CHAPTER 3

Effects of Wax Coating on Fruit Qualities and Storage Life of Vietnamese Longan Fruit cv. Long

3.1 Abstract

The impact of bees-carnauba mixed wax coating on the reduction of respiration rate, weight loss, fruit decay, and the maintenance of visual appearance and quality of Vietnamese longan cv. Long during low temperature storage was studied by coating the fruits in 2, 4, 6, 8, and 10% of mixed bees and carnauba wax for 30 seconds at room temperature, and storing at 5±1ºC for 25 days. The visual appearance of pericarp color expressed as browning index (BI), the lightness of fruit pericarp (L* value), the yellowness of fruit pericarp (b* value); pericarp pH; the respiration rate; the percentage of weight loss and fruit decay; and total soluble solids (TSS) content were studied. The results showed that the coating treatment in 6% of mixed waxes could maintain high 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. Moreover, the TSS content of the longan fruit revealed no difference over time. The results concluded that the using of 6% mixed waxes was the best method for extending storage life of 'Long' longan fruit.

3.2 Introduction

Longan fruit (*Dimocarpus longan* Lour.) has a high economic value and is one of the most important fruits of Vietnam (Tuc, 1999). According to the report of Center for Computing and Statistics, Ministry of Agriculture and Rural Development of Vietnam, in 2012, the total harvested area of longan was 78,100 hectares, and the total yield was approximately 545,300 tons. There are several cultivars of longan available in the domestic market, 'Long' is the most popular cultivar and its production rank is the first among commercial longan cultivars (Tuc, 1999; Dat, 2003). Longan fruit has a very short postharvest life of 3 to 4 days under ambient temperatures due to desiccation, rotting and browning (Tongdee, 2001; Apai, 2010). Browning can be associated with dehydration, heat stress, senescence, chilling injury or disease (Pan, 1994). The storage of 'Long' longan fruit after harvesting is a very important step for controlling price, in both in season and off season. It is also very useful in long distance of exportation to foreign markets. The recent researches showed 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). The SO_2 can reduce browning symptoms due to reducing PPO activity, 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 its toxic residue of SO_2 and carbendazim. Longan consumers are becoming cautious regarding SO_2 and carbendazim residues. There is a need to develop effective and safe methods to replace SO_2 and carbendazim treatment in Vietnam. An alternative method is the use of edible coatings containing bees wax and carnauba wax. FDA regulates these waxes or coatings as food additives approved or generally recognized as safe for human consumption (Thirupathi *et al*., 2006). Wax is an ester of aliphatic acid chain and aliphatic alcohol chain formed from a fatty acid and a high molecular weight alcohol. Bees wax is a natural wax produced in the bee hive of honey bees (*Apis* sp.). Carnauba wax (palm wax) is a wax of the leaves of the palm (*Copernicia prunifera*), a plant native to and grown only in the northeastern Brazil. Bees wax used at the rate of 5% in combination with 0.5% benomyl proved to be very effective in improving the overall quality and extending the shelf life of orange fruits cv. Blood Red (Shahid and Abbasi, 2011). Bees wax reduced plum weight loss compared to no bees wax (Navarro-Tarazaga *et al*., 2011). Carnauba wax shows potential as a natural wax substitute for paraffin wax to store cassava root (Sargen *et al*., 1995). Wax has been using as an effective technology to increase the quality of postharvest fruits and vegetables by preventing moisture loss, shriveling, and weight loss; reducing rates of respiration and ethylene production; decreasing rate of transpiration; increasing shelf life and freshness; protecting from mold growth; and maintaining attractiveness (Hagenmaier and Shaw, 1992; Kolattukudy, 2003; Thirupathi *et al*., 2006; Hung, 2008; Torres *et al*., 2009; Hu *et al*., 2011; Shahid and Abbasi, 2011).

The main purpose of this study was to investigate the effects of bees-carnauba mixed wax coating on weight loss, fruit decay, respiration rate, and visual appearance as well as the quality of fresh 'Long' longan fruit during storage at low temperatures.

3.3 Material and Methods

3.3.3 Plant materials

Mature 'Long' longan fruit of a commercial orchard in Hung Yen Province in Vietnam were used for the research. The longan fruits were harvested at commercial maturity (about from 185 to 190 days after full bloom) in the morning and packaged in 20 kg plastic baskets, lined with leaves and transported to the laboratory within 3 h. Fruits were separated for individual fruit then selected for uniformity of shape, size, and non-defected fruits, and washed, prior to use in this experiment (Figure 3.1). Their initial qualities were assessed and the results of the experiment averaged out over 18 replications. The averaged results were as follows: (i) thickness of the pericarp was 0.68 ± 0.03 millimeters (mm), (ii) thickness of the flesh was 4.2 ± 0.5 mm, (iii) diameter of the fruit was 27.09 ± 2.83 mm, (iv) weight of the fruit was 8.97 ± 1.14 grams, (v) weight of the seeds was 1.63 ± 0.29 grams, (vi) the soluble solids content was 19.4 ± 0.9 %, and (vii) the color of the fresh fruit, when expressed as L* value (lightness) was 51.5 ± 3.2; b* value (yellowness) was 30.1 ± 2.4.

Figure 3.1 A bunch of longan (a) and a fruit (b) of longan cv. Long at commercial harvesting date.

3.3.4 Studying methods

The optimal and feasible concentration of mixed between bees wax and carnauba wax (mixed waxes - MW) were selected after preliminary tests. The bees wax and carnauba wax in the ratio of 2 to 1 were melted and mixed well at 80-85°C for 30 min. Oleic acid

(4.8%) and palmitic acid (0.5%) were added to the mixture before the mixture was blended. Water was added to the mixture during stirring and blending for adjustment concentrations of MW to 2, 4, 6, 8 and 10% weight/volume (Appendix E).

