Changes of postharvest quality in passion fruit (Passiflora edulis Sims) under modified atmosphere packaging conditions

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Abstract
The modified atmosphere packaging technique was explored in order to investigate the changes of passion fruit quality during low temperature storage. Three different types of packaging condition were used in this experiment. They were (i) P-UAP, a perforated low density polyethylene (LDPE), (ii) MAP-1, a LDPE with an oxygen transmission rate (OTR) of 14000-16000 cm³/m²∙day∙atm, and (iii) MAP-2, an ethylene absorber laminated LDPE with an OTR of 12000 cm³/m²∙day∙atm. Five fresh purple passion fruits (each fruit was about 100 g) were packaged in each type of packaging and then stored at 10±1ºC, 79-84% RH. During storage, the headspace gas concentrations, physico-chemical quality and sensory acceptability were monitored. Oxygen concentration of headspace gas in MAP-1 and MAP-2 markedly decreased during 12 hours after packaging while carbon dioxide greatly increased. The gases in MAP-1 and MAP-2 reached equilibrium within 14 and 7 days, respectively. The passion fruit in all packaging conditions showed decreased presence of total soluble solids, titratable acidity and vitamin C content over the storage period. However, plastics MAP-1 and MAP-2 significantly reduced fresh weight loss and delayed fruit wrinkling. Pulp off-flavor was observed in the fruit stored in MAP-1 and MAP-2 wrapping, and this resulted in a lack of marketability. The MAP-2 plastic showed the best results in maintaining fruit quality, gas composition, and extension of storage life (up to 51 days).

Introduction
Passiflora edulis Sims., commonly known as passion fruit or granadilla, is classified as a perennial plant. The spherical-shaped fruit has a central cavity filled with a pleasant aromatic juicy pulp or arils (Chavan and Kadam, 1995; Shiomi et al., 1996a). Passion fruit contains 20-30 mg of ascorbic acid and about 1300 IU of vitamin A per 100 g of fresh weight, and, in particular, the edible seeds are good sources of dietary fiber (Homnava et al., 1990; Romero-Rodriguez et al., 1994). Furthermore, passion fruit is also abundant in natural phenolic compounds, which are known to possess activity that inhibits oxidative damage (Khanna et al., 2007; Zeraik and Yariwake, 2010; Zeraik et al., 2011). Generally, passion fruit postharvest quality depends on harvest time and storage conditions (Arjona and Matta, 1991; Bora and Narain 1997). Physiologically, passion fruit is classified as a climacteric product due to its respiratory characteristics, ethylene production, climacteric rise and certain responses (Biale, 1975; Shiomi et al., 1996a). Passion fruit quality and appearance steadily deteriorate, and the fruit starts dehydrating immediately after harvest. This is literally caused by an increase of respiration rate upon a great presence of ethylene biosynthesis during passion fruit postharvest ripening. This deterioration leads to the fruit becoming unmarketable (Shiomi et al., 1996b).

Appropriate packaging treatment and storage temperature are considered the crucial factors in maintaining the quality of various kinds of horticultural commodities, as well as and extending storage life with product safety assurance (Kader,
1986; Valero et al., 2008). Modified atmosphere packaging (MAP) technology employs the elevation of CO₂ and reduction of O₂ since most horticultural produce is O₂-sensitive (Vermeiren et al., 1999; González-Aguilar et al., 2004; Costa et al., 2011). Furthermore, another type of MAP, an active MAP maintains an equilibrium of gasses within the package, which conventional methods of packaging cannot do. It also helps to eliminate and/or diminish unwanted compounds such as O₂ and ethylene. The active MAP can be defined by means of combinations of technology involving material application and/or plastic lamination between film materials and innovative substances such as O₂ scavengers, CO₂ scavengers or emitters, ethylene absorbers, moisture regulators and natural antimicrobial agents have also been integrated as important parts of active MAP technology (Vermeiren et al., 1999; Valero et al., 2006). In the case of ethylene control, potassium permanganate-based (KMnO₄-based) mechanisms have been previously used in food industry in order to remove the unwanted compound by oxidation. Besides KMnO₄-based scavengers, Terry et al. (2007) utilized palladium-based (Pd-based) materials to remove ethylene and discovered that low amount of applied Pd-based materials effectively scavenged ethylene produced by bananas and avocados. Therefore, the use of ethylene-absorbed films would benefit to passion fruit by lowering internal ethylene concentration, resulting in diminution of postharvest ripening, moisture loss and peel deterioration, thus storage life extension.

