. After the calyxes were removed, the strawberries were cut radially from the peduncle to the apex so that each slice weighed 10 g (Ikegaya et al., 2019).
In the sensory evaluation, ‘sweetness intensity,’ ‘sourness intensity,’ and ‘overall preference’ were evaluated based on a previously described scoring method (Meilgaard et al., 2007; Sato, 1985). For ‘sweetness intensity’ and ‘sourness intensity,’ the contrast was set as 0 (same as Benihoppe), and the intensities were evaluated on a 7-point scale, from −3 (absolutely no sweetness/sourness) to +3 (extremely sweet/sour). For ‘overall preference,’ the contrast was set as 0 (same as Benihoppe), and the intensities were evaluated on a 7-point scale from −3 (highly undesirable) to +3 (highly desirable). The assessors rinsed their mouths with mineral water between samples, and no instruction was provided in regard to the order in which to eat them. Each sample was coded with three random digits. No additional information about the strawberries was given to the assessor.

**Evaluation of Strawberries Transported from Japan (Sensory Evaluation B)**

Sensory evaluation B was conducted on the four strawberry varieties transported from Japan (Amaoh, Hinishizuku, Kirapika, and Tochiotome) as described above. Benihoppe was also used as a control for these varieties. The sensory evaluation method was the same as that used for sensory evaluation A.

**Statistical Analyses**

Each value is expressed as the mean ± standard deviation. The results were evaluated using analysis of variance, and the means were compared using Tukey’s multiple range test. An unpaired t-test was used to investigate differences in the sensory evaluations of the Singaporean and Japanese assessors. Spearman’s rank correlation coefficient was used to investigate the correlation between the results of the sensory evaluations and instrumental analyses. Principal component analysis (PCA) was performed to interpret the results of the instrumental analysis. All statistical analyses were performed using SPSS 14.0 for Windows (SPSS Japan Inc., Tokyo, Japan).

**Results**

**Quality of Strawberries Distributed in the Singapore Market**

The results of the instrumental analyses for the strawberries purchased from the Singapore market and the Japanese Benihoppe are shown in Table 1. The strawberries from the US were markedly heavier than the other strawberries (55 g vs. 25–35 g, respectively). The strawberries from Egypt, Mexico, Spain, and the US were firm. The Japanese Benihoppe variety used as a comparison was soft, and the strawberries from the ROK were even softer.

In terms of the color index, the peduncle region was slightly white in the strawberries from Egypt and the US (Figure 1). However, no major difference was seen in the intermediate portion between the peduncle and apex in either type of strawberry. The strawberries from Egypt had a slightly brighter color than those from the US, which resulted in a tendency of higher L* and lower a* values; however, these differences were not significant. The strawberries from the ROK displayed a high b* value, whereas this value was low for those from Mexico and the US. The flesh of the strawberries from the ROK was slightly orange-tinged, while the fruit skin of those from Mexico and the US was tinged blue.

The juice analysis revealed high TSS in the juice made from strawberries from the US and Japan, and low TSS in the strawberries from Egypt, Mexico, and Spain. Strawberries from the US and Mexico had the highest TA, followed by those from Egypt and Spain, whereas strawberries from Japan and the ROK had lower TA. The strawberries from the US had high TSS, but also high TA, so the TSS/TA ratio was low. Strawberries from the ROK and Japan had high TSS, whereas the other strawberries had a significantly lower TA, resulting in a higher TSS/TA ratio.

PCA was performed on the data obtained by the instrumental analysis. The first two principal components (PC1 and PC2) explained 90.8% of the total variance (Figure 3a). The strawberries from the ROK appear on the far right, while those from the US and Japan with high TSS appear in higher
Table 1. Results of the instrumental analyses of strawberries purchased from markets in Singapore.

