Quality Changes in Fresh Mango Fruits (*Mangifera indica* L. ‘Nam Dok Mai’) Under Actual Distribution Temperature Profile from Thailand to Japan

Eriko YASUNAGA¹, Shinji FUKUDA², Daisuke TAKATA², Wolfram SPREER³, Vicha SARDSUD⁴ and Kohei NAKANO⁵

¹ Institute for Sustainable Agro-ecosystem Services, Graduate School of Agricultural and Life Science, The University of Tokyo, 1–1–1 Midori Machi, Nishi Tokyo, Tokyo 188-0002, Japan
² Institute of Agriculture, Tokyo University of Agriculture and Technology, 3–5–8 Saiwai-cho, Fuchu, Tokyo 183-8509, Japan
³ Preparation Office for Faculty of Food and Agriculture, Fukushima University, 1 Kanayagawa, Fukushima, 960-1296, Japan
⁴ Institute of Agricultural Engineering, University of Hohenheim, Garbenstrasse 9, 70599 Stuttgart, Germany
⁵ Faculty of Agriculture, Chiang Mai University, 239 Huay Kaew Road, Mueang District, Chiang Mai 50200, Thailand

The United Graduate School of Agricultural Science, Gifu University, 1–1 Yanagido, Gifu 501–1193, Japan

(Received January 5, 2018; Accepted February 10, 2018)

Thailand is one of the world’s highest producers of mango, the majority of which are exported to Japan via long supply chains. The mango is a climacteric fruit that ripens after harvest. Therefore, it is very important to treat immature fruits appropriately during lengthy distribution period which can takes approximately three weeks from Thailand to Japan by shipping. The present study aimed to determine the effects of postharvest distribution and storage temperature on physiological changes in fresh mango fruits (*Mangifera indica* L. ‘Nam Dok Mai’) imported from Thailand to Japan. Immature mango fruits were utilized that were transported immediately after harvest from Thailand by air, and were then stored in the actual distribution temperature conditions of shipping for 3 weeks and also heated to 25°C for 16 d in the laboratory. Postharvest ripening of immature mango fruits was observed as changes in fruit firmness, peel color, and sugar content under the storage conditions. Softening and coloring were induced during postharvest storage, especially in the first 4 d. After the first 4 d of maturation enhancement, the change in maturation level remained small.

Keywords: hardness score, peel color, sugar and organic acid contents

INTRODUCTION

Thailand is among one of the world’s five largest net exporters of fresh mango fruit (Schulze et al., 2013), most of which is exported to Japan via long supply chains. In 2013, 76,313 t of mangoes were exported with a value of 78 million USD; 58% as fresh fruit, 34% as canned mango, 4% as frozen mango and less than 1% as dried mango (Phavaphutanon, 2015). In Thailand, more than 60 types of mango varieties are cultivated, but only 7 varieties are permitted to be exported to Japan, such as ‘Nam Dok Mai’, ‘Khiao Sawoei’, ‘Chok Anan’, ‘Nang Klang Wan’, ‘Pim Sen Dang’, ‘Maha Chanok’ and ‘Rad’. Nam Dok Mai is the most popular variety for export (Kienzle et al., 2012) not only to Japan but worldwide.

Mango is a climacteric fruit that ripens after harvest. Therefore, it is very important to treat immature fruits appropriately during lengthy distribution periods from Thailand to Japan that can take approximately three weeks. However, studies showing the quality change of fruits and vegetables under such condition are rare (Techavuthiporn et al., 2008; Yasunaga et al., 2009; Kitazawa et al., 2010). Moreover, although it is possible to compare differences in fruit quality before and after distribution, the change in quality during the distribution period is still unclear (Yasunaga et al., 2012; 2013a; 2013b). It is essential to study the quality change of fruits for more appropriate and efficient quality management during transport and storage.

To date, studies to store mangoes have only been performed at a constant temperature (Medlicott et al., 1990; Ueda et al., 2001; Galli et al., 2013). However, it is not always possible to maintain a constant temperature throughout the actual distribution process. Especially in developing countries, postharvest loss occurs due to poor storage conditions and technologies (Gol and Rao, 2014). Accordingly, it is necessary for transport and storage studies to evaluate quality not just under unsteady conditions but also during a long supply chain.