Although the many benefits of MAP application have been studied previously with various kinds of fresh produce such as yellow and purple plums (Díaz-Mula et al., 2011), avocado (Terry et al., 2007) and pineapple (Montero-Calderón et al., 2008), research studies focusing on MAP conditions for passion fruit are very limited. Therefore, this study was aimed at examining the effects of MAP conditions on passion fruit postharvest quality during low temperature storage.

Materials and Methods

Raw materials

Fresh mature purple passion fruit (aged 75-80 days after flowering) were harvested from The Mokjam Royal Project Development Center located in Chiang Mai province, Thailand. The plantation site is at an altitude of 750 m above sea level with an average temperature of 22.9°C. The fruit were selected for symmetrical spherical shape, weight ranging from 90 to 100 g, and purple color stage (color break) of 80-90 percent. Subsequently, selected fruits were cleansed of biological contaminants such as soil, dust and insects. Then, all fresh samples were transported to a postharvest research center for horticultural crops at Chiang Mai University.

Sample preparation, packaging procedures and storage condition

Each fruit was dipped into 200 ppm of chlorine solution for 1 min, then wiped by a damp cloth (containing the same solution) to control fungal development and microbial spoilage during storage. All samples were left to air dry prior to the packaging procedure. Five fruit samples (about 500 g) were packaged in each package. Three selected plastic films were used in this experiment, namely perforated low density polyethylene (LDPE) package or unmodified atmosphere packaging (P-UAP) with 0.5 cm of perforated hole diameter (18 holes, totaling 3.536 cm²), polypropylene-polyethylene lamination with oxygen transmission rate (OTR) of 14000-16000 cm²/m²-day-atm (MAP-1), and active packaging (polypropylene-polyethylene lamination with ethylene absorbers) with OTR of 12000 cm²/m²-day-atm (MAP-2). The OTR range of MAP-1 was recommended for fresh produce with high respiration rates, while MAP-2 film had lower OTR and contained ethylene absorbers. Table 1 shows film characteristics and packaging conditions for each observation. All packaging was sealed by a sachet sealer (passive atmosphere packaging) and immediately analyzed for initial headspace gas composition (oxygen, carbon dioxide and ethylene concentration), and then stored at 10°C, 79-84% relative humidity (RH). During the 12 hours immediately after storing, passion fruit core temperature was monitored hourly by Thermisters probes (Model DA-42, Digicon, Japan) and temperature meter (Model DM-760, Digicon, Japan).

Determination of headspace gas composition

Twenty samples for each packaging type were used to study the changes of headspace gas composition during storage time. All packaging conditions were analyzed for internal O₂ and CO₂ concentrations hourly for 12 hours immediately after packaging, and then at 7 days intervals thereafter. One replication was completed at each sampling (totaling 20 replications/packaging condition). About 4 cm³ of headspace gas within the package was sampled via a connecting septum and analyzed by a gas analyzer equipped with chemical sensors for O₂ measurement and an internal microprocessor with NDIR technology for CO₂ measurement (Model 900151, Bridge Analyzers, USA). In addition, the headspace...
gas of the aforementioned packaging samples were also analyzed for ethylene concentration upon packaging, after 12 hours, and then at 7 days intervals until the end of storage. One cm³ of gas sample was withdrawn and analyzed by a gas chromatograph (Model 6890, Agilent Technologies, USA) fitted with HayeSep-S 100/20 (2 m × 0.75 mm) column. Helium was used as a carrier gas with oven temperature of 40°C and detector temperature (frame ionize detector (FID)) of 250°C. One replication was made at each sampling. As for a respiration rate, 500 g of passion fruit was kept in a plastic chamber (18.0 × 26.0 × 12.5 cm³) with continuous air flow (100 cm³/min) at ambient temperature and at 10°C. One cm³ of gas sample was withdrawn and analyzed for CO₂ by a gas chromatograph (Model GC-8A, Shimadzu, Japan) fitted with a Parapak Type N (80-100 Mesh, Shimadzu, Japan), equipping with an outer column (CTR-1 column; 2 m × 6 mm o.d., Alltech, USA) and helium was used as a carrier gas. Column temperature was 65°C, and thermal conductivity was 110°C.

