Original article

Modified atmosphere packaging films for qualitative storage of *Dimocarpus longan* fruit in Vietnam

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Summary

Preservation of fruit freshness in extended storage life represents a major obstacle in the fruit production industry. Modified atmosphere packaging (MAP) using either polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), 'Lifespan' L201 (LS), 'Peakfresh' (PF) or 'Zoepac' (ZP) is a lower cost way to potentially reduce postharvest fruit waste. In this research, we focused on finding the best MAP for optimal postharvest preservation of *Dimocarpus longan* fruit harvested in Tien Giang Province of Vietnam. We carried out MAP experiments at two different temperature levels of 5 or 20°C and observed the levels of CO₂ and O₂ and the quality of fruit inside the packages during 20 d storage. The results show that the CO₂ and O₂ composition of the atmosphere are most favorable in packages of LS film, giving better skin colour, total soluble solids, and higher total acidity, taste scores as well as lower weight loss and rot incidence when compared with those of other film treatments.

Keywords

MA storage, longan, postharvest, green storage, weight loss

Introduction

Dimocarpus longan Lour., commonly called as longan, is both a subtropical and tropical fruit-bearing species from the Sapindaceae family that are grown most commonly in Australia, China, Taiwan, Thailand and Vietnam (Lin et al., 2013). Thailand and Vietnam are the two main countries that export longan fruit (Jiang et al., 2002). In Vietnam, the cultivar 'Tieuhue' longan fruit are the main exported type of longan and are grown predominantly in the Tien Giang and Ben Tre provinces. Longan fruit are usually consumed fresh due to their very short storage life under adverse environmental conditions such as high temperature and high moisture (Tian et al., 2002). It has been shown that the storage life of longan only lasts several days at room temperature, or maximum of 14 d at 10°C, after which the fruit showed rapid deterioration and subsequently, skin browning and spoilage (Jiang et al., 2002; Lin et al., 2013), therefore reducing the commercial value of these fruit (Apai, 2010; Jiang et al., 2002; Khunpon et al., 2011). In addition, the optimum stor-

Significance of this study

What is already known on this subject?

- Modified atmosphere packaging (MAP) is a commonly used technique to prolong the storage life of fresh fruit with lower cost that many previous studies have studied. There is a scarcity of reports about the changes in quality of longan fruit via MAP films.

What are the new findings?

- 'Lifespan' L201 (LS) film was the most effective in storage of 'Tieuhue' longan fruit, including giving better skin colour, total soluble solids, and higher total acidity, taste scores as well as lower weight loss and rot incidence.

What is the expected impact on horticulture?

- The goal of this paper was understanding the changes in quality of longan fruit via MAP films that can effectively help the exporters to maintain quality of fruit.

age conditions that retained quality measurements of longan fruit for about 2–3 weeks consisted of temperature range of 4 to 7°C and humidity range from 90 to 95% (Jiang et al., 2002; Tian et al., 2002).

Modified atmosphere packaging (MAP) is a commonly used technique to prolong the storage life of fresh fruit due to its ability to reduce respiration rate, lower water loss, sustain metabolic rate, and lower ethylene production, while maintaining firmness as well as delaying any colour changes of fruit. Therefore, many studies have been carried out on MAP films aiming to increase the storage life of loquat fruit (Ding et al., 2002), pear (Wang and Sugar, 2013), sweet cherry (Colgecen and Aday, 2015). For longan fruit, the application of MAP could extend storage life of the fruit up to 39 days (Khan et al., 2016) but might also reduce O₂ composition within the MA packages to around 1 kPa, which can cause slight off-flavors (Cheng et al., 2009). Other measures for prevention of skin browning and rotting included treatment sodium chlorite (NaClO₂) (Khunpon et al., 2011), chlorine dioxide ClO₂ (Saengnil et al., 2014), and controlled atmospheres (15–19% O₂ + 2–4% CO₂) (Tian et al., 2002). To date, storage life-prolonging measures adopted in Vietnam consisted of cooled storage or chemical treatment. However, inappropriate fruit cooling might result in water loss and se-

vere browning under extended storage and chemical treatment may raise concern over product safety and in turn lower consumer acceptance toward the fruit. As a result, selection of MAP films is crucial in sustaining a stable production chain and facilitating exporting of the fruit, which requires strict standardized packaging procedure to maintain fruit quality. In this study, we utilized several MAP films in preserving the longan fruit and assessed quality indicators, and sensorial rating of the wrapped fruit under different storage life and temperatures.

