

## **Effect of modified atmosphere on the storage life and quality of Eksotika papaya**

(Kesan atmosfera terubahsuai terhadap tempoh simpan dan mutu betik Eksotika)

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Key words: modified atmosphere, storage life, quality, Eksotika papaya

### **Abstrak**

Penyimpanan dalam atmosfera terubahsuai pada suhu 10 °C dapat memanjangkan tempoh simpan betik Eksotika. Teknik pembungkusan dan kandungan gas persekitaran memainkan peranan yang penting semasa penyimpanan. Pembungkusan secara pukal (9–10 biji sebungkus) dengan kandungan gas CO<sub>2</sub> dan O<sub>2</sub> masing-masing pada aras 5% dan 4% dapat memanjangkan tempoh simpan selama 3–4 minggu. Tempoh simpan dilanjutkan selama 5–6 minggu apabila buah dibungkus secara tunggal dengan persekitaran yang mengandungi 4% CO<sub>2</sub> dan 8% O<sub>2</sub>. Penggunaan penyerap gas etilena semasa penyimpanan juga berkesan untuk mengurangkan kandungan gas tersebut dan seterusnya merencatkan proses kemasakan buah. Dalam keadaan ini, kesegaran buah dapat dipelihara semasa penyimpanan tanpa perubahan warna kulit dan mutu secara ketara. Buah juga masak secara biasa dalam tempoh 3–4 hari apabila dipindahkan kepada suhu ambien. Warna kulit menjadi kuning dan mutu isi masih baik dan dapat diterima.

### **Abstract**

Storage in modified atmosphere at 10 °C extended the storage life of Eksotika papaya. The packaging technique and composition of gases in the storage environment played important roles during storage. Bulk packaging (9–10 fruit/pack) containing CO<sub>2</sub> and O<sub>2</sub> at 5% and 4% respectively helped to extend the storage life up to 3–4 weeks. The storage life was extended to about 5–6 weeks when the fruit were wrapped individually with gas composition in the environment containing 4% CO<sub>2</sub> and 8% O<sub>2</sub>. The use of ethylene absorbent during storage was also effective in reducing the ethylene gas content and thus the ripening process was retarded. With these conditions, the freshness of the fruit was maintained during storage without significant changes in the skin colour and fruit quality. Fruit ripened normally within 3–4 days when transferred to ambient temperature. The skin changed to yellow, and the pulp quality was still good and acceptable.

### **Introduction**

Modification of the storage environment is one of the postharvest preservation techniques which has been found to be

successful in extending the storage life of some fruits and vegetables. This technique can be achieved by two methods, namely controlled atmosphere (CA) and modified

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atmosphere (MA). CA relies on the continuous measurement of the gas composition of the storage space and, when warranted, injection of an appropriate gas or gas mixture into the storage space to maintain the desired gas composition (O'Connor et al. 1992). MA is generated in a static system with no monitoring of the gas composition during storage. CA has been widely used for commercial storage of apples and pears with limited usage for cabbage, kiwifruit and onion (Abdul Shukor 1993). Application of MA technology is still limited even though various studies have been conducted on the responses of tropical fruits to MA environment (Kader 1993). Only bananas had been successfully transported commercially using this technology because of the favourable response of the fruit to MA. The Mas bananas, for example, when harvested at the mature green stage can be stored for 8 weeks under MA at 14 °C (Abdullah and Mohd. Salleh 1993). Under this condition, the fruit can be transported by ship for long distances.

Another tropical fruit which has shown favourable response towards MA packaging, is the Eksotika papaya (*Carica papaya* L.), a new hybrid variety in Malaysia. With the introduction of this new variety, demand for the fruit is increasing, especially from the Gulf States and Europe. However, these highly perishable fruit can be air-freighted to these countries in limited amount. Extension in the storage life will enable the fruit to be transported cheaply, in a larger quantity by ship. The potential for extending the storage life of Eksotika papaya using MA has been studied (Lazan et al. 1990; Lazan and Ali 1991; Latifah et al. 1993) and transportation of the fruit has also been shown to be possible under MA (Rohani and Zaipun 1995).