**Determination of chemical quality and bioactive compounds**

Passion fruit in all packaging conditions were sampled immediately after packaging, after 12 hours, and then every 7 days intervals thereafter. Three packaging samples from each packaging condition were tested, totaling 15 fruit per packaging type. Four fruits were used for chemical quality analysis, and 11 fruits for sensory evaluation. Passion fruits were equatorially cut and the yellowish soft arils with seeds spooned off. Filtered juice was assayed for total soluble solids (TSS) using a digital refractometer (Model PR-101, Atago Co.Ltd., Tokyo, Japan) and results were expressed in percentage unit. As for titratable acidity (TA), 10 ml of filtered juice was mixed with distilled water to make 100 ml of mixture. The pH was measured using a pH meter (Model CG842, Schott, Hofheim, Germany). The titratable acidity was determined against the titration of a prior mixture with 0.1N NaOH to a pH end point of 8.2 using a digital burette (Model RS232, Brand, Werthiem, Germany). The value was expressed as percentage of anhydrous citric acid equivalent per 100 ml of fruit juice. Vitamin C content was determined by diluting 10 ml of filtered passion fruit juice with 90 ml of 0.4% oxalic acid, mixed thoroughly and filtered through No.1 filter paper. Then an aliquot of the solution was titrated with 0.04% 2,6-dichlorophenol-indophenol by a digital burette until the color turned rose pink; the result was expressed in mg of vitamin C per 100 ml of fruit juice (Ranganna, 1995). Total carotenoids content was evaluated by dimethylsulphoxide tonoplast hydrolysis using the method of Pawelzik (2005). Two ml of fruit juice was added to 10 ml of dimethylsulphoxide solution and then was stirred for 5 minutes. Then sample was left for 16 h in dark conditions. After this, the sample was again stirred and centrifuged at 10000 rpm at 24.0°C for 10 minutes (Model Z216MK Refrigerated Microcentrifuge, Hermle, Wehingen, Germany). Three ml of the supernatant liquid was used to measure the absorbance at 665, 649 and 480 nm (Model Genesys10UV-Scanning, Thermo Spectronic, Wisconsin, USA) followed by the calculation described by Pawelzik (2005). The juice was also tested for ethanol concentration using an ethanol test kit (Test 8-38, MACHEREY-NAGEL GmbH & Co., Germany) coupled with a compact photometer (PF-12, MACHEREY-NAGEL GmbH & Co., Germany).

As for determination of bioactive compounds, 2 ml of filtered juice was added to 20 ml of absolute methanol (extraction solution). The mixture was consistently stirred for 1 h under dark conditions and later filtered through No.1 filter paper. The filtered aliquot was diluted 5 times by extraction solution and again filtered by 0.45 µm nylon filter in order to obtain the passion fruit crude extract. Total phenolic compound was determined by the Folin-Ciocalteu colorimetric assay described by Sellappan et al. (2002) and antioxidant activity was determined by 2’,2’-diphenyl-1-pycrylhydrazyl (DPPH) radical scavenging activity assay (DPPH assay) described by Manthey (2004).

**Weight loss and storage life**

Weight loss was expressed as a percentage scale calculated from the difference between initial weight and tested-date weight using a digital balance (Model EK-600H, Sartorius, USA). In the case of storage life, judgments were made by panels. The scores of overall quality and juice off-flavor were used to determine passion fruit storage life.

**Sensory evaluation**

The evaluation was done by 15 trained panels consisting of nine females and six males (age 21-34 years). All panelists had experience and were trained in evaluating passion fruit quality from former experiments. Passion fruit were rated for visual quality, peel color (darkening) and peel shriveling using a score of 5 to 1, in which 5 was excellent, 4 was good, 3 was fair, 2 was poor and 1 was unusable. Visual quality was classified as unacceptable when the score was below 3. Furthermore, 4 samples from each packaging technique were kept under the same...
conditions and monitored for wrinkle incidence by visually rating the percentage of wrinkled area from 0 to 50%.

