Technical paper

Elasticity Index, Quality and Shelf-life of 16 Tree-ripe Mango Cultivars

Masahiko FUMURO^{1*}, Takaaki MAEDA² and Naoki SAKURAI³

¹Experimental Farm, Kindai University, Yuasa, Wakayama 643-0004, Japan

²Department of Environmental and Horticultural Science, Minami Kyushu University, Miyakonojo, Miyazaki 885-0035, Japan

³Graduate School of Biosphere Science, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-0046, Japan

Received April 12, 2018 ; Accepted June 11, 2018

Elasticity index (EI), quality during storage, and shelf-life (SL) were assessed in 16 cultivars of tree-ripe mango fruit. All fruits were individually wrapped in polyethylene film and stored for 10 days at 25 °C. EI rapidly declined over the first 2 days of storage regardless of the cultivar, after which the decline was more gradual. EI reduction rate (EIRR) from day 2 to day 10 of storage was lowest (7 % and 9 %) in ‘Irwin’ and ‘Glenn’, followed by ‘Khiao Sawoei’. After 10 days, the EI for these cultivars was $57\text{--}79 \times 10^5 f_2^2 \cdot m^{2/3}$ (f_2 , second resonance frequency; m , fresh weight of a fruit). In contrast, EIRRs for ‘Dot’ and ‘Valencia Pride’ cultivars were 66 % and 59 %, respectively, and that of ‘Amataiko’ was 48 %; EI after 10 days of storage for these cultivars was $23\text{--}30 \times 10^5 f_2^2 \cdot m^{2/3}$. EIRRs of the other 10 cultivars were between 23 % and 41 %. Weight loss after 10 days of storage was highest in ‘Dot’ and ‘Amataiko’ (4.6 % and 3.6 %), but lower in the other cultivars (1.4 % to 2.4 %). The degree of water-soaked symptoms (WSS, translucent flesh tissue) was greatest in ‘Alphonso’, followed by ‘Valencia Pride’, ‘Dot’, ‘Spirit of ‘76’, ‘Nam Doc Mai’, ‘Golden Lippens’, and ‘Aikou’. In contrast, no WSS were observed in ‘Irwin’, while ‘Beni Keitt’, ‘Edward’ and ‘Glenn’ showed few symptoms, and ‘Amataiko’ showed slightly more WSS. SL score of each fruit was calculated by adding the score obtained by EI (0 to 3) to a score based on the degree of WSS after 10 days of storage (also 0 to 3). SLs (SL of more than 10 days under room temperature can be estimated) were good for ‘Irwin’, ‘Glenn’, ‘Edward’, and ‘Khiao Sawoei’; moderate (SL of 8–10 days) for ‘Beni Keitt’, ‘Sensation’, ‘Florigon’, and ‘Tommy Atkins’; poor (SL of 4–5 days) for ‘Amataiko’, ‘Aikou’, ‘Nam Doc Mai’, ‘Golden Lippens’, and ‘Spirit of ‘76’; and very poor (SL of 2–3 days) for ‘Alphonso’, ‘Valencia Pride’, and ‘Dot’. These results clearly revealed cultivar differences in EIRRs, WSS and SLs of ripe mangoes, and suggested the possibility of estimating SL based on EI and the degree of WSS after storage.

Keywords: flesh firmness, *Mangifera indica* L., polyethylene film, second resonance frequency, water-soaked symptoms

Introduction

In Japan, the total area dedicated to mango growth was 430 ha and the total production was 3,805 t in 2015; these values have decreased after peaking in 2011 (Ministry of Agriculture, Forestry and Fisheries, 2018). The early-maturing ‘Irwin’ mango cultivar accounts for more than 95 % of mango production. ‘Keitt’, an intermediate/late-maturing cultivar, is grown in a smaller area. In addition, cultivation of ‘Lippens’

and ‘Valencia Pride’ has been encouraged to complement the production of ‘Irwin’ and ‘Keitt’ during the off-season in Okinawa Prefecture, which is the leading domestic production region (i). The import of foreign mangoes is increasing, but these are mainly processed goods; in contrast, the consumption of domestic mango is decreasing. The development and introduction of new cultivars of mango with characteristics that appeal to consumers might help reverse this decline in

*To whom correspondence should be addressed.

E-mail: fumuro@nara.kindai.ac.jp

consumption.

Important mango fruit characteristics include eating quality as well as shelf-life (SL). Some mangoes are imported at the fully ripe stage, but most imported mangoes are harvested at the mature-green stage, then transported to Japan and sold with hard flesh. These fruits ripen and are consumed at home; thus, the SL is not so critical. However, domestic mangoes are harvested after reaching edible maturity while they are still on the tree (i.e., the flesh is already in a moderately soft state, and delicious without further ripening); they are then shipped and sold. Because they are already in an advanced state of ripening, the SL of domestic fruits is very short compared to imported mangoes.

'Irwin' is favored by consumers in Japan because of its bright red peel, soft fleshy texture, and sweet scent; and it is also preferred by farmers and distributors because of its high productivity and excellent SL. It is considered the best cultivar for fully ripe mango production. The SL is specific to each mango cultivar, so any new mango that is introduced must have a good SL.

An SL of approximately 10 days is necessary for mango fruits because 2–3 days are necessary for distribution from the farm to the retail stores *via* the markets, and at least 7 days are necessary to sell the product to reduce the disposal loss for the retail stores as much as possible. Therefore, a fully ripe mango cultivar with a minimum 10 days of SL is desired.

When evaluating the SL of ripe mango fruits, it is necessary to evaluate external quality changes comprehensively, such as peel color, occurrence of darkening, wrinkles, and loss of luster, and internal quality changes, such as softening, water-soaked symptoms (WSS, translucent flesh tissue) and darkening of flesh, including decay and the occurrence of physiological disorders. However, softening and WSS of flesh change during storage. For Japanese consumers, the occurrence of WSS greatly diminishes the commercial value, as they tend to focus on the vividness of the flesh. Therefore, since flesh firmness and the degree of WSS were considered to be the most important evaluation criteria related to internal quality, these two criteria were used to evaluate the SL of ripe fruit.

