International Food Research Journal 22(4): 1596-1606 (2015)
Journal homepage: *http://www.ifrj.upm.edu.my*

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

[1,2]Maniwara, P., [1*]Boonyakiat, D., [3]Poonlarp, P. B., [4]Natwichai, J. and [2]Nakano, K.

[1]*Division of Horticulture, Chiang Mai University, 239 Suthep, Chiang Mai, 50200, Thailand*
[2]*Graduate School of Science and Technology, Niigata University, 8050 Ikarashi 2-no-cho, Nishi-ku, Niigata, 950-2181, Japan*
[3]*Division of Food Engineering, Chiang Mai University, Maehea, Chiang Mai, 50100, Thailand*
[4]*Department of Computer Engineering, Chiang Mai University, 239 Suthep, Chiang Mai, 50200, Thailand*

Article history

Received: 19 September 2014
Received in revised form: 22 December 2014
Accepted: 24 December 2014

Keywords

Passion fruit
Postharvest quality
Modified atmosphere packaging
Storage

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 cm^3/m^2·day·atm, and (iii) MAP-2, an ethylene absorber laminated LDPE with an OTR of 12000 cm^3/m^2·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; Arjona *et al*., 1992). Postharvest deterioration is mainly caused by the loss of moisture content, peel color darkening, microbial contamination and nutritional loss. These factors contribute to the unacceptable appearance of fresh produce; this includes symptoms such as wrinkles, non-preferable color, postharvest decay and lack of nutritional content (Pruthi 1963; 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,

*Corresponding author.
Email: *danai.b@cmu.ac.th*

1986; Valero *et al*., 2008). Modified atmosphere packaging (MAP) technology employs the elevation of CO_2 and reduction of O_2 since most horticultural produce is O_2-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 O_2 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 O_2 scavengers, CO_2 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 ($KMnO_4$-based) mechanisms have been previously used in food industry in order to remove the unwanted compound by oxidation. Besides $KMnO_4$-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 avocadoes. 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 22.9ºC. 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 cm^2), polypropylene-polyethylene lamination with oxygen transmission rate (OTR) of 14000-16000 cm^3/m^2·day·atm (MAP-1), and active packaging (polypropylene-polyethylene lamination with ethylene absorbers) with OTR of 12000 cm^3/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 10ºC, 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 O_2 and CO_2 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 cm^3 of headspace gas within the package was sampled via a connecting septum and analyzed by a gas analyzer equipped with chemical sensors for O_2 measurement and an internal microprocessor with NDIR technology for CO_2 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 cm^3 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 cm^3) with continuous air flow (100 cm^3/min) at ambient temperature and at 10˚C. One cm^3 of gas sample was withdrawn and analyzed for CO_2 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 24.0ºC 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.

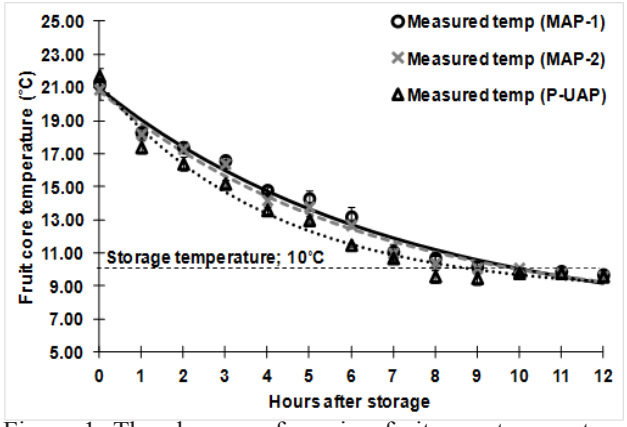

Figure 1. The changes of passion fruit core temperature packaged in 3 different packaging conditions and refrigerated at 10˚C

