CHAPTER 4

Effects of Oxalic Acid Dipping and Wax Coating on Pericarp Browning and Storage Life of Fresh Vietnamese Longan Fruit cv. Long

4.1 Abstract

This research was designed to study the impacts of oxalic acid (OA) and bees-carnauba mixed wax (MW) on pericarp browning and storage life of fresh Vietnamese longan fruit cv. Long. The experiments were carried out by soaking fruits in 5 and 7.5% OA for 5 min. After drying, soaked fruits were coated in 6% MW for 30 seconds, and stored at 5±1ºC for 30 days. Untreated fruits were used as control. Pericarp browning, pericarp color, pericarp pH, total aerobic bacteria, the percentage of weight loss and fruit decay, and total soluble solids (TSS) content were monitored during storage period. The results showed that 7.5% OA soaking in combination with 6% MW coating could postpone pericarp browning for 25 days in storage which was indicated by the lowest browning index, and high lightness (L* value) and yellowness (b* value) of fruit pericarp. Moreover, this treatment maintained low pericarp pH, low total aerobic bacteria, low fruit decay, and low weight loss; and the TSS content of the longan fruit revealed no difference over time. The results indicate that the using of 7.5% OA and 6% MW can be considered for commercial application in extending storage life and maintaining fruit quality 'Long' longan fruit.

4.2 Introduction

Longan fruit (*Dimocarpus longan* Lour.) is a non-climacteric subtropical fruit, and it is one of the most valuable fruits in Vietnam for domestic and export markets because of its delicious taste and excellent nutritional properties. *Nhan* is the local term for the longan in Vietnam, and the most popular cultivar in the north of the country is the *Nhan Long* (longan cv. Long), which produces large fruit with a small seed (80 to 100

fruits/kg) (FAO, 2004). Longan fruit has a very short postharvest life of 3 to 4 days under ambient temperatures due to desiccation, rotting and browning (Tongdee, 2001; Jiang *et al*., 2002; Apai, 2010). Postharvest longan has faced rapid discoloration caused by desiccation during storage at either too low or too high temperatures (Apai, 2009 and 2010). Browning can be associated with dehydration, heat stress, senescence, chilling injury or disease (Pan, 1994). Pericarp browning of fresh fruit results from phenolic compounds oxidized by endogenous polyphenol oxidase (PPO) and pigment formation (Jiang *et al*., 2002). Fruits are susceptible to various postharvest pathogens. The high sugar and moisture content in longan fruits induce various decay organisms to rot the fruit rapidly. Fruit rot usually follows skin browning (Apai, 2010). Recently published works indicate that the shelf life of 'Long' longan fruits could be extended by carbendazim dipping (Hoan *et al*., 2001), SO_2 fumigation (Thuy and Duyen, 2011), and sodium metabisulfite soaking (Hai, 2011; Hai *et al*., 2011). SO_2 can reduce browning symptoms due to reducing PPO activity, and it also acts as a bleaching agent (Wu *et al*., 1999; Tongdee, 2001). Carbendazim and SO_2 play an important role in decay and fungal growth inhibition (Hoan *et al*., 2001; Tongdee, 2001). However, there were many reports on the negative effects of the toxic residue of SO_2 and carbendazim in humans, and other reactions with sensitive individuals. Alternative treatments for SO_2 and carbendazim treatments on longan fruit cv. Long were studied such as chitosan coating (Huyen and Thuy, 2011), mixed (bees-carnauba) wax coating (Hai *et al*., 2014). However, the results showed only temporary postponement of discoloration and fruit decay with less than 20 days in storage (at 5°C). Thus there is a need to develop effective and safe methods not only to replace SO_2 and carbendazim treatments but also to prolong the shelf life of fresh 'Long' longan fruit longer than 20 days are needed. An alternative method is the use of oxalic acid dipping in combination with mixed wax coating. The inhibitory effects of acids on browning are generally due to the lowering of the pericarp pH (Apai, 2010). Acidulants, such as citric acid and oxalic acid retard browning by lowering the pH of the product to minimize the activity of PPO, and are generally recognized as safe (GRAS) (Suttirak and Manurakchinakorn, 2010). Oxalic acid is a natural component of large number of plants such as spinach, broccoli, tomatoes and turnips (USDA/HMS, 1984) and appears to inhibit enzymatic browning (Whangchai *et al*., 2006). Oxalic acid prevented pericarp browning due to inhibited PPO activity in longan fruit (Boonin *et al*., 2006; Whangchai *et al*., 2006).

Zheng and Tian (2006) reported that oxalic acid can effectively control the pericarp browning of litchi fruit during postharvest storage due to increase of membrane integrity, inhibition of anthocyanin degradation, decline of oxidation, and maintenance of relatively low peroxidase activity in the fruit. Oxalic acid has been shown to suppress apple browning and was previously shown as a potential anti-browning agent for apple PPO (Yoruk *et al*., 2002). Saengnil *et al*., 2006 demonstrated that soaking litchi fruits cv. Hong Huay in a solution of oxalic acid at concentration of 10% for 15 min was the most effective combination in controlling browning. Inhibition of PPO by oxalic acid was due to its binding with copper to form an inactive complex, and the inhibition was characterized as noncompetitive. Oxalic acid was a more potent inhibitor of PPO compared with other structurally related acids (Yoruk and Marshall, 2003). Whangchai *et al*. (2006) also reported that oxalic acid at concentration of 5% was a more potent anti-browning agent compared with other acids on longan fruit cv. "Daw". In a previous experiment (Hai *et al*., 2014), longan fruits cv. Long coated with 6% mixed waxes (bees-carnauba wax) could maintain L* and b* values; low pericarp pH, low respiration rate, and low weight loss; with the fruit showing no signs of severe pericarp browning or fruit decay throughout the 20 days in storage.