The present study aimed to obtain data that could be applied to quality control during the distribution. For this purpose, we used immature mango fruits transported immediately after harvest from Thailand by air, and then stored under the actual temperature condition of ocean freight shipping for 3 weeks in the laboratory. The postharvest ripening state of immature mango fruits was investigated by monitoring the changes in fruit hardness, peel color, ascorbic acid and sugar-acid ratio.
QUALITY CHANGES IN MANGO

MATERIALS AND METHODS

Plant materials

Immature fresh mango fruits (Mangifera indica L. ‘Nam Dok Mai’) of exportable grade were picked from an orchard in Phrao, Thailand, on May 23, 2014. The harvested mangoes were exposed to hot water and vapor heat treatments to kill fruit flies at the packing house in Ayutthaya on May 24, packed and transported from the Suvarnabhumi International Airport by air on May 26. The mango fruits arrived at the Narita International Airport on May 27, and were used for the laboratory experiments within 5 d after harvest.

Storage conditions

The mango is a climacteric fruit that ripens after harvest, we tested two different temperature conditions: one was set under the actual distribution temperature conditions of shipping for 3 weeks, and the other was under the actual distribution condition, and then set to heat to 25°C after 16 to 18 d (Fig. 1), by storing the fruit samples in a temperature-controlled environment chamber (KCL-2000A, Tokyo Rikakikai Co., Ltd., Tokyo, Japan).

In our previous studies, mango fruits were transported under long-term low temperature conditions close to the temperature that caused chilling injury as found in ship transport, which increased the total sugar content but the fruits did not reach adequate ripeness, resulting in poor taste (data is not shown). For this reason, we set up another temperature condition in which fruit samples were kept at 25°C for 16 to 18 d to accelerate ripening during the distribution period.

Color measurements

Color changes of fruit peel were monitored using a CIELAB color reader (CR-13, Konica Minolta Sensing Inc., Osaka, Japan) that measured the L*, a*, and b* values of CIE (Commission International de l’Eclairage) 1976 L*a*b* color space units (CIELAB system), on a predetermined time (Table 1). The L* value corresponds to a white-black scale (white, L* = 100; black, L* = 0), the a* value corresponds to a red-green scale (red, positive; green, negative), the b* value corresponds to a yellow-blue scale (yellow, positive; blue, negative) and the C* value corresponds to a vivid-dull scale (vivid, positive; dull, negative) (Fukuda et al., 2014); therefore, we assumed that the a* and b* values represented de-greening caused by chlorophyll loss and the yellowing due to the synthesis of β-carotene, respectively.

Determination of hardness score

Hardness score was determined at three longitudinal points along the fruit surface using a hand-held penetrometer (KM-5, Fujiwara Scientific Co., Ltd., Tokyo, Japan) equipped with a core-shaped probe. The three values were averaged for analyses.

Extraction of nutrient component

Mango fruits were sliced, homogenized and stored at −80°C until analyses were performed. For sugar and organic acid determination, frozen pulp aliquots were weighed to 10 g and mixed with 40 mL ultra-pure water for 30 s using a Labo Milser (LM-PLUS, Iwatani Ltd., Japan). For ascorbic acid determination, 5 g frozen pulp sample were weighed and mixed with 20 mL of 5% metaphosphoric acid solution for 30 s using the Labo Milser. The mixture was centrifuged at 3,000 x g for 20 min at 5°C using a high speed refrigerated micro centrifuge (MX-307, TOMY SEIKO CO., Ltd., Japan). Supernatants from samples after centrifugation were filtered through a 0.45 L pore size syringe filter (DISMIC-25HP, Toyo Roshi Kaisha, Ltd., Japan).