To date, few studies have explored cultivar differences in SL among fully ripe mangoes, and no evaluation standard for SL has been developed. Investigation of changes in the firmness of flesh after fruit has been harvested is important for assessing SL (Taniwaki *et al.*, 2010). However, conventional destructive methods make it impossible to assess the firmness of the same fruit continuously during storage and ripening, and require a large number of fruits for measurements.

Recently, a nondestructive resonance method was developed allowing follow-up measurements to be made with high accuracy even in a small number of fruits (Taniwaki and Sakurai, 2010). This new technique has been used to investigate the ripening of various fruits including pears (Murayama *et al.*, 2006; Terasaki *et al.*, 2006), kiwifruits

(Muramatsu *et al.*, 1997, 1999; Terasaki *et al.*, 2001), apples (Muramatsu *et al.*, 1999), persimmons (Muramatsu *et al.*, 1999; Taniwaki *et al.*, 2009), nectarines (Muramatsu *et al.*, 1996), pitayas (Fumuro *et al.*, 2013), and mangoes (Fumuro and Sakurai, 2014; Fumuro *et al.*, 2015).

When the vibrations reach the fruit, resonances occur at specific frequencies within the fruit, and the second resonance frequency (SRF) is closely related to flesh firmness (Taniwaki and Sakurai, 2010). However, because SRF declines as fruit weight increases, the elasticity index (EI), which is calculated using fruit weight and SRF and minimizes the effect of fruit weight, is used as an indicator of flesh firmness (Cooke, 1972; Terasaki *et al.*, 2001). In addition, positive correlations between the EI, as determined by nondestructive resonance vibrations, and flesh firmness, as determined by destructive methods, were reported for several fruits, such as pears (Murayama *et al.*, 2006), apples (Motomura *et al.*, 2004), kiwifruits (Muramatsu *et al.*, 1999; Terasaki *et al.*, 2001), and mangoes (Fumuro and Sakurai, 2014; Fumuro *et al.*, 2015).

In many mango cultivars, WSS can develop during extended storage as the flesh softens, adversely affecting taste and darkening the flesh. WSS are considered to be an aging phenomenon of flesh. WSS in mango fruit are similar in appearance to watercore in Japanese pear and apple. The physiological, environmental, and cultivation factors affecting watercore in Japanese pear and apple have been studied in detail (Yamada, 2002). However, few studies have explored the susceptibility of different mango cultivars to the development of WSS during SL.

In the present study, 16 cultivars of tree-ripe mango fruit were used to investigate the estimation of SL of ripe fruit using two criteria, EI and WSS, by means of nondestructive evaluation of changes in flesh firmness during storage and measurement of fruit quality after storage.

Materials and Methods

Cultivars and production method From 2007 to 2013, several mango (*Mangifera indica* L.) cultivars were planted in containers (32 cm in diameter, 35 cm in height, 25 L in volume; or 55 cm in diameter, 35 cm in height, 75 L in volume) filled with a soil mix (perlite:vermiculite:peat moss mixed at 1:1:1) and placed in a greenhouse (7 m × 24 m, 168 m²) and three plastic houses (6 m × 18 m, 108 m²; 6 m × 24 m, 144 m²; and 6 m × 21 m, 126 m²) located at Kindai University experimental farm (Wakayama Prefecture, Japan).

In 2015, the following 16 cultivars were used in this study: 'Irwin', 'Glenn', 'Tommy Atkins', 'Edward', 'Aikou', 'Florigon', 'Alphonso', 'Khieo Sawoei', 'Spirit of '76', 'Amataiko', 'Dot', 'Nam Doc Mai', 'Golden Lippens', 'Sensation', 'Valencia Pride', and 'Beni Keitt'. Two of the 16 cultivars were bred at Kindai University; 'Aikou' was bred by crossing 'Irwin' with 'Chiin Hwang No. 1' (Kindai University, 2008), and 'Amataiko' was selected from 'Edward' seedlings

Table 1. Planting years, harvest times and average fruit weights in 16 tree-ripe mango cultivars.

Cultivar	Planting year	Harvest time	Average fruit weight (g)
Irwin	2009	Aug. 3–4	390.3 ± 47.0 ^z
Glenn	2007	Aug. 5–8	528.8 ± 96.9
Tommy Atkins	2007	Aug. 19–25	561.9 ± 36.0
Edward	2007	Aug. 21–26	703.5 ± 134.1
Aikou	2009	Aug. 23–24	608.4 ± 49.3
Florigon	2007	Aug. 23–30	439.4 ± 92.3
Alphonso	2007	Aug. 24–29	388.2 ± 52.2
Khieo Sawoei	2007	Aug. 26–Sep. 1	406.1 ± 45.3
Spirit of '76	2009	Aug. 27–29	527.0 ± 94.2
Amataiko	2013	Aug. 30–Sep. 6	801.9 ± 80.7
Dot	2007	Aug. 31–Sep. 6	480.8 ± 103.4
Nam Doc Mai	2007	Sep. 11–21	338.2 ± 31.5
Golden Lippens	2007	Sep. 3–23	574.6 ± 127.8
Sensation	2007	Sep. 7–15	578.9 ± 97.3
Valencia Pride	2007	Sep. 12–22	625.3 ± 160.6
Beni Keitt	2009	Sep. 18–Nov. 30	1247.7 ± 340.2

^zAverage ± standard deviation.

(Fumuro, 2016). 'Amataiko' trees were between 3 and 6 years old; 'Irwin' and 'Aikou' trees were 8 years old; the other cultivars were 10 years old. Rootstock of all cultivars was from a Taiwanese strain.