The main purpose of this study was to investigate the effects of oxalic acid dipping in combination with mixed wax coating on pericarp browning and storage life of fresh 'Long' longan fruit during storage at low temperatures.

4.3 Material and Methods

4.3.1 Plant materials

Mature 'Long' longan fruit (at harvesting date about from 185 to 190 days after full bloom) of a commercial orchard in harvesting crop of 2014 in Hung Yen Province in Vietnam were used for this research. The longan fruits were harvested, transported, individually cut and selected similar to those of chapter 3, prior to use in this experiment (Figure 4.1). Their initial qualities were assessed and the results of the experiment averaged out over 18 replications. The averaged results are as follows: (i) the soluble solids content was 19.9 ± 1.4 %, and (ii) the color of the fresh fruit, when expressed as L* value (lightness) was 55.3 ± 2.1; b* value (yellowness) was 30.8 ± 1.9.

Figure 4.1 Longan fruits cv. Long at commercial harvesting date

4.3.2 Studying methods

The optimal and feasible concentrations of oxalic acid (5 and 7.5% OA) were selected after preliminary tests. The best treatment of 6% mixed between bees wax and carnauba wax (bees-carnauba mixed wax; MW) was selected in the Chapter 3, and made according to the method of Hai *et al*. (2014).

The fruits were first soaked in 5 and 7.5% OA solution for 5 min, and dried for 1 h at room temperature. Then the soaked fruits were coated with 6% MW for 30 seconds at room temperature; while the control fruits were not soaked and coated. The soaked and coated fruits were dried for 8 h and 1 kg per bag of longan fruit were packaged in polypropylene bags (305 x 457 mm in size, and 0.035 mm thick with 4 holes of 0.8 cm^2 per hole). The fruits were then stored at 5±1ºC in a cold room and sampled/analyzed at 5 day intervals. Each treatment had three replications.

A completely randomized design was used for the experiment. Three treatments were applied to the longan fruit as following:

T_0 = non-treated fruit (control)

T_1 = fruit was soaked in 5% OA for 5 min and air dried before coated with 6% MW

T_2 = fruit was soaked in 7.5% OA for 5 min and air dried before coated with 6% MW

The data collection methods used for this research in terms of observing changes in the fruits visual appearance; measurement of the fruit pericarp color and total soluble solids content; an assessment of the percentage of fruit decay and weight loss; determination of pericarp pH; evaluation of storage life; and the statistical analysis, were all similar to the methods described in Chapter 3.

Analysis Polyphenol oxidase (PPO) activity was analyzed. Firstly, PPO was extracted by homogenizing 10 g longan peel in 40 ml of 0.05 M potassium phosphate buffer (pH 6.2) containing 1 M KCl and 2% polyvinylpyrrolidone and after that centrifuging for 5 min at 13,500 rpm (Hermel-Z383K) at 4ºC. The enzyme extract expressed as supernatant was collected (Huang *et al*., 1990; Whangchai *et al*., 2006). Then PPO activity was assayed following the methods of Jiang and Fu (1998) and Whangchai *et al*. (2006) by using the reaction mixture of 0.05 M potassium phosphate buffer (pH 7.5) containing 0.2 M catechol (0.2 ml) and crude enzyme (0.5 ml). Tubes were incubated for 5 min at 30ºC and absorbance was measured at 420 nm by visible spectrophotometer (Thermo Spectronic). The unit of enzyme activity was defined as the amount of enzyme that caused a change of 0.01 in absorbance per minute.

4.4 Results and Discussion

4.4.1 Change in visual appearance during storage period

The changes in visual appearance expressed as browning index (BI) of treated fruits, and control fruits during storage period at 5°C are shown in the Figure 4.2. Fruits with BI above 2.0 (more than 25% pericarp browning area) were considered as unacceptable for marketing purposes. As shown in the Figure 4.2, there was significant difference in BI of treated fruits and control fruits during the storage period ($P \leq 0.05$), and by day 10 in storage control fruits had BI higher than 2.0 and were not acceptable by day 10 in storage. Our result is in accordance with the reported data on BI of untreated longan fruits cv. Long (Hai *et al*., 2011; Hai, 2011; Hai *et al*., 2014a). Apai (2010) reported that untreated longan fruits have pericarp browning after 5 days in storage. Jaitrong (2006) also found that untreated longan fruit pericarp browned during storage at 2-7ºC for 5 days. At 20 days in storage, the BI of T_1 and T_2 treatments were lower than 2.0 and were not different. After 25 days in storage, there was significantly different BI between T_1 and T_2 treatments ($P \leq 0.05$), and the T_1 treatment was not acceptable because of BI

