Comparative Quality Changes of Fresh-cut Melon in Bio-based and Petroleum-based Plastic Containers during Storage

Huijuan ZHOU, Shuso KAWAMURA, Shigenobu KOSEKI and Toshinori KIMURA

School of Agricultural Science, Hokkaido University, Sapporo, Hokkaido 060-8589, Japan

(Received September 25, 2015; Accepted January 6, 2016)

INTRODUCTION

Sales of fresh-cut fruit in the U.S. have been increasing at rates of 7% to 54% growth. Sales of fresh-cut melon have been also increasing at the fastest rate, and expected to continue over the next few years (Martín-Belloso and Soliva-Fortuny, 2011). Fresh-cut produce has become popular because of consumers’ demand for more convenient foods. However, fresh-cut fruits are very perishable and usually have a shelf life of 5-7 days at 1-7°C (Rico et al., 2007). Fresh-cut processing alters the integrity of fruits and vegetables, leading to negative effects on product quality such as browning, off-flavor development, texture breakdown, and growth of microorganisms. Thus, the shelf life of fresh-cut fruit commodities are inevitably shortened (Lee et al., 2003; Martín-Belloso, 2006; Oms-Oliu, 2007; Raybaudi-Massilia et al., 2007).

Minimally processed fresh-cut melon with relatively higher pH (>5.2) than that of other fruits (Zhang et al., 2013) is considered to be highly perishable (Soliva-Fortuny and Martín-Belloso, 2003). Previous studies on quality preservation of fresh-cut melon have focused on edible coatings, modified atmosphere packaging (MAP), an absorbent pad, mild heat and calcium treatment, and UV radiation (Lamikanra and Watson, 2007; Raybaudi-Massilia et al., 2008; Fernández et al., 2010; Manzocco, et al., 2011). However, there have been few studies on bio-based packaging for quality conservation of fresh-cut melon.

Various materials are currently used for packing fresh produce. The market is dominated by polyethylene terephthalate (PET) and polystyrene (PS) for rigid containers and polyolefins for bags, and all of the materials are made from petroleum-based polymers. One alternative is the use of bio-based packaging materials. According to European Bioplastics (2015), total amount of bioplastic production was 1.7 million tonnes in 2014. Non-biodegradable bioplastic was 60.9% and biodegradable bioplastic was 39.1% of the total production. Non-biodegradable bio-based PET had the highest production at 35.4%, followed by biodegradable and compostable polylactic acid (PLA) at 16.1% of the total bioplastics production. It was reported that the bioplastics market would continue to grow and would have a 5% share of the entire plastic packaging market within 20 years (Byun and Kim, 2014).

Polylactic acid (PLA), biodegradable, made from natural resources such as corn or sugar cane (Garlotta, 2001; Zhang and Sun, 2005; Kale et al., 2007), is one of the most widely available bio-based plastic materials. PLA possesses mechanical properties comparable to those of PET and PS (Auras et al., 2005). It is transparent and it is food contact approved by the U.S. Food and Drug Administration (FDA) (John et al., 2007; Almenar et al., 2008) and can be degraded in a composting system (Kijchavengkul and Auras, 2008). Thus, PLA would be a good alternative for food packaging material from the viewpoint of the environmental conservation and sustainability. Most PLA packaging application are limited to rigid packaging. PLA has been tested as a packaging material for some types of fresh produce and it has been shown to be useful for quality conservation of fruits.
Almenar et al. (2008) reported that blueberries packaged in PLA containers remained fresher during storage at 10 or 23°C than did fruits packaged in common commercial packages, vented clamshell containers.

In this study, packaging containers made from PLA and PET were tested for their ability to preserve the quality of fresh-cut melon under low temperature conditions (< 10°C). The choice of packaging material was made with the following objectives: (1) to compare the effects of a petroleum-based packaging material versus a bio-based packaging material with comparable properties on the changes in quality of fresh-cut melon and (2) to determine the performance of a bio-based material as a packaging material for fresh-cut melon under a low temperature condition.