High Performance Liquid Chromatography (HPLC) analysis

Quantification of sugar and ascorbic acid contents were performed with ion exclusion chromatography-phase HPLC based on methods described by Yasunaga et al. (2009) and Hernández et al. (2006). Briefly, a HPLC (Shimadzu Prominence Module, SHIMADZU, Kyoto, Japan) equipped with a Shim-pack SCR-101N analytical column (SHIMADZU, Kyoto, Japan), and refractive index detector (RID-20A, SHIMADZU, Kyoto, Japan) for sugar, and a scanning UV-VIS detector (SPD-20A, SHIMADZU, Kyoto, Japan) for ascorbic acid were used. In addition, quantification of organic acid in aliquots of extracts used an ODS column (VP-ODS, SHIMADZU, Kyoto, Japan) based

| Storage days | 0  | 1  | 2  | 3  | 4  | 6  | 8  | 10 | 12 | 14 | 16 | 17 | 18 | 19 | 20 |
|--------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Distribution temperature | 95 | 75 | 70 | 65 | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 10 | 5  | 5  | 5  |
| 25°C         |    |    |    |    |    |    |    |    |    |    |    |    |    | 15 | 10 | 5  | 5  |
on the method described by Medlicott and Thompson (1985).

Sugar contents
The mobile phase consisted of Mill-Q water that was degassed with a flow rate of 0.8 mL min⁻¹, and the column was maintained at 50°C using a Shimadzu CTO-20AC chromatography column oven. Sucrose, glucose, and fructose compounds were detected by a refractive index detector.

Ascorbic acid contents
The mobile phase consisted of 3% meta-phosphoric acid that was degassed with a flow rate of 0.6 mL min⁻¹, and the column was maintained at 30°C using a Shimadzu CTO-20AC chromatography column oven. Ascorbic acid compounds were detected by a UV-VIS detector at 243 nm.

Organic acid contents
The mobile phase consisted of 0.2 M KH₂PO₄ adjusted to pH 2.4 with H₂PO₄ that was degassed with a flow rate of 0.8 mL min⁻¹, and the column was maintained at 25°C using a Shimadzu CTO-20AC chromatography column oven. Citric acid and malic acid compounds were detected by a UV-VIS detector at 210 nm.

Statistical analysis
All the obtained data are presented as means and standard error (S.E.). Data analysis of the slope of the two temperature treatments between 16 and 20 d were performed by the analysis of covariance. The significance level was set at $P < 0.05$.

RESULTS AND DISCUSSION

Softening and coloring
Progress in postharvest ripening of mango fruits stored under actual distribution temperature was assessed by the changes in hardness score (Fig. 2) and peel color (Fig. 3). The extent of softening of the mangoes was influenced by the storage temperature and elapsed time since harvesting. In the first 4 d, the difference in hardness between immature (Day 0) and ripening (Day 4) samples was significantly large. In general, fruits ripening is related with textural alterations, which are dramatic in climacteric fruits. Fruits such as mango, papaya, avocado, sapota, and banana undergo drastic and extensive textural softening from “stone hard” stage to a “soft pulpy” stage (Prasanna, 2007). Changes in turgor pressure as well as degradation of cell

![Fig. 2](image-url) Changes in hardness score of mango fruits during storage under two temperature treatments. Vertical bars on the graph indicate S.E. ($n=5$).

![Fig. 3](image-url) Colorimetric changes in peel color in mango fruits during storage under two temperature treatments. Peel color was determined by colorimeter and expressed as values in CIELAB system, namely $L^*$ (a), $a^*$ (b), $b^*$ (c), and $C^*$ (d). Vertical bars on the graph indicate S.E. ($n=95~5$).
QUALITY CHANGES IN MANGO

Wall polysaccharides and starch determine the extent of fruit softening (Brady, 1987). Thus, in the high temperature condition in the first 4 d after harvesting, dramatic changes in the texture of fresh mango fruit occurred, and postharvest ripening progressed.

Similarly, coloring was enhanced in the fruit samples stored in the higher temperature treatment. Peel color was non-destructively determined using a colorimeter and the changes in peel color were expressed as values in the CIELAB system (Fig. 3). Similar to the ripening results, no significant differences were found in softening and color results between the two treatments. Color changes in mango fruits resulted in the disappearance of chlorophyll and appearance of other pigments. Chloroplasts are transformed to chromoplasts containing yellow or red pigments (Singh et al., 2013). Also, in this study, it seems that the pericarp color has changed due to the disappearance of chlorophyll and the appearance of other pigments by ripening, but the influence of heating in the later period of the distribution was not observed.

As a result of ANCOVA analysis on the slope of the two temperatures treatments between 16–20 d, $L^*$, $a^*$, $b^*$, and $C^*$ showed a significant difference ($P<0.05$). As shown by the decrease of all indices of peel color it was suggested that the postharvest ripening was promoted by the high temperature.