higher than 2.0, while T_2 treatment was less than 2.0 (Figure 4.2). Pericarp browning in longan fruit increased with increasing storage time (Whangchai *et al*., 2006). The T_2 treatment had the lowest BI, and it showed the best pericarp color and the longest storage life for 25 days. This result demonstrates that the doses of 7.5% OA dipping and 6% MW inhibited pericarp browning as expressed by BI scale. Our results are consistent with reported data on BI of longan fruit pericarp (Apai, 2009; Apai *et al*., 2009; Apai, 2010; Hai, 2011). Water loss from the pericarp was significantly positively correlated with pericarp browning index (Apai, 2009). Browning of longan fruits results from the oxidation of phenolic compounds by endogenous polyphenol oxidase (PPO) (Jiang *et al*., 2002). PPO is activated by moisture loss from the fruit (Su and Yang, 1996). The fruit coated with wax could prevent moisture loss (Hagenmaier and Shaw, 1992; Kolattukudy, 2003; Thirupathi *et al*., 2006; Hung, 2008; Torres *et al*., 2009; Hu *et al*., 2011; Shahid and Abbasi, 2011). Hai *et al*. (2014a) concluded that 6% MW coating prevents pericarp browning as expressed by BI scale in 'Long' longan fruits for 20 days in storage at 5°C. Oxalic acid retards browning by lowering the pH of the product to minimize the activity of PPO (Suttirak and Manurakchinakorn, 2010). Oxalic acid prevented pericarp browning due to inhibited PPO activity in longan fruit (Boonin *et al*., 2006; Whangchai *et al*., 2006). Zheng and Tian (2006) reported that oxalic acid can effectively control the pericarp browning of litchi fruit during postharvest storage. Oxalic acid at concentration of 10% for 15 min was the most effective in controlling browning of litchi fruits cv. Hong Huay (Saengnil *et al*., 2006). The temperature at 5ºC was most suitable for storage and delayed browning in longan fruits due to less severe chilling injury (Apai, 2009).

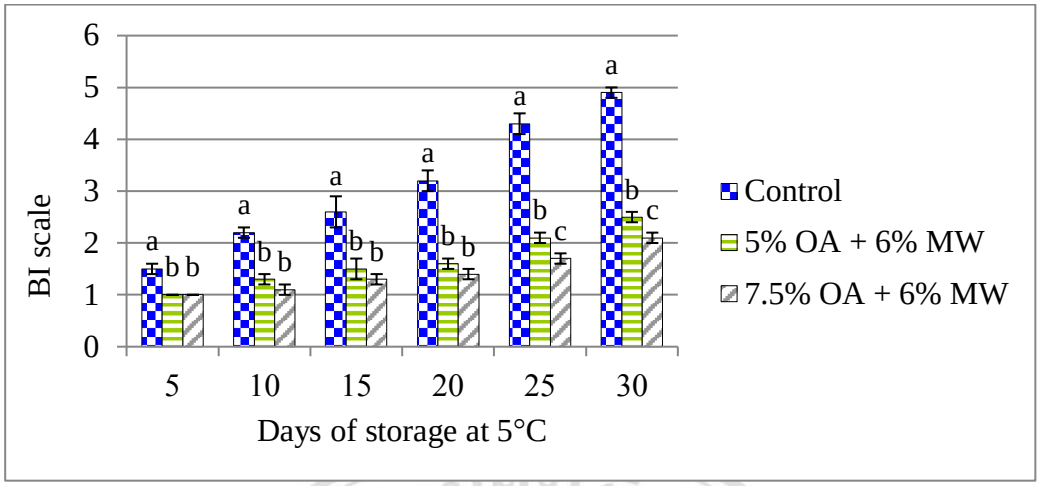

Figure 4.2 Change in BI of longan fruit pericarp either treated or not, during the storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significant differences ($P \leq 0.05$).

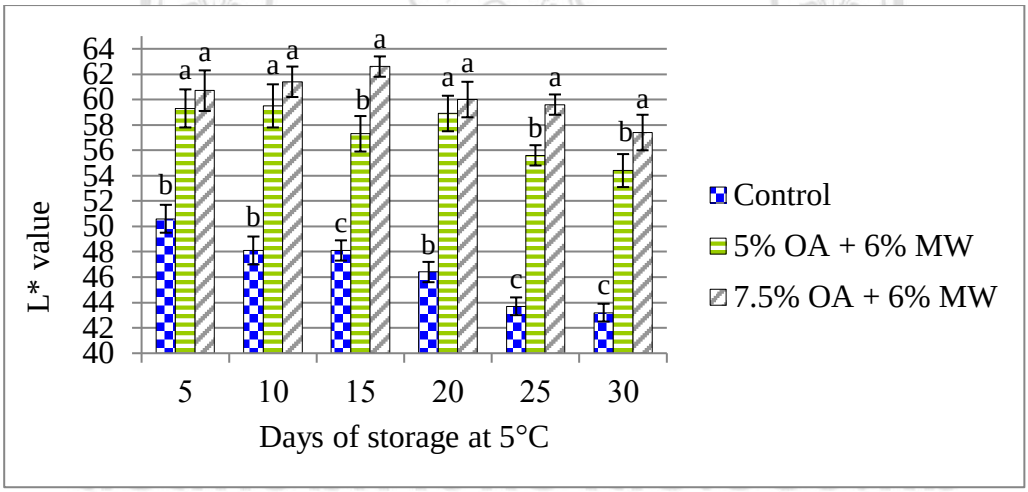

Figure 4.3 Change in L* values of treated and control longan fruits during storage at 5°C.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significant differences ($P \leq 0.05$).

