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Packaging affects the postharvest quality of atemoya fruits (*Annona cherimola* M. × *Annona squamosal* L.)

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ABSTRACT

The aim of the present study was to investigate the postharvest quality of atemoya fruits (*Annona cherimola* M. x *Annona squamosa* L.) keeping under different packaging materials in refrigerated conditions. Fruits were treated with 1000 ppm of ethrel at 25°C for three days and packaging by 1) individually sealed in a low-density polyethylene bag (LDPE), 2) wrapped polyvinylchloride (PVC) film, and 3) unpacked as the control, and then stored at 5°C for eleven days. Data of ripening days, weight loss, fruit firmness, total soluble solids (TSS), titratable acidity (TA), peel and flesh color, chilling injury index, and browning index were recorded at the ripening stage. Both packaged fruits had 13 days of postharvest life, and higher fruit firmness. The least fresh weight loss during storage is showed by PVC film. There were no significant differences in TSS, TA, and peel and flesh color among all treatments; however, the LDPE and PVC packed fruits showed the least levels of chilling injury and browning, as well.

Keywords: *Annona* fruit, modified atmosphere packing, fruit quality.

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INTRODUCTION

Atemoya (*Annona cherimola* M. x *Annona squamosal* L.) is an exotic subtropical fruit consumed in many countries because of its rich flavor and sweet flesh when fully ripe (Pinto et al., 2005), and thus become an important commercial fruit in Taiwan. In general, atemoya fruits are harvested when fully mature and green color (Pinto et al., 2005), then kept to ripen under storage conditions. Atemoya fruits reach acceptable eating quality accompanied with softening at the beginning of the post-climacteric period, with a postharvest shelf-life about 3 to 6 days depending on harvest days (Pereira et al., 2010).

Atemoya is a climacteric fruit with a high respiration rate and ethylene production during the ripening process (Brown et al., 1988; Morena and De La Plaza, 1993) leading to skin browning (Martinez et al., 1993; Lima et al., 1994) and fruit softening without proper postharvest handling, thus affecting the market value. It is reported that low temperature storage (between 7 and 12°C) is an alternative to prolong the shelf-life of *Annona* without deterioration in appearance or flavor depending on cultivars (Pareek et al., 2011). Although lower temperature is generally used for postharvest preservation of atemoya (Batten, 1990), but the fruit is very sensitive to low temperatures, showing chilling injury e.g., browning of skin, and deterioration in flavor and texture with subsequent shriveling (Batten, 1990; Wills et al., 1984). Furthermore, when *Annona* fruits were stored at 4°C for one week serious discoloration occurred (Batten, 1990; Brown and Scott, 1985), as well as abnormal ripening (Alique and Zamorano, 2000). Since atemoya is easily perishable when stored at either low temperatures or in the ambient environment, how to maintain the fruit quality and prolong its shelf-life during the postharvest period is very important. Among various postharvest technologies that have been developed, modified atmosphere packing (MAP) along with low temperature storage is generally used for extending shelf-life of fruits and vegetables.

MAP uses a polymeric film package to modify the O_2 and CO_2 percentage within the package atmosphere (Mangaraj et al., 2009), thus maintaining fruit quality and increasing its shelf-life (Ding et al., 2002). Reports

showed that MAP along with a low storage temperature is useful to maintain fruit color in rambutan (*Nephelium lappaceum*) (Mohamed and Eshah, 1988), a reduction in weight loss in litchi (*Litchi chinensis*) (Somboonkaew and Terry, 2010), higher fruit firmness in pomegranate (*Punica granatum*) (Nanda et al., 2001), and longer preservation of atemoya 'Genifer' (Silva et al., 2009).

However, the postharvest quality of atemoya fruits with regard to different MAP and storage temperatures remains understudied in the literature. Therefore, the aim of the present study was to investigate effects of different packages under constant refrigerated storage on the postharvest quality of this fruit.

MATERIALS AND METHODS

Site description

Atemoya fruits (*Annona cherimola* M. x *Annona squamosal* L.) were obtained from 20-year-old trees grown in a commercial atemoya orchard in Beinan Township, Taitung County, Taiwan (lat. 22.47°N, long. 121.07°E, elevation 200 m).