Washed fruits were coated in 2, 4, 6, 8 and 10% MW for 30 seconds at room temperature; while the control fruits were not coated. The coated fruits were dried for 8 h and 1 kg per a bag of longan was packaged in polypropylene bag (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 and 80-85% relative humidity in a cold room and sampled/analyzed at 5 day intervals. A completely randomized design was used for the experiment. All measurements of each treatment were the average of three replications.

Total soluble solids (TSS) content was measured by a digital refractometer (PAL-1, Atago, Japan). Eighty fruits per treatment were used to determine TSS content. The flesh of each fruit was pressed by hand and approximately 0.3 ml juice of each fruit was placed onto the prism surface. The measurement was taken, and TSS content of each fruit (%) was displayed.

Visual appearance expressed as pericarp browning was estimated by observing the extension of total browned area on each fruit surface using the following scales: 1 = 0% (no browning); 2 = 1-25% (slight browning); 3 = 26-50% (moderate browning); 4 = 51-75% (extreme browning), and; 5 = 76-100% (extreme browning with poor quality) pericarp browning area. A browning index (BI) was calculated using the following formula: browning scale x percentage of corresponding fruits in each scale. Fruits with BI above 2.0 were considered as unacceptable (Jiang and Li, 2001).

1 = 0% pericarp browning area

2 = 1 - 25% pericarp browning area

3 = 26 - 50% pericarp browning area

4 = 51 - 75% pericarp browning area

5 = 76 - 100% pericarp browning area

Figure 3.2 Browning index (scales) of longan pericarp (Jiang and Li, 2001).

The pericarp color was measured using a colorimeter (Konica Minolta CR-300, Japan) and L* indicated lightness, ranged from black = 0 to white = 100, b* indicated chromaticity on a blue (-) to yellow (+) axis (MacGuire, 1992).

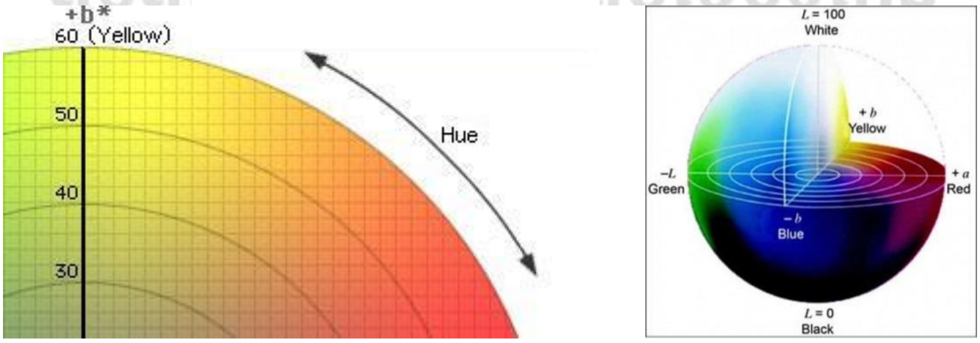


Figure 3.3 Color chart of Minolta model CR-300 (Apai, 2009)

The pericarp pH, which indicated the acid response in pericarp homogenate, was measured using the method of Joas *et al*. (2005) and Apai (2010). 200 g of fruits per treatment, 10 in each replicate were used to prepare the samples. The pericarp of each fruit was ground using a blender (Moulinex, France). Three grams of grind material were then homogenized (Wiggen Hauser, Germany) in 30 ml of distilled water and the pH of the pericarp homogenate was measured by a digital pH meter (Consort C831, Belgium) while continuously stirring.

Respiration rate was measured according to the method of Jiang and Li (2001), with 250 g of fruits sealed in a glass chamber for 2 hours at 5°C, and a 5 ml gas sample was withdrawn with a gas-tight hypodermic syringe and analyzed by gas chromatography (GC-7820A, Agilent Technology). The respiration rate was expressed as mg CO_2 /kg (fresh weight)/h.

Percentage of weight loss was calculated by weighing the whole fruits packed in PP bags before and after storage (taken as 100%).

Fruit decay was assessed as the percentage of fruit decay as follows:

$$\text{Percentage of fruit decay} = \frac{\text{Number of fruit decay}}{\text{Total fruit}} \times 100$$

Storage life of longan fruit was assessed by using the below indices, the postharvest quality of the longan fruit was deemed to be unacceptable when fruit had a BI above 2.0; when the percentage of fruit decay was above 10%; or when percentage of weight loss was above 10%.

Data were statistically analyzed by using the statistical package for the social sciences (SPSS) software (version 20.0) and Duncan's Multiple Range Test ($P \leq 0.05$) to analyze the significantly different of means between the treatments and control.

3.4 Results and Discussion

3.4.1 Change in visual appearance during storage period

Figure 3.4 indicates the changes in visual appearance expressed as browning index (BI) of longan fruits coated with various concentrations of MW, and the control during the storage period at 5°C. Fruits with BI above 2.0 (more than 25% pericarp browning area) were considered as unacceptable for marketing purposes. After 5 days in storage, the BI of coated and control fruits was lower than 2, and were not significantly different ($P \leq 0.05$). By day 10 in storage fruits coated with 2% MW and control fruits had BI higher than 2.0 and were not acceptable. Hai *et al*. (2011) reported that 2.5% sodium metabisulfite treated and the control longan fruits cv. Long had BI more than 2.0 and they were not acceptable by day 7 in storage. For the untreated longan fruits, pericarp browning occurred after a delay of 5 days with a BI above 2.0 (Apai, 2010). Jaitrong (2006) also found that untreated longan fruit pericarp browned during storage at 2-7ºC for 5 days. At 20 days in storage, there were significant differences in BI, and the 2, 4, 8, 10% MW treatments were not acceptable because of BI more than 2.0 while 6% MW coated fruit was less than 2.0. Whangchai *et al*. (2006) reported that pericarp browning increased with increasing storage time. The 6% MW coating showed the best pericarp color and the longest storage life for 20 days with the lowest BI. This result explains that coating fruits in 6% MW prevented pericarp browning as expressed by BI scale. Our results are consistent with reported data on BI of longan fruit pericarp (Whangchai *et al*., 2006; Nguyen *et al*., 2001; Apai, 2009 & 2010). Postharvest longan fruit changed the pericarp color rapidly due to desiccation during storage at either too low or high temperature (Apai, 2010). Water loss from the pericarp was significantly positively correlated with pericarp browning index (Apai, 2009). 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). Baldwin *et al*. (1999) concluded that carnauba wax coating significantly reduced water loss compared to uncoated mango fruits.