4.4.2 Change in pericarp color expressed as L* and b* values

Figure 4.3 indicates the changes in L* values (lightness) of fruit pericarp during the storage period. The L* values of treated fruits were much higher than those of control fruits, and they were markedly different during the storage period ($P \leq 0.05$). Our result is consistent with the reporting of Apai (2010); Hai (2011); Hai *et al*. (2011 and 2014a)

who demonstrated that untreated fruits had lower L* values. This result justifies the effectiveness of organic acid in combination with edible coating in maintaining the lightness of fruit pericarp. Jiang (1999) reported that the browning reaction on fruit pericarp is caused by oxidation of phenolic compounds by PPO activity. Oxalic acid inhibited PPO activity in longan fruit (Boonin *et al*., 2006; Whangchai *et al*., 2006). When the PPO was incubated with oxalic acid, the activity was not recovered via dialysis (Son *et al*., 2000). Zheng and Tian (2006) reported that oxalic acid can maintain relatively low peroxidase activity in the fruit. Oxalic acid was previously shown as a potential anti-browning agent for apple PPO (Yoruk *et al*., 2002). Oxalic acid is a more potent inhibitor of PPO compared with other structurally related acids (Yoruk and Marshall, 2003). Apai (2009) reported that water loss from the pericarp resulted in an increase in activity of PPO. Weight loss means the amount of water lost from fruits and vegetables (Shahid and Abbasi, 2011). Hai *et al*. (2014a) found that 6% MW coating has the best effectiveness on reducing the weight loss in longan fruit cv. Long during the storage period. As seen Figure 4.3, at the first 20 days in storage, the L* value of T_1 and T_2 treatments was similar. After that, there was significant difference in L* values between T_1 and T_2 treatments by day 25 and 30 in storage ($P \leq 0.05$). Overall, the L* values tended to decrease with increasing of storage time in treated fruits and control fruits. Our results are in accordance with the reported data on L* values of longan fruit cv. Long (Hai, 2011; Hai *et al*., 2011; Huyen and Thuy, 2011; Thuy and Duyen, 2011; Hai *et al*., 2014a). The L* values of longan fruit pericarp decreased from 53.5 to 42.3 when treated fruits were stored at 5ºC for 24 days (Thavong, 2009). Our results are also consistent with reported data on L* values of pericarp of longan fruit (Rattanapanone *et al*., 2001; Jaitrong, 2006; Shodchit *et al*., 2008; Apai, 2009). As shown in the Figure 4.3, the T_2 treatment had the highest L* value during the storage period. This result confirms that 7.5% OA dipping in combination with 6% MW coating markedly maintained the lightness of color on longan pericarp cv. Long.

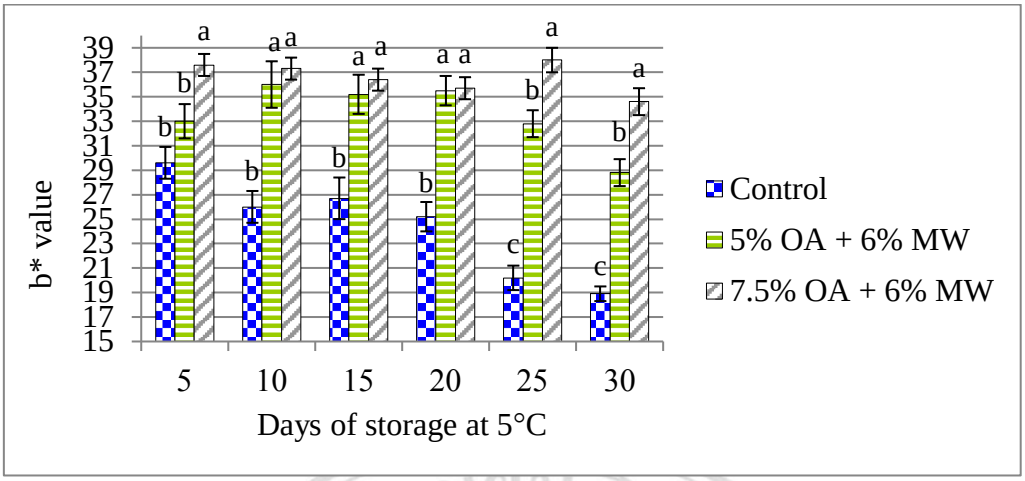

Figure 4.4 Change in b* values of treated and control longan fruits during storage at 5°C.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significant differences ($P \leq 0.05$).

The b* values (yellowness) of fruit pericarp were measured and results are shown in the Figure 4.4. There was significant difference in b* value between control fruits and treated fruits during the first 30 days in storage ($P \leq 0.05$). At the first 20 days in storage, the b* value of T_1 and T_2 treatments was not different, but thereafter the b* value of T_1 and T_2 treatments markedly differed by day 25 and 30 in storage ($P \leq 0.05$). After 30 days, the b* value of control fruits, T_1, and T_2 treatments was 18.9, 28.8, and 34.6 respectively (Figure 4.4). Our result was higher than the reported data on b* values from 20 to 30 days in storage of 'Long' longan fruits of Huyen and Thuy (2011), Thuy and Duyen (2011), Hai (2011), and Hai *et al*. (2011 and 2014a). Generally, the b* values of control fruits and treated fruits tended to decrease with increasing of storage time, and the b* values of treated fruits were much higher than b* values of the control fruits during storage period (Figure 4.4). This result demonstrates the effectiveness of oxalic acid in combination with mixed wax coating in maintaining the yellowness of fruit pericarp by inhibiting the activity of PPO and preventing water loss from pericarp as described by Shi (1990); Son *et al*. (2000); Yoruk and Marshall (2003); Zheng and Tian (2006); Boonin *et al*. (2006); Whangchai *et al*. (2006); Thirupathi *et al*. (2006); Shodchit *et al*. (2008); Hai *et al*. (2014a). The b* value of T_2 treatment at day 25 and 30 was 38.0 and 34.6 respectively, and it was the highest during the 30 days in storage

(Figure 4.4). This result indicates that 7.5% oxalic acid dipping in association with 6% MW coating best maintained the longevity of yellowness of fruit pericarp.