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

Table 1. Film's characteristics and packaging conditions

Parameters \ Package	MAP-1	MAP-2	P-UAP	Remarks
• **Package**				
Packing dimensions (width × length) (cm)	22.5 × 25.0	22.5 × 25.0	22.5 × 25.0	-
Thickness (µm)	24.5	26.9	45.0	-
OTR ($cm^3/m^2 \cdot day \cdot atm$)	15236 a	11883 b	N/A	*, **
WVTR ($g/m^2 \cdot day \cdot atm$)	21.7 a	19.3 b	N/A	*, **
Antifogging agent	Yes	Yes	No	-
Emitter/absorber	No	C_2H_4 absorber	No	-
Fruit load (g)	478.0±6.3	475.3±7.3	473.6±1.8	ns, **
Headspace volume (cm^3)	1251.7±36.6	1276.7±81.9	N/A	ns, **
• **Respiration rate** (mg CO_2/kg/hr)				
At ambient	592.9±14.9	572.7±25.6	621.4±15.4	ns
At 10°C (day 1)	330.9±9.0 a	274.1±9.0 b	348.7±13.9 a	*

*Means followed by at least one common letter, in the row, do not differ by Duncan's multiple range test at 5% (presented in Mean ± S.E.), while ns means not significant different

**The observations were made on Day 0, at 23˚C

N/A means not available

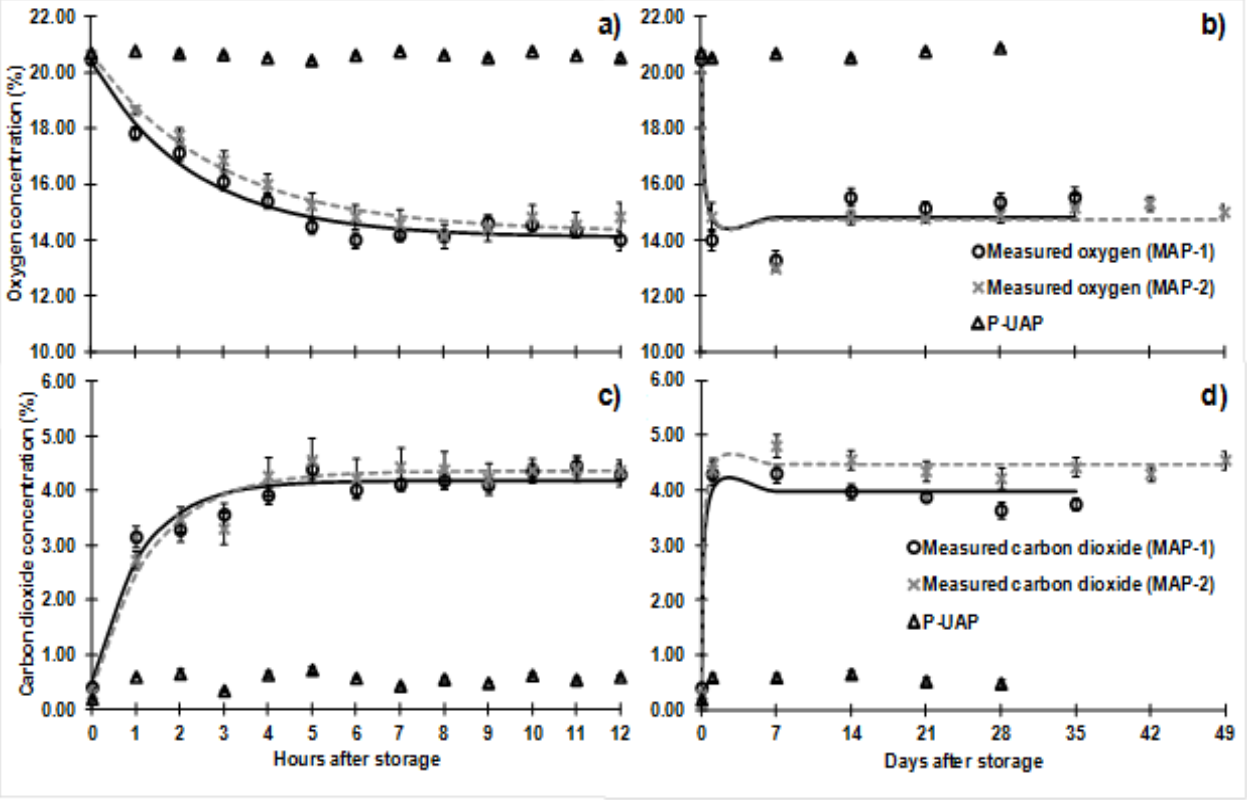

Figure 2. The changes of oxygen and carbon dioxide concentrations in the headspace of 3 packaging conditions monitored hourly (a and c) and every 7 days interval thereafter (b and d)