Materials and methods

'Tieuhue' longan fruit were harvested at commercial maturity (81–84 d after full bloom) from three trees representing three replicates. Trees were located in a longan orchard in the Cai Lay district (Tien Giang province, Vietnam). Harvested fruit were placed into three individual boxes corresponding to three plants and transported on the same day to the Southern Horticultural Research Institute, Vietnam, where they were cut from the cluster into individual fruit. A portion of fruit stalk length (about 0.5 cm) was kept on the fruit. Damaged, diseased, mechanically injured or fruit with signs of irregular ripening were excluded and only fruit with uniform size and colour with an individual weight of 12 ± 2 g were chosen. Afterwards, the content of each box was divided into two equal parts and put into two rooms with different temperatures. Fruit were washed with 250 ppm chlorine water and then placed under a fan for 30 min to air dry.

Preparation of MAP films

MAP films including the PE, PP, PVC, HDPE, LS, PF, ZP packages were prepared with the dimension 18×13 cm. Characteristics of used films were summarized in Table 1. After being trimmed of stalks and dried of fruit, the longan fruit were distributed into the above films (20 fruit for each MAP film) while the control fruit were not packaged by any films. These films were sealed by a foot petal sealer (Duoqi SF-600, Wenzhou Xingye Machinery Equipment Co., Ltd., Zhejiang, China), and the China PVC films were sealed by a hand food wrapper (HW-450, Zhejiang Haizhou Packing Machine Co., Ltd., Zhejiang, China). Fruit in the different MA packages were placed into perforated cardboard boxes for storage. Each treatment involved eight boxes consisting fruit wrapped with same type of film. Initial longan fruit quality was assessed by weight, colour measurement, total soluble solids (TSS) and titratable acidity (TA), sensory quality (taste). MA packages together with the control fruit were then stored at two different temperatures of 5°C or 20°C with humidity ranging from 80% to 85%. The whole process was performed at two storage temperatures. The quality of longan fruit was assessed during storage at 8, 12, 16 and 20 d

for fruit stored at 5°C and at 4 and 8 d for fruit stored at 20°C. Three replications, corresponding to three longan plants, were designed following a completely randomised factorial design with one factor.

Fruit quality assessments

The CO₂ and O₂ composition inside the MA packages was measured with a headspace gas analyser (Dansensor CheckMate 3, Mocon Europe A/S, Denmark), equipped with septums (PBI 45 mm, grey, 1,000 pcs, Dansensor CheckMate 3, Mocon Inc., Viking, Denmark). Weight loss was measured by analytical balance (UX420S, 420 g $\pm$ 0.01, Japan) by the formula:

$$\text{Weight loss (\%)} = \frac{(\text{Initial wt} - \text{wt after storage time}) / \text{initial wt} \times 100.}$$

Skin colour (L^* , a^* , b^*) of 20 individual fruit per replicate treatment was measured by a chromameter (CR400, Minolta Camera Co. Ltd., Osaka, Japan). The browning severity index of 20 individual fruit was assessed visually based on browning areas of the skin surface according to the following scale: 0 = no browning; 1 = 1 to 10% slight browning; 2 = <25% browning; 3 = 25 to 50% browning; and 4 = $\geq$ 50%. A weighted mean browning severity index (BI), which ranges from 0 to 4, was calculated by the following formula:

$$\text{BI} = \frac{\sum (\text{Browning level} \times \text{Nr. of fruit at browning level})}{\text{Total number of fruit in the treatment.}}$$

The percentage incidence of 20 fruit was calculated as the number of fruit with browning severity index of 1 or higher/ the total number of fruit $\times$ 100. The fruit that reach browning severity index 3 or greater are considered unacceptable by consumers. Similarly a rot severity index of 20 individual fruit was calculated based on the percentage of areas that developed fungi on the surface of fruit divided by total fruit surface according to the following scale: 0 = no decay; 1 = <10%; 2 = 10 to 30% decay; 3 = 31 to 70% decay; and 4 = >70% decay. The percentage incidence, which ranges from 0 to 4, was calculated as the number of fruit with decay/ the total fruit number $\times$ 100. TSS of 10 fruit was measured in % using a digital refractometer (Atago, Tokyo, Japan) for crushed fruit flesh. TA of 10 fruit was determined via fruit juice according to AOAC (1990). Briefly, 5 mL of fruit juice was siphoned from the fruit which was then titrated with 0.1 N of sodium hydroxide and with 3 drops of 1% phenolphthalein. The results expressed as citric acid percentage ratio: TA % = $0.0064 \times \text{volume of titrated 0.1 N NaOH} \times 100 / \text{volume of sample analytic}$. Taste of 20 longan fruit in MAP treatments was evaluated by 20 trained panelists based on a nine-point scale (9 = excellent; 7 = good; 5 = acceptable,

TABLE 1. Properties of examined MA packages.