4.4.3 Change in pericarp pH

There were marked differences in pericarp pH between treated and control fruits during storage period ($P \leq 0.05$), and pH values ranged from 5.2 to 5.8 for control fruits, 3.2 to 4.0 for T_1 treatment and 3.1 to 3.6 for T_2 treatment after 30 days in storage (Figure 4.5). Overall, pericarp pH of treated and control fruits tended to increase with increasing of storage time, and the treated fruits had lower pericarp pH than control fruits during storage period. As seen in the Figure 4.5, at the first 20 days the pericarp pH of T_1 and T_2 treatments was similar, differed significantly by day 25 and 30 in storage ($P \leq 0.05$). The T_2 treatment maintained the lowest pericarp pH during the storage time. The pH optimum for maximum PPO activity in longan fruit is 6.5 (Jiang, 1999). Enzymatic browning occurs as a result of the oxidation by PPO (Jiang *et al*., 2002; Yoruk and Marshall, 2003). Caro and Joas (2005) and Joast *et al*. (2005) found that pericarp browning effects could be postponed by reducing pericarp pH. Oxalic acid retards browning by lowering the pH of the product to minimize the activity of PPO. At pH values below 4, PPO has little activity due to the loss of copper at the active site (Suttirak and Manurakchinakorn, 2010). Inhibition of PPO by oxalic acid was due to its binding with copper to form an inactive complex, and the inhibition was characterized as noncompetitive. Oxalic acid was a more potent inhibitor of PPO compared with other structurally related acids (Yoruk and Marshall, 2003). Whangchai *et al*. (2006) reported that oxalic acid at concentration of 5% was more potent anti-browning agent compared with other acids on longan fruit cv. "Daw". Oxalic acid can effectively control the pericarp browning of litchi fruit (Saengnil *et al*., 2006; Zheng and Tian, 2006). Yoruk *et al*. (2002) reported that oxalic acid has been shown to suppress apple browning and was previously shown as a potential anti-browning agent for apple PPO. Our results are in accordance with the findings of Apai (2010), but much lower than the findings of Apai *et al*. (2009) and Hai *et al*. (2014a) on pericarp pH of treated longan fruits cv. Daw and cv. Long respectively. Our results also are consistent with the report data on pericarp pH of litchi fruit (Saengnil *et al*., 2006). Apai (2010) also reported that the browning index of logan fruits decreased as pericarp pH decreased. This study indicates that low pericarp pH correlated with low browning index (Figure

4.2 and Figure 4.5). Our result demonstrates that 7.5% OA in combination with 6% MW coating significantly maintained visual appearance by maintaining the lowest pericarp pH of longan fruits cv. Long during the first 25 days in storage.

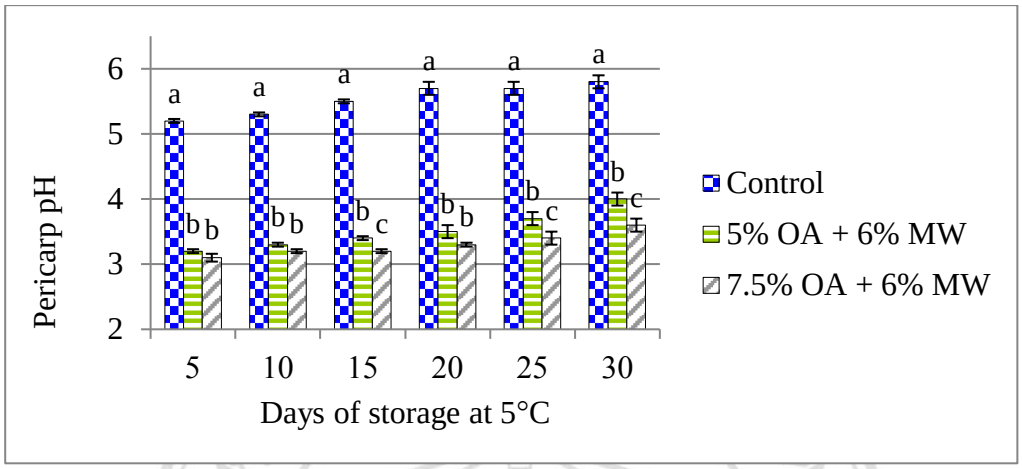

Figure 4.5 Change in pericarp pH of treated and control fruits during storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

4.4.4. Change in PPO activity

Figure 4.6 shows the changes in PPO activity in longan pericarp of treated and control fruits during the storage period. There was significant difference in PPO activity between treated and control fruits during the storage period ($P \leq 0.05$). The PPO activity of T_1 and T_2 treatments was similar during the first 20 days, after that it significantly differed by day 25 in storage ($P \leq 0.05$). Overall, the PPO activity of treated and control fruits tended to decrease with increasing of storage time (control fruits increased from 2.9 to 4.5 unit/mg protein; T_1 and T_2 treatments increased from 1.6 and 1.5 to 2.8 and 2.2 unit/mg protein respectively after 25 days in storage), and T_2 treatment maintained the lowest PPO activity during the storage period. The results in this study explain the effectiveness of the dose of OA in inhibiting PPO activity in longan pericarp. This study also indicates that low PPO activity correlated with low pericarp pH and low browning index (Figure 4.2, Figure 4.5, and Figure 4.6). Our results are in accordance with the reported data on PPO activity in longan pericarp (Whangchai et al., 2006; Apai *et al*., 2009; Hai *et al*., 2011). Tissue browning pericarp of longan fruit is dependent upon PPO activity (Kader, 2002). PPO is activated by moisture loss from the fruit (Su and Yang,

1996). Fruits coated with wax could prevent moisture loss (Thirupathi et al., 2006). OA retards browning by lowering the pH of the product to minimize the activity of PPO (Suttirak and Manurakchinakorn, 2010). The optimum pH for maximum PPO activity in longan fruit is 6.5 (Jiang, 1999). At pH value below 4, PPO has little activity due to the loss of copper at the active site (Sutirak and Manurakchinakorn, 2010). Inhibition of PPO by OA is due to its binding with copper to form an inactive complex, and the inhibition was characterized as noncompetitive (Yoruk and Marshall, 2003). OA prevented pericarp browning due to inhibited PPO activity in longan fruit (Boonin *et al*., 2006; Whangchai *et al*., 2006).