The greenhouse and plastic houses were heated from 5 December, 2014, to a minimum temperature of 6 °C. This minimum temperature was gradually increased from 20 February, 2015, maintained at 18–20 °C from the middle of March until the middle of April during the flowering period, and thereafter ventilated by a fan to keep the internal air temperature below 35 °C. Both side windows were kept open from June until October, and the plants were irrigated daily by automatic irrigation. Slow-release fertilizer (N:P₂O₅:K = 10:10:10%) was applied in February, March, April, May, June, July, September, and November, and the annual quantities of nitrogen, phosphoric acid, and potassium supplied were approximately 15 kg per 1,000 m² of cultivation area. Disease (anthracnose, canker, gray mold, etc.) and pest (thrips species, aphids, spider mites, etc.) controls were carried out approximately 14 times a year. In late July, all fruits were covered with bag-shaped nets to prevent them from falling to the ground. Pruning began when harvest was almost complete and ended in late September.

Harvesting procedure Fully tree-ripe fruits were harvested as follows. Because fruits of 'Irwin', 'Glenn', 'Tommy Atkins', 'Edward', 'Aikou', 'Spirit of '76', and 'Amataiko' naturally drop after reaching edible maturity on the tree, these were collected immediately after fruits dropped into the nets. In contrast, 'Beni Keitt' fruits do not drop, even when overripe on the tree. Furthermore, the fruits of other cultivars naturally

drop when they reach edible maturity on the tree, but are usually overripe when they drop. Therefore, the fruits of these remaining nine cultivars were assessed in terms of edible maturity based on peel color and firmness. Specifically, mango fruits were considered tree-ripe when the entire peel color changed to the cultivar-specific bright color from a dark tone tinged with ash purple or gray-brown, and when tapping the fruit yielded a low, dull sound rather than a high, sharp sound.

Ten fruits from each cultivar were harvested on two to four separate occasions, and tested under the storage conditions described below. The harvest times and average weights in grams (± standard deviation) of each cultivar of fruit, starting with those harvested earliest, are shown in Table 1.

Storage condition The mango harvesting season in Japan is usually between May and August; therefore, the storage temperature for the SL test was set at 25 °C, which is in line with the room temperature in air-conditioned spaces. The storage period was set at 10 days.

To minimize weight loss and flesh softening, immediately after harvest, fruits were individually wrapped with polyethylene film (30 cm width, 11 µm thickness; Ube Film Co., Ltd., Sanyo-Onoda, Japan) (Fumuro and Sakurai, 2014), with a water vapor transmission rate of 10 g·m⁻²·d⁻¹ (25 °C, 90 % relative humidity) and an oxygen transmission rate of 18 g·m⁻²·d⁻¹·atm⁻¹ (23 °C, upon drying), which is commonly used commercially. Then the fruits were stored in incubators (LPH-200 RDS; Nippon Medical & Chemical Instruments Co., Ltd., Osaka, Japan) maintained at 25 °C and 50 % relative humidity.

SRF, EI, weight, and peel color measurements during

Fig. 1. The degree of water-soaked symptoms (WSS) after 10 days of storage.

Degree 0 (Nothing): Flesh is healthy, and no WSS appear.

Degree 1 (Slight): Wispy WSS appear in flesh just under the peel.

Degree 2 (Moderate): Clear WSS appear in flesh just under the peel and around the nucleus.

Degree 3 (Severe): Clear WSS appear in the entire flesh.

storage Changes in the second resonance frequency (SRF), weight, and peel color were determined after 0, 2, 4, 6, 8, and 10 days of storage. The SRF was measured using portable vibration measurement equipment (Vp-2; Seibutsu-Sindo-Kenkyusyo, Higashi-Hiroshima, Japan). The vibrator and the receiver were positioned centrally on the dorsal and ventral sides of the fruit. Vibrations (0–3 kHz swept sine wave signal, 1.35 Hz resolution for 10 s) generated by a personal computer (PC) were applied to the fruit, and vibrations from the fruit were detected by the receiver. The corresponding voltage signals were transferred to the PC. The resonance frequency of the fruit was determined by fast Fourier transformation (FFT) of the acquired signal.

The EI was calculated according to the following formula (Cooke, 1972; Terasaki *et al.*, 2001): $EI = f_2^2 \cdot m^{2/3}$, where f_2 (Hz) is the SRF and m (g) is the fresh weight of a fruit. The EI reduction rate (EIRR) was calculated by dividing the EI after 2 days of storage by the EI after 2, 4, 6, 8, and 10 days of storage, respectively.

Peel color (Hunter's L -, a -, and b -value) was measured using a color-difference meter (CR-400; Konica-Minolta, Tokyo, Japan) positioned centrally on the side of the fruit. Regarding the a -value, the higher the value, the stronger the reddish tinge; while the smaller the value, the stronger the green tinge. Regarding the b -value, the higher the value, the stronger the yellow tinge. Regarding the L -value, the higher the value, the brighter the tone.

Fruit quality measurements after storage On the final day of storage (10 days), the measurements of flesh firmness, total soluble solids (TSS), and citric acid content were taken. To measure flesh firmness, a piece of peel 3 cm in diameter was

removed using a sharp knife, and firmness was determined using a Magness–Taylor fruit penetrometer (FT011; Effegi, Alfonsine, Italy) with a plunger 11.3 mm in diameter. The plunger was pushed into the fruit, and the maximum force when penetrating 7 mm into the flesh through the cut surface was recorded. Measurements were performed on each side at the equatorial region of the fruit, and the average value was calculated.

Flesh was collected from a central point on each side of the fruit. Juice from the fruit was squeezed and filtered through gauze, and TSS together with titratable acidity were determined. TSS was determined using a refractometer (PAL-1; Atago, Tokyo, Japan), and titratable acid was determined by the titration method with 0.1 N NaOH to a phenolphthalein endpoint and converted into citric acid content. Citric acid was calculated according to the following formula (Chachin, 1983): Citric acid (mg/juice 1 mL) = 0.1 N NaOH titer (mL) $\times F \times 6.40$ mg, where F is a factor of 0.1 N NaOH.