Materials and storage conditions

Unripe fruits were harvested in the early morning on 24 March 2013, 167 days after anthesis (DAA), and shift to the laboratory within 12 h. All fruits were selected for uniformity (e.g., size, pre-climacteric hard green color, and free of defects and diseases), and were ripened with 1000 ppm of ethrel at 25°C for three days. The atemoya fruits were randomly divided into three groups; individually packed in a 0.03 mm low-density polyethylene bag (LDPE), wrapped in a polyvinylchloride (PVC) film, and unpacked as the control. Afterward, all fruits were placed in a storage chamber (RS0571BHA TECO, Taiwan) at 5°C (85 to 95% relative humidity (RH)) for eleven days. On the twelfth day, they were moved to the ambient temperature of 25°C, unwrapped, and kept until they reached the ripe stage for quality analysis.

Weight loss

Five fruits of each group were weighed before and after storage, and at the ripe stage using a digital balance (SCALTEC SBA-51, Germany). The fresh weight loss rate was calculated as follows: ((initial fresh weight before storage – fresh weight at ripe stage)/(initial fresh weight before storage))×100%, and the average was then determined.

Assessment of fruit ripeness

Atemoya fruits are considered to be ripe and edible when the epicarp of the equator and stalk of fruit are soft to finger pressure.

Chilling injury evaluation

After storage, each fruit was visually evaluated for the presence and severity of chilling injury (e.g., hard and black pitting on the peel). The symptoms of chilling injury were those described followed Alique and Zamorano (2000). A non-chilling injury was expressed as 1; 2, 10% chilling injury; 3, 10-30% chilling injury; and 4, more than 30% chilling injury.

Fruit peel and flesh color analysis

Peel color measurement was taken on the two ends of equator, respectively. Each side of the fruit was measured using a tristimulus colorimeter (HunterLab ColorFlex, USA) for L*, a*, and b* values. The hue angle (h^o) = ($\tan^{-1}$ b*/a*) and chroma (C*) = square root of ($a^{*2}+b^{*2}$), were calculated from a* and b*. The readings were then averaged to represent the color of the fruit peel. The same fruit samples were cut into two halves along the vertical axis procedure, and used for flesh color analysis, following the same procedure.

Browning investigation

After flesh color measurement, the browning area of each half pulp was visually assessed as 1, non-browning; 2, 10% browning; 3, 10-30% browning; 4, more than 30% browning.

Fruit firmness

The same five fruits were used for firmness measurements, which were made in opposite sides of each half using a penetrating probe at a point around the equator equidistant from the distal and proximal ends of the fruit. A penetrometer (Fudoh Rheometer, NRM-2020J-CW, Japan) was used for the measurements, and the readings were averaged and expressed in units of kilograms per square centimeter ($kg \cdot cm^{-2}$).

Total soluble solid, titratable acidity and TSS to TA ratio

A few drops of juice from both halves of each fruit were placed on a refractometer (ATAGO PAL-1, Japan), and the readings from were averaged and expressed as °Brix (%).The same fruit juice was used to assess titratable acidity by titrating with 0.1 N NaOH to a final pH of 8.1, and it was expressed as percentage of citric acid. The TSS to TA ratio was expressed as the (TSS / TA).

Statistical analysis

The data was collected and analyzed by analysis of variance (ANOVA) using SAS (version 9.2; SAS Institute, Cary, NC). Mean value separations were performed using a least significant difference (LSD) test at a 5% significance level ($P \leq 0.05$).

RESULTS

Fruit physicochemical characteristics

The TSS and TA of the atemoya fruits were not affected by whether they were packaged or not; the highest TSS value was 26.8, as found in control fruits, whereas the lowest value was 25.6, found in LDPE bag wrapped fruits (Table 1). In addition, the results showed that packaging did not alter the TSS/TA ratio of atemoya fruits (Table 1), indicating that fruit flavor could be maintained when wrapped in LDPE and PVC.