MATERIALS AND METHODS

Fresh-cut operations

Fresh and sound melons (‘Rupia red’ cultivar), harvested at Biratori, Hokkaido, Japan, with the same sizes and ripening degrees were purchased from a local supermarket in Sapporo, Japan. Prior to the experiment, the melons were stored at 4°C for 24 h. Before cutting, the outer surfaces of the melons were washed thoroughly with cool tap water to remove surface dirt and melons were scrubbed with a clean produce brush, as specified by the U.S. FDA 2005 Model Food Code Section 3–302.15. The melons were hand-cut with a sharp knife into eight slices; sharp sterile knives were used to reduce the stress produced during processing. Melon slices were parallel to the longitudinal axis, and blossom stem-ends, seeds, placenta and peel were discarded. The pulp was hand cut in trapezoidal shaped sections (Silveira et al., 2010). Each cube was about 20 g.

Packaging materials and packing

Water vapor transmission rate (WVTR) and water vapor permeability coefficient (WVPC) of both packaging materials (PLA and PET) were measured by a modified technique of the wet cup method according to the American Society for Testing and Materials (ASTM) E 96 (ASTM, 2005). Plastic sheets of PLA and PET containers were sealed on cups that contained 15 mL of distilled water. Test cups were placed in desiccators at a relative humidity (3 replications for each packaging condition) and temperature (3 replications for each storage temperature) which were divided into two groups and stored in darkness at 4 and 10°C for 10 d. Physical and physicochemical analyses of melon cubes stored in each type of container and at each storage temperature (3 replications for each packaging condition) were carried out on each sampling day (0, 1st, 3rd, 5th, 7th, 10th days) during storage.

Weight loss

The weight of each package of fresh-cut melon was determined on day 0 and on each sampling day using a digital precision balance (±0.01 g) (CPA 62025, Sartorius Japan K.K., Japan). Values of weight loss are shown as the percentage loss of the initial total weight.

Juice leakage

Melon cubes were packed in snap-fit containers and stored at 4 and 10°C for 10 d. Juice leakage of the samples recovered with a syringe was evaluated by weighing the amount of juice loss from the fruit at increasing storage
periods. Results are shown as liquid quantity (g) recovered per 100 g of fresh-cut melon in the package (Manzocco et al., 2011).

**Surface color measurement**

Fresh-cut melon color was measured directly with a Minolta CR-400 chroma meter (Konica Minolta Sensing, Inc., Japan) using the CIE scale L*, a*, b*. The equipment was calibrated using a standard white tile. The maturation pattern of melon starts from the fruitlets at the base of the fruit and moves up to the crown, resulting in different stages of maturity of the fruitlets throughout the whole fruit. Because of such a complex fruit anatomy and maturity pattern, fresh-cut melon cubes are non-uniform in color and texture. Therefore, each value represents the mean of a duplicate determination of 15 different samples of each storage condition. CIE L*(lightness), a*(red-green) and b* (yellow-blue) values are determined by reflectance measurements. The parameter ΔE (Rizzo and Muratore, 2009) is defined as the visible difference of color. This value was calculated as follows:

\[
\Delta E = \sqrt{(L^*-L_0)^2 + (a^*-a_0)^2 + (b^*-b_0)^2}
\]

where the parameters of melon cubes on the initial day were \( L_0 = 61.15, a_0 = 15.45 \) and \( b_0 = 39.57 \).

**Firmness**

Tissue softening is one of the major problems that limit the shelf life of fresh-cut fruit, and firmness is an important factor that influences the consumer acceptability of these products. The firmness of the fresh-cut melon cube center was measured as the force applied by a flathead probe of 10 mm in diameter with the crosshead speed set at 0.5 mm s\(^{-1}\). The fruit cubes were compressed by 50% using a Rheo Meter (NRM-2002J, Rheotech Corp., Japan). Fifteen fruit cubes of each packaging condition on each sampling day were measured, and the values were averaged. The results are shown as force in Newtons (N).