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, CO_2 concentrations in MAP conditions markedly increased during the first 5 hours after sealing. This was especially true in the first hour wherein CO_2 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 CO_2 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

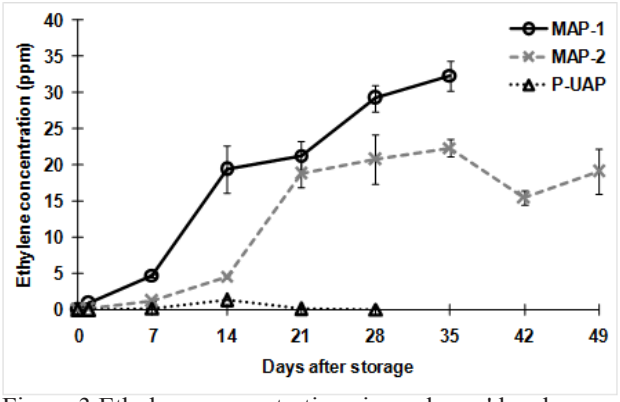

Figure 3.Ethylene concentrations in packages' headspace

higher in MAP-2 compared to MAP-1 and perforated UAP. In the obtained results, the amount of CO_2 corresponded to those values studied by Meir *et al.* (1997), who reported similar CO_2 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% CO_2, and 14-18% O_2 concentrations. These levels were found to be effective in delaying postharvest ripening and reducing ethylene production. Marrero and Kader (2006) suggested that a CO_2 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 CO_2 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 O_2 level typically lowered ethylene biosynthesis by reduction of 1-aminocyclopropane-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 O_2 and/or CO_2 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. CO_2 elevation and O_2 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