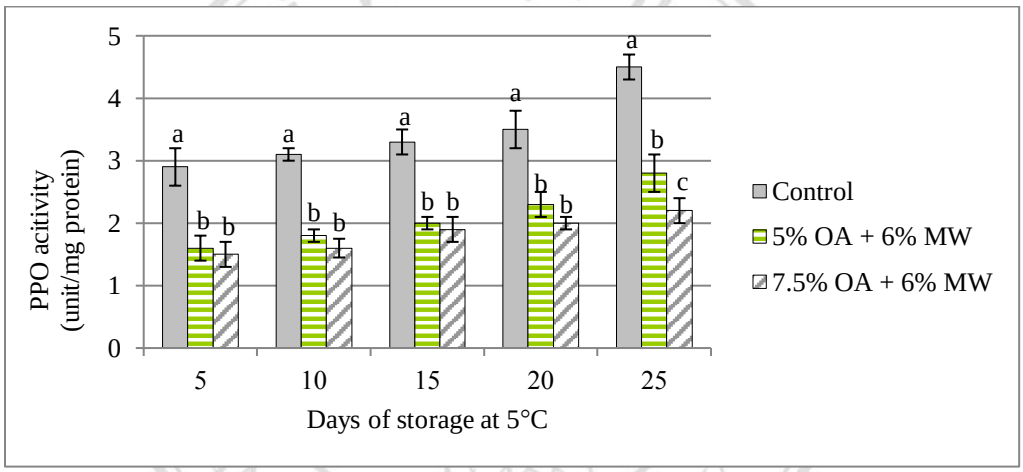

Figure 4.6 Change in PPO activity in longan pericarp of treated and control fruits during storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

4.4.5 Change in percentage of weight loss

The weight loss of stored longan fruits cv. Long is shown in the Figure 4.7. At the first 5 days in storage, the percentage of weight loss in control fruits was 3.3%, and it reached 9.2 and 13.0% by day 25 and 30 respectively. The weight loss of treated fruits at the first 5 days was 1.0%, and it ranged from 4.4 to 4.7% and 7.6 to 7.8% by day 25 and 30 in storage respectively. Hai *et al.* (2014a) found that the untreated longan fruits cv. Long had the highest weight loss (9.8%) and 6% MW coating remained the lowest weight loss (4.6%) after 25 days in storage. Generally, the treated fruits had lower percentage of weight loss than control fruits, and their weight loss tended to increase

with increasing of storage time. The weight loss of T_1 and T_2 treatments was similar, and they differed markedly with the weight loss of control fruits during the storage period ($P \leq 0.05$). Our results are consistent with reported data on percentage of weight loss of longan fruit cv. Long (Thuy and Duyen, 2011; Huyen and Thuy, 2011; Hai *et al*., 2014a), and are lower than the findings of Hoan *et al*.(2001) who reported that the percentage of weight loss of longan fruit cv. Long was approximately 10% after 20 days in storage at low temperature. Our results are also in accordance with the reported data on weight loss of longan fruit (Jiang and Li, 2001; Sodchit *et al*., 2008). This study shows that high weight loss correlated with high browning index and high pericarp pH (Figure 4.2, Figure 4.5, and Figure 4.7). Weight loss means the amount of water lost from fruits and vegetables (Shahid and Abbasi, 2011). The purpose of the wax coating is to reduce the weight loss in fruits and vegetables (Thirupathi *et al*., 2006). Hai *et al*. (2014a) concluded that 6% MW coating has the best effectiveness on reducing the weight loss in longan fruit cv. Long during the storage period. Shi (1990) reported that use of two different waxes reduced water loss from longan fruit cv. Tongbi over 2 days at ambient temperature. Carnauba wax coating significantly reduced water loss compared to uncoated mango fruits (Baldwin *et al*., 1999). Shahid and Abbasi (2011) found that 5% bees wax showed the minimum weight loss in sweet orange fruits cv. Blood red at room temperature storage. Hu *et al*. (2011) concluded that Sta-Fresh 2952 wax (60g/l) was more effective in alleviating weight loss in pineapple fruits. Waxing tomato fruits allow delaying in weight loss (Torres *et al*., 2009). Waxing of Xiang Sui and Pien Pu pears reduced weight loss at all storage temperatures (Sornsrivichai *et al*., 1990). Farooqi *et al*. (1988) reported that wax emulsions Fruitex, Britex-561 and SB 65 coated on oranges, kinnow, lemons and grape fruits reduced weight loss.