| Country of origin             | Weight (g) | Firmness (N) | L*           | a*    | b*           | TSS (Brix%) | TA (%) | TSS/TA ratio |
|-------------------------------|------------|--------------|--------------|-------|--------------|-------------|--------|--------------|
| Egypt                         | 30.1 ± 9.8 | b c 5.4 ± 0.4 | 38.6 ± 5.8   | a 35.4 | 5.8 b 4.0    | 7.5 ± 0.6   | c 1.18 | ± 0.10 b 6.4 | ± 0.6 b |
| Mexico                        | 34.7 ± 5.1 | b 5.3 ± 0.4 a 34.5 | ± 2.1 ab 40.0 | ± 3.0 ab 18.7 | ± 3.2 b 7.7 | ± 0.3 c 1.33 | ± 0.16 ab 5.8 | ± 0.6 b |
| Republic of Korea             | 25.0 ± 3.8 | c 3.6 ± 0.4 c 36.8 | ± 1.9 a 42.4 | ± 3.0 ab 26.0 | ± 3.8 a 8.3 | ± 0.8 ab 0.54 | ± 0.10 c 15.9 | ± 3.7 a |
| Spain                         | 28.8 ± 7.4 | b c 5.7 ± 0.4 | 36.3 ± 2.0 a 40.7 | ± 2.9 ab 22.6 | ± 3.8 ab 7.7 | ± 0.8 bc 1.14 | ± 0.15 b 6.8 | ± 0.8 b |
| United State of America       | 54.7 ± 11.9 | a 5.7 ± 0.4 a 31.9 | ± 3.1 b 39.2 | ± 4.6 ab 16.7 | ± 5.8 b 9.3 | ± 0.5 a 1.39 | ± 0.20 a 6.8 | ± 0.7 b |
| Japan, Benihoppe (control)    | 35.1 ± 5.2 | b 4.7 ± 0.4 b 32.2 | ± 1.6 b 43.2 | ± 2.7 a 20.5 | ± 2.9 ab 8.9 | ± 0.6 a 0.70 | ± 0.09 c 13.0 | ± 2.1 a |

Data are expressed as mean ± standard deviation (n = 10). Mean values of each column with different letters are significantly different based on Tukey’s multiple range test (p<0.05). TSS: total soluble solids; TA: titratable acidity.
positions. Figure 3b shows a plot of the PC1 of the strawberries by TA, TSS/TA ratio, and firmness. PC2 separated the strawberries by TSS (Figure 3b).

**Quality of Strawberries Transported from Japan**

The results of the instrumental analyses of the strawberries transported from Japan are shown in Table 2. Hinoshizuku were smaller, with no difference in size among the remaining brands. Benihoppe displayed the highest firmness, while Amaoh displayed the lowest. In terms of color index, the L* value was high in Hinoshizuku and low in Amaoh. The a* value was lower in Amaoh than in the other varieties. The b* value was high in Hinoshizuku and low in Amaoh, which was likely because Hinoshizuku has a bright, slightly orange-tinged color, while Amaoh has a slightly purplish tinge. No difference in TSS was found between brands. Amaoh and Benihoppe displayed high TA, and Kirapika and Tochiotome displayed low TA. Kirapika and Tochiotome displayed higher TSS/TA ratios, which was a reverse trend to that of TA.

PCA was also performed on these data. PC1 and PC2 explained 80.5% of the total variance (Figure 4a). PC1 separated the strawberries by TA, the TSS/TA ratio, and the color index (Figure 4b). PC2 separated the strawberries by TSS, firmness, and weight (Figure 4b). Strawberries with high TSS appear in higher positions. Benihoppe and Tochiotome had similar PC1 and PC2 values (Figure 4a).

**Sensory Evaluation A**

The results of the sensory evaluations of strawberries purchased from the Singapore market are shown in Table 3. Different tendencies were observed in the results between the Singaporeans and Japanese. Therefore, we analyzed the evaluations separately as well as overall. For both the Singaporean and Japanese assessors, sweetness intensity was ranked lower for the strawberries from Egypt and higher for those from the ROK. No difference in the evaluations of sourness intensity were found between the Singaporean and Japanese assessors. In terms of overall preference, the Singaporean assessors ranked strawberries from the ROK higher and from Egypt lower. However, even the strawberries from the ROK had a score of – 0.1. In addition, a significant difference was observed between the Singaporean and Japanese assessors for the sweetness intensity of the strawberries from Egypt and Spain, and the overall preference for strawberries from Egypt.
Table 2. Results of the instrumental analyses of strawberries from Japan.