The evaluation of juice flavor was done using the definition of taste and retronasal aroma perceptions. Passion fruits were equatorially cut and presented to the judges at random in order to avoid personal bias and factors affecting personal judgment. Fifteen panelists rated off-flavor incidence using a score of 1 to 5, in which 1 was extremely off-flavor (fermented), 2 was highly off-flavor, 3 was moderately off-flavor, 4 was slightly off-flavor and 5 was normal taste and aroma (non-fermented). Fruit juice was classified as unacceptable when the score was below 3. Sweetness was scored from 1 to 5, in which 1 was considered the lowest sweetness level and 5 the highest sweetness level. Satisfaction (overall quality) in terms of consumer’s satisfaction was also tested to determine the acceptability of fruit packaged in all packaging conditions using a score of 1 to 5, in which 5 was the most acceptable level.

Statistical analysis
Statistical analysis was performed using SPSS v.17.0 software (SPSS Inc., IL, USA). Data was subjected to a completely randomized analysis of variance (ANOVA). Duncan’s multiple range test was used to determine significance \((P < 0.05)\) between samples.

Results and Discussion

Packaging condition and respiration rate of passion fruit
Packing dimensions were carefully measured in order to take up the same dimensions in width and length, thus avoiding uneven headspace volume especially in MAP-1 and MAP-2. As for the OTR and WVTR values, MAP-1 allowed higher permeability than ones observed in MAP-2. There were no significant differences in the fruit load and initial headspace volume for each package.

The respiration rates of passion fruit at ambient temperature in all packaging conditions were similar, ranging between 572.7 to 621.4 mgCO\(_2\)/kg/hr. Newly harvested passion fruit (aged about 70-80 days after flowering) typically have a very high respiration rate as described by Shiomi et al. (1996a). However, after storing the packaged fruit for 1 day, the passion fruit showed a decreased respiration rate. Furthermore, the fruit packaged in MAP-2 showed the lowest respiratory rate compared to those fruit packaged in MAP-1 and P-UAP. This occurred because the ethylene absorber laminated in MAP-2 film material might help to retard the respiratory process by diminishing the ethylene concentration in the headspace gas. Another reason might be the OTR of 11883 cm\(^3\)/m\(^2\)∙day∙atm. At 10°C, the oxygen permeability is theoretically lower than it would be at 23°C, which would affect respiration rate due to the limitation of O\(_2\) in the packaging.

Headspace gas composition
During the 12 hours after sealing, oxygen concentrations in the headspace gas of MAP-1 and MAP-2 decreased rapidly while headspace gas composition of P-UAP was unchanged (Figure 2a). The newly packaged passion fruit at an initial temperature of 21.3°C began consuming O\(_2\) immediately after sealing since the high temperature allowed a high level of respiration (Table 1). Fruit respiration consistently decreased along with fruit temperature until hour 8 when the product temperature reached at 10.3°C (in MAP-1 and MAP-2) (Figure 1). In the case of passion fruit packaged in P-UAP, core temperature apparently decreased faster than those observed in other packaging films. The faster rate was clearly associated with a rapid eventually-circulated cool air within the package, allowing a fast heat exchange between samples and cool air upon its perforated characteristic.

Figure 2b displays O\(_2\) concentrations which continued to decrease slowly and arrived at their lowest point on day 7 (15.29 and 14.99%, for MAP-1 and MAP-2, respectively). Both MAP conditions allowed O\(_2\) concentrations to develop equilibriums within 14 days. During the equilibrium stage, MAP-1 had slightly higher O\(_2\) concentration than the values observed in MAP-2, which was due to MAP-2’s OTR. Because of the differences in the barrier properties, the film’s OTR, and plastic lamination, passion fruit packaged in MAP-2 seemed to have appropriate respiration. The different gas compositions were
related to the selective barrier properties of the film used (Del Nobile, et al. 2006; Conte et al., 2009; Bree et al. 2010; Costa et al., 2011). Due to the respiration of the produce, CO₂ concentrations in MAP conditions markedly increased during the first 5 hours after sealing. This was especially true in the first hour wherein CO₂ escalated from 0.41% to 3.16% in MAP-1, and from 0.29% to 2.73% in MAP-2 (Figure 2c). The carbon dioxide concentration in MAP-1 reached the highest point during day 1 with the a value of 4.30%, and slightly decreased over storage time (35 days) to 3.75%. The barrier properties of MAP-2 allowed CO₂ concentration to reach 4.81% on day 7, and the film barrier maintained equilibrium modified atmosphere (EMA) for the whole storage period (Figure 2d). The carbon dioxide accumulated
higher in MAP-2 compared to MAP-1 and perforated UAP. In the obtained results, the amount of CO₂ corresponded to those values studied by Meir et al. (1997), who reported similar CO₂ concentration (4-5%) when storing ‘Hass’ avocado fruit in MAP condition during low temperature storage (5 and 7°C). And the storage in such condition effectively reduced weight loss and delayed peel deterioration. Also, Díaz-Mula et al. (2011) discovered that the storage of fresh plum (at commercial ripening stage) in MAP conditions were able to established 2-6% CO₂ and 14-18% O₂ concentrations. These levels were found to be effective in delaying postharvest ripening and reducing ethylene production. Marrero and Kader (2006) suggested that a CO₂ concentration of 10% effectively helps to prevent chilling injury and quality losses for tropical fruits in modified atmosphere storage. However, in our obtained results, the CO₂ concentration never reached this amount but it was found to be effective for delaying postharvest loss of passion fruit, in the MAP-2 packaging.