After storing for 11 days at 5°C, the control fruits ripened within two days at 25°C, and those wrapped with

Table 1. Effects of package on ripening day, total soluble solid, titratable acidity, TSS/TA ratio, weight loss, and firmness of atemoya fruit stored at 5°C for 11 days followed by ripening at ambient temperature (25°C).

Treatments	Days taken for ripening	TSS (°Brix)[z]	TA (%)[z]	TSS/TA[z]	Weight loss (%)[z]	Firmness (kg·cm^{-2})[z]
CK	1 - 2	26.8 ± 0.1 a[y]	0.30 ± 0.01 a	89.3 ± 1.1 a	6.82 ± 0.05 a	0.25 ± 0.01 b
LDPE bag	2 - 3	25.6 ± 0.1 a	0.28 ± 0.01 a	91.4 ± 1.3 a	7.38 ± 0.08 a	0.39 ± 0.01 a
PVC film	2 - 3	26.2 ± 0.1 a	0.27 ± 0.02 a	97.0 ± 1.2 a	5.70 ± 0.1 b	0.38 ± 0.02 a

[z]Values are means ± SE, for n = 5.
[y]Values in a column with different letters are statistically different by a least significance difference (LSD) test at P ≤ 0.05.

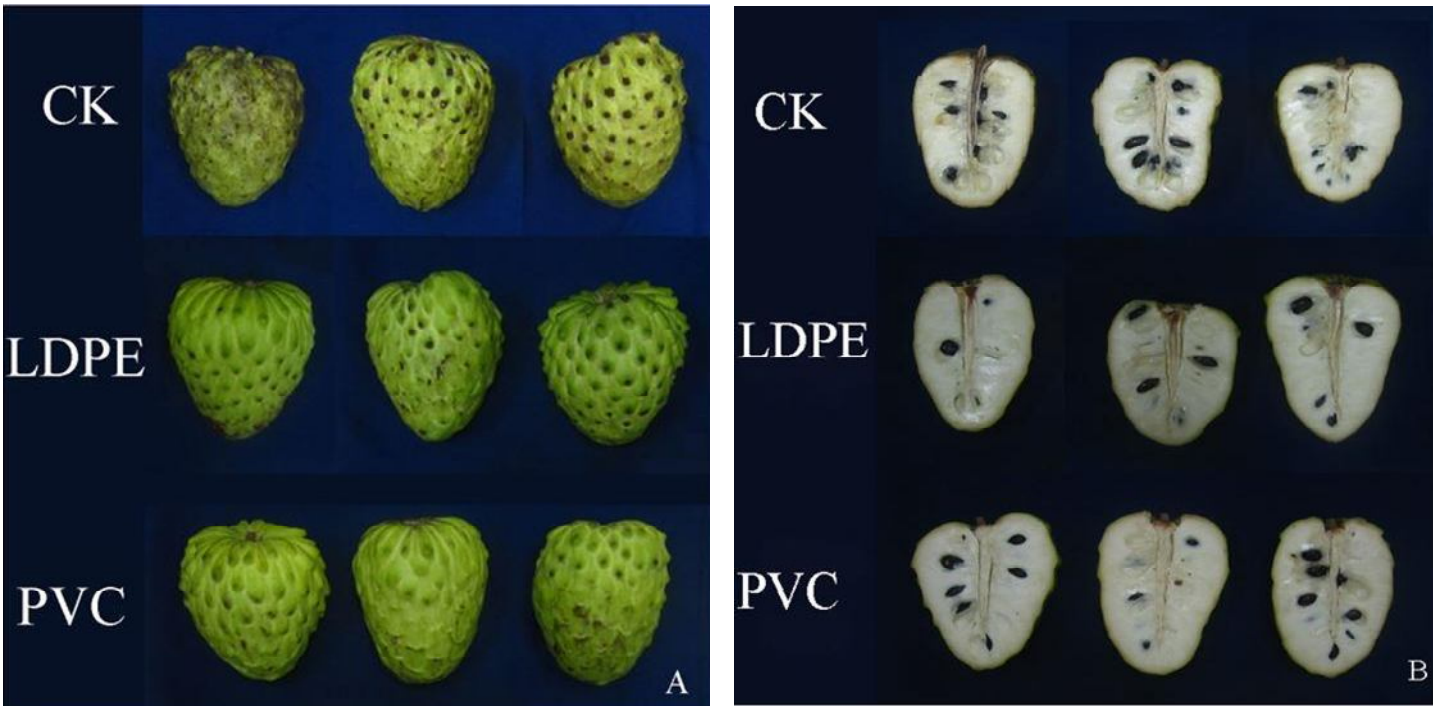

Figure 1. Effects of package on peel appearance (A) and flesh color (B) of atemoya fruit stored at 5°C for 11 days followed by ripening at ambient temperature (25°C).

PVC and LDPE ripened one day later (Table 1). Although the weight loss (non-significant) of LDPE wrapped fruits, PVC packaged fruits, and non-packaged fruits were 4.52, 4.42 and 4.14%, respectively, a significant difference in weight loss was found when they reached the ripe stage. Non-sealed fruits and LDPE wrapped fruits had greater weight loss than the PVC packed fruits, losing 6.82, 7.38 and 5.70%, respectively (Table 1).

Fruit firmness

Both LDPE bag and PVC packed fruits showed no differences in fruit firmness, and both were significantly more firm than the non-sealed fruits after storage. The fruit firmness of the LDPE and PVC packed fruits were 0.39 and 0.38 kg·cm^{-2}, respectively, while that of the control fruits was 0.25 kg·cm^{-2} (Table 1).

Peel and flesh color