| Variety       | Weight (g) | Firmness (N) | L*     | a*     | b*     | TSS (Brix%) | TA (%) | TSS/TA ratio |
|---------------|------------|--------------|--------|--------|--------|-------------|--------|--------------|
| Amaoh         | 33.7 ± 2.5 | a 2.93 ± 0.28 d | 28.7 ± 4.8 b | 37.5 ± 3.8 b | 14.7 ± 3.0 b | 9.4 ± 0.4 b | 0.80 ± 0.10 a | 11.9 ± 1.6 b |
| Hinoshizuku   | 23.1 ± 1.7 | b 3.64 ± 0.24 c | 34.1 ± 2.1 a | 43.5 ± 2.9 a | 25.3 ± 4.6 a | 9.3 ± 0.6 a | 14.6 ± 0.05 b | 14.6 ± 1.5 b |
| Kirapika      | 30.8 ± 2.5 | a 3.78 ± 0.18 b c | 32.6 ± 3.2 ab | 44.4 ± 2.7 a | 18.9 ± 2.4 b | 8.9 ± 0.6 a | 17.7 ± 2.2 a | 17.7 ± 2.2 a |
| Tochiotome    | 35.3 ± 3.2 | a 3.97 ± 0.32 b | 29.9 ± 3.8 ab | 41.9 ± 3.3 ab | 16.8 ± 4.5 ab | 8.8 ± 0.5 b | 14.7 ± 1.5 ab | 14.7 ± 1.5 ab |
| Benihoppe (control) | 35.1 ± 5.2 | a 4.69 ± 0.39 a | 32.2 ± 1.6 ab | 43.2 ± 2.7 a | 20.5 ± 2.9 ab | 8.9 ± 0.6 b | 13.0 ± 2.1 b | 13.0 ± 2.1 b |

Data are expressed as mean ± standard deviation (n = 10). Mean values of each column with different letters are significantly different based on Tukey’s multiple range test (p<0.05). TSS: total soluble solids; TA: titratable acidity.
Figure 4. Data scores(a) and variable loading (b) plots on the plane made up of the first two principle components (PC1 against PC2) by strawberries transported from Japan.

Table 3. Results of the sensory evaluations of strawberries purchased from markets in Singapore (Sensory evaluation A).

| Assessor | Country of origin | Sweetness intensity | Sourness intensity | Overall preference |
|----------|-------------------|---------------------|--------------------|--------------------|
| Total    | Egypt             | -2.1 ± 0.9 b        | -0.4 ± 1.8        | -1.9 ± 0.9 b       |
|          | Mexico            | -0.7 ± 1.4 ab       | -0.3 ± 1.4        | -0.8 ± 1.3 ab      |
|          | Republic of Korea | 0.6 ± 1.5 a         | -0.7 ± 1.1        | -0.1 ± 1.5 a       |
|          | Spain             | -0.7 ± 1.7 ab       | 0.0 ± 1.5         | -0.9 ± 1.3 ab      |
|          | United State of America | -0.5 ± 1.4 a | -0.4 ± 1.6        | -0.7 ± 1.4 ab      |
| Singaporean | Egypt         | -2.6 ± 0.5 b'       | -0.4 ± 2.3        | -2.4 ± 0.5 b'      |
|          | Mexico           | -0.4 ± 1.7 ab'      | 0.1 ± 1.7         | -0.6 ± 1.6 ab'     |
|          | Republic of Korea| 0.9 ± 1.6 a'        | -0.7 ± 1.1        | -0.1 ± 1.6 a'      |
|          | Spain            | 0.3 ± 1.8 a'        | 0.1 ± 1.6         | -1.1 ± 1.6 ab'     |
|          | United State of America | -0.3 ± 1.6 ab' | -0.6 ± 1.5        | -0.4 ± 1.5 ab'     |
| Japanese | Egypt            | -1.6 ± 1.0 b'       | -0.3 ± 1.4        | -1.3 ± 1.0         |
|          | Mexico           | -1.0 ± 1.2 ab'      | -0.7 ± 1.1        | -1.0 ± 1.0         |
|          | Republic of Korea| 0.4 ± 1.5 a'        | -0.7 ± 1.1        | 0.0 ± 1.6          |
|          | Spain            | -1.7 ± 0.8 b'       | -0.1 ± 1.5        | -0.7 ± 1.0         |
|          | United State of America | -0.7 ± 1.3 ab | -0.3 ± 1.7        | -1.0 ± 1.3         |

Each item was evaluated from -3 to +3 with Japanese Benihoppe as the control (0). Data are expressed as mean ± standard deviation (n = 14). Mean values of each column with different letters are significantly different based on Tukey’s multiple range test (p<0.05). * indicates a significant difference at the 5% level using an unpaired t-test.