MA packages	Permeability of CO ₂	Permeability of O ₂	Thickness	References
PE	1,435 cc 100 m ² 24 hr ⁻¹ atm	258 cc 100 m ² 24 hr ⁻¹ atm	0.035 mm	Mangaraj et al., 2009
PP	88 $\times$ 10 ⁷ cm ³ μ m m ⁻² h atm	73 $\times$ 10 ⁸ cm ³ μ m m ⁻² h atm	40 μ m	Mangaraj et al., 2009
PVC	34 $\times$ 10 ⁷ cm ³ μ m m ⁻² h atm	66 $\times$ 10 ¹⁰ cm ³ μ m m ⁻² h atm	9 μ m	Wall et al., 2011
HDPE	89 $\times$ 10 ⁶ cm ³ μ m m ⁻² h atm	162 $\times$ 10 ⁶ cm ³ μ m m ⁻² h atm	20 μ m	Mangaraj et al., 2009
LS	5.330 $\times$ 10 ⁻¹³ mol s ⁻¹ m ⁻² Pa ⁻¹	1.271 $\times$ 10 ⁻¹³ mol s ⁻¹ m ⁻² Pa ⁻¹	20 μ m	Wall et al., 2011
PF	4.430 $\times$ 10 ⁻¹¹ mol s ⁻¹ m ⁻² Pa ⁻¹	7.176 $\times$ 10 ⁻¹² mol s ⁻¹ m ⁻² Pa ⁻¹	35 μ m	Wall et al., 2011
ZP	60 $\times$ 10 ⁹ cm ³ μ m m ⁻² h atm	41 $\times$ 10 ¹⁰ cm ³ μ m m ⁻² h atm	25 μ m	Candir et al., 2012

MA packages included polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), 'Lifespan' L201 (LS), 'Peakfresh' (PF), 'Zoepac' (ZP).

but with limited marketability; 3 = poor; and 1 = extremely poor). The fruit in each type of MA packages were presented in separate, randomly numbered trays to panelists. Three fruit per treatment were evaluated by each panelist.

Statistical analysis

All data were presented as the mean and the standard deviations produced by JMP 10.0 software (SAS Institute Inc., Cary, NC, U.S.A.). Three replications, corresponding to three longan plants, were designed following a completely randomised factorial design with one factor.

Results and discussion

CO₂ and O₂ composition inside MAP films

The results show that the CO₂ composition of fruit wrapped with seven MAP films (PE, PP, PVC, HDPE, LS, PF, and ZP) progressively increased during storage at 5°C (4–20 d) as shown in Figure 1a and 20°C (4–8 d) as shown in Figure 2a. Meanwhile the O₂ composition progressively decreased in storage at the same assessment times as with CO₂ (Figures 1b and 2b). Generally, our results indicate that

fruit in MAP films stored at 20°C have higher CO₂ and lower O₂ composition when compared to those stored at 5°C with the same MAP films with the same assessment time. Those trends could be explained by storage temperature, which can greatly influence the respiration rates and ethylene production in fruit. To be specific, longan fruit stored at 20°C have average respiration rates twice and triple as much as ethylene production rate in comparison with those of longan fruit stored at 10°C and 5°C, respectively (Wall et al., 2011). In addition, the gas permeability of these MAP films leads to decreased O₂ and increased CO₂ compositions inside the MA packages due to the fruit itself having respiration. As a result, longan fruit stored at 20°C had a shorter storage life than those stored at 5°C.

During storage at 5°C, highest CO₂ composition (17.33 kPa) was recorded in the PP film treatment after 20 d while the PF film treatment showed lower CO₂ levels and was considerably different when compared to the other films. Besides, gas composition after 20 d storage at 5°C showed the lowest O₂ composition in PVC (2.17 kPa), HDPE (2.84 kPa), PP (1.33 kPa), and PE (2.5 kPa) films, which is close to the anaerobic respiration threshold that begins around 2 kPa or

FIGURE 1. Effects of MAP films on changes in CO₂ and O₂ composition of *D. longan* fruit during storage at two difference temperatures: (a) CO₂ composition at 5°C, (b) O₂ composition at 5°C.

FIGURE 2. Effects of MAP films on changes in CO₂ and O₂ composition of *D. longan* fruit during storage at two difference temperatures: (a) CO₂ composition at 20°C, (b) O₂ composition at 20°C.

TABLE 2. Influence of MAP films on weight loss, browning and rot incidence and severity, total soluble solids (TSS), titratable acidity (TA), skin colour a^* and b^* values of *D. longan* fruit during storage at 5°C.