**Soluble solids content (SSC), pH, titratable acidity (TA) and vitamin C**

Flavor is composed of sugar, organic acids and aromatic compounds. Differences in sensory quality have been based on the level and proportion of these flavor components (Almenar et al., 2010). Melon pieces, by the fact of being alive, continue the respiration process, consuming sugars and varying SSC levels, which reflect sugar contents (Lamikanra et al., 2000).

Flavor was positively correlated with pH and SSC, confirming consumers’ preference for fruits with a high pH and high sugar content. Twelve fruit cubes from each packaging condition were wrapped in paper towels and squeezed by hand. The expressed juice was used for determination of SSC, pH, TA and vitamin C. SSC was measured at 20°C by using a pocket refractometer (PAL-1, Atago Co., Ltd., Japan), and results are shown in Brix (°). The value of pH was measured with a pH meter (JF 18, Horiba Ltd., Japan). TA was determined by diluting each 1-mL aliquot of melon juice in 50 mL of distilled water and titrating to pH 8.1 using 0.1 mol L\(^{-1}\) sodium hydroxide (NaOH). Total acid contents were determined as citric acid equivalents (Montero-Calderón et al., 2008). The quantity of vitamin C was determined by using ascorbic acid reflectoquant test strips in combination with an RQflex® plus 10 reflectometer (Merck Millipore Corp., Germany) (Merck KGaA, 2012)

**Sensory analysis**

Sensory evaluation of fresh-cut melon was carried out. Samples were given to panelists in a completely randomized order. The sensory quality of the fresh-cut melon under each packaging condition was evaluated by using a panel of 10 untrained judges, researchers and students of the Laboratory of Food Processing and Engineering of Hokkaido University in Japan. Odor, color and overall acceptance were selected as quality attributes. A structured scale was used for odor, color and overall acceptability of melon cubes: 3, very good; 2, good; 1, fairly good; 0, fair; −1, slightly poor; −2, poor; −3, very poor. During the test sessions, the sample presentation order was randomized and sensory evaluation was carried out on the 0, 5th and
10th sampling days.

Statistical analysis

Data were subjected to one-way and factorial analysis of variance (ANOVA) using Statistical Product and Service Solutions version 22 (SPSS Inc., Chicago, IL, USA). Significant differences between means of all measurement items among storage conditions and each sampling day during the 10 d of storage were determined by Tukey’s post hoc comparison test ($P < 0.05$).

RESULTS AND DISCUSSION

As shown in Fig. 2, melon cubes that had been stored at 10°C were greatly deteriorated on the 10th sampling day. A large amount of fungi was clearly observed in the PET containers. Much worse spoilages and smells of alcohol in PET containers at 10°C were also noted by panelists during sensory evaluation. Quality changes of fresh-cut melon were determined for 7 d for melons stored at 10°C and for 10 d for melons stored at 4°C.

Weight loss

Confirmation of leakproofness was carried out. The amounts of air leakages through gaps between the lids and bottoms of the PLA and PET containers were so small that both types of containers could be regarded as being airproof (data not shown).