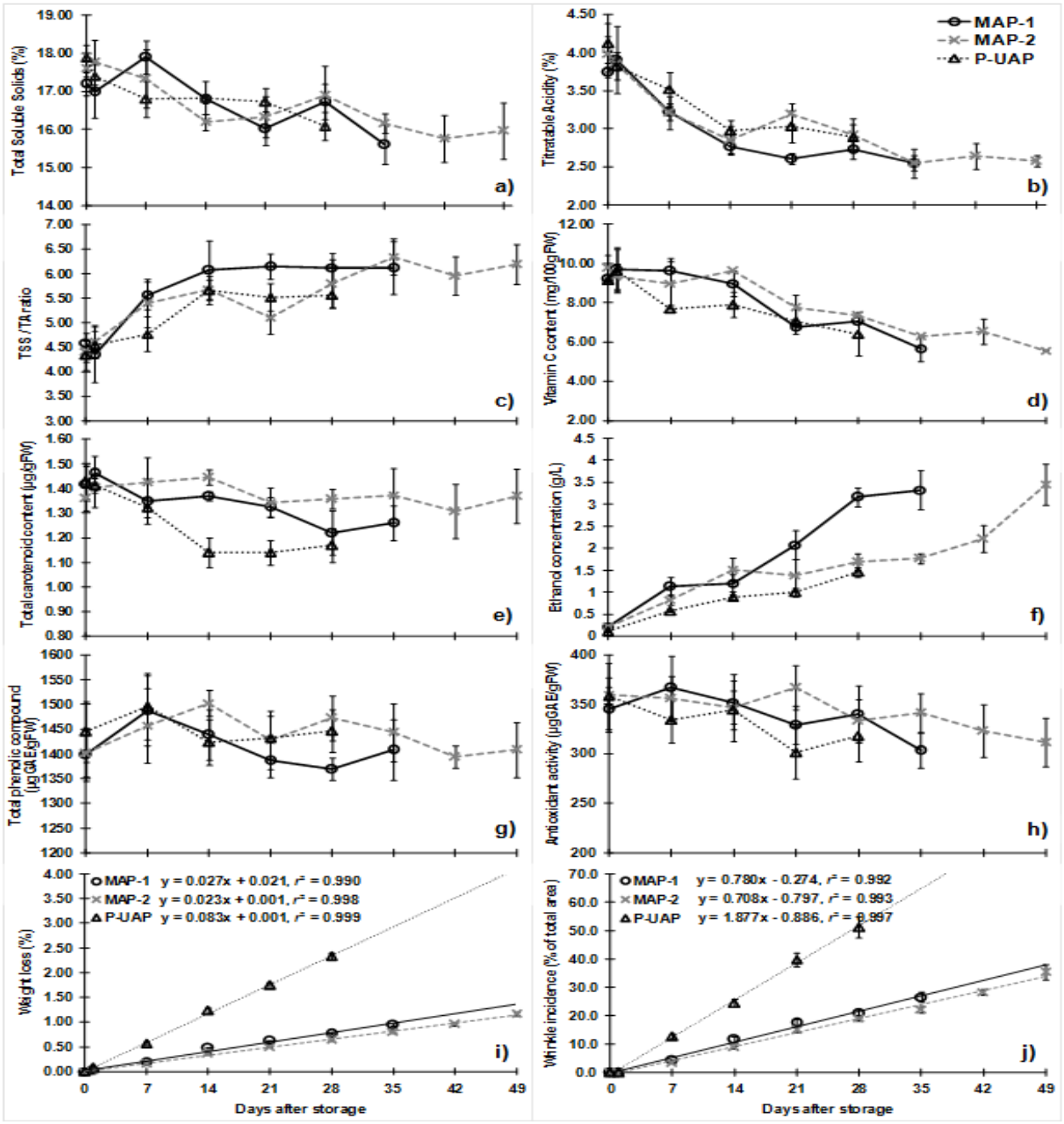

Figure 4. Changes of physico-chemical quality of passion fruit during storage at 10˚C under 3 packaging conditions

O_2, 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 O_2 might have helped to delay the oxidation of the vitamin C, while high levels of CO_2 might have helped to retard the vitamin C related oxidizing enzyme activity. Vinci *et al*. (1995) also reported that passion fruit stored at 4ºC 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 O_2 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

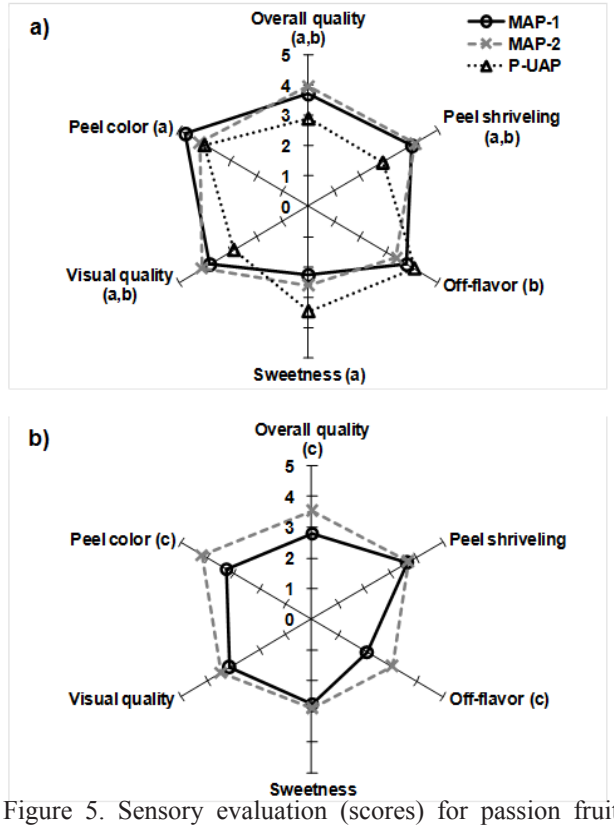

Figure 5. Sensory evaluation (scores) for passion fruit packaged in 3 different packaging conditions and stored at 10ºC, 76-83%RH for 28 days (Figure 8a) and for 35 days (Figure 8b). Significant differences are marked with a, b, and c, where a; difference between MAP-1 and P-UAP, b; difference between MAP-2 and P-UAP, and c; difference between MAP-1 and MAP-2

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 O_2 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 CO_2 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 CO_2 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. O_2 and CO_2 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.

Acknowledgement

Research funds and passion fruit samples were supported by The Royal Project Foundation (Thailand).

Reference

Arjona, H. E. and Matta, F. B. 1991. Postharvest quality

of passion fruit as influenced by harvest time and ethylene treatment. HortScience 26: 1297-1298.

Arjona, H. E., Matta, F. B. and Garner, J. O. 1992. Temperature and storage time affect quality of yellow passion fruit. HortScience 27: 809-810.