MA environment can be generated in a package by the interaction of the produce, the package and the external atmosphere (Ben-Yehoshua et al. 1993). The initial atmosphere may be either air or a gas

mixture, and different additives affecting the atmosphere may be introduced into the package before it is sealed. Various packaging materials such as polyethylene, polyvinyl chloride and polyolefin which have low permeability to gases, can be used to create the MA condition. New packaging materials such as 'smart packaging', 'reduced O<sub>2</sub> packaging' (Bedrosian 1991; Anon. 1992) and 'anti-aging' packaging materials (Anon. 1990) capable of regulating the diffusion of gases are also being manufactured and used for the creation of MA environment. However, the MA created in the packages will have O<sub>2</sub> below the atmospheric level (<21%) and CO<sub>2</sub> above the atmospheric level (>0.03%) (O'Connor et al. 1992). To be more specific, the minimum concentration of O<sub>2</sub> tolerated by some commodities is 1–5% and the maximum concentration of CO<sub>2</sub> is 2–15% (Kader et al. 1989). These are the conditions found to be beneficial in extending the storage life of fruits and vegetables.

Therefore, this study was conducted to determine the effect of MA on the storage life and quality of Eksotika papaya stored at low temperature (10 °C). The technique of packaging suitable for sea transportation of Eksotika papaya and the concentration of gases within the packages were also determined.

## Materials and methods

### Preparation of samples

Eksotika papayas at commercial maturity were bought from FAMA in Chuicak, Perak. Only fruit having a tinge of yellow at the blossom end (colour index 2) were selected for the study. The selected fruit were transported in plastic baskets to the Food Technology Research Centre, MARDI, Serdang.

At the laboratory, the fruit were washed with cold water and the peduncles were trimmed. After washing, they were subjected to double hot water treatment (42 °C for 30 min followed by 49 °C for 20 min) to control diseases and as a quarantine

treatment against fruit flies (Lam and Sepiah 1989). They were then cooled in running tap water (ambient temperature) for 20 min before dipping in fungicide, propiconazole at 250 ppm, for 5 min (Sepiah et al. 1991) to control fungus such as *Colletotrichum* sp. The fruit were allowed to dry properly before packing.

### ***Packaging and storage***

All the fruit were individually packed using polystyrene foam netting to protect them from damage due to contact against each other. To create the MA environment, the fruit were wrapped with 0.04 mm thick low density polyethylene (LDPE) bags. The fruit were wrapped using three treatments. In the first treatment (PE), the bottom of a 30 cm x 37 cm x 17 cm corrugated fiberboard box (CFB) specially designed for Eksotika papaya was lined with a LDPE bag measuring 66 cm x 72 cm. Ten fruit were placed inside the bag whose opening was then twisted and tied tightly with a rubber band. In the second treatment (PE + Abs), the packaging was done similar to the first treatment but with the inclusion of two sachets (30 g) of ethylene absorbent (*Cleanpack*). In the third treatment [PE + Abs (S)], the fruit were individually wrapped in LDPE bags measuring 20 cm x 30 cm and one sachet (15 g) of ethylene absorbent was inserted inside each bag. The opening of the bag was then heat-sealed. After wrapping, 10 fruit were placed in each of the CFB. For the control, 10 fruit were taken and placed in the CFB without wrapping. All of the boxes were closed and stored at 10 °C for 7 weeks. Each treatment was replicated four times.

### ***Observation and sampling***

Observation and sampling of the fruit were carried out at 0, 1, 3, 5, and 7 weeks after storage. At 0 week, the observation was done 24 h after storage at 10 °C. At each sampling period, analyses were done on the composition of gases in the LDPE bags, the physical and chemical quality of the fruit.