Table 4. Results of the sensory evaluations of strawberries from Japan (Sensory evaluation B).

| Assessor | Variety | Sweetness intensity | Sourness intensity | Overall preference |
|----------|---------|---------------------|--------------------|--------------------|
| Total    | Amaoh   | 0.1 ± 1.2 ab        | 0.1 ± 0.9 a        | -0.2 ± 1.2 b       |
|          | Hinoshizuku | -0.3 ± 1.1 b      | -0.5 ± 0.8 ab      | -0.3 ± 1.1 b       |
|          | Kirapika | 1.3 ± 0.8 a        | -1.3 ± 0.9 b       | 1.0 ± 1.0 a        |
|          | Tochiotome | 0.1 ± 1.5 ab      | -0.5 ± 1.1 ab      | 0.1 ± 1.3 ab       |
| Singaporean | Amaoh   | 0.3 ± 1.4          | 0.6 ± 0.5 a        | -0.1 ± 1.3 ab      |
|          | Hinoshizuku | -0.1 ± 1.3        | -0.4 ± 1.0 ab      | -0.4 ± 1.1 b       |
|          | Kirapika | 1.6 ± 0.5          | -1.6 ± 1.1 b       | 1.4 ± 0.8 a        |
|          | Tochiotome | 0.3 ± 1.8          | -0.6 ± 1.4 ab      | 0.1 ± 1.6 ab       |
| Japanese | Amaoh   | 0.0 ± 1.2 b        | -0.4 ± 1.0         | -0.3 ± 1.1         |
|          | Hinoshizuku | -0.4 ± 0.8 ab     | -0.6 ± 0.5         | -0.1 ± 1.1         |
|          | Kirapika | 1.0 ± 1.0 a        | -1.0 ± 0.6         | 0.6 ± 1.0          |
|          | Tochiotome | 0.0 ± 1.2 ab      | -0.4 ± 0.8         | 0.0 ± 1.2          |

Each item was evaluated from -3 to +3 with Japanese Benihoppe as the control (0). Data are expressed as mean ± standard deviation. Total: (n = 14); Singaporean and Japanese: (n = 7). Mean values of each column with different letters are significantly different based on Tukey’s multiple range test (p<0.05).
**Sensory Evaluation B**

The results of the sensory evaluations of strawberries transported from Japan are shown in Table 4. These results were also analyzed separately for Singaporean and Japanese in addition to overall. The Singaporean assessors rated Kirapika higher and Hinoshizuku lower in terms of overall preference, and Amaoh higher and Kirapika lower for sourness intensity, whereas the Japanese assessors reported no brand-based differences. The Singaporean assessors reported no differences in sweetness intensity; however, the Japanese assessors ranked Kirapika higher and Amaoh lower.

**Relationship between Sweetness Intensity, Soursness Intensity, and Overall Preference by Sensory Evaluations**

The relationships between sweetness intensity, sourness intensity, and overall preference by sensory evaluations are shown in Table 5. A high correlation was observed between sweetness intensity and overall preference for both the Singaporean and Japanese assessors.

**Relationship between the Instrumental Analyses and Sensory Evaluations**

The results of the instrumental analyses and sensory evaluations regarding the comparison of strawberries purchased from the Singapore market are shown in Table 6. TSS content and the TSS/TA ratio were generally higher for strawberries transported from Japan compared to those distributed in Singapore.