Ascorbic acid contents

Ascorbic acid is one of the most important indicators of the fresh fruit quality. Ascorbic acid concentrations showed a large decrease in the beginning 4 d, and later gradually decreased until Day 16, and slightly increased afterwards (Fig. 4). In addition, increase in ascorbic acid concentrations during the last 2 d was similar to the Thomas’s study report (Thomas, 1975) which showed that the synthesis of ascorbic acid occurred due to temperature changes during storage, which might depend on the temp. Despite the higher temperature between Days 16–18, temperature-driven synthesis was not observed in this study. In our previous study, ascorbic acid increased in case of 25 and 35°C, but not in 15°C (Yasunaga et al., 2018). However, the sudden increase in storage temperature to 25 °C resulted in the slight increase of ascorbic acid, whereas ascorbic acid increased later when storage temperature gradually increased after Day 19. Temporality such as timing and graduality of temperature changes may affect the ecophysiological process related to the dynamics of ascorbic acid.

Sugar/acid contents

It is well known that both the absolute values and balance in sugar contents and acidity in fresh mango fruits largely determine the eating quality (Singh et al., 2013). During postharvest ripening under actual distribution temperature, no significant increases in sugar content in the time zero mangoes were observed (Fig. 5a). Instead, compared to immature samples examined prior to storage, there was significant decrease in acidity during the first 4 d of storage in most samples stored at the actual distribution temperature.
temperature (Fig. 5b); thus, the sugar/acid ratio increased (Fig. 5c). Sucrose is the major constituent of soluble sugars and increased slightly during storage, whereas the other constituents decreased slightly. The majority of the organic acid was citric acid and significant decrease were observed during storage, whereas a slight increase in malic acid was observed. Singh et al. (2013) also reported that citric acid is the major constituent in several mango cultivars and loss in its concentration leads to decreased acidity during ripening. In general, citric and succinic acid decrease during ripening while malic acid shows variable changes with different cultivars. Thus, in the ‘Nam Dok Mai’, malic acid was shown to be an increasing acid component by ripening.

The slope of the two temperatures treatments between 16 and 20 d were analyzed by analysis of covariance. From this, it was found that glucose, total organic acid, malic acid and sugar/organic acid ratio showed a significantly difference ($P<0.05$). As shown by the decrease in organic acid concentration and increase in the sugar/acid ratio, ripening was promoted by the high temperatures at 25°C.

CONCLUSION

The present study investigated the changes in the quality of mango fruit under artificially reproduced storage temperature conditions from Thailand to Japan. The quality of the fresh mango fruit significantly changed until the mangoes were loaded onto the ship. Quality changes occurred slowly; thus, and stable because the storage temperature was maintained suitable for long-term transport. This study confirmed that postharvest ripening was promoted with the increased temperature treatment at 25°C. For instance, as shown by the decrease of organic acid and the increase of sugar/acid ratio, postharvest ripening was promoted by the high temperature treatment, which may result in improved tasting quality at market. The effect of high temperature treatment was limited in terms of the hardness and ascorbic acid. This may be partly because ripening had already progressed to some extent prior to the high temperature treatment. The results can contribute to the development of an improved long distance distribution system for exporting fresh mango fruits from Thailand to Japan.

ACKNOWLEDGEMENTS

The present study was supported in part by the Grant-in-Aid for Scientific Research (B) (Grant No. 16H05800). We thank Yasuhiya Yamamoto, Kengo Izumi, and Kenichiro Ichikawa for their technical supports of this study.

REFERENCES

Brady, C. J. 1987. Fruit ripening. Annu. Rev. Plant Physiol. 38: 155-178.

Fukuda, S., Yasunaga, E., Nagle, M., Yuge, K., Sardsud, V., Spreer, W., Müller, J. 2014. Modelling the relationship between peel colour and the quality of fresh mango fruit using Random Forests. J. Food Eng. 131: 7-17.

Galli, J. A., Soares, M. B. B., Marting, A. L. M., Galli, J. C. 2013. Storage of ‘Espada’ mango fruits in modified atmosphere and cooling: effects on conservation. Fruits 68: 291-302.