Destructive measurements (flesh firmness, TSS, etc.) before storage were not performed because the amount of the fruit for all measurements was not sufficient for some cultivars.

WSS After storage, the fruit were cut longitudinally near the nucleus, and the degree of WSS (Fig. 1) was visually estimated based on the criteria shown below, according to the criteria used to determined watercore in Japanese pear (Sakuma, 2002).

Degree 0: no symptoms. Degree 1: slight symptoms. Degree 2: moderate symptoms. Degree 3: severe symptoms. Intermediate values of each degree were set at 0.5 units.

SL score Each fruit was given a score of 0–6 (0: poor, 6: good) by adding the score of 0–3 for the EI after 10 days of

Fig. 2. Time-course changes of the elasticity index in 16 cultivars of tree-ripe mango fruit during storage for 10 days at 25 °C. Each ten-fruit reaching the edible maturity on the trees were individually wrapped with polyethylene film (11 µm in thickness). EIRR indicates elasticity index reduction rate from day 2 to day 10 of storage. Vertical bars represent $\pm$ SE. Numbers in parentheses indicate EIRR values.

storage at 25 °C (0: $0-20 \times 10^5 f_2^2 \cdot m^{2/3}$; after this the unit was omitted, 0.5: $20-30 \times 10^5$, 1.0: $30-40 \times 10^5$, 1.5: $40-50 \times 10^5$, 2.0: $50-60 \times 10^5$, 2.5: $60-70 \times 10^5$, 3.0: $>70 \times 10^5$) to the score of 0–3 (0: Degree 3, 1.0: Degree 2, 2.0: Degree 1, 3.0: Degree 0) based on the degree of WSS, described above.

Statistical analysis Analyses of cultivar differences were conducted with Tukey-Kramer's multiple range test. Values followed by the same letter are not significantly different ($P < 0.05$).

Results

Changes in the EI and fruit quality over time during

storage In all the cultivars, the EI rapidly declined over the first 2 days of storage, after which there was a gradual decline until day 10 (Fig. 2). Since the EIRR greatly differed among the 16 cultivars, they were divided into four categories: 0–20 %, 20–30 %, 30–40 %, and more than 40 %. The EIRR from days 2 to 10 of storage was lowest in 'Irwin' and 'Glenn' (6.9 % and 8.7 %, respectively), followed by 'Khieo Sawoei' (12.6 %). In contrast, the EIRRs in 'Dot' and 'Valencia Pride' were 65.7 % and 59.4 %, respectively, and that of 'Amataiko' was 48.3 %. The EIRRs in the other 10 cultivars were between 23 % and 41 %.

The EIs after 10 days of storage at 25 °C were highest in

Fig. 3. Time-course changes of the water loss in 16 cultivars of tree-ripe mango fruit during storage for 10 days at 25 °C. Vertical bars represent $\pm$ SE.

'Khieo Sawoei' and 'Glenn' (79.3×10^5 and 71.1×10^5 , respectively). In contrast, the EIs after 10 days of storage were lowest in 'Dot', 'Amataiko', and 'Valencia Pride' (22.7×10^5 , 29.8×10^5 , and 30.3×10^5 , respectively). The EIs in the other 11 cultivars were between 33 and 58×10^5 . The EI after 10 days of storage at 25 °C in 'Irwin' was 57.1×10^5 .

Weight loss in all cultivars increased with storage time (Fig. 3) and was particularly high in 'Dot' and 'Amataiko'. After 10 days of storage, the percentage of weight loss was 4.9 % in 'Dot' and 3.6 % in 'Amataiko'. Values ranged between 1.4 % and 2.4 % in the other cultivars, and differences were minimal.

The *a*-value in 'Irwin' and 'Valencia Pride' initially increased during storage and thereafter gradually declined (Fig. 4). In contrast, values were almost constant throughout the storage period in 'Sensation', 'Tommy Atkins', 'Spirit of '76', 'Glenn', and 'Dot', and gradually increased during storage in the remaining nine cultivars. The *a*-value was relatively high (between 13 and 24) in 'Irwin', 'Sensation', 'Tommy Atkins', 'Spirit of '76', 'Aikou', 'Beni Keitt', 'Valencia Pride', and 'Glenn', but 10 or less in the other eight cultivars.

The *b*-value gradually decreased during storage in 'Dot', but remained constant or gradually increased in the other cultivars (Fig. 5). The values were relatively high in 'Alphonso', 'Golden Lippens', 'Florigon', 'Edward', 'Nam Doc Mai', and 'Khieo Sawoei' (29–35); intermediate in 'Dot', 'Glenn', 'Valencia Pride', 'Amataiko', and 'Spirit of '76' (20–27); and low in 'Beni Keitt', 'Irwin', 'Sensation', 'Aikou', and 'Tommy Atkins' (10–18).

The *L*-value showed relatively little change over time in all

cultivars; it ranged from 30 to 60, and remained almost constant throughout the storage period (Fig. 6). Values were relatively high in 'Alphonso', 'Golden Lippens', 'Florigon', 'Nam Doc Mai', and 'Edward' (57–60); intermediate in 'Khieo Sawoei', 'Dot', 'Valencia Pride', 'Amataiko', 'Glenn', and 'Spirit of '76' (46–55); and low in 'Beni Keitt', 'Irwin', 'Sensation', 'Aikou', and 'Tommy Atkins' (30–41).

Fruit quality after storage and estimation of the SL of fully ripe fruit As a result of measurement after 10 days of storage at 25 °C, the 'Khieo Sawoei' cultivar had the firmest flesh ($8.7 \text{ N}\cdot\text{cm}^{-2}$), followed by 'Edward', 'Alphonso', 'Glenn', 'Irwin', 'Florigon', and 'Beni Keitt' in descending order (Table 2). In contrast, 'Valencia Pride' had the softest flesh ($1.0 \text{ N}\cdot\text{cm}^{-2}$), followed by 'Dot', 'Amataiko', and 'Aikou' in ascending order.