As for ethylene concentration, in such low temperature storage, the synthesis of ethylene gas is greatly decreased. In this study, passion fruit showed a difference in ethylene accumulation within MAP-1 and MAP-2. Headspace gas of MAP-1 had a faster ripening gas accumulation than that observed in MAP-2 one week earlier (Figure 3). Ethylene concentration in MAP-1 packaging continued to rise rapidly from day 7 onward, while the concentration of ethylene in MAP-2 rose during the 3rd week, and only changed slightly thereafter. MAP-2’s barrier properties, low OTR value and ethylene scavenging lamination significantly reduced the ripening gas. Low O₂ level typically lowered ethylene biosynthesis by reduction of 1-amino-cyclopropane-1-carboxylic acid oxidase (ACO) activity (Pretel et al., 1993). In the mean time, lamination of ethylene absorber scavenged a certain molecule from headspace gas. Nonetheless, the results indicated that in spite of the presence of ethylene, passion fruit showed no climacteric respiration (based on the consumption of O₂ and/or CO₂ emission). This might be because of storage at such a low temperature, at 10°C, respiratory-related enzymes could be retarded, resulted in a suppression of climacteric peak. Another possible reason was a modified atmosphere condition. CO₂ elevation and O₂ diminution could limit respiration rate and respiratory quotient (Fonseca et al., 2002).

**Physico-chemical quality of passion fruit during storage**

**Chemical properties**

Passion fruit packaged in all conditions showed a decrease of total soluble solids over storage time. The passion fruit lost about 10% of its initial TSS (Figure 4a). MAP-1 and MAP-2 could not retain soluble solids in the pulp, resulting in no significant difference from the values observed in passion fruit in P-UAP. Typically, fully ripe purple passion fruit accumulates soluble solids in the pulp, mostly organic acids and sucrose molecules. However, once picked, passion fruit can consume and convert certain compounds by aerobic respiration or anaerobic processes (Arjona et al., 1992; Shiomi et al., 1996b). Like TSS, titratable acidity from passion fruit juice notably decreased over time in all packaging conditions (Figure 4b). Passion fruit juice lost about 40% of organic acids during storage (from an initial value of 4.0%, ending at 2.5%). The diminishing of organic acids such as ascorbic and citric acids in purple passion fruit usually occurs because of acid metabolism and degradation (Arjona and Matta, 1991). After harvest, purple passion fruit lose acids and moisture rapidly in ambient temperatures and atmosphere due to the high level of respiration and the increase of related enzymatic acidic degradation (Shiomi et al., 1996a; Shiomi et al., 1996b). In this study, no significant difference in titratable acidity was observed in any of the packaging materials. As a part of sensory quality survey, the ratio of TSS and TA was also analyzed and compared. Perforated-UAP packaging allowed the TSS/TA ratio to increase rapidly over 2 weeks, while MAP-1 and MAP-2 showed relatively slow increases. (Figure 4c). The MAP-1 and MAP-2 packaging seemed to delay flavor enhancement of passion fruit juice. Modified atmosphere probably affected the TSS and TA, thus resulting in the difference in TSS/TA ratio from non-MAP packaging.