### ***Measurement of gas composition***

Measurement of gases such as CO<sub>2</sub>, O<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> were taken only for fruit wrapped with LDPE bags. The gases were extracted from the bags immediately upon removal from the cold room. The CO<sub>2</sub> in the bag was measured by injecting 1 mL of the air from the bag into a Varian 1420 thermal conductivity detector gas chromatograph fitted with a stainless steel column packed with Porapak R of size 80/100 mesh. The carrier gas was helium at a flow rate of 25 mL/min with 30 °C column temperature.

Similarly, the O<sub>2</sub> was also measured using the Varian 1420 gas chromatograph using molecular sieve type 5A column with the flow rate of helium at 30 mL/min.

The amount of C<sub>2</sub>H<sub>4</sub> was measured using the Varian 1440 flame ionization detector gas chromatograph fitted with Porapak T column of 100/120 mesh size. The carrier gas was nitrogen at a flow rate of 30 mL/min and oven temperature of 100 °C.

### ***Quality analyses***

Both physical and chemical quality of fruit were analysed immediately after removal from cold storage and subsequently upon fruit ripening. The LDPE bags were removed when the fruit were transferred to ambient temperature. Five fruit from each treatment were analysed immediately while the remaining five were allowed to ripen at ambient temperature (28 °C) within 3–4 days.

Physical analyses included weight loss, changes in skin and pulp colour, development of chilling injury and diseases. Weight loss was determined by subtracting the fruit weight at each observation from the initial weight at 0 week.

Changes in skin and pulp colour were measured using the Minolta CR200 chromameter which expresses colour in three numerical notation system as  $L^*$ ,  $a^*$  and  $b^*$  values.  $L^*$  denotes the lightness and darkness of the colour while  $a^*$  and  $b^*$  denote the hues which represented two

colour axes with  $a^*$  the red-green axis and  $b^*$  the yellow-blue axis. The chroma ( $C^*$ ) which indicates the intensity of the colour was also calculated using the formula  $C^* = \sqrt{(a^{*2} + b^{*2})}$ .

Development of chilling injury (observed as sunken brown watery spots on the skin) and diseases were recorded using a numerical score where 0 = not affected, 1 = <25% of skin affected, 2 = 25–50% of skin affected and 3 = >50% of skin affected.

The analysis of chemical quality of the fruit included the pH, percentage of total soluble solids (TSS), total titratable acidity (TTA) and total sugars (TS). The pH was determined by blending half of the fruit at room temperature and readings were taken using the Orion digital pH meter model SA520. The TSS of the expressed fruit juice was measured using an Atago digital refractometer (0–32% Brix). The TTA was determined by titrating a known weight of blended fruit sample to pH 8.1 with 0.1N NaOH and the results expressed as percentage of citric acid. The TS were analysed by the method of Lane and Eynon (AOAC 1975).

The data were statistically analysed with analysis of variance and the Duncan's Multiple Range Test was used as the test of significance.

## Results and discussion

### *Composition of gases in the modified atmosphere environment*

Wrapping the fruit with LDPE bags with and without ethylene absorbent created a modified atmosphere (MA) environment around the fruit. The respiratory activity of the fruit quickly modified the gas composition. Within 24 h, the air in the bags differed from atmospheric air. Elevation of  $\text{CO}_2$ , reduction of  $\text{O}_2$  and accumulation of  $\text{C}_2\text{H}_4$  occurred in all packages (Figure 1). There were differences in the amounts of gases accumulated within the packages during the 7-week storage period. These differences were affected by the number of fruit and the presence of ethylene absorbent