'Amataiko' had the greatest level of TSS (21.0 %), followed by 'Khieo Sawoei' (18.6 %) and 'Edward' (17.0 %) (Table 2). In contrast, 'Beni Keitt' had the lowest level of TSS (13.1 %). The other cultivars had TSS levels between 14 % and 16 %, with relatively small differences.

Citric acid content was the highest in 'Alphonso' (0.35 %), followed by 'Dot' (0.23 %) (Table 2). Values were between 0.11 % and 0.19 % in 'Amataiko', 'Spirit of '76', 'Beni Keitt', 'Irwin', and 'Edward', and were less than 0.1 % in each of the remaining nine cultivars.

The degree of WSS was greatest in 'Alphonso', followed by 'Valencia Pride', 'Dot', 'Spirit of '76', 'Nam Doc Mai', 'Golden Lippens', and 'Aikou' (Table 2). In contrast, no WSS were observed in 'Irwin', while 'Beni Keitt', 'Edward' and 'Glenn' showed few symptoms, and 'Amataiko' showed

Fig. 4. Time-course changes of the a -value in 16 cultivars of tree-ripe mango fruit during storage for 10 days at 25 °C. Group I: the a -value gradually declined after an initial increase. Group II: it remained nearly constant. Group III: it gradually increased. Vertical bars represent $\pm$ SE.

Fig. 5. Time-course changes of the b value in 16 cultivars of tree-ripe mango fruit during storage for 10 days at 25 °C. Vertical bars represent $\pm$ SE.

Fig. 6. Time-course changes of the *L* value in 16 cultivars of tree-ripe mango fruit during storage for 10 days at 25 °C. Vertical bars represent $\pm$ SE.

Table 2. Fruit qualities in 16 tree-ripe mango cultivars after storage for 10 days at 25°C.

Cultivar	Flesh firmness (N·cm ⁻²)	Total soluble solids (%)	Citric acid (%)	Degree of WSS ^z
Irwin	6.9 abc ^y	14.8 e	0.14 cde	0.0 g
Glenn	7.4 abc	14.3 ef	0.09 e	0.5 efg
Tommy Atkins	4.8 def	14.5 ef	0.10 e	2.1 bc
Edward	7.9 a	17.0 c	0.11 de	0.4 fg
Aikou	2.4 ghi	15.3 de	0.08 e	2.4 abc
Florigon	6.0 bcd	15.6 de	0.10 e	1.3 de
Alphonso	7.6 ab	15.3 de	0.35 a	3.0 a
Khieo Sawoei	8.7 a	18.6 b	0.10 e	1.6 cd
Spirit of '76	3.4 fgh	14.7 e	0.18 bcd	2.7 ab
Amataiko	2.3 ghi	21.0 a	0.19 bc	0.9 def
Dot	1.5 hi	16.3 cd	0.23 b	2.8 ab
Nam Doc Mai	3.7 efg	16.4 cd	0.08 e	2.7 ab
Golden Lippens	3.4 fg	15.0 e	0.09 e	2.6 ab
Sensation	4.7 def	14.9 e	0.09 e	1.2 de
Valencia Pride	1.0 i	14.7 e	0.10 e	2.9 ab
Beni Keitt	5.5 cde	13.1 f	0.15 bcde	0.4 g

^zWSS (water-soaked symptoms). 0: no symptoms. 1: slight symptoms. 2: moderate symptoms. 3: severe symptoms.

^yValues followed by same letter indicate not significantly differ ($P < 0.05$) according to the Tukey–Kramer's multiple range test.

Fig. 7. SL score in 16 cultivars of tree-ripe mango fruit after storage for 10 days at 25 °C. SL score of each fruit shows the degree of SL, and calculated by adding the score obtained by EI (0 to 3) to a score based on the degree of WSS after 10 days of storage (0 to 3). Vertical bars represent $\pm$ SE. Values followed by same letter indicate not significantly differ ($P < 0.05$) according to the Tukey–Kramer’s multiple range test.

slightly more WSS.

Estimation of the SL of fully ripe fruit The SL scores were highest for ‘Irwin’ (5.1) and ‘Glenn’ (5.0), followed by ‘Edward’, ‘Khieo Sawoei’, ‘Beni Keitt’, ‘Sensation’, and ‘Florigon’ (Fig. 7). In contrast, the scores were lowest for ‘Dot’, ‘Valencia Pride’, and ‘Alphonso’ (less than 1), followed by ‘Spirit of ‘76’, ‘Golden Lippens’, ‘Nam Doc Mai’, and ‘Aikou’.

Discussion

Changes in the EI and fruit quality over time during storage Fumuro and Sakurai (2014), and Fumuro *et al.* (2015) reported positive correlations between EI and flesh firmness, and revealed the high utility of EI for estimating mango flesh firmness and conducting ongoing measurements on the same fruits. In addition, their experiments suggest that flesh firmness may be estimated from EI, regardless of mango cultivar. Simple regression analysis between the EI and flesh firmness at 10 days after storage was performed using 16 cultivars, and a positive correlation between these two variables (correlation coefficient $R = 0.689$) was identified. We also determined the softening characteristics of different cultivars by measuring reductions in the EI during storage.

Ongoing measurements of the same fruits showed that the EI for all cultivars rapidly declined over the first 2 days of storage, and thereafter decreased gradually over the following 8 days. Such declines in EI during fruit ripening have been reported for fruits such as pears (Murayama *et al.*, 2006; Terasaki *et al.*, 2006), kiwifruit (Terasaki *et al.*, 2001), grape (Takahashi *et al.*, 2010), and pitaya (Fumuro *et al.*, 2013); in mango, they have previously been observed in ‘Irwin’ and ‘Aikou’ (Fumuro and Sakurai, 2014; Fumuro *et al.*, 2015).