The passion fruit juice lost vitamin C (one of the major organic acids enriching the juice) during storage. However, MAP-1 and MAP-2 packaging slightly delayed the loss of vitamin C compared with P-UAP for the first 2 weeks (Figure 4d). Vitamin C degradation was mainly caused by the exposure to...
O₂, light and high temperatures. Therefore, in this study, oxygen played an important role in vitamin C diminution (Vermeiren et al., 1999) owing to MAP-1 and MAP-2 packaging. In MAP-1 and MAP-2, low levels of O₂ might have helped to delay the oxidation of the vitamin C, while high levels of CO₂ might have helped to retard the vitamin C related oxidizing enzyme activity. Vinci et al. (1995) also reported that passion fruit stored at 4°C lost 40% of its ascorbic acid after only 1 week of storage in a conventional cool room. Vitamin C is also one of the respiratory metabolites, which means it is possible that the faster diminution could caused by the higher respiration rate observed in P-UAP. Similar to vitamin C, Figure 4e illustrates the changes in total carotenoid content in each package. The application of MAP-1 and MAP-2 plastics clearly delayed the degradation of certain compounds, while P-UAP showed a gradual loss over time. Carotenoids are considered to be crucial precursors for terpene complex formation, the major chemical substances contributing to the unique aroma and flavor of purple passion fruit. However, they are light and oxygen-sensitive compounds (Leavitt, 1988; Janzantti et al., 2012). Therefore, based on the results, low levels of O₂ concentration in the headspace gas would be ideal to minimize carotenoid degradation. MAP-2 packaging was most effective in delaying the loss of compounds such as β-carotene, lycopene and phytoene over time.

Passion fruit is vulnerable to pulp spoilage due
to juice fermentation. The high density peel acts as a barrier that obstructs gas permeability into the fruit’s internal cavity. Anaerobic respiration produces acetaldehydes and as it ferments, ethanol. During the experiment, ethanol concentration in passion fruit juice markedly increased over the storage period in all the packages (Figure 4f). Ethanol reached up to 3.5 g/L within 5 weeks under MAP-1 packaging. The juice obtained from passion fruit packaged in MAP-2 reached the same amount in 7 weeks. Ke and Kader (1992) suggested that ethanol accumulation was the most common and important detrimental effect that limited fruit tolerance to low \( O_2 \). On the other hand, Saltveit (1989) reported that stress and ripening conditions were considered key factors attributed to endogenously ethanol synthesis. Based on our empirical data, the increase of alcoholic compound seemed likely to be influenced by ethylene concentration in the headspace gas rather than the \( O_2 \) deficiency and \( CO_2 \) enrichment effects. Therefore, in MAP-1, where a higher ethylene concentration observed, higher accumulation of ethanol was probably induced via the higher and faster ripening process.

After observing the changes of total phenolic compound of passion fruit crude extract, fluctuating trends were apparent during the early storage period. However, all packaging conditions had no obvious effects on total phenolic compound (Figure 4g). The flavone C-glucoside is a major phenolic compound found in passion fruit juice, considered to be a strong antioxidative agent (Dhawan et al., 2004). Typically, high temperature and \( O_2 \) exposure induce the oxidation of the compound. Figure 4h provides evidence of the slight decrease in antioxidant activity in passion fruit crude extracts over time. The MAP-2 packaging delayed the lowering of antioxidant activity in crude extract for over 2 weeks when compared with the value obtained from MAP-1 packaging (day 35 for MAP-1 and day 49 for MAP-2). The decreases of antioxidant activities in this study could be associated with total carotenoid content and total phenolic compound tendencies since they are also in the family of radical scavengers found in passion fruit.

**Weight loss and storage life**

Weight loss was greater in passion fruit packaged in P-UAP; fruit samples continually lost their moisture content through perforated film, and became shriveled over the storage time. However, regression models presented in Figure 4i shows a higher y-axis intercept (0.021) for MAP-1 than P-UAP condition (0.001). This probably occurred because on day 0 (during cooling), packaged fruit in MAP-1 gradually lost moisture via respiration higher than fruit in P-UAP since they were cooled relatively slower (Figure 1).

After harvest, purple passion fruit lose weight rapidly, which causes shriveling under conventional packaging conditions. Higher moisture loss usually occurs in fruit peels rather than in pulp. Thus, fruit peels appear wrinkled and become visually unacceptable even if the sensory evaluation of the inside of the fruit indicates acceptable satisfaction among consumers (Pruthi, 1963; Shiomi et al., 1996a). Figure 4i illustrates the weight loss trends of the 3 packaging conditions. The MAP-2 packaging was the most efficient in controlling the weight loss and wrinkling, based on the lowest slope of linear regression. Both MAP-1 and MAP-2 packaging yielded total weight losses of less than 1.20% at the end of storage. Furthermore, with the lower WVTR and respiration rate at 10°C (Table 1), MAP-2 effectively delayed moisture loss better than MAP-1 with a significant difference over time. Kader et al. (1989) suggested that higher moisture loss in horticultural commodities corresponds to higher...
respiration and ethylene response. A lower level of O₂ and ethylene concentrations within MAP-2 packaging obviously helped to reduce the weight loss of the passion fruit. To avoid peel desiccation and excessive weight loss, the application of special plastic films could help to minimize fruit shrivelling (Kader, 1986; Kader et al., 1989).