After low temperature (5°C) storage, both packaged and non-packaged fruits showed some black pitting on the peel (Figure 1A); however, there was no significant difference in peel color between both packing treatments (Table 2). Similarly, atemoya fruits with and without packaging showed little browning in flesh (Figure 1B); while, neither packed nor non-packed fruits had any significant differences in flesh color (Table 2).

Chilling injury and browning

Non-wrapped atemoya fruits showed a significant chilling injury index in comparison with wrapped fruits (Figure 1A, Table 2); the highest chilling injury was 2.7, found for the non-wrapped atemoya fruits. Both wrapped fruits showed

Table 2. Effects of package on peel and flesh color, chilling injury, and browning of atemoya fruit stored at 5°C for 11 days followed by ripening at ambient temperature (25°C).

Treatment	L*[z]	C*[z]	h°[z]	Chilling[y]	Browning[x]
Peel					
Control	50.8 ± 1.3 a[w]	35.2 ± 1.0 a	97.2 ± 1.1 a	2.7 ± 0.4 a	-
LDPE bag	53.3 ± 1.1 a	36.8 ± 0.9 a	99.0 ± 0.8 a	1.5 ± 0.1 b	-
PVC film	54.2 ± 0.7 a	36.4 ± 1.1 a	98.5 ± 1.2 a	1.2 ± 0.3 b	-
Flesh					
Control	80.1 ± 1.4 a	12.9 ± 1.0 a	92.2 ± 1.1 a	-	2.6 ± 0.2 a
LDPE bag	82.7 ± 1.0 a	13.2 ± 1.0 a	94.0 ± 1.0 a	-	1.3 ± 0.3 b
PVC film	83.1 ± 1.4 a	12.6 ± 1.1 a	95.4 ± 1.2 a	-	1.0 ± 0.1 b

L* value is ranging from 0 = black to 100 = white. Chroma (C*) is the saturation of color. Hue angle (h°) of 0 (360) = red, 90 = yellow, 180 = green, and 270 = blue.
[z]Values are means ± SE, for n = 5.
[y]Chilling injury was investigated on the peel only.
[x]Browning was evaluated on the flesh only.
[w]Values in a column with different letters are statistically different by a least significance difference (LSD) test at P ≤ 0.05.

no differences in chilling injury. On the other hand, a significant difference in browning index was found between the control and wrapped fruits, but there was no significant difference between LDPE and PVC treatments (Figure 1B, Table 2). The highest browning index was 2.6, found for the non-packaged fruits.