Indicators	Storage life (days)	ZP	PVC	LS	HDPE	PP	PE	PF	Control
Weight loss (%)	8	0.13 ± 0.02	0.70 ± 0.03	0.22 ± 0.02	0.17 ± 0.02	0.17 ± 0.01	0.16 ± 0.03	0.19 ± 0.01	7.84 ± 0.22
	12	0.19 ± 0.02	0.81 ± 0.02	0.23 ± 0.02	0.17 ± 0.02	0.22 ± 0.02	0.25 ± 0.34	0.23 ± 0.02	8.45 ± 0.09
	16	0.19 ± 0.02	1.22 ± 0.02	0.35 ± 0.11	0.32 ± 0.30	0.42 ± 0.09	0.31 ± 0.10	0.29 ± 0.04	8.49 ± 0.11
	20	0.42 ± 0.07	1.48 ± 0.06	0.36 ± 0.13	0.32 ± 0.02	0.48 ± 0.01	0.39 ± 0.02	0.98 ± 0.61	8.59 ± 1.08
Browning severity index (from 0 to 4)	12	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	16	0.78 ± 0.12	1.02 ± 0.07	0.68 ± 0.03	0.92 ± 0.12	0.95 ± 0.06	0.98 ± 0.12	0.72 ± 0.03	2.70 ± 0.17
	20	1.48 ± 0.25	1.55 ± 0.24	0.90 ± 0.30	1.95 ± 0.13	2.17 ± 0.26	1.82 ± 0.33	1.63 ± 0.12	4.00 ± 0.00
Browning incidence (%)	12	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	16	16.67 ± 4.01	28.33 ± 3.33	11.67 ± 1.67	23.33 ± 4.01	25.00 ± 2.89	26.67 ± 4.01	13.33 ± 1.67	75.00 ± 4.77
	20	66.67 ± 4.33	65.00 ± 2.89	45.00 ± 3.20	76.67 ± 4.26	78.33 ± 4.14	65.00 ± 5.00	71.67 ± 1.67	100.00 ± 0.00
Rot severity index (from 0 to 4)	12	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	16	0.000 ± 0.00	0.100 ± 0.10	0.000 ± 0.00	0.020 ± 0.02	0.017 ± 0.02	0.050 ± 0.03	0.030 ± 0.02	0.130 ± 0.13
	20	0.28 ± 0.26	0.20 ± 0.15	0.03 ± 0.02	0.03 ± 0.03	3.08 ± 0.37	0.78 ± 0.37	0.03 ± 0.02	0.27 ± 0.18
Rot incidence (%)	12	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	16	0.0 ± 0.00	5.0 ± 5.00	0.0 ± 0.00	1.7 ± 1.67	1.7 ± 1.67	5.0 ± 2.89	3.3 ± 1.67	3.3 ± 3.33
	20	8.33 ± 4.01	10.00 ± 4.77	3.33 ± 1.67	3.33 ± 3.33	78.33 ± 4.14	23.33 ± 4.28	3.33 ± 1.67	6.67 ± 4.41
TSS (%)	8	20.10 ± 0.51	20.08 ± 0.20	19.57 ± 0.29	19.57 ± 0.52	19.47 ± 0.32	19.87 ± 1.19	19.83 ± 0.18	19.53 ± 0.43
	12	20.17 ± 0.09	20.53 ± 0.23	20.67 ± 0.20	20.47 ± 0.19	20.27 ± 0.13	20.30 ± 0.03	20.17 ± 0.46	20.90 ± 0.35
	16	19.3 ± 0.28	19.6 ± 0.03	20.1 ± 0.20	19.7 ± 0.06	19.1 ± 0.38	19.2 ± 0.50	19.9 ± 0.50	19.5 ± 0.35
	20	19.1 ± 0.15	19.3 ± 0.32	19.8 ± 0.30	19.0 ± 0.33	18.5 ± 0.18	19.0 ± 0.09	19.5 ± 0.32	18.2 ± 0.21
TA (%)	8	0.053 ± 0	0.047 ± 0	0.050 ± 0.01	0.050 ± 0.01	0.057 ± 0	0.047 ± 0.01	0.053 ± 0	0.047 ± 0
	12	0.036 ± 0	0.043 ± 0	0.047 ± 0	0.047 ± 0	0.050 ± 0	0.033 ± 0	0.040 ± 0	0.040 ± 0.01
	16	0.033 ± 0	0.037 ± 0	0.030 ± 0	0.030 ± 0	0.043 ± 0	0.030 ± 0	0.030 ± 0	0.040 ± 0
	20	0.023 ± 0	0.036 ± 0	0.026 ± 0	0.030 ± 0	0.037 ± 0	0.027 ± 0	0.030 ± 0	0.030 ± 0
a^* value	8	3.39 ± 0.29	3.61 ± 0.24	2.85 ± 0.71	3.81 ± 0.80	3.02 ± 0.58	3.87 ± 1.14	3.70 ± 1.30	7.49 ± 0.90
	12	4.36 ± 1.30	4.06 ± 0.90	4.23 ± 1.14	4.36 ± 1.96	5.30 ± 0.90	4.55 ± 1.30	4.04 ± 1.45	9.25 ± 1.14
	16	4.99 ± 0.58	4.65 ± 0.78	4.53 ± 1.45	5.59 ± 1.30	6.17 ± 1.20	5.92 ± 0.90	4.09 ± 0.80	9.47 ± 0.90
	20	6.13 ± 1.14	6.57 ± 1.20	5.79 ± 0.90	6.21 ± 1.30	7.38 ± 0.90	7.87 ± 0.90	5.25 ± 1.20	9.68 ± 0.90
b^* value	8	34.76 ± 0.52	34.56 ± 0.80	37.08 ± 0.16	36.22 ± 1.38	34.46 ± 0.12	35.68 ± 0.67	38.35 ± 0.82	34.51 ± 1.20
	12	32.29 ± 0.78	33.79 ± 0.90	35.85 ± 0.24	35.32 ± 0.29	33.71 ± 0.71	34.68 ± 0.32	37.36 ± 0.58	32.91 ± 0.23
	16	31.34 ± 2.24	33.76 ± 2.45	34.50 ± 2.81	35.29 ± 1.45	33.14 ± 0.73	31.29 ± 2.08	37.02 ± 1.89	32.59 ± 0.17
	20	30.96 ± 1.51	33.05 ± 1.19	33.44 ± 1.30	33.25 ± 2.54	31.72 ± 1.71	30.27 ± 1.14	33.89 ± 1.96	27.38 ± 0.58