Gol, N. B., Rao, T. V. R. 2014. Influence of zein and gelatin coatings on the postharvest quality and shelf life extension of mango (Mangifera indica L.). Fruits 69: 101-115.

Hernández, Y., Lobo, M. G., González, M. 2006. Determination of vitamin C in tropical fruits: A comparative evaluation of methods. Food Chem. 96: 654-664.

Kienzle, S., Sruamsiri, P., Carle, R., Srisakulwat, S., Spreer, W., Neidhart, S. 2012. Harvest maturity detection for ‘Nam Dokmai #4’ mango fruit (Mangifera indica L.) in consideration of long supply chains. Postharvest Biol. Technol. 72: 64-75.

Kitazawa, H., Ishikawa, Y., Lu, F., Hu, Y., Nakamura, N., Shiina, T. 2010. Analysis of shock during strawberry transport and damage estimation. Hortic. Res. (Japan) 9: 221-227.

Medlicott, A. P., Thompson, A. K. 1985. Analysis of sugars and organic acids in ripening mango fruits (Mangifera indica L. var Keitt) by high performance liquid chromatography. J. Sci. Food Agric. 36: 561-566.

Medlicott, A. P., Sigrist, J. M. M., Sy, O. 1990. Ripening of mangoes following low-temperature storage. J. Am. Soc. Hortic. Sci. 115: 430-434.

Phayaphutanon, L. 2015. Fruit production, marketing and research and development system in Thailand. http://www.fftc.agnet.org/library.php?func=view&style=type&id=20150811091012

Prasanna, V., Prabha, T. N., Tharanathan, R. N. 2007. Fruit ripening phenomena-an overview. Crit. Rev. Food Sci. Nutr. 47: 1-19.

Schulze, K., Spreer, W., Keit, A., Ongprasert, S., Müller, J. 2013. Mango (Mangifera indica L. cv. Nam Dokmai) production in Northern Thailand — Costs and returns under extreme weather conditions and different irrigation treatments. Agric. Water Manage. 126: 46-55.

Singh, Z., Singh, R. K., Sane, V., Nath, P. 2013. Mango - postharvest biology and biotechnology. Crit. Rev. Plant Sci. 32: 217-236.

Techavuthiporn, C., Nakano, K., Maewaza, S. 2008. Prediction of ascorbic acid content in broccoli using a model equation of respiration. Postharvest Biol. Technol. 47: 373-381.

Thomas, P. 1975. Effect of post-harvest temperature on quality, carotenoids and ascorbic acid content of alphonso mangoes on ripening. J. Food Sci. 40: 704-706.

Ueda, M., Sasaki, K., Utunomiya, N., Inaba, K., Shimabayashi, Y. 2001. Effect of temperature and time on some properties during storage of mango fruit (Mangifera indica L. ‘Irwin’) cultured in plastic house. (in Japanese text with English abstract) Nippon Shokuhin Kagaku Kaishi 48: 349-355.

Yasunaga, E., Uchino, T., Yoshida, S., Tanaka, F., Chikushi, I. 2009. A proposed model to predict change in nutrient contents of garland chrysanthemum (Chrysanthemum coronarium) under distribution conditions. J. Soc. High Technol. Agric. 21: 154-161.

Yasunaga, E., Yuge, K., Fukuda, S., Sardsud, V., Wanwarang, P., Spreer, W. 2012. Effect of post-harvest distribution environment on quality deterioration of mango fruits. Acta Hortic. 934: 921-927.

Yasunaga, E., Fukuda, S., Yuge, K., Sardsud, V., Spreer, W., Wanwarang, P. 2013a. Comparison of changes in quality deterioration of mango fruits between Thailand-Fukuoka and Okinawa-Fukuoka transportation. Acta Hortic. 989: 221-224.

Yasunaga, E., Fukuda, S., Yuge, K., Sardsud, V., Spreer, W., Wanwarang, P. 2013b. Comparison of postharvest quality changes of export mango fruits from different harvest site in Thailand. Acta Hortic. 1006: 423-426.

Yasunaga, E., Fukuda, S., Nagle, M., Spreer, W. 2018. Effect of storage conditions on the postharvest quality changes of fresh mango fruits for export during transportation. Environ. Control Biol. 56: 39-44.