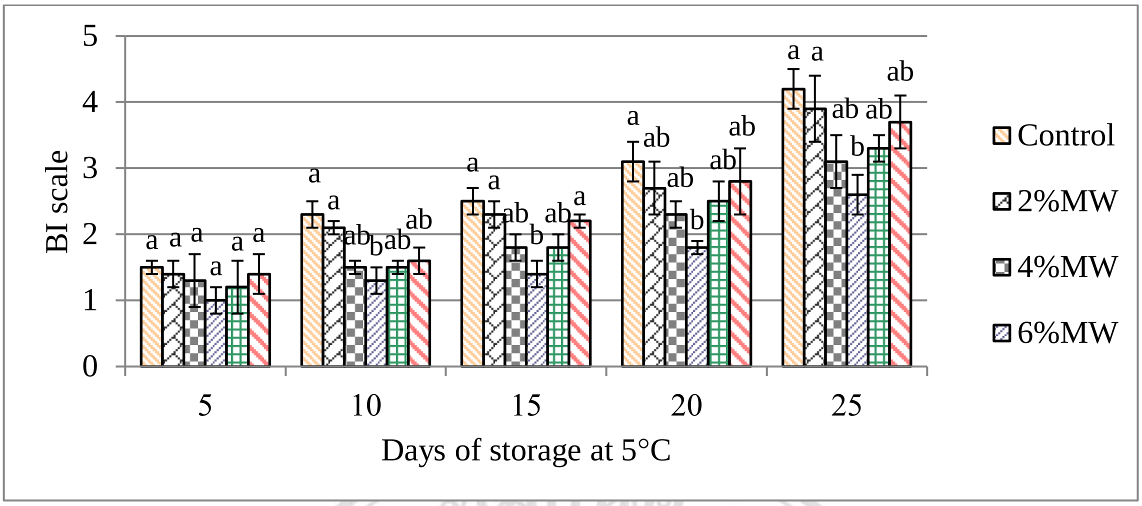


Figure 3.4 Change in BI of longan fruit pericarp either coated or not, during the storage period at 5ºC.

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

3.4.2 Changes in L* and b* values

The L* values (lightness) of fruit pericarp were measured and results are shown in Figure 3.5. At 20 days in storage, there was significantly different L* values between the control and MW coatings ($P \leq 0.05$). The L* values of 6% MW coating was 52.5 and it was higher than other treatments and the control. When compared with L* value of fruits at harvesting time, L* value of 6% MW coated fruits was similar by day 20 in storage (52.2 compared with 52.5 respectively). Overall, the L* values of coated fruits was higher than L* values of the control fruits during the storage period. This result demonstrates the effectiveness of 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. Water loss from the pericarp resulted in an increase in activity of PPO (Apai, 2009). Using wax could reduce the water loss during handling and marketing of fruits and vegetables (Thirupathi *et al*., 2006). Use of two different waxes reduced water loss from longan fruit cv. Tongbi over 2 days at ambient temperature (Shi, 1990). Apai (2009) also reported that the temperature at 5ºC was most suitable for storage and delayed browning due to less severe chilling injury. After 25 days in storage, there was significant difference on L* values in all treatments and the control, and the L* values ranged from 41.6 to 51.2, and tended to decrease in all treatments ($P \leq 0.05$). Our results are 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). 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). Apai (2010) demonstrated that untreated fruits had lower L* values. According to Figure 3.5, the fruits coated in 6% MW had higher L* values than the fruits which underwent other treatments and the control during the storage period. This result confirms that coating with 6% MW significantly maintained the lightness of color on longan pericarp cv. Long ($P \leq 0.05$).

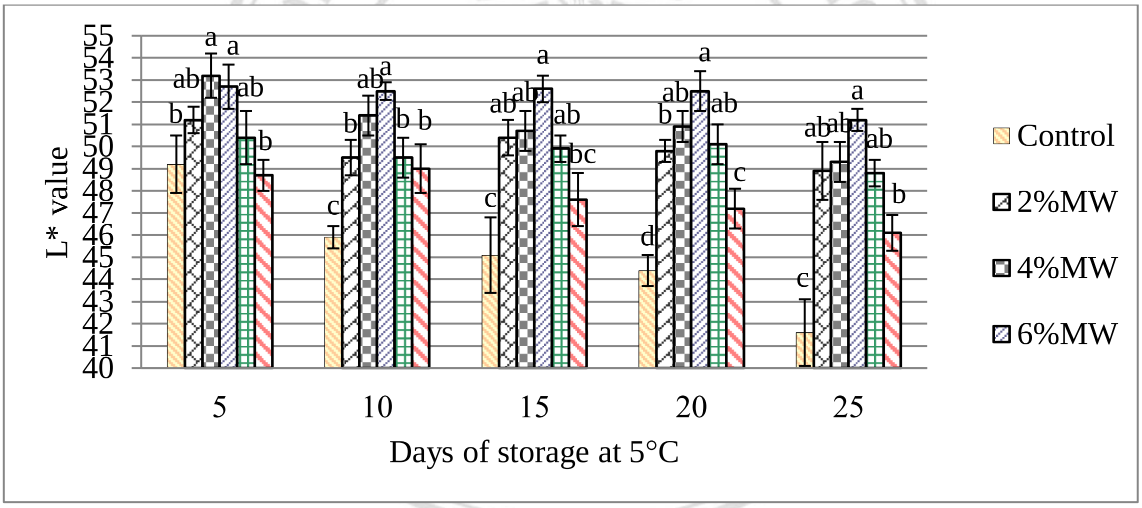


Figure 3.5 Change in L* values of MW coated and control longan fruits during storage at 5°C.