Arjona, H. E., Matta, F. B. and Garner, J. O. 1994. Wrapping in polyvinyl film slows quality loss of yellow passion fruit. HortScience 29: 295-296.

Biale, J. B. 1975. Synthetic and degradative processes in fruit ripening. In Haard, N. F. and Salunkhe, D. K. (Eds.). Postharvest biology and handling of fruits and vegetables, p. 5-18. Westport: AVI.

Bora, P.S. and Narain, N. 1997. Passion fruit. In Mitra, S. (Ed.). Postharvest physiology and storage of tropical and sub tropical fruits, p. 375-378. Singapore: C.O.S. Printers.

Bree, I. V., Meulenaer, B. D., Samapundo, S., Vermeulen, A., Ragaert, P., Maes, K. C., Baets, B. D. and Devlieghere, F. 2010. Predicting the headspace oxygen level due to oxygen permeation across multilayer polymer packaging materials: A practical software simulation tool. Innovative Food Science and Emerging Technologies 11: 511-519.

Chavan, U. D. and Kadam, S. S. 1995. Passion fruit. In Salunkhe, D. K. and Kadam, S. S. (Eds.). Handbook of fruit science and technology, production, composition, storage and processing, p. 445-454. New York: Marcel Dekker.

Conte, A., Scrocco, C., Brescia, I. and Del Nobile, M. A. 2009. Packaging strategies to prolong the shelf life of minimally processed lampascioni *(Muscari comosum)*. Journal of Food Engineering 90: 199-206.

Costa, C., Lucera, A., Conte, A., Mastromatteo, M., Speranza, B., Antonacci, A. and Del Nobile, M. A. 2011. Effects of passive and active modified atmosphere packaging conditions on ready-to-eat table grape. Journal of Food Engineering 102: 115-121.

Del Nobile, M. A., Baiano, A., Benedetto, A. and Massignan, L. 2006. Respiration rate of minimally processed lettuce as affected by packaging. Journal of Food Engineering 74: 60-69.

Dhawan, K., Dhawan, S. and Sharma, A. 2004. Passiflora: a review update. Journal of Ethnopharmacology 94: 1-23.

Díaz-Mula, H. M., Martínez-Romero, D., Castillo, S., Serrano, M. and Valero, D. 2011. Modified atmosphere packaging of yellow and purple plum cultivars. 1. Effect on organoleptic quality. Postharvest Biology and Technology 61: 103-109.

Fonseca, S. C., Oliveira, F. A. R. and Brecht, J. K. 2002. Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering 52: 99-119.

González-Aguilar, G. A., Ruiz-Cruz, S., Cruz-Valenzuela, R., Rodríguez-Félix, A. and Wang, C. Y. 2004. Physiological and quality changes of fresh-cut pineapple treated with antibrowning agents. LWT-Food Science and Technology 37: 369-376.

Homnava, A., Rogers, W. and Eitenmiller, R. R. 1990. Provitamin A activity of specialty fruit marketed in the United States. Journal of Food Composition and Analysis 3: 119-133.

Janzantti, N. S., Macoris, M. S., Garruti, D. S. and Monteiro, M. 2012. Influence of the cultivation system in the aroma of the volatile compounds and total antioxidant activity of passion fruit. LWT-Food Science and Technology 46: 511-518.

Kader, A. A. 1986. Biochemical and physiological basis for effects of controlled atmospheres. Food Technology 40: 99-104.

Kader, A. A. and Ben-Yehoshua, S. 2000. Effects of superatmospheric oxygen levels on postharvest physiology and quality of fresh fruits and vegetables. Postharvest Biology and Technology 20: 1-13.

Kader, A. A., Zagory, D. and Kerbell, E. L. 1989. Modified atmosphere packaging of fruits and vegetables. Critical Reviews in Food Science and Nutrition 28: 1-30.

Ke, D. and Kader, A. A. 1992. External and internal factors influence fruit tolerance to low-oxygen atmospheres. Journal of the American Society for Horticultural Science 117: 913-918.

Khanna, D., Sethi, G., Ahn, K. S., Pandey, M. K., Kunnumakkara, A. B. and Sung, B. 2007. Natural products as a gold mine for arthritis treatment. Opinion in Pharmacology 7: 344-351.

Leavitt, P. R. 1988. Experimental determination of carotenoid degradation. Journal of Paleolimnology 1: 215-227.