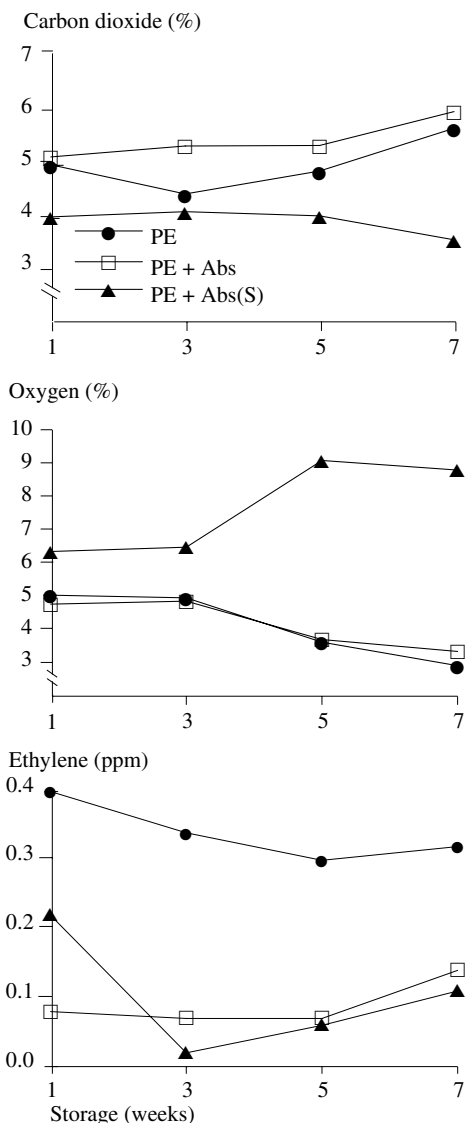


Figure 1. Changes in the levels of carbon dioxide, oxygen and ethylene in the modified atmosphere packages during 7-week storage of Eksotika papaya at 10 °C

(Table 1). On the average, individually wrapped fruit [PE + Abs (S)] had significantly a lower concentration of  $\text{CO}_2$  but higher concentration of  $\text{O}_2$  probably because its respiratory activity was much lower than 10 fruit packed together (PE and PE + Abs). A smaller amount of  $\text{O}_2$  was used and thus a smaller amount of  $\text{CO}_2$  was produced. On the average, the individually

Table 1. Average levels of gas composition in modified atmosphere packages of Eksotika papaya during 7-week storage at 10 °C

Treatment	CO <sub>2</sub> (%)	O <sub>2</sub> (%)	C <sub>2</sub> H <sub>4</sub> (ppm)
PE	5.02a	4.34b	0.370a
PE + Abs	5.41a	4.34b	0.079b
PE + Abs (S)	4.00b	8.14a	0.124b

Mean values in the same column with same letters are not significantly different using DMRT with  $p \leq 0.05$

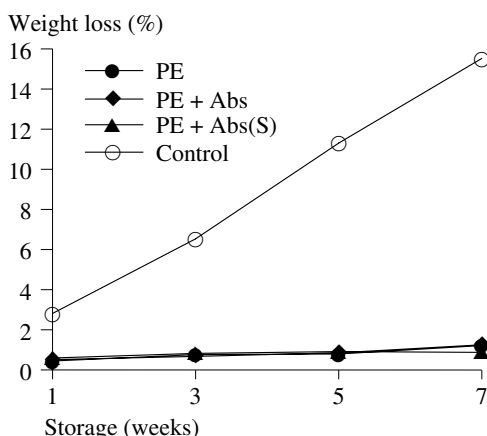


Figure 2. Effect of modified atmosphere packaging on weight loss of Eksotika papaya during 7-week storage at 10 °C

packed fruit had about 4% CO<sub>2</sub> and 8% O<sub>2</sub>, while the 10-fruit packs had 5% CO<sub>2</sub> and 4% O<sub>2</sub> (Table 1).

Packages containing ethylene absorbent also had significantly a smaller amount of C<sub>2</sub>H<sub>4</sub> gas. The absorbent was effective in reducing about 73% of the ethylene accumulated within the packages. Fruit that were wrapped without the ethylene absorbent (PE) produced about 0.370 ppm C<sub>2</sub>H<sub>4</sub> while those packed with the absorbent [PE + Abs and PE + Abs (S)] had only 0.079 and 0.124 ppm respectively (Table 1).