Remarkable differences in EIRR were observed among cultivars from day 2 to day 10 of storage at 25 °C; EI decreased very slightly during storage in ‘Irwin’, ‘Glenn’, and ‘Khieo Sawoei’, and after 10 days, the EI for these cultivars remained relatively high. In contrast, EI decreased significantly during storage in ‘Dot’, ‘Valencia Pride’, and ‘Amataiko’; the EI after 10 days of storage for these cultivars was relatively low.

These data constitute the first nondestructive measurements of flesh firmness for 14 cultivars used in this study (all but ‘Irwin’ and ‘Aikou’). Fumuro *et al.* (2015) reported that EI was lower in ‘Aikou’ than in ‘Irwin’, and that the flesh of ‘Aikou’ was more likely to soften. This study of 16 cultivars of mango fruits clearly revealed cultivar differences in EIRR, which is important when evaluating a cultivar’s softening characteristics and SL. Cultivars with lower EIRR and higher EI after storage were considered to have excellent SL.

Wrapping fruits in polyethylene film tends to slow down softening (Wavhal and Athale, 1989; Singh *et al.*, 2001), and has been shown to maintain a higher EI by reduction of weight loss in pear (Chino *et al.*, 2011) and mango (Fumuro and Sakurai, 2014). Nonetheless, in the present study, the rates of weight loss in ‘Dot’ and ‘Amataiko’ were 5 % and 3.6 %, respectively, approximately 2–3 times higher than in the other cultivars, although all fruits were wrapped in film. This weight loss could explain the low EI values in these two cultivars. Throughout the storage period, no symptoms of gas disorder or off-flavor were observed in the 16 cultivars of ripe mango fruits.

It is also noteworthy that the level of transpiration from fruit peel is closely related to the development of the waxy cuticle of epidermal tissue, the periderm, and the number of lenticels (Baba, 2007). The surface of the peel in both of these cultivars is rough, and lenticels develop as fruit ripening progresses, raising the level of transpiration from the peel.

The 16 cultivars were divided into three groups (I, II, III) based on changes in the *a*-value during storage. In Group I cultivars, the *a*-value gradually declined after an initial increase; these included ‘Irwin’ and ‘Valencia Pride’. In Group II cultivars, the value remained almost constant; these included ‘Sensation’, ‘Spirit of ‘76’, ‘Tommy Atkins’, ‘Glenn’, and ‘Dot’. Group III consisted of the remaining nine cultivars, in which the value gradually increased. The *b*- and *L*-values were closely correlated; cultivars with a high *b*-value showed a high *L*-value. In contrast, the *a*-value tended to drop as the *b*- and

L-values increased, and cultivars with a stronger yellow color displayed a weaker red color. The *a*-, *b*-, and *L*-values did not greatly fluctuate during storage; however, the luster of the peel decreased and fine wrinkles appeared on the surface as water evaporated.

The introduction of 'Irwin' triggered the mango boom in Japan, as consumers found its bright red peel, soft fleshy texture, and sweet scent appealing. Therefore, peel color is an important quality attribute in mangoes, and when the entire surface is red, fruits generally have higher commercial value. Therefore, red cultivars, including 'Sensation', 'Tommy Atkins', 'Spirit of '76', 'Aikou', 'Beni Keitt', 'Valencia Pride', and 'Glenn', have greater potential to appeal to Japanese consumers.

Fruit quality after storage and estimation of the SL of fully ripe fruit The EI values measured after the 10-day storage period were loosely related to the fruit penetrometer readings. Firmness was higher in 'Alphonso', but the EI after 10 days of storage at 25 °C was low. It appears that there was a conflict between such results. The flesh of the fruit was white and spongy, which suggests that the flesh had collapsed as a result of physiological disease in the tree (Ishihata, 2000).

TSS was not measured before storage, so the effect of storage time on TSS cannot be discussed. Previous studies reported that after 10 days of storage at 25 °C, glucose levels decreased and sucrose levels increased in 'Irwin', but that no significant differences appeared in total sugar content or TSS in 'Irwin' and 'Aikou' (Fumuro and Sakurai, 2014; Fumuro *et al.*, 2015). However, since it is possible that the influence of storage on TSS content differs between cultivars, it is necessary to examine the influence on TSS content when estimating SL.

The citric acid contents in 'Amataiko', 'Spirit of '76', 'Beni Keitt', and 'Irwin' were all in the range of 0.14% to 0.19%, which is considered to reflect good quality. However, the content in nine cultivars, including 'Florigon', was 0.1% or less. Tezuka and Kato (2014) reported that cultivars with high acidity at harvest tend to have better SL, and Yamazaki *et al.* (1971) indicated that acid content in fruit is an important factor for taste and storability. Therefore, SLs of these cultivars with low acid content after storage are presumed to be low. The content in 'Alphonso' was the highest (0.35%), but because fruits that have been damaged by flesh disease contain high levels of citric acid (Ishihata, 2000), disease may have affected the results.

WSS were not observed in 'Irwin', which is the leading cultivar in Japan, and few were observed in 'Beni Keitt', which has recently become more prevalent. In contrast, symptoms were severe in several cultivars, including 'Alphonso', 'Valencia Pride', 'Dot', 'Spirit of '76', 'Nam Doc Mai', and 'Golden Lippens'. The WSS of mango are morphologically similar to the watercore of Japanese pears (Sakuma, 2002). Because Japanese pears are harvested when they reach the fully ripe stage on the tree, watercore develops when the fruit is

overripe. Cultivar differences in the incidence of watercore are considerable, and are greatly affected by cultivation and weather conditions (Sakuma, 2002). However, very little information is available about the causes and evaluation of WSS in mango.