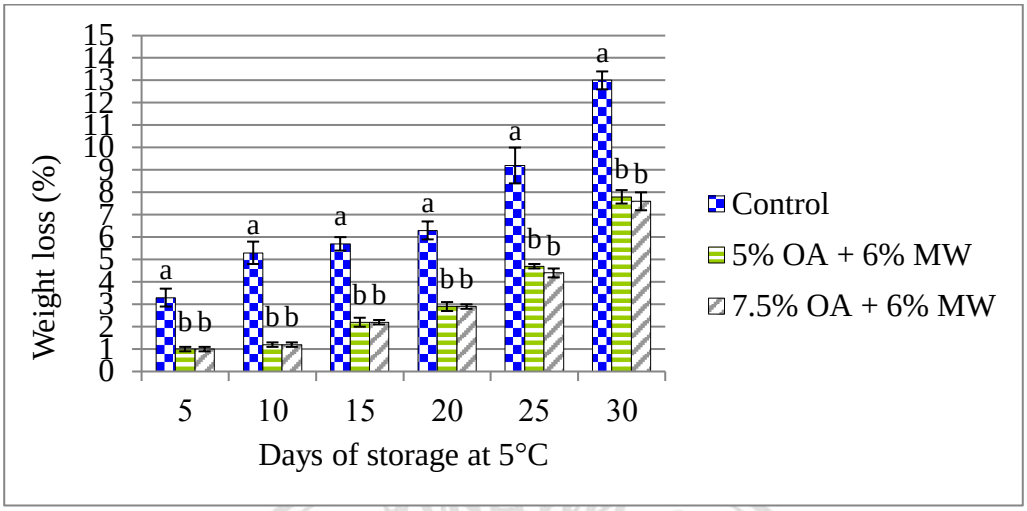

Figure 4.7 Change in weight loss of treated and control fruits during storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

4.4.6 Fruit decay

The control fruits began to decay after 10 days in storage (3.3%), thereafter increasing with the time spent in storage (after 25 days it was 50.4% and after 30 days it was 91.0%) (Figure 4.8). Hai *et al*. (2014a) reported that the control longan fruits cv. Long began to decay (4.5%) after 10 days, and increased with increasing of storage time. This result is consistent with the finding of Hai *et al*. (2011). Apai (2009) reported that the control fruits had the highest disease development and flesh rot along with the highest browning index during the storage period. Increased decay of longan fruit caused wilt and freshness reduction and resulted in browning on the pericarp (Shodchit *et al*., 2008). There was little or no disease development during the first 5 days of storage, after that disease incidence increased with increasing of storage time (Apai, 2010). In contrast to control fruits, the T_1 and T_2 treatments had decay by day 25 (6.3% and 2.6% respectively) and they were not significantly different ($P \leq 0.05$). After 30 days in storage, the percentage of fruit decay between T_1 and T_2 treatments was significantly different (T_1 was 17.8%, and T_2 was 6.6%) (Fig. 4.8). Hai *et al*. (2014a) found that 6% MW coating maintained the lowest the percentage of fruit decay of longan fruits cv. Long for 25 day in storage. Our results are in accordance with the reported data on fruit decay of longan fruit cv. Long (Hai *et al*., 2011; Thuy and Duyen, 2011), and are much lower than the results of Hoan *et al*. (2001); Huyen and Thuy (2011). Tongdee (2001)

reported that fruit deteriorates rapidly after harvest, mainly on account of fruit rotting caused by saprophytic fungal growth on the fruit surface and dehydration of the rind. The main applications of oxalic acid include cleaning or bleaching (Wikipedia, 2014). Waxing is primarily done to protect from mold growth in fruits and vegetables (Thirupathi *et al*., 2006). Postharvest pathogens typically require a film of free moisture on the product's skin to grow. Waxing creates a hydrophobic (non-water compatible) surface which is not conducive to pathogen growth and development (Postharvest Handling Technical Bulletin, 2004). Waxed fruit had less spoilage than uncoated samples (Hagenmaier and Shaw, 1992). Baldwin *et al*. (1999) concluded that the carnauba wax coating reduced fruit decay in mango fruits during storage. Figure 4.8 shows that there was marked difference in fruit decay between treated fruits and the control fruits during the storage period ($P \leq 0.05$), and T_2 treatment had the lowest percentage of fruit decay during the first 30 days in storage. This result justifies that the doses of 7.5% OA and 6% MW coating significantly reduced fruit decay for 30 days in storage.

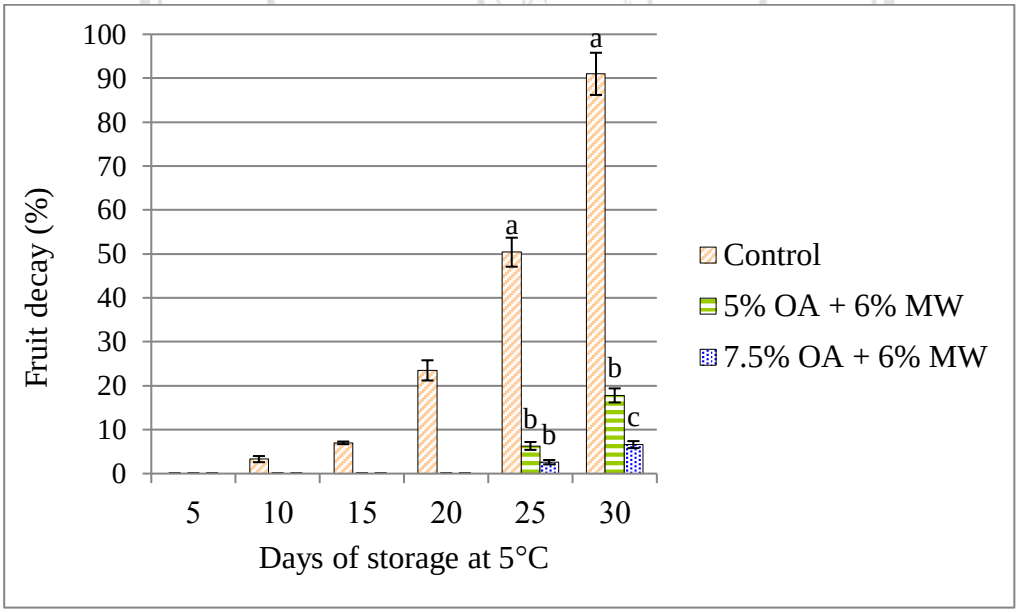

Figure 4.8 The percentage of fruit decay of treated and control fruits during storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