### Table 5. Correlation coefficients between sweetness intensity and sourness intensity, and overall preference by sensory evaluation.

| Sample | Assessor | Sweetness intensity vs. Overall preference | Sourness intensity vs. Overall preference |
|--------|----------|------------------------------------------|------------------------------------------|
| Strawberries distributed in Singapore (Sensory evaluation A) | Total | 0.665 *** | 0.075 |
| | Singaporean | 0.643 *** | 0.102 |
| | Japanese | 0.758 *** | 0.044 |
| Strawberries transported from Japan (Sensory evaluation B) | Total | 0.819 *** | -0.176 |
| | Singaporean | 0.831 *** | -0.246 |
| | Japanese | 0.782 *** | -0.057 |

Correlations between the sweetness and sourness intensities and overall preferences were obtained by Spearman’s rank correlation coefficient. For sensory evaluation A, Total: (n = 70, 14 assessors x 5 samples); Singaporean and Japanese: (n = 35, 7 assessors x 5 samples). For sensory evaluation B, total: (n = 56, 14 assessors x 5 samples); Singaporean and Japanese: (n = 28, 7 assessors x 4 samples). *** indicates a significant correlation at p < 0.001.

### Table 6. Correlation coefficients between the instrument analyses and sensory evaluations of strawberries from markets in Singapore.

| Assessor | Item       | Overall preference | Sweetness intensity | Sourness intensity |
|----------|------------|-------------------|--------------------|-------------------|
| Total    | Firmness   | 0.002             | -0.045             | 0.173             |
|          | TSS        | 0.363 **          | 0.459 ***          | 0.005             |
|          | TA         | -0.052            | -0.136             | 0.055             |
|          | TSS/TA ratio | 0.255 *           | 0.377 **           | -0.001            |
| Singaporean | Firmness  | 0.042             | 0.070              | 0.157             |
|           | TSS        | 0.492 **          | 0.488 **           | -0.034            |
|           | TA         | 0.057             | -0.190             | 0.064             |
|           | TSS/TA ratio | 0.220             | 0.448 **           | -0.065            |
| Japanese | Firmness   | -0.054            | -0.175             | 0.203             |
|           | TSS        | 0.260             | 0.417 *            | 0.026             |
|           | TA         | -0.125            | -0.058             | 0.057             |
|           | TSS/TA ratio | 0.341 *           | 0.290              | 0.059             |

Correlations between the sensory evaluations and instrumental analyses were obtained by Spearman’s rank correlation coefficient. Total: (n = 70, 14 assessors x 5 samples); Singaporean and Japanese: (n = 35, 7 assessors x 5 samples). *, **, and *** indicate significant correlations at p<0.05, p<0.01, and p<0.001, respectively. TSS: total soluble solid; TA: titratable acidity.
TA ratio were found to be positively correlated with overall preference, as well as with sweetness intensity. Regarding the overall preference, a correlation was found with TSS for Singaporean and the TSS/TA ratio for Japanese assessors.

Data regarding the correlations between the instrumental analyses and sensory evaluations of the strawberries transported from Japan are shown in Table 7. A positive correlation was found between overall preference and the TSS/TA ratio, and a negative correlation was seen with TA. The TSS/TA ratio was also found to be positively correlated with sweetness intensity. Furthermore, sourness intensity was positively correlated with TSS and TA, and negatively correlated with the TSS/TA ratio. However, substantial differences were observed between Singaporeans and Japanese in regard to these results, and the evaluation results for the Japanese were not correlated in all instrumental analyses.

**Discussion**

We purchased strawberries produced in Egypt, Mexico, the ROK, Spain, and the US from the market in Singapore. There were significant differences in appearance, quality, and price. The results of the instrumental analyses indicated that the strawberries from Egypt, Mexico, Spain, and the US were firm. They also had superior shelf stability, but their TSS/TA ratios were low, indicating that these strawberries have strong sourness. The TSS/TA ratio can be used to evaluate the sweetness of sour fruits such as citrus and strawberries (Fawole and Opara, 2013; Ikegaya et al., 2019; Qiu et al., 2015; Zhou et al., 2018). The strawberries from the US had a low TSS/TA ratio, but high TSS and TA, which suggests that these strawberries have a rich taste. Strawberries from the ROK had very low TA and high TSS. In terms of quality, the results of the PCA suggested that the strawberries from Mexico, Spain, and Egypt were relatively similar, but that of strawberries from the other countries was significantly different (Figure 3a). The strawberries purchased from the Singapore market provided no additional information on their packaging other than country of origin, which made it impossible to identify the cultivar. However, as no other studies have been carried out on the quality of strawberries produced in different countries at the same time, this study should serve as a reference example.