Loss of moisture is the major reason for fruit weight loss and it is the result of respiration and transpiration processes occurring during postharvest. In closed packaging systems, moisture loss of fresh produce is determined mainly by the permeability to water vapor of the packaging material (Joo et al., 2011). As can be seen in Fig. 3, ‘Rupia red’ fresh-cut melon in PLA and PET containers showed a progressive loss of weight during storage. Throughout the storage period, there were significant differences between weight losses in the PLA and PET containers at 4 or 10°C. In closed packaging systems, moisture loss of the fresh produce is determined mainly by the permeability to water vapor of the material. Figure 3 shows the differences in fresh-cut melon weight loss caused by the packaging material. Greater weight loss were observed for the PLA-packaged melon than for the PET-packaged melon: 0.62% vs. 0.35% at 4°C on the 10th sampling day and 1.22% vs. 0.34% at 10°C on the 7th sampling day. The greater weight loss of melon cubes in the PLA containers was due to the higher water losses.
vapor transmission rate (WVTR) of PLA. Values of 18.18 and 2.09 g m⁻² d⁻¹ were measured for PLA and PET used in this study at standard room temperature of 23°C and 46% relative humidity differences (Table 1). Similar results for WVTR and WVPC were obtained in other studies (Auras et al., 2003; 2005). Greater differences in fresh-cut melon weight loss at a higher temperature are shown in Fig. 3. Shriveling and loss of plumpness are dependent on temperature. The higher the temperature is, the greater the effect of the plastic container can be. A weight loss of more than 5% is a cause of reduction in retail value of vegetables and fruits (Almenar et al., 2008). Weight loss of 5-10% or more has been shown to be associated with a significant reduction in the firmness of fresh products (Almenar et al., 2010). Weight losses of fresh-cut melon stored at 4°C and 10°C in the PLA and PET containers were less than 1.5%, indicating that PLA containers were as suitable as PET containers for moisture conservation of fresh-cut melon during storage at 4°C and 10°C.

**Juice leakage**

Results for juice leakage from fresh-cut melon pieces inside the containers during 10 d of storage at 4 and 10°C are shown in Fig. 4. No significant differences in juice leakage were found between the different packaging and temperature conditions.

**Surface color measurement**

Color is the most evident parameter by which consumers judge fresh-cut melon quality. Changes in color parameters \(L^*, a^*\) and \(b^*\) of fresh-cut melon were studied throughout 10 d of storage at 4 and 10°C. More initial statistical differences of melon cubes in PET containers in \(\Delta E\), calculated by color spaces \(L^*, a^*\) and \(b^*\) among packaging conditions, were observed (Fig. 5). These meant melon cubes lost redness and yellowness gradually during the storage in both containers.

Color changes in \(L^*, a^*\) and \(b^*\) values of sample cubes in PET containers were larger than those of sample cubes in PLA containers during the storage period. Compared with the \(L^*, a^*\) and \(b^*\) values on the initial day, the values of sample cubes stored at 10°C in PET containers on 7th sampling day decreased by about 27% and 42%, respectively. Physiologically, this could be attributed to wounding of living tissue in the fresh-cut process, which starts a cascade of metabolic reactions that can result in discoloration and other undesirable phenomena that can render the product unmarketable. Temperature also showed an influence on color parameters. All of the color changes resulted from browning of sample cubes.

**Firmness**

Texture of fresh-cut fruit is a very important quality parameter. Firmness of fresh-cut melon cubes in PLA and PET containers decreased from 7.4 N to 4.4-4.7 N throughout the storage period at 4 and 10°C (Fig. 6). Firmness values of samples stored in PLA containers at 4°C were the highest throughout the storage period. The storage temperature of 10°C, compared to storage at 4°C, increased the respiration of the fruit and gave rise to some enzymatic processes that caused softening of the fresh-cut melon cubes. No significant difference was found in texture firmness values of fresh-cut melon in PLA and PET containers during storage.

**Fig. 7** Soluble solids content (SSC), pH, titratable acidity (TA) and vitamin C of fresh-cut melon cubes packaged in PLA and PET containers at 4 and 10°C during 10 d of storage (n=10).
Soluble solids content (SSC), pH, titratable acidity (TA) and vitamin C

As shown in Fig. 7, in general, SSC, pH and vitamin C of fresh-cut melon in PLA and PET containers declined during storage at 4 or 10°C. TA values showed only slight increases. The containers and temperatures showed no effect on SSC during storage. No significant difference in pH or TA between the packaging materials was found before 5 d of storage at 10°C. On the 7th sampling day, the values ranged from 6.2 to 6.7 for pH and 1.8% to 2.3% for TA. There were no significant differences in SSC, pH, TA and vitamin C of fresh-cut melon cubes in PLA containers at 4°C during storage.