Data were presented as mean ± standard deviation ($N=3$); severity of skin browning were on a scale from 0 to 4, with a score of 0 = no browning; 1 = 1 to 10% slight browning; 2 = <25% browning; 3 = 25 to 50% browning; and 4 = ≥50%. Severity of disease incidence were on a scale from 0 to 4, with a score of 0 = no decay; 1 = <10%; 2 = 10 to 30% decay; 3 = 31 to 70% decay; and 4 = >70% decay. MA packages included polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), 'Lifespan' L201 (LS), 'Peakfresh' (PF) and 'Zoeprac' (ZP).

lower O_2 concentrations. O_2 composition was still highest in PF films (8.8 kPa) after 20 d storage at 5°C. However, the O_2 composition after 8 d storage at 20°C reached the highest value in the LS (4.2 kPa) and in PF (3.4 kPa) films. Meanwhile, other MAP film treatments with O_2 composition reduced to under 1.63 kPa can initiate anaerobic respiration, in turn expediting skin browning and causing darker skin colour.

For LS film treatments, Figures 1 and 2 indicate that CO_2 and O_2 composition in the films were 6.8 kPa and 5.7 kPa after 20 d storage at 5°C and 8.87 kPa and 4.2 kPa after 8 d storage at 20°C, respectively. This result on CO_2 and O_2 composition inside the LS films at both storage temperatures was more favorable than other film treatments, contributing to exhibition of brighter skin colour, minimized weight loss and reduced browning and decay. Current findings are in accordance with the results reported by Wall et al. (2011), where longan fruit packaged in microperforated (MP), clam-shell (CL) containers or PF film stored at 10°C exhibited the best external quality, the lowest disease rates, and the longest storage life compared with those of LS film or fiberboard boxes. Similar results were also reported by another study of Wall et al. (2010) suggesting the use of MP or CL resulted in storage life that was longer than those of PF, LS film or fiberboard boxes (23 d).

Weight loss (%)

Our results indicate that the percentage weight loss for fruit preserved in MA packages gradually increased during storage at 5°C and 20°C as shown in Tables 2 and 3, respectively. The control treatment had the highest weight loss percentage (11.13% after 8 d storage at 20°C and 8.59% after 20 d storage at 5°C) due to the fact that the control fruit were stored without any MAP films which led to accelerated water loss and in turn rapid browning and skin deterioration. The percentage of weight loss at 20°C is generally higher than that at 5°C due to the higher temperatures, which promotes higher respiration rates and simultaneously increased water loss. Fruit packaged with PF, HDPE and PP exhibited lowest weight loss, measured at 0.53%, 0.46% and 0.54%, respectively, after 8 d storage at 20°C. LS film, although exhibiting higher weight loss than those of three mentioned treatments, is still negligible at both storage temperatures. Similar findings were found by Wall et al. (2010) indicating that longan fruit packaged in PF film at a storage temperature of 10°C showed the lowest weight loss percentage (0.7%) with a spoilage ratio of 22% after 19 d storage.