Normally, low oxygen levels combined with moderate to high CO₂ levels are the recommended conditions for extending the storage life of horticultural commodities because these levels can retard cell respiration and regulate chilling injury resistance. These conditions are also recommended for fruit packaging, shipping and storage procedures (Kader et al., 1989; Kader and Ben-Yehoshua, 2000; Marrero and Kader, 2006). Likewise, in this study, passion fruit packaged in MAP-1 and MAP-2 had longer storage lives than the fruit packaged in P-UAP. These storage lives were 35, 51 and 28 days, respectively. Both MAP-1 and MAP-2 retained fruit quality and assured a fresh appearance during the storage period. The obtained results agree with those reported by Arjona et al. (1994), who found that the use of polyvinyl chloride film wrapping of yellow passion fruit helped to prevent moisture loss and retained fruit freshness for over 2 weeks at 10°C. Passion fruit packaged in MAP-2 had a much longer storage life than the fruit in MAP-1. In spite of the low OTR of MAP-2, the film lamination with ethylene absorbing functions helped to lessen respiration, metabolic processes and moisture loss resulting in preferable appearance and taste.

Sensory evaluation

Figure 5a shows the score for each variable used for quality evaluation. After 28 days of storage, the score of passion fruit peel color, visual quality, sweetness, peel shriveling and overall satisfaction from fruit packaged in P-UAP were significantly different from the score of passion fruit packaged in MAP-1, especially peel shriveling score, which affected consumer satisfaction greatly, and contributed to whether a sample was rejected. Panelists rated scores of satisfaction at only 2.89 (below 3.0). Thus, passion fruit in P-UAP were considered unmarketable even though the score for sweetness was higher than others and they were only slightly off-flavor. In fact, partially shriveled fruit were typically sweeter. The TSS/TA ratio was also used as an accompanying factor for sweetness rating (Figure 4c). However, the ratio showed no significant difference. The main factor affecting passion fruit quality is its peel characteristics, and in particular, shriveling. Consumers and markets are concerned with the outer appearance more than the internal taste. The study revealed that the occurrence of peel shriveling was directly accompanied by moisture loss (Figure 4i; Figure 4j). Therefore, passion fruit rated as unsatisfactory could be acceptable in palatable terms but not nutritionally.

Passion fruit stored for 35 days revealed more off-flavor incidence, especially the fruit packaged in MAP-1; the score reached above moderately off-flavor while the visual appearance score was still high and peel shriveling was found to be at acceptable levels (Figure 5b). Off-flavor in passion fruit juice is associated with anaerobic respiration with the key enzyme being alcohol dehydrogenase and a result of ethanol, which developed an unwanted odor and flavor (Kader, 1986). Low levels of oxygen and/or high levels of CO₂ and ethylene concentration increased the development of certain compounds (Ke and Kader, 1992). In this study, passion fruit packaged in MAP-1 developed off-flavor metabolites at a higher rate than fruit packaged in MAP-2, which was caused by the accumulation of ethylene within the package. Therefore, consumer satisfaction scores dropped below 3.0 and were considered unacceptable mainly due to off-flavors (scores of 2.13), even though peel characteristic scores were rated as positive (scores of 3.66).

Conclusions

This study demonstrated that MAP and active MAP had potential to be used to store fresh purple passion fruit under low temperature. O₂ and CO₂ gas equilibriums were developed based on films’ permeability. Of the tested packages, MAP was far superior to a conventional P-UAP. For instance, MAP alone was not effective to maintain fruit quality, whereas active MAP provided better physico-chemical quality retention and longer storage life extension. The findings could offer the basis for the changes in passion fruit quality under MAP conditions. In future work, gas compositions of package’s headspace will be focused in order to further develop gas prediction models and understand a clearer gas dynamics.

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Reference

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