#### Effect of MA on quality and storage life

The MA packaging significantly helped to reduce weight loss of Eksotika papaya during storage at 10 °C (Figure 2). There was minimal reduction in weight when the fruit were packed in LDPE bags either

individually or in bulk. The LDPE bag formed an effective barrier in preventing moisture loss from the fruit, thus creating a water-saturated atmosphere surrounding the fruit (Lazan and Ali 1991). On the average, there was less than 1% weight loss compared with the control fruit which had lost about 16% of the total weight during the storage period.

Preservation of the freshness and firmness of the fruit was also affected by the MA environment. The concentration of gases within the packages (Table 1) especially O<sub>2</sub> (4–8%) was sufficiently low to suppress the respiratory activities of the fruit without affecting the product quality. Various studies have shown that a pronounced decrease in respiration was observed when O<sub>2</sub> concentration fell to 12% or below (Kader et al. 1989; Abd. Shukor 1995). Reduction in the respiratory activities slowed down various vital processes and helped to prolong the maintenance of postharvest quality such as reduction in weight loss and retention of textural quality. Lazan et al. (1993) had shown that MA condition was effective in retarding firmness decrease and texture change in Eksotika papaya particularly when the fruit were stored at moderately low temperature. Softening was prevented due to a reduction in the activity of the cell wall hydrolases, such as polygalacturonase, pectin methylesterase and β-galactosidase, as well as reduction in the solubilization and depolymerization of the cell wall pectin (Ali et al. 1993). As a result, the freshness of the fruit was preserved and the fruit remained firm throughout the storage period.

The MA condition was effective in maintaining the fresh green colour of the fruit, packed individually or in bulk, during storage at 10 °C as measured in the negative  $a^*$  values (Table 2). There was no change in the skin colour possibly because the amount of C<sub>2</sub>H<sub>4</sub> accumulated around the fruit (0.08–0.37 ppm) was insufficient to trigger the ripening process (Table 1). These results were similar to those obtained by Lam

(1990) which showed no change in skin colour indices of papaya stored at 10 °C because the production of  $C_2H_4$  was less than 1 ppm. Elevated  $CO_2$  levels (above 1%) have been shown to retard fruit ripening due to the inhibition of  $C_2H_4$  activity (Kader et al. 1989). Therefore, the presence of 4–5%  $CO_2$  in the packages (Table 1) was sufficiently high to suppress the activity of  $C_2H_4$  and thus its role in initiating the ripening process was retarded. The MA environment created around the fruit also reduced the respiration rates and the sensitivity of the fruit to  $C_2H_4$  action (Kader et al. 1989). This, combined with the decrease in  $C_2H_4$  production, delayed the process of senescence resulting in the retention of chlorophyll (green colour) and textural quality (turgidity) of the fruit. These results were in agreement with the studies conducted by Lazan et al. (1990) and Latifah et al. (1993). In the control fruit, the negative  $a^*$  values were significantly higher even though the skin colour was still green. The hue had changed probably due to changes in the chlorophyll content or skin damage because of chilling injury and weight loss.

The pulp colour of the fruit was not greatly affected by MA during storage. No significant difference was observed among the treatments in the red hue of the pulp as represented by the positive  $a^*$  values (Table 2). A significant difference was only observed in the intensity of the red colour ( $C^*$  values) especially when the fruit were individually packed [PE + Abs (S)].

The occurrence of chilling injury during storage was significantly affected by the MA condition (Table 2). Chilling injury was the most important factor affecting the overall quality and storage life of the fruit. This physiological disorder will affect the overall appearance, disease development and ripening process of the fruit. Less chilling injury, as indicated by the presence of lesser sunken brown watery spots, developed in fruit that were packed in MA. The development of chilling injury was especially low in individually packed fruit. Similar observations were also reported by Latifah et al. (1993). The incidence and severity of chilling injury were greatly reduced with the presence of low  $O_2$  and high  $CO_2$  concentrations (Kader et al. 1989). This beneficial effect was observed because the levels of  $O_2$  (4–8%) and  $CO_2$  (4–5%, Table 1) in the MA environment were still within the limits tolerated by the fruit. The development of chilling injury was also slower in fruit stored in MA than those stored in air (Figure 3). In the air-stored fruit (control), chilling injury developed rapidly. The sunken brown watery spots were observed a week after storage and the symptoms spread as the storage period was extended. Under MA condition, the initial symptoms of chilling injury were observed at 3 weeks after storage in the 10-fruit packs and at 5 weeks in the individually packed fruit.