FIGURE 3. Influence of MAP films on changes in skin colour (L^* value) of *D. longan* fruit during storage at 5°C.

Changes of skin colour

The skin colour of longan fruit changes rapidly after harvest leading to the development of browning, senescence, water loss and rotting. The effect of gas composition created inside the MA packages on changes in the skin colour of *D. longan* fruit is demonstrated in Figures 3 and 4 and Tables 2 and 3. During storage at 5°C or 20°C the L^* and b^* values progressively decreased. The L^* and b^* values show the highest decrease in the control treatment at 5°C. L^* and b^* values after 8 d storage at 20°C did not vary among the MA treatments, but observations showed the PP film treatments had the highest browning severity index and high decay percentage because of the high CO_2 and low O_2 composition which greatly decreased skin lightness. The skin lightness after 20 d storage at 5°C was still highest in the LS and PF film treatments since they created a more suitable CO_2 and O_2 composition. Besides, the a^* values progressively increased during storage at both temperatures with the highest increases in the control treatment.

Incidence and severity of skin browning of longan fruit during storage

The incidence (%) and severity (BI) increased steadily during storage at 20°C and 5°C as shown in Tables 2 and 3. Notably the control treatment showed the highest increase in the BI and percentage incidence. However, these values were only just starting to increase at the storage temperature of 5°C after 16 d. The percentage incidence and BI at 20°C was higher than at 5°C, which parallels the changes in skin colour and weight loss that are greatly influenced by temperature. After 8 days of storage at 20°C as shown in Table 2, the browning percentage reached the highest in the control fruit (91.67%) and in the PP and HDPE film treatments while reaching the lowest levels in the PF, ZP and LS films. After 16 d storage at 5°C LS films show the lowest browning in comparison with all other treatments (Table 3).

Browning rates in the PP films and in the HDPE films as well as in the control treatment stored at 20°C were higher than those of the other MAP film treatments and correlated with rapidly decreasing L^* and b^* values in skin colour. According to our experimental results, browning severity indexes of fruit maintained in PF and LS films at 5°C were lower than those preserved in other MA packages, possibly due to O_2 composition in the PF films (8.8 kPa) and LS films (5.7 kPa) compared to those of other MA packages that had O_2 compositions of 3 kPa or lower. An increase in the brown-

FIGURE 4. Influence of MAP films on changes in skin colour (L^* value) of *D. longan* fruit during storage at 20°C.

TABLE 3. Influence of MAP films on weight loss, browning and rot incidence and severity, total soluble solids (TSS), titratable acidity (TA), skin colour a^* and b^* values of *D. longan* fruit during storage at 20°C.