DISCUSSION

The results of this study showed that both sealed and non-sealed atemoya fruits can be stored at least for 13 days (11 days in storage at 5°C plus two days to ripen at 25°C) (Table 1), which was different from previous studies. Yamashita et al. (2002) indicated that non-packaged atemoya fruits had a shelf-life of 13 days at 15°C, and fruits wrapped with PD-955 (copolymer) could last to 17 days. The difference between these two studies is probably first all the fruits in the current study were treated with 1000 ppm of ethrel at 25°C for three days before wrapping, and thus the ripening process was triggered initially, and then affected its normal metabolism by later refrigerated storage. Second, the package materials have different water, O_2, and CO_2 transmission rates leading to different shelf-life. Third, the longer atemoya fruits stored in the low temperature, the quicker ripening of fruit when moved to the ambient temperature of 25°C. Montero et al. (1995) reported that cherimoya fruits were not fully ripened when fruits were stored at 6°C, while Alique et al. (1994) found that cherimoya fruits should be transferred to 20°C for ripening after storing at 8°C for 12 days. Therefore, the combination of package materials and storage temperatures used in this study retarded the ripening process of *Annona* fruits leading to extension of postharvest life.

The major weight loss resulted from water transpiration during the postharvest period. There was no significant difference found in weight loss during storage, but a significant difference in weight loss was found when atemoya fruits reached the ripened stage (Table 1). Yamashita et al. (2002) reported that packaged atemoya fruits showed 10 times lower weight loss compared to those kept unwrapped after being stored for the same time and at the same temperatures. In our study, the weight loss was different to those reported by Yamashita et al. (2002), and this is probably due to differences in film permeability, storage temperature and relative humidity in the two works. High humidification of the storage chamber could cause less water loss to the fruit during storage (Yamashita et al., 2002), while moving the fruits to the atmosphere and temperature (25°C) resulted in more loss of water.

Weight loss directly affects fruit quality, in terms of reduced fruit firmness and loss of brightness in the appearance. In the present study, control fruits had high weight loss and the lowest fruit firmness, as expected, similar to previous studies (Batten, 1990; Yamashita et al., 2002; Vishnu Prasanna et al., 2000). However, the LDPE wrapped fruits had the highest weight loss and the highest fruit firmness, in contrast the earlier reports. Although low temperature storage could prolong postharvest life, non-packaged fruits could have higher respiration rates in comparison with LDPE and PVC packaged fruits, leading to faster ripening (Yamashita et al., 2002), and thus the unpacked fruits were softer and had more TSS content than packaged fruits. On the other hand, weight loss was not associated with fruit peel or color in this study. A non-significant difference in fruit appearance and flesh among these packaging treatments was found, although there were some black pitting on the peel, and browning on the flesh (Table 2 and Figure 1A and B).

Previous studies found that *Annona* are sensitive to low temperatures, depending on cultivars, resulting in chilling injury, showing surface pitting and blackening (Batten, 1990; Brown and Scott, 1985; Fuster and Prestamo, 1980; Vishnu Prasanna et al., 2000; Yonemoto et al., 2002). Batten (1990) stated that atemoya 'African Pride' fruits stored at 4°C for a week showed deterioration in appearance due to chilling injury. Campos-Vargas et al. (2008) reported that fresh cut cherimoya exhibited browning in the pulp when stored at 0°C for six days. Although all fruits were stored at 5°C for 11 days in the current study, we found that the non-sealed fruits suffered more obvious chilling injury than the packaged fruits (Table 2 and Figure 1A and B). This could be explained by the fact that packaging retarded the ripening and consequently maintained the fruit quality and prolonged its shelf-life.

Conclusion

Our results indicated that LDPE bag and PVC film packing could extend atemoya postharvest life to 13 days (11 days in storage at 5°C, plus two days to ripen at 25°C) without showing severe evidence of deterioration in the peel or flesh. In addition, both LDPE and PVC packaging could retain the firmness, TSS, TA, and flavor of atemoya fruit during low temperature storage. In the future, more studies on different types of film packaging and ranges of storage temperature are needed to see how they affect the shelf-life of atemoya fruits.

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