Disease development during storage was affected by the number of fruit packed together rather than the MA condition. The scores for diseases were not significantly

Table 2. Effect of modified atmosphere on the physical quality of Eksotika papaya during 7-week storage at 10 °C

Treatment	Skin colour ( $a^*$ value)	Pulp colour (values)		Chilling injury (score)	Disease (score)
		$a^*$	$C^*$		
Control	–11.37a	23.73a	38.87a	0.98a	0.15a
PE	–14.35b	22.75a	37.40ab	0.32b	0.15a
PE + Abs	–14.87b	23.83a	37.67ab	0.28b	0.13a
PE + Abs (S)	–14.09b	24.15a	36.93b	0.11c	0.05b

Mean values in the same column with same letter are not significantly different using DMRT  $p \leq 0.05$

different when 10 fruit were packed together as indicated by fruit that were stored in air (control) and those that were packed in PE and PE + Abs (Table 2). However, fruit in

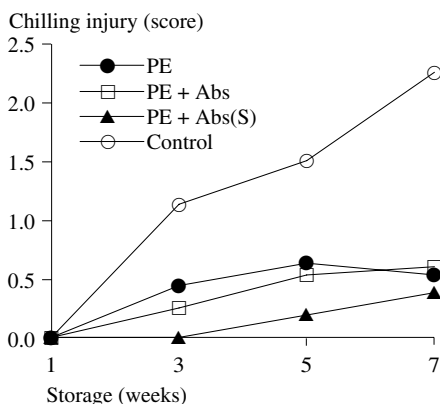


Figure 3. Development of chilling injury on *Eksotika* papaya during 7-week storage in modified atmosphere at 10 °C

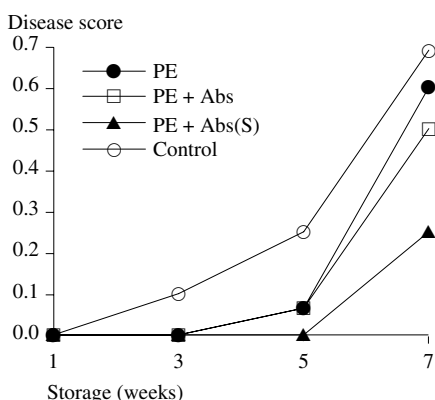


Figure 4. Development of diseases on *Eksotika* papaya during 7-week storage in modified atmosphere at 10 °C

individual packaging [PE + Abs (S)] showed significantly lower occurrence of diseases. More disease infection, especially caused by the fungus *Phomopsis caricae-papayae*, developed in the 10-fruit packs probably due to chilling injury which was significantly higher than those in the singly packed fruit. The infection was also faster on chill-injured fruit. It was observed during storage that the infection began on control fruit after a week, which had significantly higher occurrence of chilling injury, followed by fruit in bulk at 3 weeks and individually packed fruit at 5 weeks (Figure 4). ‘Soilage effect’ or secondary rot infection from one fruit to the other might also be a causal factor of higher disease infection rate when 10 fruit were packed together. In individually packed fruit, this effect was prevented because the packaging material acted as a protective barrier for each fruit.