Indicators	Storage life (days)	ZP	PVC	LS	HDPE	PP	PE	PF	Control
Weight loss (%)	4	0.44 ± 0.09	1.27 ± 0.02	0.28 ± 0.02	0.24 ± 0.01	0.30 ± 0.01	0.31 ± 0.02	0.25 ± 0.01	6.69 ± 0.35
	8	0.58 ± 0.02	2.23 ± 0.13	0.74 ± 0.10	0.46 ± 0.03	0.54 ± 0.01	0.56 ± 0.02	0.53 ± 0.02	10.13 ± 0.07
Browning severity index (from 0 to 4)	4	0.80 ± 0.12	0.80 ± 0.06	0.60 ± 0.12	2.35 ± 0.11	1.78 ± 0.29	1.60 ± 0.28	1.02 ± 0.12	2.90 ± 0.10
	8	1.52 ± 0.17	3.02 ± 0.48	1.10 ± 0.10	2.62 ± 0.33	3.20 ± 0.33	2.72 ± 0.17	1.32 ± 0.09	4.03 ± 0.15
Browning incidence (%)	4	40.00 ± 3.77	38.33 ± 1.67	30.00 ± 3.77	81.67 ± 4.01	63.33 ± 4.67	66.67 ± 4.26	43.33 ± 1.67	83.33 ± 3.33
	8	55.00 ± 2.89	65.00 ± 4.41	51.67 ± 1.67	83.33 ± 3.33	80.00 ± 3.00	78.33 ± 3.01	51.67 ± 1.67	91.67 ± 3.33
Rot severity index (from 0 to 4)	4	0.05 ± 0.05	0.15 ± 0.09	0.02 ± 0.02	0.05 ± 0.03	0.05 ± 0.03	0.05 ± 0.03	0.07 ± 0.02	0.05 ± 0.03
	8	1.15 ± 0.10	0.35 ± 0.10	0.37 ± 0.02	0.58 ± 0.11	1.75 ± 0.50	0.75 ± 0.14	0.88 ± 0.27	0.65 ± 0.23
Rot incidence (%)	4	5.00 ± 4.00	15.00 ± 4.66	1.67 ± 1.67	5.00 ± 2.89	5.00 ± 2.89	5.00 ± 2.89	6.67 ± 1.67	5.00 ± 2.89
	8	41.67 ± 3.33	20.00 ± 3.64	26.67 ± 3.01	21.67 ± 4.41	53.33 ± 4.93	28.33 ± 3.33	31.67 ± 4.82	30.00 ± 4.41
TSS (%)	4	20.57 ± 0.23	20.10 ± 0.20	20.60 ± 0.15	21.13 ± 0.33	20.70 ± 0.28	20.43 ± 0.20	20.40 ± 0.18	20.13 ± 0.33
	8	19.77 ± 0.32	19.17 ± 0.15	19.87 ± 0.13	17.40 ± 0.19	19.07 ± 0.20	19.67 ± 0.52	19.80 ± 0.35	19.80 ± 0.19
TA (%)	4	0.056 ± 0.01	0.052 ± 0.01	0.047 ± 0.01	0.042 ± 0.01	0.045 ± 0	0.045 ± 0	0.044 ± 0.01	0.045 ± 0.01
	8	0.042 ± 0.01	0.047 ± 0	0.042 ± 0.01	0.038 ± 0.01	0.036 ± 0.01	0.038 ± 0	0.042 ± 0	0.038 ± 0.01
a^* value	4	3.44 ± 0.24	4.41 ± 1.51	3.61 ± 0.90	3.54 ± 0.58	3.97 ± 0.82	3.57 ± 1.14	3.87 ± 0.90	6.77 ± 1.96
	8	4.55 ± 0.71	5.14 ± 0.80	4.63 ± 0.82	4.76 ± 1.30	4.95 ± 0.90	4.25 ± 0.90	4.27 ± 1.96	7.40 ± 1.30
b^* value	4	31.58 ± 0.71	30.98 ± 0.58	32.51 ± 0.32	34.14 ± 1.89	34.54 ± 1.19	36.83 ± 0.73	33.77 ± 0.67	30.62 ± 0.58
	8	27.07 ± 1.3	27.18 ± 2.08	30.93 ± 1.89	30.22 ± 0.90	26.92 ± 2.08	27.95 ± 1.71	28.63 ± 1.14	25.82 ± 1.30

Data were presented as mean ± standard deviation (N=3), severity of skin browning were on a scale from 0 to 4, with a score of 0 = no browning; 1 = 1 to 10 % slight browning; 2 = <25% browning; 3 = 25 to 50% browning; and 4 = ≥50%. Severity of disease incidence were on a scale from 0 to 4, with a score of 0 = no decay; 1 = <10%; 2 = 10 to 30% decay; 3 = 31 to 70% decay; and 4 = >70% decay. MA packages included polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), high-density polyethylene (HDPE), 'Lifespan' L201 (LS), 'Peakfresh' (PF) and 'Zoepac' (ZP).

ing severity index during storage can be due to increased oxidative phenolic compounds, heat stress, senescence, water loss, chilling injury, low O_2 , high CO_2 , injury, disease, rot and ethylene production (Jiang et al., 2002; Lin et al., 2016). Previously, Saengnil et al. (2014) and Tian et al. (2002) concluded that skin browning in Chuliang and Shixia, 'Daw' longan fruit was worsening in parallel with increasing PPO and POD activities and that the decreasing of total phenolic content led to decreased L^* values.

Incidence and severity of decay in longan fruit during storage

Results show that decay of *D. longan* fruit (incidence and severity) in the MAP treatments progressively increased during storage at 20°C and 5°C as shown in Tables 2 and 3. Spoilage of *D. longan* fruit during storage at 20°C was higher than at 5°C simply because of the greater formation of water vapour inside the MA packages from longan fruit transpiration leading to higher decay. PVC and LS films after 8 d storage at 20°C showed the lowest decay compared with the other MAP treatments as shown in Table 2. Besides, ZP and LS films after 16 d storage at 5°C were decay free meanwhile the other MAP films started to show signs of spoilage as shown in Table 3. In particular, the control treatment showed relatively low levels of decay compared with the MAP treatments, which can be due to the fact that high water loss without free water condensation on the surface of the packaging leads to less spoilage development. Meanwhile, free water condensation on the surface of the PP film treatments was higher than in other treatments and resulted in higher levels of decay.