4.4.7 Change in total soluble solids (TSS) content

The changes in TSS content of 'Long' longan fruits during storage period were measured and results are shown in the Figure 4.9. After the first 20 days there was no difference in TSS content between treated and control fruits ($P \leq 0.05$), and TSS content ranged from 19.1 to 23.0%. Our results are consistent with the finding of Hai *et al*. (2014a) in which the TSS content of MW coated fruits and control fruits ranged from 20.6 to 23.7% after 20 days in storage. Our results are in accordance with the reported data on TSS content of longan fruit (Tuc, 1999; Hoan *et al*., 2001; Thavong, 2009; Apai, 2009 & 2010; Hai, 2011; Hai *et al*., 2011; Huyen and Thuy, 2011). By day 25 and 30 in storage, the TSS content ranged from 20.5 to 23.5%, and control fruits had higher TSS content than treated fruits (Fig. 4.9). The Figure 4.9 also indicates that the TSS content of T_1 and T_2 treatments were similar, and they significantly differed with control fruits by day 25 and 30 in storage ($P \leq 0.05$). During the storage period, the treated fruits maintained TSS content which was close to those found in the fresh longan cv. Long at harvesting time (19.9%). Hai *et al*. (2011 and 2014a) found that the treated fruits had TSS content which was close to the TSS content of fresh longan cv. Long at harvesting time. From these results it can be assumed that the doses of OA and MW used in this research had no effect on the TSS content of 'Long' longan fruit. Hoan *et al*. (2001); Hai *et al*. (2011); Hai *et al*. (2014a) reported that the doses of carbendazim, sodium metabisulfite, and MW did not effect the TSS content of 'Long' longan fruit during the storage period. In this study the TSS measurement showed no consistent pattern between treatments or the control fruits, but generally the TSS content of fruit in all treatments and the control increased after storage time perhaps due to dehydration. Apai (2010), Hai *et al*. (2011), and Hai *et al*. (2014a) also assumed that the increase of TSS content in longan fruits during the storage period was perhaps due to dehydration.

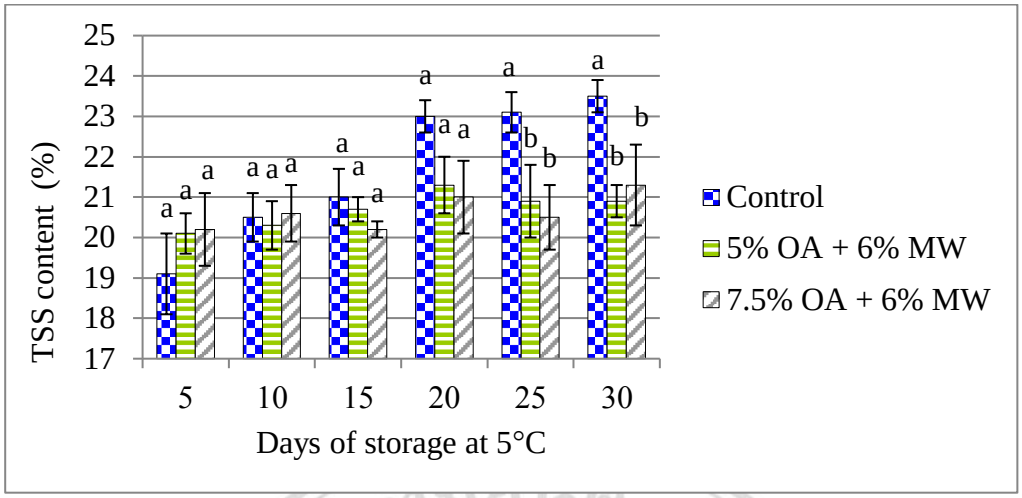

Figure 4.9 Changes in TSS content of treated and control fruits during storage period at 5ºC.

Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

4.4.8 Storage life of longan fruits

Fruits under the control were not acceptable by day 10 in storage. While fruits under the T_2 treatment showed the best results after 25 days in storage, the T_1 treatment was not acceptable after this time (Table 4.1; and Figures 4.10 and 4.11).

Table 4.1 The storage life of 'Long' longan fruits were considered as acceptable for marketing purposes

Treatment	Storage life (days)	Cause of limitation when extend storage time
Control (T_0)	5	BI above 2.0, high fruit decay and weight loss
5% OA + 6% MW (T_1)	20	BI above 2.0, high fruit decay
7.5% OA + 6% MW (T_2)	25	BI above 2.0

(BI: Browning Index)

4.5 Conclusions

Use of 7.5% oxalic acid in association with 6% bees-carnauba mixed wax seems to provide an interesting technological alternative method for the prevention of pericarp browning and the maintenance of postharvest quality in longan fruits cv. Long for 25 days in storage at 5°C. This treatment suggests that application of the above preservative agents could be feasible for longan fruits storage on a commercial scale.

(a)

(b)

(c)

Figure 4.10 Treated and control longan fruits cv. Long after 5 (a), 10 (b) and 15 (c) days in storage at 5°C.

(d)

(e)

(f)

Figure 4.11 Treated and control longan fruits cv. Long after 20 (d), 25 (e) and 30 (f) days in storage at 5°C.