During storage, the chemical quality of the fruit was greatly influenced by the MA condition (Table 3). The total soluble solids (TSS) and total titratable acidity (TTA) of fruit stored in 5% CO<sub>2</sub> and 4% O<sub>2</sub> (PE and PE + Abs) were significantly lower than those stored in 4% CO<sub>2</sub> and 8% O<sub>2</sub> [PE + Abs (S)], and in air (control). TSS and TTA were attributable to the presence of soluble carbohydrates and organic acids in the fruit tissues, and they served as important respiratory metabolites in ripening fruit (Lazan and Ali 1991). Under MA condition, retardation in the respiratory activity also seemed to retard the synthesis and use of these metabolites resulting in the smaller amounts of TSS and TTA presence in the

Table 3. Effect of modified atmosphere on the chemical quality of *Eksotika* papaya during 7-week storage at 10 °C

Treatment	Total soluble solids (%)	Total titratable acidity (%)	Total sugars (%)	pH
Control	11.82a	0.150a	7.51bc	5.12a
PE	11.29bc	0.125b	7.74ab	5.27a
PE + Abs	10.85c	0.132b	7.85a	5.19a
PE + Abs (S)	11.61ab	0.153a	7.31c	5.15a

Mean values in the same column with same letter are not significantly different using DMRT  $p \leq 0.05$

tissues. A smaller amount of TTA present was probably due to the inhibition of the activities of various enzymes such as NADP-malic (Halimah et al. 1991), malic and PEP-carboxylase (Lazan and Ali 1991) which were responsible for organic acid metabolism. In an environment containing 4% CO<sub>2</sub> and 8% O<sub>2</sub> [PE + Abs (S)], the respiratory activity of the fruit was not completely inhibited as indicated by the ability of the fruit to synthesize, and use TSS and TTA which were not significantly different from those of the control fruit (Table 3).

The MA environment was also effective in preventing loss of carbohydrates from the fruit tissues during storage. This was indicated by the presence of larger amounts of total sugars, especially in fruit that had been stored in 5% CO<sub>2</sub> and 4% O<sub>2</sub> (PE and PE+Abs, Table 3). In this environment, a larger amount of total sugars was retained in the fruit tissues probably due to a slower decline in the metabolites during storage. This may be attributed to the presence of a high CO<sub>2</sub> concentration (5%) which inhibited the respiratory activity of the fruit. Similar observations had been reported by Wang (1990) in crops such as Chinese cabbage, sugarbeet, apricot and peaches when stored under CA. In an environment containing 4% CO<sub>2</sub> and 8% O<sub>2</sub> [PE + Abs (S)], it was again shown that the respiratory activity was not completely inhibited since the amount of total sugars retained within the fruit was not significantly different from that of the

control fruit (Table 3). During storage, the MA environment did not affect the fruit pH which remained at about 5 regardless of the treatments (Table 3).

#### *Quality of fruit after ripening*

Eksotika papaya ripened within 3–4 days at ambient temperature (28 °C). All fruit changed from green to yellow colour regardless of the treatment given. However, visual observation showed that the skin colour development was more even in fruit that had been stored in MA. The control fruit had patches of green colour and sunken spots on the skin, and the overall appearance was dull and lifeless. Measurement of the colour using the chromameter showed significant differences in the yellow hue of the fruit as indicated by the *b*\* values (Table 4). Fruit stored in MA had significantly higher *b*\* values than those stored in air. The average *b*\* values for fruit wrapped in bulk (PE and PE + Abs) were 57.75 and 59.51 respectively. Individually wrapped fruit [PE + Abs (S)] had a value of 45.71 while the average value for the control fruit was only 39.23. These values indicated that fruit stored in MA developed better yellow colour during ripening than the control fruit. The colour developed fully due to loss in total chlorophyll and synthesis of total carotenoids (Ali et al. 1994). This was also an indication that the ACC oxidase activity functioned normally when placed at ambient temperature. Development of the yellow colour was more pronounced when 10 fruit were wrapped in bulk rather than singly. The

Table 4. Effect of modified atmosphere on the physical quality of Eksotika papaya during ripening at ambient (28 °C) within 7-week storage at 10 °C