For strawberries transported from Japan, no differences in TSS were found, and the differences in firmness and TA were minor compared with the differences in quality when compared with the overseas strawberries. These findings suggest that in Japan, where the volume of strawberries produced is high, consumers eat strawberries with almost the same level of quality, even if the cultivar and production region differ. By contrast, in countries with a large import volume, consumers are accustomed to eating strawberries with a diverse range of quality.

### Table 7. Correlation coefficients between the instrumental analyses and sensory evaluations of strawberries from Japan.

| Assessor      | Item        | Overall preference | Sweetness intensity | Sourness intensity |
|---------------|-------------|--------------------|---------------------|--------------------|
| Total         | Firmness    | 0.249              | 0.177               | -0.161             |
|               | TSS         | -0.125             | -0.063              | 0.345 *            |
|               | TA          | -0.295 *           | -0.263              | 0.500 ***          |
|               | TSS/TA ratio| 0.419 **           | 0.376 **            | -0.317 *           |
| Singaporean   | Firmness    | 0.256              | 0.184               | -0.311             |
|               | TSS         | -0.154             | -0.072              | 0.463 *            |
|               | TA          | -0.372             | -0.266              | 0.627 **           |
|               | TSS/TA ratio| 0.475 *            | 0.378 *             | -0.476 *           |
| Japanese      | Firmness    | 0.250              | 0.176               | 0.042              |
|               | TSS         | -0.091             | -0.046              | 0.206              |
|               | TA          | -0.217             | -0.246              | 0.352              |
|               | TSS/TA ratio| 0.377              | 0.051               | -0.104             |

Correlations between the sensory evaluations and instrumental analyses were obtained by Spearman’s rank correlation coefficient. Total: (n = 56, 14 assessors × 5 samples); Singaporean and Japanese: (n = 28, 7 assessors × 4 samples).*, **, and *** indicate significant correlations at p<0.05, p<0.01, and p<0.001, respectively. TSS: total soluble solid; TA: titratable acidity.
The sensory evaluation indicated that the strawberries from the ROK and Egypt were the most and least preferred overall, respectively. The assessors rated the strawberries from the ROK at about the same level as the control strawberries (Benihoppe) from Japan (Table 3).

Regarding the comparison of the Japanese strawberries, the assessors ranked Kirapika and Hinoshizuku as the sweetest and least sweet, respectively (Table 4). No difference in TSS was seen in any of the strawberries. When sugar and organic acids are mixed, sweetness is reduced (Green et al., 2010). Therefore, the difference in sweetness intensity was thought to have been due to differences in TA and the TSS/TA ratio. In the sourness intensity evaluation, the assessors rated Amaoh and Kirapika as the most and least sour, respectively; this was consistent with the TA results shown in Table 2.

We also investigated what kinds of strawberries tended to be preferred based on the results of the sensory evaluations. The correlations between overall preference and sweetness and sourness intensities were calculated (Table 5). The results revealed a strong correlation between overall preference and sweetness intensity by both the Singaporean and Japanese assessors, indicating a preference for highly sweet strawberries. No correlation with sourness intensity was observed in either group, which suggests the presence of individual differences.

Sensory evaluations require the cooperation of a large number of assessors. Since this test was conducted overseas, it was particularly difficult to obtain the cooperation of assessors. In addition, storage adversely affects the quality of fresh strawberries. As a result, sensory evaluations were associated with additional difficulties and could not be conducted on several different occasions. Therefore, future quality evaluations should be carried out using instrumental analysis. To do this, it is essential to analyze the relationship between the results of instrumental analyses and sensory evaluations.