Manthey, J. A. 2004. Fractionation of orange peel phenols in ultrafiltered molasses and mass balance studies of their antioxidant levels. Journal of Agricultural and Food Chemistry 52: 7586-7592.

Marrero, A. and Kader, A. A. 2006. Optimal temperature and modified atmosphere for keeping quality of fresh-cut pineapples. Postharvest Biology and Technology 39: 163-168.

Montero-Calderón, M., Rojas-Graü, M. A. and Martín-Belloso, O. 2008. Effect of packaging conditions on quality *and shelf-life of fresh-cut pineapple* (Ananas comosus). Postharvest Biology and Technology 50: 182-189.

Pawelzik, E. 2005. Workshop on the nutritional quality and phytochemicals of tropical and sub-tropical fruits. Chiang Mai: Postharvest Technology Institute.

Pretel, M. T., Serrano, M., Martínez, G., Riquelme, F., Romojaro, F. 1993. Influence of films of different permeability on ethylene synthesis and ripening of MApackaged apricots. Lebensmittel-Wissenschaft and Technologie 26: 8-13.

Pruthi, J. S. 1963. Physiology, chemistry and technology of passion fruit. Advances in Food Research 12: 203-282.

Ranganna, S. 1995. Handbook of analysis and quality control for fruit and vegetable products. New Delhi: Tata McGraw Pub. Co.

Romero-Rodriguez, M. A., Vazquez-Oderiz, M. L., Lopez-Hernandez, J. and Simal-Lozano, J. 1994. Composition of babaco, feijoa, passion fruit and tamarillo produced in Galicia (north-west Spain). Food Chemistry 49: 23-

27.
Saltveit, M. E. 1989. Effect of alcohols and their interaction with ethylene on the ripening of epidermal pericarp discs of tomato fruit. Plant Physiology 90: 167-174.
Sellappan, S., Akoh, C. C. and Krewer, G. 2002. Phenolic compounds and antioxidant capacity of Georgia-grown blueberries and blackberries. Journal of Agricultural and Food Chemistry 50: 2432-2438.
Shiomi, S., Kubo, Y., Wamocho, L. S., Koaze, H., Nakamura, R. and Inaba, A. 1996a. Postharvest ripening and ethylene biosynthesis in purple passion fruit. Postharvest Biology and Technology 8: 199-207.
Shiomi, S., Wamocho, L. S. and Agong, S. G. 1996b. Ripening characteristics of purple passion fruit on and off the vine. Postharvest Biology and Technology 7: 161-170.
Terry, L. A., Ilkenhans, T., Poulston, S., Rowsell, L. and Smith, A. W. J. 2007. Development of new palladium-promoted ethylene scavenger. Postharvest Biology and Technology 45: 214-220.
Valero, A., Begum, M., Hocking, A. D., Marín, S., Ramos, A. J. and Sanchis, V. 2008. Mycelial growth and ochratoxin A production by *Aspergillus* section Nigri on simulated grape medium in modified atmospheres. Journal of Applied Microbiology 105: 372-379.
Valero, D., Valverde, J. M., Martínez-Romero, D., Guillén, F., Castillo, S. and Serrano, M. 2006. The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safety and functional properties of table grapes. Postharvest Biology and Technology 41: 317-327.
Vermeiren, L., Devlieghere, F., Beest, M. V., Kruijf, N. D. and Debevere, J. 1999. Developments in the active packaging of foods. Trends in Food Science and Technology 10: 77-86.
Vinci, G., Botrè, F., Mele, G. and Ruggieri, G. 1995. Ascorbic acid in exotic fruits: a liquid chromatographic investigation. Food Chemistry 53: 311-314.
Zeraik, M. L. and Yariwake, J. H. 2010. Quantification of isoorientin and total flavonoids in *Passiflora edulis* fruit pulp by HPLC-UV/DAD. Microchemical Journal 96: 86-91.
Zeraik, M. L., Serteyn, D., Deby-Dupont, G., Wauters, J., Tits, M., Yariwake, J. H., Angenot, L. and Franck, T. 2011. Evaluation of the antioxidant activity of passion fruit (*Passiflora edulis* and *Passiflora alata*) extracts on stimulated neutrophils and myeloperoxidase activity assays. Food Chemistry 128: 259-265.