Sensory analysis

Appearance is one of the most critical factors in the initial purchase of fresh and fresh-cut products. Appearance therefore needs to be maintained in order to attract consumer preference and choice. Odor and color play the most important factors for helping consumers make decisions. Figure 8 shows that the scores of odor, color and overall acceptability of sample cubes in all storage conditions declined throughout the storage. The panelists indicated that differences between melon cubes packaged in different containers at different temperatures were mainly based on color, odor and overall acceptability. Spoilage of melon cubes was observed at 10°C, especially in PET containers on the 10th sampling day. Although there were no significant differences between PLA and PET at the same temperature, melon cubes in PLA containers showed higher scores during sensory evaluation.

Overall evaluation of the fresh-cut melon

When fresh fruits are cut and handled in production, the internal tissues of the fruits are directly exposed to the environment and the fruits tissue corresponds to the damage by increasing its respiration rate to survive and repair the damage (Garrett, 1999). Due to increase in respiration of fresh-cut fruits, water/water vapor in the environment around the fruits will be increased. Higher moisture content in fruits and headspace atmosphere in packaging increase non-enzymatic browning, enzyme activity, mold and bacteria growth (Krochta, 2006). In addition, the higher humidity environment would promote spoilage of fresh-cut fruits in a packaging. As shown in Table 1, PLA indicated significantly higher water vapor transmission rate than that of PET, and Mochizuki (2005) also reported that water vapor permeability of PLA was about 10 times higher than that of PET. PLA packaging increased more weight loss in fresh-cut melon cubes during the storage in this study (Fig. 3). However, in turn, this weight loss would result in less color change and also inhibition of mold growth in fresh-cut melon stored in the PLA containers than those in the PET containers.

In addition, melon respires by taking oxygen and giving off carbon dioxide, the packaging material must be permeable to these gases (Garrett, 1999). Fresh-cut process increased respiration of melon cubes, so that oxygen inside the packaging containers was consumed very quickly. Mochizuki (2005) reported that oxygen permeability of PLA was over 10 times as high as that of PET. Due to much lower oxygen permeability of PET material, the fresh-cut melon might start anaerobic respiration, which might be reasonable for the production of alcohol and an increase of spoilage even further in fresh-cut melon cubes during storage in this study. Consequently, the PLA containers maintained appearance and quality of fresh-cut melon better than those of PET containers during storage.

CONCLUSION

The results showed that overall quality of fresh-cut melon declined during storage. Melon cubes in both packages showed increases in weight loss, juice leakage, surface

![Fig. 8](image-url) Sensory analysis (odor, color and overall acceptability) of fresh-cut melon cubes packaged in PLA and PET containers at 4 and 10°C during 10 d of storage (n=10).
color ($L^\ast$, $a^\ast$, $b^\ast$), firmness, SSC, pH, vitamin C and sensory evaluation. No significant differences in color, firmness, pH, TA or sensory evaluation were found between the different packages at 4°C. However, due to higher water vapor and oxygen permeability of PLA than that of PET, significant differences in color of melon cubes between in the PLA and in PET containers were found on the 7th sampling day of storage at 10°C. The PLA containers used in this study maintained quality of fresh-cut melon better than did the PET containers in overall quality conservation of fresh-cut melon at 10°C during 10 d of storage. Therefore, with consideration of sustainability and quality conservation performance, bio-based PLA is a suitable alternative to petroleum-based PET for storage of fresh-cut melon in retail markets.

ACKNOWLEDGEMENTS

The first author would like to express sincere gratitude to the China Scholarship Council (CSC) for offering a fellowship.

REFERENCES


Martín-Belloso, O., Soliva-Fortuny, R., Oms-Oliu, G. 2006. Fresh-cut fruits. In “Handbook of Fruits and Fruit Processing” (ed. by Hui, Y.H.), Blackwell publishing, Iowa, p 129-144.