The relationship between instrumental analyses and sensory evaluations has been extensively studied for a number of foods and drinks (Liu et al., 2015; Sherman et al., 2018; Souflieres et al., 2001). However, few reports are available on fresh fruits (Gunness et al., 2009; Saftner et al., 2008). As the quality of individual fruits differ, it is difficult to obtain consistent results (Gunness et al., 2009). Therefore, a high correlation could not be obtained in this study. Nevertheless, both TSS and the TSS/TA ratio were found to be positively correlated with an overall preference for overseas strawberries (Table 6). The relationship between the results of instrumental analyses and sensory evaluations of strawberries has been investigated (Gunness et al., 2009; Rosenfeld and Ness, 2000; Sone et al., 2000), and fruit with high TSS and a high TSS/TA ratio were found to be evaluated highly in terms of taste (Gunness et al., 2009; Sone et al., 2000); those findings are consistent with the results of the present study.

The correlation data between the instrumental analysis and sensory evaluation of strawberries from Japan (sensory evaluation B) showed a different tendency from sensory evaluation A (Table 7). As no difference in TSS was found between the samples, a positive correlation was seen between overall preference and the TSS/TA ratio, and a negative correlation was observed with TA.

These results indicate that TSS is the most important item in assessing strawberry palatability by instrumental analysis. Furthermore, TA may be important if there is no significant difference in TSS.

In addition, novel observations were made by analyzing the results by the nationality of the assessors (Singaporeans vs. Japanese). For sensory evaluation B, a correlation was observed between overall preferences and the TSS/TA ratio in the evaluations by the Singaporean assessors (Table 7). The TSS/TA ratio was also correlated with sweetness intensity. In addition, a positive correlation was seen between sourness intensity, and a negative correlation between sourness intensity and the TSS/TA ratio. Moreover, there tended to be a negative correlation between TA and overall preference, although this difference was not significant. On the other hand, no correlation was found in terms of the Japanese assessors. These findings suggest that Singaporeans are more sensitive to sourness than are Japanese. Bitterness and sourness suggest the presence of poisons and that the food may be unripe or rotten. Thus, living beings, including humans, tend to avoid these tastes (Chandrashekar et al., 2006). Sensitivity to bitterness is thought to change because of genetic and dietary factors (Horio, 2009), but few reports have been published on such changes in
regard to sourness sensitivity. Preferences are established by training the palate through the repeated consumption of foods with characteristic tastes (Yamaguchi, 2009). Japan produces and consumes large volumes of strawberries, so Japanese people repeatedly consume fresh strawberries. No statistics are available on the consumption of fruits in Singapore, so we referenced the statistics for Malaysia, a neighboring country. The results showed that the types of fruit with consumption exceeding 1 kg/year per person were (from highest to lowest): coconuts, bananas, pineapples, durian, watermelon, guava, sweet corn, mango, jackfruit, papaya, mangosteen, and rambutan (Department of Statistics Malaysia, 2018). None of these fruits are highly sour, which suggests that there is little experience eating sour fruit in Southeast Asia. Therefore, we considered that people in this region have a strong sensitivity to sourness because they have less opportunity to eat fruits with a strong sour flavor. Based on this finding, fruit palatability may differ depending on ethnicity and region. However, in this survey, the number of assessors was kept small to investigate differences in preference between Singaporean and Japanese assessors. Since fresh fruits of the same quality were not available, it was difficult to conduct follow-up. Nevertheless, we hope to evaluate this issue through further research in the future.

In this study, we found that strawberries distributed around the world vary in quality, and that consumers prefer strawberries with high TSS and low TA. Therefore, producing strawberries with these characteristics is desirable to increase their competitiveness in the global market.

Acknowledgments

We express our sincere gratitude to Fumiaki Yano, Yohei Mochizuki, and Ayako Watanabe of JA Shizuoka Keizairen Co., Ltd., and to Reiko Nishime of Mitsui Chemicals Singapore R&D Center, Hirokazu Ikenaga of Mitsui Chemicals, Inc., and Rieko Yoshizumi and Shinjiro Nagakura of the Shizuoka Prefectural Government for their considerable efforts in this research.

Disclosure Statement

The authors declare no conflict of interest or relationships, financial or otherwise.

Ethical Approval

All procedures performed in this study were carried out in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Institutional Review Board of Shizuoka Prefectural Research Institute of Agriculture and Forestry.

Informed Consent

Informed consent was obtained from all individual participants in this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

ORCID

Atsushi Ikekaya  http://orcid.org/0000-0001-7617-5630
Tomoyasu Toyoizumi  http://orcid.org/0000-0003-0127-1382
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