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 Figure 3.6. At 20 days in storage, the b* values ranged from 21.5 to 26.3, and there was significant difference in b* value between control and MW coated fruits ($P \leq 0.05$). Fruits coated with 6% MW had the highest b* value (26.3) by day 20 in storage. Hai *et al*. (2011) reported that b* value of sodium metabisulfite (SMB) treated and untreated longan fruits cv. Long ranged from 16.9 to 27.4 by day 21 in storage. Our result was higher than the reported data on b* values after 20 days in storage of 'Long' longan fruits of Huyen and Thuy (2011), and Thuy and Duyen (2011). At 25 days in storage, the b* values ranged from 20.4 to 23.7. The fruits in control, 2, 4, and 10% MW coating had b* values which were similar, and they were significant different from coated fruits in 6 and 8% MW ($P \leq 0.05$). The b* value of longan fruit cv. Long soaked in 7.5% SMB for 10 min was 22.0 after 28 days in storage (Hai *et al*., 2011). Our b* values were higher than reported data on b* values of longan fruit cv. Long which ranged from 18.5 to 19 (Huyen and Thuy, 2011; Thuy and Duyen, 2011). The b* values of coated fruits were higher than b* values of the control fruits during the storage period. This result justifies the effectiveness of mixture of bees and carnauba wax coating in maintaining the yellowness of fruit pericarp by preventing water loss from pericarp, and thence decreasing activity of PPO as described by Apai (2009). PPO is activated by moisture loss from the fruit and treatments to reduce desiccation also reduce browning (Su and Yang, 1996). It can be seen from Figure 3.6, the b* values tended to decrease in all treatments and the control after 25 days in storage. Shodchit *et al*. (2008) demonstrated that b* values of treated fruits tended to decrease with increasing storage time. The fruits coated in 6% MW had higher b* values than the fruits which underwent other coating treatments and the control during the storage period. This result shows that coating with 6% MW maintained the longevity of yellowness of fruit pericarp better than other coating treatments.

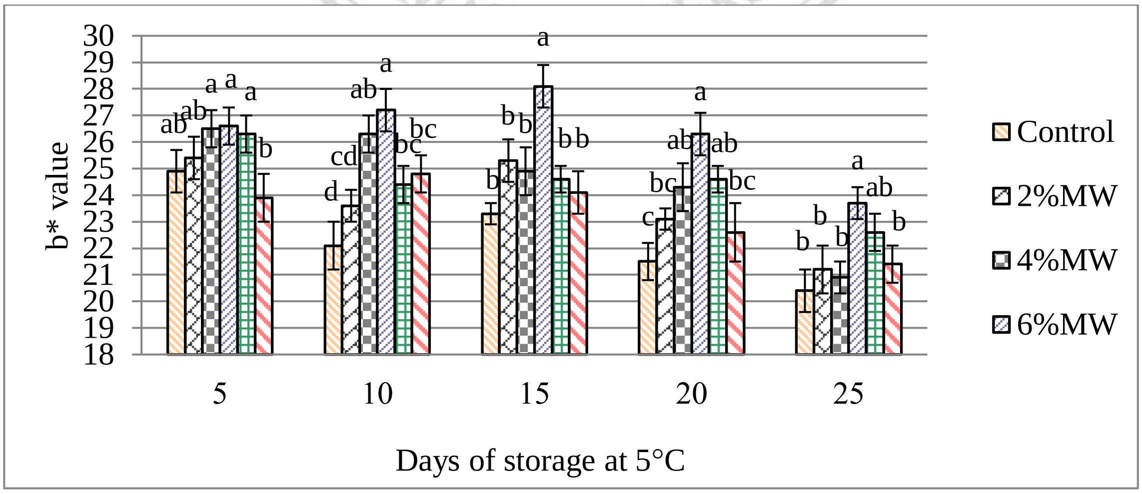


Figure 3.6 Change in b* values of MW coated and control longan fruits during storage at 5°C.

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

3.4.3 Change in pericarp pH

Figure 3.7 illustrates the changes in pH in ‘Long’ longan pericarp of coated and control fruits during the storage period at 5ºC. There was no difference in pericarp pH in all treatments and the control after 10 days in storage ($P \leq 0.05$). After 20 and 25 days in storage, the pericarp pH of coated and control fruits was significantly different, and the pH value ranged from 4.9 to 5.9 and 5.0 to 5.9 respectively. In general, pericarp pH of coated and control fruits tended to increase with increasing storage time, and the control fruits maintained higher pericarp pH than coated fruits during preservative period. According to Figure 3.7, the 6% MW coated fruits maintained the lowest pericarp pH during the storage time. Water loss from the pericarp causes an increase pericarp pH value (Apai, 2009). Wax coating can retard water loss (Mac Guire and Hallman, 1995; Baldwin *et al*., 1997; Hung, 2008; Hu *et al*., 2011). 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, of phenolic compounds to quinones and their eventual polymerization to melanin pigments (Jiang *et al*., 2002; Yoruk and Marshall, 2003). Low pH retards browning by minimizing the activity of PPO. At pH values below 4, the PPO has little activity due to the loss of copper at the active site (Suttirak and Manurakchinakorn, 2010). Our results are in accordance with the findings of Apai *et al*. (2009), where applying a solution of 1.2% chitosan dissolved in 1% citric acid yielded the lowest pericarp pH value (pH 4.97). This study indicates that low pericarp pH correlated with low browning index (Figure 3.4 and Figure 3.7). The browning index of logan fruits decreased as pericarp pH decreased, and most PPO could be irreversibly inactivated at pH below 3.0 in fruits treated with HCl (Apai, 2010). Wu *et al*. (1999) found that SO_2 inhibited enzymatic skin browning during storage by reducing the pH of pericarp cytoplasm, inhibited PPO activity, and increasing the free and bound total phenolic contents. Caro and Joas (2005) and Joast et al. (2005) found that pericarp browning effects could be postponed by reducing pericarp pH when dipping litchi fruits in a solution of citric acid and 1% chitosan. The fruits coated in 6% MW had the lowest pericarp pH values which ranged from 4.7 to 5.0 during 25 days in storage. This result demonstrates that 6% MW coating significantly maintained visual appearance by maintaining the lowest pericarp pH of longan fruits cv. Long during the storage period when compared with the control and other treatments.