Estimation of the SL of fully ripe fruit Estimation of the SL should be comprehensively assessed based on external qualities (e.g., peel intact, no scratches or evidence of pathogens, color) and internal qualities (e.g., flesh intact and firm, TSS, citric acid content). However, in this study, the SL of 16 mango cultivars was estimated based on scores for EI and WSS, reducing the number of criteria assessed and limiting the number of fruits required. Cultivars with higher EI and a lesser degree of WSS have higher SL scores.

The 16 cultivars were divided into four groups (A, B, C, D) based on the SL score. Assuming that the EI of $50 \times 10^5 f_2^2 \cdot m^{2/3}$ or more is required for delicious fruit from the regression equation of EI and flesh firmness reported by Fumuro *et al.* (2015), the number of days during which quality can be maintained was estimated from the change of EIRR and SL score. As a result, Group A (SL score 4–6, good SL) included 'Irwin', 'Glenn', 'Edward', and 'Khieo Sawoei'. SL of more than 10 days under room temperature can be estimated. Group B (SL score 3–4, moderate SL) included 'Beni Keitt', 'Sensation', 'Florigon', and 'Tommy Atkins'. Similarly, SL of 8–10 days can be expected. Group C (SL score 2–3, poor SL) included 'Amataiko', 'Aikou', 'Nam Doc Mai', 'Golden Lippens', and 'Spirit of '76'. SL of 4–5 days can be expected. Group D (SL score 0–2, very poor SL) included 'Alphonso', 'Valencia Pride', and 'Dot'. SL of 2–3 days can be expected.

Among the cultivars in group A, the EIRRs during storage were lowest for 'Irwin', 'Glenn', and 'Khieo Sawoei', and that of 'Edward' was also relatively low. 'Khieo Sawoei' had the highest EI after storage, but also had a relatively high occurrence of WSS. The appearance and firmness of 'Irwin' were well maintained during storage, with little deterioration in internal quality. It is already clear that 'Irwin' is an excellent cultivar from a shipping and sales perspective. The early-maturing 'Glenn' with its red peel and relatively low acidity, the late-maturing 'Beni Keitt' with its large fruit (>1 kg), and the middle-maturing 'Amataiko' with its high TSS and large fruit are promising cultivars for the future.

In this study, the restricted and simplified assessment criteria (EI and WSS) to gauge the SL of mango fruits were used. These two factors are extremely important, but should only be used to make approximate SL estimates. Therefore, more comprehensive criteria should be developed to include other external and internal factors, and also to assess a wider range of cultivars.

Conclusions

EI, quality during storage, and SL were assessed in 16 cultivars of tree-ripe mango fruit. EIRR from day 2 to day 10

of storage varied greatly depending on the cultivar, and EI after storage was higher the lower the EIRR. EIRR was lowest in 'Irwin' and 'Glenn', followed by 'Khieo Sawoei'. In contrast, EIRRs of 'Dot' and 'Valencia Pride' were highest, followed by 'Amataiko'. EIRRs of the other 10 cultivars were intermediate. The degree of WSS also varied greatly depending on the cultivar. WSS was greatest in 'Alphonso', followed by 'Valencia Pride', 'Dot', 'Spirit of '76', 'Nam Doc Mai', 'Golden Lippens', and 'Aikou'. No WSS were observed in 'Irwin', while 'Beni Keitt', 'Edward' and 'Glenn' showed few symptoms, and 'Amataiko' showed slightly more WSS. SLs (SL of more than 10 days under room temperature can be estimated) were good for 'Irwin', 'Glenn', 'Edward', and 'Khieo Sawoei'; moderate (SL of 8–10 days) for 'Beni Keitt', 'Sensation', 'Florigon', and 'Tommy Atkins'; poor (SL of 4–5 days) for 'Amataiko', 'Aikou', 'Nam Doc Mai', and 'Golden Lippens', and 'Spirit of '76'; and very poor (SL of 2–3 days) for 'Alphonso', 'Valencia Pride', and 'Dot'. These results clearly revealed cultivar differences in EIRRs, WSS and SLs of ripe mangoes, and suggested the possibility of estimating SL based on EI and the degree of WSS after storage.

