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

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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; weight loss; fruit decay; total aerobic bacteria; and total soluble solids (TSS) content were monitored during the 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 of 'Long' longan fruit.**

Keywords **– 'Long' Longan, Bees - Carnauba Mixed Wax, Oxalic Acid, Weight Loss, Fruit Decay.**

I. 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) [7]. Longan fruit has a very short postharvest life of 3 to 4 days under ambient temperatures due to desiccation, rotting and browning [3], [20], [39]. Postharvest longan has faced rapid discoloration caused by desiccation during storage at either too low or too high temperatures [1], [3]. Pericarp browning can be associated with dehydration, heat stress, senescence, chilling injury or disease [25]. Browning of fresh fruit results from phenolic compounds oxidized by endogenous polyphenol oxidase (PPO) and pigment formation [20]. 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 [3]. Recently published works indicate that the shelf life of 'Long' longan fruits could be extended by carbendazim dipping [13], SO_2 fumigation [38], and sodium metabisulfite soaking [10], [11]. SO_2 can reduce browning symptoms due to reducing PPO activity, and it also acts as a bleaching agent [39], [45]. Carbendazim and SO_2 play an important role in decay and fungal growth inhibition [13], [39]. 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 [16], mixed (bees-carnauba) wax coating [12]. 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. 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 [3]. 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) [35]. Oxalic acid is a natural component of large number of plants such as spinach, broccoli, tomatoes and turnips [42] and appears to inhibit enzymatic browning [43]. Oxalic acid prevented pericarp browning due to inhibited PPO activity in longan fruit [5], [43]. [48] 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 [47]. [28] 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 [47]. [43] 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 [12], 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 waxes coating on pericarp browning and storage life of fresh 'Long' longan fruit during storage at low temperatures.

II. Materials And Methods

A. Plant materials

Mature 'Long' longan fruit of a commercial orchard in harvesting crop of 2014 in Hung Yen Province in Vietnam were used for the research. The longan fruits were harvested in the morning and packaged in 20 kg plastic baskets, lined with leaves and transported to the laboratory within 3 h. Fruits were then selected for uniformity of shape, size, and non-defected fruits prior to use in this experiment.

B. Studying methods

The optimal and feasible concentrations of oxalic acid (5 and 7.5% OA) were selected after preliminary tests. The 6% mixed between bees wax and carnauba wax (bees - carnauba mixed wax - MW) was made according to the method of [12].

The fruits were first soaked in 5 and 7.5% OA solution for 5 min, and dried for 1 hour 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 cm² 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. T_0 was the control, and the T_1 and T_2 fruits were soaked in 5 and 7.5% OA for 5 min and coated with 6% MW respectively.

The total soluble solids content was determined using a digital refractometer (PAL-1, Atago, Japan).

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 [19].

The pericarp color was measured using a colorimeter (Konica Minolta CR-300, Japan) and L* indicated lightness, ranged from black = 0 to white = 100, while b* indicated chromaticity on a blue (-) to yellow (+) axis [24].

The pericarp pH, which indicated the acid response in pericarp homogenate, was measured using the method of [3] and [21]. 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.

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

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

$$\text{Fruit decay (\%)} = \frac{\text{Num. of fruit decay}}{\text{Total fruit}} \times 100$$

The total aerobic bacteria count was determined according to the Vietnam Standards (TCVN 5165:1990). For each sample of fruits, 30 g of fruit pericarp was chopped up and extracted by 270 ml sterile distilled water by shaking 180 rpm for 30 min at room temperature. Afterward, 1 ml sample suspension was spread over normal agar medium (1% peptone, 0.5% NaCl, 0.1% glucose, 2% agar). The agar plates were incubated at 30°C for 72 h and the survival of aerobic bacteria was expressed as the mean number of colony forming units ($CFUg^{-1}$).

Statistical analysis was carried out using the SPSS software (version 20.0) and Duncan's Multiple Range Test ($P \leq 0.05$) was used to determine the significant difference of means between the treatments and control.

III. Results And Discussion

Changes in visual appearance

The changes in visual appearance expressed as browning index (BI) of treated and control fruits during the storage period at 5°C are shown in the Fig. 1. Fruits with BI above 2.0 (more than 25% pericarp browning area) were considered as unacceptable for marketing purposes. As shown in the Fig. 1, there was significant difference in BI of treated 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. Our result is in accordance with the reported data on BI of untreated longan fruits cv. Long [10], [11], [12]. [3] reported that untreated longan fruits have pericarp browning after 5 days in storage. [17] 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 lower than 2.0 and was 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 (Fig. 1). Pericarp browning in longan fruit increased with increasing storage time [43]. 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 [1], [2], [3], [10]. Water loss from the pericarp was significantly positively correlated with pericarp browning index [1]. Browning of longan fruits results from the oxidation of phenolic compounds by endogenous polyphenol oxidase (PPO) [20]. PPO is activated by moisture loss from the fruit [34]. The fruit coated with wax could prevent moisture loss [9], [14], [15], [22], [29], [37], [40]. [12] 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 [35]. Oxalic acid prevented pericarp browning due to inhibited PPO activity in longan fruit [5], [43]. [48] 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 [28]. The temperature at 5°C was most suitable for storage and delayed browning in longan fruits due to less severe chilling injury [1].