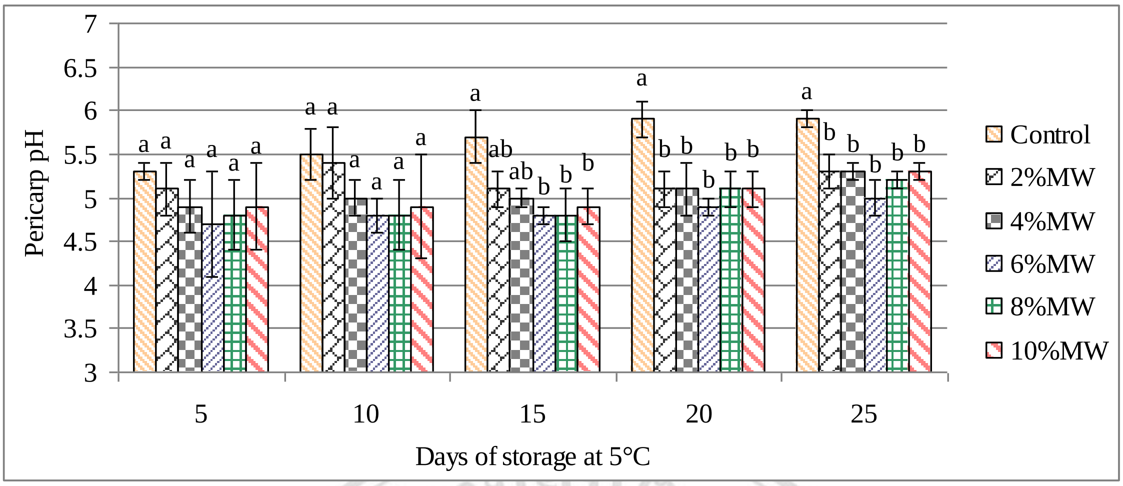


Figure 3.7 Change in pericarp pH of coated and control longan fruits during the storage period at 5ºC.

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

3.4.4 Change in percentage of weight loss

The percentage of weight loss in 'Long' longan fruits during the storage period is shown in Figure 3.8. After 20 days in storage, weight loss ranged from 2.9 to 6.9%, and there was significant difference in the percentage of weight loss in 6% MW coating, 4% MW coating, and 2, 8, 10% MW coating and the control fruits ($P \leq 0.05$). After 25 days in storage, the control and 2% MW coating had the highest weight loss (9.8 and 8.9% respectively). The weight loss of 4, 8, and 10% MW coating were similar and ranged from 7.1 to 7.7%. Generally, percentage of weight loss of coated and control fruits tended to increase with increasing of storage time, and the control fruits had higher weight loss than coated fruits during storage period. This study indicates that high weight loss correlated with high browning index and high pericarp pH (Figure 3.4, Figure 3.7 and Figure 3.8). Fruits coated in 6% MW had the lowest weight loss after 20 and 25 days in storage (2.9 and 4.6% respectively) which was significantly different from other treatments and the control fruits ($P \leq 0.05$). This result justifies that 6% MW coating has the best effectiveness on reducing the weight loss in longan fruit cv. Long during the storage period. Our results are in accordance with the reported data on weight loss of longan fruit (Jiang and Li, 2001; Sodchit *et al*., 2008; Apai *et al*., 2009). Thuy and Duyen (2011) reported that the weight loss of longan fruits cv. Long increased with increasing storage time. Our results are consistent with reported data on percentage of weight loss of longan fruit cv. Long (Huyen and Thuy, 2011), and are much lower than the finding 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. The purpose of the wax coating was to reduce the weight loss in fruits and vegetables (Thirupathi *et al*., 2006). Weight loss means the amount of water lost from fruits and vegetables and it is related to the shelf life of the produce (Shahid and Abbasi, 2011). Use of two different waxes reduced water loss from longan fruit cv. Tongbi over 2 days at ambient temperature (Shi, 1990). Baldwin *et al*. (1999) concluded that carnauba wax coating significantly reduced water loss compared to uncoated mango fruits. Sta-Fresh 2952 wax (60g/l) was more effective in alleviating weight loss in pineapple fruits (Hu *et al*., 2011). Shahid and Abbasi (2011) reported that 5% bees wax showed the minimum weight loss in sweet orange fruits cv. Blood red at room temperature storage. Waxing tomato fruits allow delaying in weight loss (Torres *et al*., 2009). Wax emulsions Fruitex, Britex-561 and SB 65 coated on oranges, kinnow, lemons and grape fruits reduced weight loss and kept the fruits firmer, thus maintaining their fresh look (Farooqi *et al*., 1988). Sornsrivichai *et al*. (1990) reported that waxing of Xiang Sui and Pien Pu pears reduced weight loss at all storage temperatures.