References

- Baba, T. (2007). Soshikikozo to seiri. In "Engeisakumotsu hozoron – Syukakugoseiri to hinshitsuhozen—" ed. by Chachin, K., Izumi, H., Imabori, Y., Ueda, Y., Terai, H., Nakamura, R., and Yamauchi, N., Kenpakusha Inc., Tokyo, Japan, pp. 85–90 (in Japanese).
- Chachin, K. (1983). Organic acid. In "Horticultural science experiment / practice" ed. by Nakagawa, S., Ohsawa, T., Sakanishi, Y., Iwata, T., and Takahashi, R., Yokendo Inc., Tokyo, Japan, pp. 162–165 (in Japanese).
- Chino, S., Matsumoto, T., Tokuda, M., Futatsugi, A., Ohta, Y., Saito, Y., Sakai, Y., and Kojima K. (2011). Relationship between elasticity index and water loss in 'Le Lectier' pears during low-temperature storage. *Hort. Res. (Japan)*, **10**, 413–419 (in Japanese).
- Cooke, J. R. (1972). An interpretation of the resonant behavior of intact fruits and vegetables. *Trans. ASABE*, **15**, 1075–1080.
- Fumuro, M., Sakurai, N., and Utsunomiya, N. (2013). Improved accuracy in determining optimal harvest time for pitaya (*Hylocereus undatus*) using the elasticity index. *J. Jan. Soc. Hort. Sci.*, **82**, 354–361.
- Fumuro, M. and Sakurai, N. (2014). Effects of ripening stage, temperature, and film wrapping on the elasticity index as determined by a nondestructive resonance vibration method and fruit quality in Irwin mango. *HortScience*, **49**, 791–797.
- Fumuro, M., Sasaki, K., and Sakurai, N. (2015). Effects of harvest time and storage temperature on the elasticity index and fruit quality of juicy and soft fleshy mango Aikou fruit. *Hort. Res. (Japan)*, **14**, 381–390 (in Japanese).
- Fumuro, M. (2016). Breeding and characteristics of new large fruit mango cultivar Amataiko with high sugar content using Edward for the seed parent. *Hort. Res. (Japan)*, **15** (Suppl. 1), 94 (in Japanese).
- Ishihata, K. (2000). Nettaikaju mango saibai no shingijutsu. Shibundo Inc., Kagoshima, Japan, pp. 1–46 (in Japanese).
- Kindai University. (2008). Aikou. Cultivar registration. 16162.
- Matsuda, T., Yano, T., Murayama, A., and Kumagai, H. (1994). Antimicrobial activities of organic acids determined by minimum inhibitory concentrations at different pH ranged from 4.0 to 7.0. *J. Jpn. Soc. Food Sci. Technol. (Nippon Shokuhin Kogyo Gakkaishi)*, **41**, 687–702. (in Japanese).
- Ministry of Agriculture, Forestry and Fisheries. (2018). "Heisei 27 nendo tokusankaju seisandotai tou chosa" (in Japanese).
- Motomura, Y., Nagao, T., and Sakurai, N. (2004). Nondestructive and noncontact measurement of flesh firmness of 6 apple cultivars by laser Doppler vibrometer (LDV). *Jpn. Soc. Food Sci. Technol. (Nippon Shokuhin Kagaku Kogaku Kaishi)*, **51**, 483–490 (in Japanese).
- Muramatsu, N., Sakurai, N., Yamamoto, R., and Nevins, D. J. (1996). Nondestructive acoustic measurement of firmness for nectarines, apricots, plums, and tomatoes. *HortScience*, **31**, 1199–1202.
- Muramatsu, N., Sakurai, N., Yamamoto, R., Nevins, D. J., Takahara, T., and Ogata, T. (1997). Comparison of a nondestructive acoustic method with an intrusive method for firmness measurement of kiwifruit. *Postharvest Biol. Technol.*, **12**, 221–228.
- Muramatsu, N., Sakurai, N., Wada, N., Yamamoto, R., Tanaka K., Asakura T., Ishikawa-Takano Y., and Nevins D. J. (1999). Remote sensing of fruit textural changes with a laser Doppler vibrometer. *J. Am. Soc. Hortic. Sci.*, **125**, 120–127.
- Murayama, H., Konno, I., Terasaki, S., Yamamoto, R., and Sakurai, N. (2006). Nondestructive method for measuring fruit ripening of 'La France' pears using a laser Doppler vibrometer. *J. Jpn. Soc. Hortic. Sci.*, **75**, 79–84.
- Sakuma, F. (2002). Studies on the cultural factors which induce the occurrence of watercore in Japanese pear 'Housui' (*Pyrus pyrifolia* Nakai). *Special bulletin of Ibaraki Agric. Cent., Hortic. Res. Inst.*, **2**, 1–89 (in Japanese).
- Singh, Z., Janes, J., and Nair, S. (2001). Packaging materials affect physiological weight loss, fruit colour and quality of mango during storage. *Acta Hortic.*, **553**, 603–604.
- Takahashi, M., Taniwaki, M., Sakurai, N., Ueno, T., and Yakushiji, H. (2010). Changes in berry firmness of various grape cultivars on vines measured by nondestructive method before and after veraison. *J. Jpn. Soc. Hortic. Sci.*, **79**, 377–383.
- Taniwaki, M., Hanada, T., and Sakurai, N. (2009). Postharvest quality evaluation of 'Fuyu' and 'Taishuu' persimmons using a nondestructive vibrational method and an acoustic vibration technique. *Postharvest Biol. Technol.*, **51**, 80–85.
- Taniwaki, M., Tohro, M., and Sakurai, N. (2010). Measurement of ripening speed and determination of the optimum ripeness of melons by a nondestructive acoustic vibration method. *Postharvest Biol. Technol.*, **56**, 101–103.
- Taniwaki, M. and Sakurai, N. (2010). Evaluation of the internal quality of agricultural products using acoustic vibration techniques. *J. Jpn. Soc. Hortic. Sci.*, **79**, 113–128.
- Terasaki, S., Wada, N., Sakurai, N., Muramatsu, N., Yamamoto, R., and Nevins, D. J. (2001). Nondestructive measurement of kiwifruit

- ripeness using a laser Doppler vibrometer. *Trans. ASAE.*, **44**, 81–87.
- Terasaki, S., Sakurai, N., Zebrowski, J., Murayama, H., Yamamoto, R., and Nevins, D. J. (2006). Laser Doppler vibrometer analysis of changes in elastic properties of ripening ‘La France’ pears after postharvest storage. *Postharvest Biol. Technol.*, **42**, 198–207.
- Tezuka, T. and Katou, O. (2014). Temperature control of the goods issue and post-breed-specific retention effect of freshness peach fruit with ice storage. *Y-CROST research report*, **9**, 21–25.
- Wavhal, K. N. and Athale, P. W. (1989). Studies to prolong shelf-life of mango fruits. *Acta Hortic.*, **231**, 771–775.
- Yamada, H. (2002). Seirishogai, shizensaigai, byogaicyu. In “Saishin-kajuengeigaku” ed. by Mizutani, F., Hiratsuka, S., Banno, K., Kubo, N., Ishii, T., Wakana, A., Kataoka, I., Yonemori, K., Kubo, Y., and Yamada, H., Asakurashoten Inc., Tokyo, Japan, pp. 218–234 (in Japanese).
- Yamazaki, T., Niizuma, T., and Taguchi, T. 1971. The relationship between organic acid and potassium content in apple juice. *J. Jpn. Soc. Hortic. Sci.*, **40**, 268–271.

URL cited

- i) <https://www.nikkei.com/article/> (Apr. 12, 2018)