Treatment	Skin colour (values)		Pulp colour (values)		Chilling injury (score)	Disease (score)
	<i>b</i> *	<i>C</i> *	<i>a</i> *	<i>C</i> *		
Control	39.23c	39.66c	22.68b	39.40c	1.20a	0.91a
PE	57.75a	58.64a	24.22a	42.62b	0.91b	0.61b
PE + Abs	59.51a	60.27a	24.74a	43.93a	0.44c	0.35c
PE + Abs (S)	45.71b	45.94b	23.86a	39.35c	0.35c	0.25c

Mean values in the same column with same letter are not significantly different using DMRT  $p \leq 0.05$



intensity of the yellow colour was also brighter as indicated by the higher  $C^*$  values (58.64 and 60.27). Control fruit had lower  $b^*$  (39.23) and  $C^*$  (39.66) values indicating that the fruit ripened with dull yellow colour probably due to inefficient  $C_2H_4$  formation. The enzyme system may have been damaged during cold storage because of chilling injury. This phenomenon was also observed by Latifah et al. (1994).

Similarly, the pulp colour ( $a^*$  and  $C^*$  values) was significantly better in fruit stored in MA, especially in the 10-fruit packs (PE and PE + Abs, *Table 4*). The orangey-red pulp was brighter and more intense than that of control and singly packed fruit [PE + Abs (S)]. The differences in the hue and intensity of the pulp colour were probably due to the different levels of pigments such as lycopene and carotene being synthesized during the ripening process (Ali et al. 1994). The synthesis of these pigments seemed to be more effective in fruit that had been stored in MA.

Both chilling injury symptoms and diseases continue to develop in the ripened fruit but the degree of infection was significantly lower in fruit stored in MA. The symptoms developed much faster in the control fruit during ripening. Sunken watery spots and diseases were observed even after 1-week storage. In fruit stored in MA, the symptoms appeared after 3-week storage for fruit packed in bulk and 5 weeks in fruit that were packed singly.

The chemical quality of the fruit after ripening was not affected as there was no significant difference in the development of

TSS, TTA and pH during ripening (*Table 5*). These results showed that Eksotika papaya under MA storage was able to resume its normal respiratory activities when placed at ambient. The fruit could fully synthesize and use their respiratory metabolites such as organic acids and soluble carbohydrates. However, during ripening, the MA stored fruit seemed to have faster development of total sugars, thus a higher percentage of the compounds was present in the fruit tissues resulting in sweeter taste than the control fruit.

### Conclusion

Storage of Eksotika papaya in MA at 10 °C was found to be beneficial because it helped to extend the storage life with minimal deterioration in the fruit quality. MA storage reduced weight loss, retained the freshness and firmness of the fruit, caused lower incidence of chilling injury and reduced disease infection. The storage life was extended to about 3–4 weeks when the fruit were wrapped in bulk (10 fruit/pack) and 5–6 weeks for individually wrapped fruit. The fruit ripened normally when placed at ambient temperature with good skin colour, pulp colour and flavour development. With the extension in storage periods, the fruit can be exported to distant markets using sea shipments. The storage period of 3–4 weeks for the 10-fruit packs was sufficient for exporting the fruit to Hong Kong and the Middle East. However, individual wrapping is laborious and time consuming, even though such technique can extend the storage life of the fruit to 5–6 weeks.

Table 5. Effect of modified atmosphere on the chemical quality of Eksotika papaya during ripening at ambient temperature (28 °C) within 7-week storage at 10 °C

Treatment	Total soluble solids (%)	Total titratable acidity (%)	Total sugars (%)	pH
Control	11.75a	0.158a	7.05b	4.90a
PE	11.74a	0.153a	7.68a	4.78a
PE + Abs	11.78a	0.165a	7.34ab	4.67a
PE + Abs (S)	11.57a	0.153a	7.23ab	4.87a

Mean values in the same column with same letter are not significantly different using DMRT  $p \leq 0.05$

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