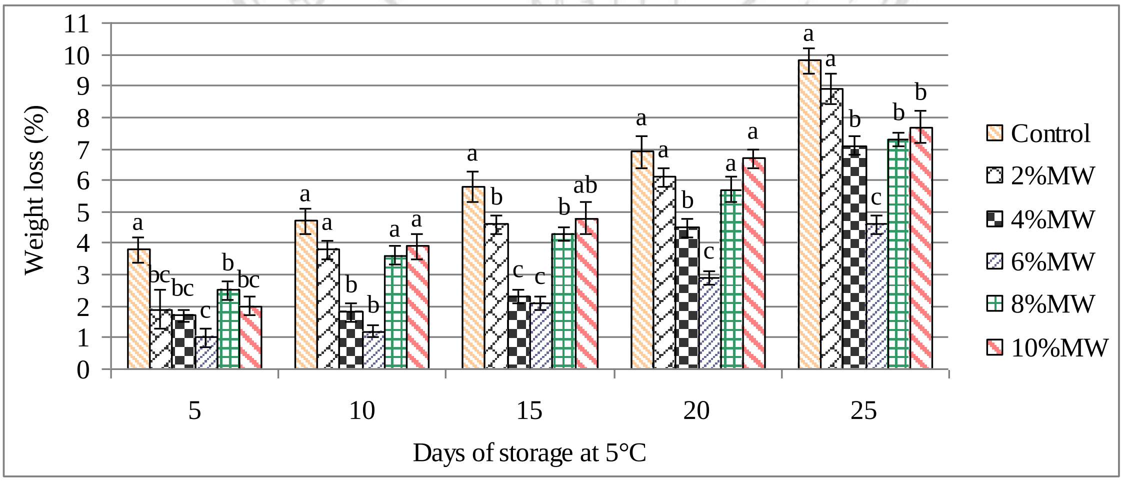


Figure 3.8 The percentages of weight loss of coated and control fruits during the storage period at 5ºC.

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

3.4.5 Fruit decay

Figure 3.9 shows the percentage of fruits decay in coated and control 'Long' longan fruits during the storage period at 5ºC. After 10 days in storage, the control and 2% MW coating showed fruit decay (4.5 and 2.5% respectively), and they increased to 7.6 and 6.7% respectively by day 15 in storage. Apai (2010) demonstrated that there was little or no disease development during the first 5 days of storage, after that, disease incidence increases with increasing storage time. There was significant difference in fruit decay between 4; 6; 8% MW coating and other treatments and the control fruits ($P \leq 0.05$), and 4; 6; 8% MW coating showed no fruit decay after 20 days 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) which found that fruits soaked in 5 or 7.5% SMB for 10 min, and SO_2 fumigation at the rate of 9g per 10 kg of fruit for 20 and 30 min showed no fruit decay by day 21 in storage at 5°C. Our results are much lower than the finding of Huyen and Thuy (2011) who reported that the fruit decay of treated and untreated 'Long' longan fruits ranged from 11.4 to 24.8 by day 20 in storage at 10°C. After 25 days in storage, fruits coated in 4; 8; 10% MW were not different and they were significantly different from other treatments and control fruits ($P \leq 0.05$). Overall, the percentage of fruit decay ranged from 9.4 to 45.3%, and control fruits had the highest fruit decay (45.3%), and 6% MW coating maintained the lowest fruit decay (9.4%) by day 25 in storage. The control fruits had the highest disease development and flesh rot in accordance with the highest browning index during the storage period (Apai, 2009). The more fruit decay of longan fruit caused wilt and freshness reduction and resulted in browning on the pericarp (Shodchit *et al*., 2008). These results demonstrate that the doses of 6% MW coating significantly prevented fruit decay in 'Long' longan fruit during the storage period. Tongdee (2001) explained 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 most important microorganisms are *Botryodiplodia* sp., and yeasts *Saccharomyces* sp. Waxing is primarily done to protect from mold growth in fruits and vegetables (Thirupathi *et al*., 2006). Carnauba wax shows potential as a natural wax substitute for paraffin wax to store cassava root (Sargen *et al*., 1995). Baldwin *et al*. (1999) concluded that the carnauba wax coating reduced fruit decay in mango fruits during storage. Waxing establishes a barrier against the entrance of fungal and bacterial pathogens into the product. 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 fruit (Hagenmaier and Shaw, 1992).

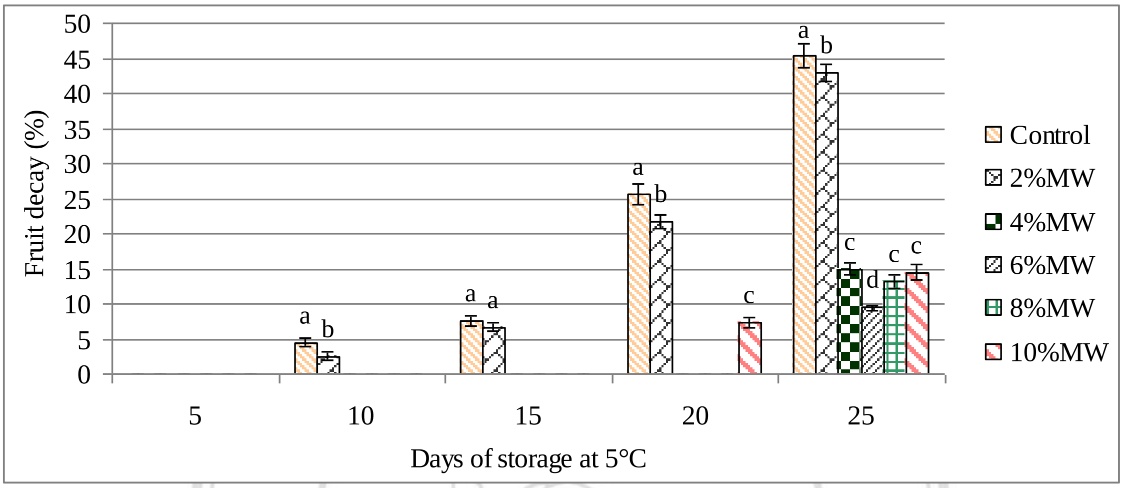


Figure 3.9 The percentage of fruit decay of coated and control fruits during the storage period at 5ºC.