Postharvest spoilage of longan fruit is mainly caused by fungi such as *Lasioidiplodia theobromae* (Pat.) Griff. & Maubl. (Zhang et al., 2018). According to Apai (2010), the initial 5 d of storage are decay free or show minimal decay that then increases during further storage. According to our assessments, decay appeared mainly at the stem end of the fruit and then spread throughout or was associated with water condensation on the surface of package in contact with the fruit's skin, or was the result of injury to the fruit. These observations concur with previous research by Apai (2010) where high moisture causes browning, which rapidly causes fruit to rot. In our experiment, *D. longan* fruit after 8 d storage at 20°C and 20 d storage at 5°C showed decay levels above 20% with the amount of decay dependent on the specific film used. The fruit that decayed rapidly during postharvest storage are most likely the result of saprotrophic fungi

development on the fruit surface and water loss leading to skin browning (Shodchit et al., 2008).

Changes in TSS and TA during storage

The results of the internal quality assessments of longan fruit are shown in Tables 2 and 3. After 8 d storage at 20°C, TSS values decreased to the lowest level in the HDPE film treatment (17.4%) and was considerably different when compared to the other MAP treatments (Table 2). After 20 d storage at 5°C, TSS values in the PP, LS, and PVC MAP treatments were maintained at higher levels than those in the other treatments (Table 3). In contrast, TA values decreased during storage at 5°C and 20°C. TA values at 20°C were not considerably different among the MAP film treatments after 8 d storage. However, TA values at 5°C in the PP and PVC treatments after 20 d storage were higher than those of all the other MAP films. Meanwhile, most marked reductions were recorded in the ZP, LS, and PE treatments.

According to Wall et al. (2010), longan fruit packaged in PP films retained a higher TSS content of 18–19%. In our experiment, initial TSS values were about 19.4% at commercial maturity and then increased after several days of storage (4 d at 20°C and 12 d at 5°C), showing that the fruit continue to ripen during postharvest storage and biochemical changes in the fruit are still ongoing. Such changes in fruit are possibly attributed to the temperature of storage. At the end of storage, the decrease in TSS content can be due to browning, disease and/or senescence cells increasing and this result in downgrading the quality of longan fruit. Besides this, according to Tian et al. (2002), TSS content in longan was not affected by air concentration inside packages.

Sensory quality (taste) during storage

Taste of longan fruit showed gradual decline during storage at 5°C and at 20°C as shown in Figures 5 and 6 especially. In particular, the reduction in taste was more rapidly at the end of storage life. During storage, the fruit packaged with PP films showed the lowest taste score (after 20 d at 5°C with taste reach 3.0 and after 8 d at 20°C with taste reach 3.1) compared with those of other film treatment. Meanwhile, the LS film showed highest taste score at the end of storage in both storage temperatures (Figures 5 and 6). This can be due to higher free water condensation on the surface, possibly attributable to lower vapor permeability, and gas composition that approximates anaerobic respiration threshold, of the PP film treatment, resulting in higher levels of decay and skin

FIGURE 5. Influence of MAP films on changes in taste scores of *D. longan* fruit during storage at 5°C.

FIGURE 6. Influence of MAP films on changes in taste scores of *D. longan* fruit during storage at 20°C.

browning, consequently lowered sensory score. Therefore, under storage life of 8 d at 20°C, or 20 d at 5°C, fruit packaged with the LS film exhibited better quality indicators and favorable sensorial score. On the other hand, the sensorial score of the control fruit is within acceptable range that is lower than that of LS but higher than PP film treatment. This is possibly due to the gas composition in the ambient atmosphere that is more tolerable for fruit respiration than in anaerobic conditions. Generally, lowest sensorial scores were recorded in fruit that exhibited surface free water condensation and aggravated rot and browning. The results on optimal preservation conditions are consistent with Wall et al. (2011) reporting that storage life of 14 d at 10°C gave greatest sensory ratings.

Conclusions

It was clearly demonstrated that MAP treatment can greatly influence the quality of *D. longan* fruit during storage which increased CO₂ and lower O₂ concentrations inside the MA packages, while limiting weight loss, browning and spoilage in the longan fruit. The desirable CO₂ and O₂ composition observed within MA package films used in this study suggest the potential of MA technique in extending the storage life, maintaining quality and reducing browning and decay of *D. longan* fruit. Of the seven MAP films tested, the LS films showed the best preservation efficacy with a CO₂/O₂ composition 6.8 kPa/5.7 kPa after 20 d storage at 5°C and a composition of 8.87 kPa/4.2 kPa after 8 d storage at 20°C, which was concurrent with decreased weight loss. In addition, LS films were also capable of excellently maintaining the skin color of *D. longan* fruit, with lower browning index percentages and lower spoiling index rates and higher taste rating. Further developments on utilization of LS films are suggested and could allow for prolonged preservation of *D. longan* fruit required during long-distance transport.

Acknowledgments

This study was supported by the Southern Horticultural Research Institute (SOFRI) under grant 71/KQNC.

Declaration of competing interest

None.

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Received: Aug. 31, 2020

Accepted: Nov. 10, 2020

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