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

3.4.6 Change in respiration rate

Figure 3.10 illustrates the changes in respiration rate of coated and control longan fruits cv. Long during storage period at 5ºC. The respiration rate of both coated and control fruits tended to decrease during the first 20 days in storage (except 2 and 10% MW coating, and the control fruits slightly increased by day 20 in storage). After that, respiration rate tended to increase in both coated and the control fruits by day 25 in storage. This study shows that the increasing of respiration rate correlated with the increasing of fruit decay (Figure 3.9 and Figure 3.10). Jiang and Li (2001) reported that respiration rate decreased markedly when longan fruits were stored at low temperatures, however, they increased at the later stage of storage. The treatments with chitosan coating reduced respiration rate, or delayed the increase in the respiration rate. The increase in respiration rate of longan fruit during later storage could be related to disease development (Zhou *et al.*, 1997; Jiang and Li, 2001). Shi (1990) recorded a gradual increase in respiration rate in harvested 'Tongpe' longan fruit at 25°C. The respiration rate of longan fruit cv. Shixia decreased on the first day after harvest and then increased (Pan *et al*., 1996). As seen in Figure 3.10, the respiration rate of fruits in 4-10% MW coating was similar, and was significantly different with 2% MW coating and the control fruits (P ≤ 0.05). The control fruits had respiration rate which was markedly different and much higher than coated fruits during storage period (P ≤ 0.05). These results explain that MW coating in this study significantly inhibited respiration rate of longan fruits during storage period when compared with the control. The surface coating was relatively impermeable to O_2 and CO_2 and water (Thirupathi *et al*., 2006). Commercial fruit wax has also been shown to reduce the respiration rate of coated fruit (Hagenmaier and Shaw, 1992). Wax emulsions Fruitex, Britex-561 and SB 65 coated on oranges, lemons and grape fruits reduced rates of respiration (Farooqi *et al*., 1988). In this study, the longan fruits coated in 6% MW had the lowest respiration rate during storage period, with a respiration rate of 1.2 mg CO_2/kg/hour by day 20 in storage. This result demonstrates that 6% MW coating significantly prevented respiration rate in longan fruit cv. Long during the storage period at 5°C.

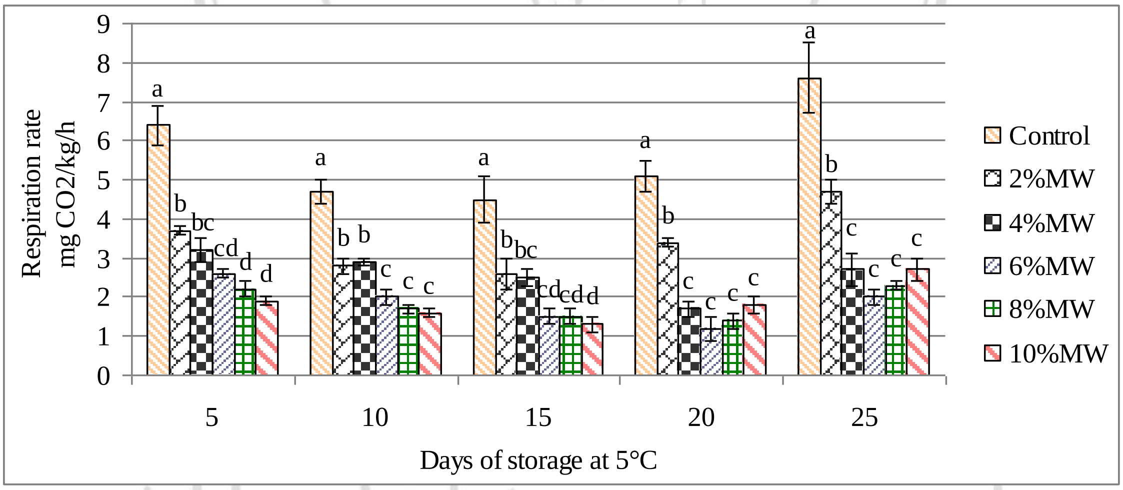


Figure 3.10 Changes in respiration rate of coated and control fruits during the storage period at 5ºC.

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

3.4.7 Change in total soluble solids (TSS) content

The TSS contents of ‘Long’ longan fruits are shown in Figure 3.11. After 20 days in storage, the TSS content of coated and control fruits ranged from 20.6 to 23.7%. The

TSS content of 2 and 8% MW coatings and control fruits was similar, and the TSS content of 4 and 6% MW coatings also was similar ($P \leq 0.05$). These TSS contents are in accordance with the reported data on TSS content of longan fruit cv. Long which ranged from 15.5 to 20.9% (Tuc, 1999; Hoan *et al*., 2001; Hai, 2011; Hai *et al*., 2011; Huyen and Thuy, 2011). Our results also are in accordance with the reported data on TSS content of longan fruit which ranged from 19.3 to 20.4% (Thavong, 2009; Apai, 2009 and 2010). After 25 days in storage, the TSS content ranged from 20.8 to 24.9%, and the TSS content of 2, 8, and 10% MW coatings was significantly different from the control fruits and other coatings ($P \leq 0.05$). The 6% MW coating maintained TSS content which was close to those found in the fresh longan cv. Long at harvesting time (19.4%). Hai *et al*. (2011) found that the TSS contents of SMB treated longan fruits cv. Long are close to those found in the fresh longan (17 and 21%). From these results it can be assumed that the doses of MW used in this research had no effect on the TSS content of 'Long' longan fruit. Hoan *et al*. (2001) and Hai *et al*. (2011) reported that the doses of carbendazim and SMB did not effect the TSS content of 'Long' longan fruit during the storage period. In this study the TSS contents measurement showed no consistent pattern between treatments or the control fruits, but generally these TSS contents of fruit in all treatments and the control increased after 25 days in storage perhaps due to dehydration. Apai (2010) and Hai *et al*. (2011) also assumed that the increase of TSS contents in longan fruits during the storage period was perhaps due to dehydration.

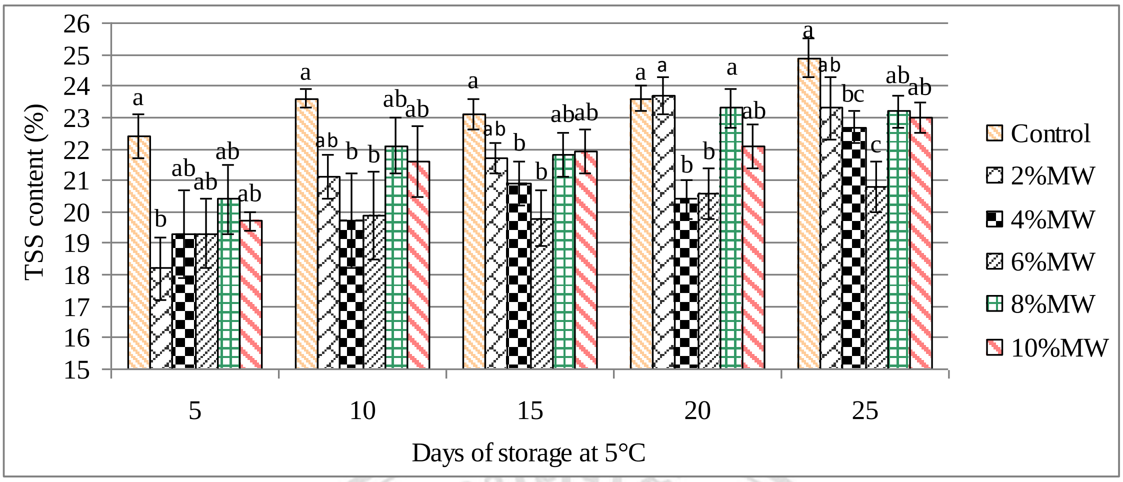


Figure 3.11 The TSS content of coated and control fruits during the storage period at 5ºC.

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

3.4.8 Storage life of longan fruits

Fruits under the control and 2% MW were not acceptable by day 10, and 10% MW did not accept by day 15 in storage. Fruits coated in 4 and 8% MW maintained acceptable for marketing purposes after 15 days, while fruits under the 6% MW treatment showed the best results after 20 days in storage (Table 3. 1 and Figure 3.12).

Table 3.1 The storage life of longan fruits were considered as acceptable for marketing purposes

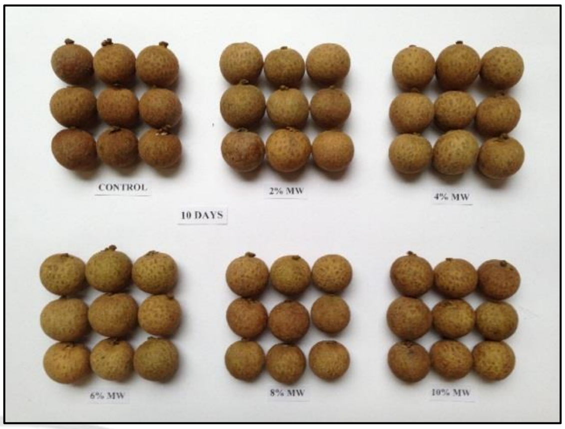
Treatment	Storage life (days)	Cause of limitation when extend storage time
Control	5	BI above 2.0, high fruit decay and weight loss
2% MW	5	BI above 2.0, high fruit decay and weight loss
4% MW	15	BI above 2.0, high fruit decay
6% MW	20	BI above 2.0
8% MW	15	BI above 2.0, high fruit decay
10% MW	10	BI above 2.0, high fruit decay

(BI: Browning Index)

3.4. Conclusions

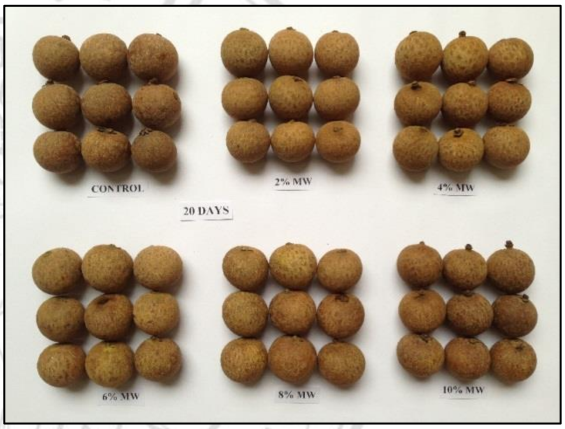
Coating 'Long' longan fruit in 6% bees-carnauba mixed wax for 30 seconds can be used instead of carbendazim dipping and chitosan coating. It provides an interesting technological alternative method for maintaining postharvest quality, L* and b* values, low pericarp pH, low respiration rate, and low weight loss, with the fruit showing no signs of severe pericarp browning or fruit decay during the first 20 days in storage. Moreover, this method is not only an appropriate technique and good for extending storage life of 'Long' longan fruit but it is also safe for the consumers.

(a)

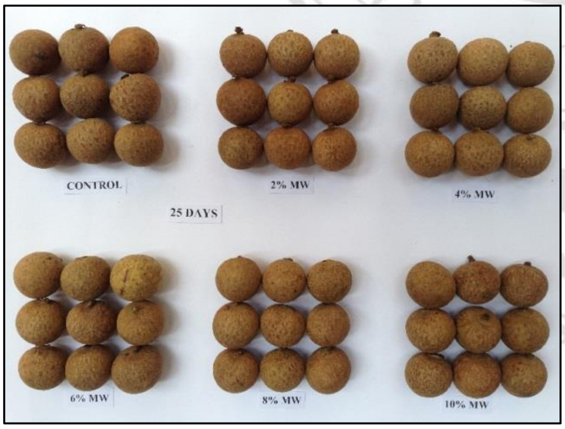


(b)

(c)



(d)



(e)

Figure 3.12 MW coated and control longan fruits cv. Long after 5 (a), 10 (b), 15 (c), 20 (d), and 25 (e) days in storage at 5°C.