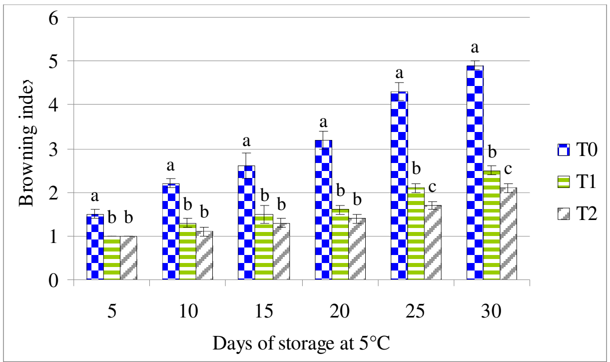

Fig.1. Changes in browning index (BI) of longan fruit pericarp either treated or not, during the storage period at 5°C. BI: 1 = 0%; 2 = 1 - 25%; 3 = 26 - 50%; 4 = 51 - 75%; and 5 = 76 - 100% pericarp browning area. Fruits with BI above 2.0 were considered as unacceptable. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

Changes in pericarp color expressed as L and b* values*

Fig. 2 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 [3], [10], [11], [12] 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. [18] 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 [5], [43]. When the PPO was incubated with oxalic acid, the activity was not recovered via dialysis [32]. [48] 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 [46]. Oxalic acid is a more potent inhibitor of PPO compared with other structurally related acids [47]. [1] 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 [29]. [12] found that 6% MW coating has the best effectiveness on reducing the weight loss in longan fruit cv. Long during the storage period. As can be seen the Fig. 2, 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 and control fruits. Our results are in accordance with the reported data on L* values of longan fruit cv. Long [10], [11], [12], [16], [38]. The L* values of longan fruit pericarp decreased from 53.5 to 42.3 when treated fruits were stored at 5°C for 24 days [36]. Our results are also consistent with reported data on L* values of pericarp of longan fruit [1], [17], [27], [31]. As shown in the Fig. 2, 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.

The b* values (yellowness) of fruit pericarp were measured and results are shown in the Fig. 3. There was significant difference in b* value between control 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 it 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 (Fig. 3). Our result was higher than the reported data on b* values from 20 to 30 days in storage of 'Long' longan fruits of [10], [11], [12], [16], [38]. Generally, the b* values of control 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 (Fig. 3). 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 [5], [12], [30], [31], [32], [37], [43], [47], [48]. 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 (Fig. 3). This result indicates that 7.5% oxalic acid dipping in association with 6% MW coating best maintained the longevity of yellowness of fruit pericarp.

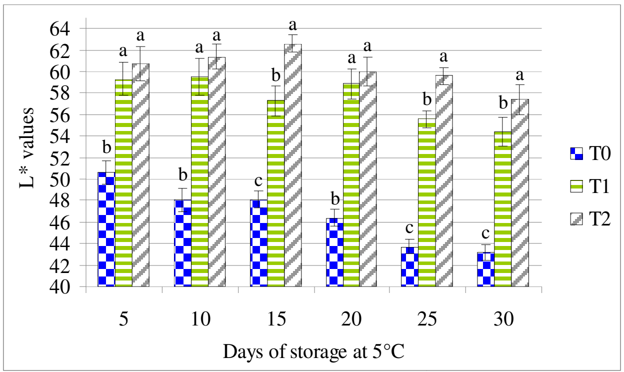

Fig.2. L* value indicates the lightness of longan fruit pericarp. Analyses were realized on eighteen fruits per time in each treatment and the control during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

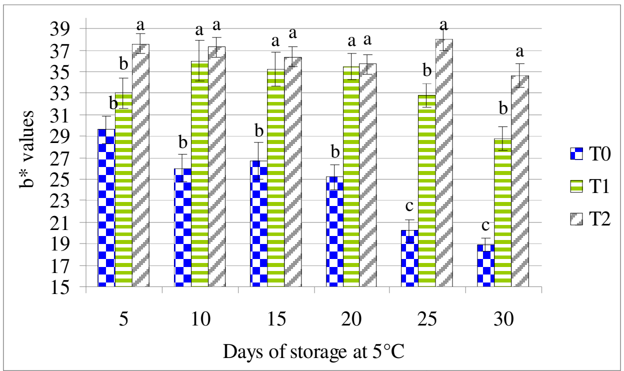

Fig.3. b* value indicates the yellowness of longan fruit pericarp. Analyses were realized on eighteen fruits per time in each treatment and the control during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

Changes in pericarp pH

The pericarp pH of treated and control fruits during the storage period were measured and results are shown in the Fig. 4. There was marked differences in pericarp pH between treated and control fruits during the 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. 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 the storage period. As seen in the Fig. 4, 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 [18]. Enzymatic browning occurs as a result of the oxidation by PPO [20], [47]. [6] and [21] 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 [35]. 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 [47]. [43] 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 [28], [48]. [46] 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 [3], but much lower than the findings of [2] and [12] 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 [28]. [3] 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 (Fig. 1 and Fig. 4). 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.

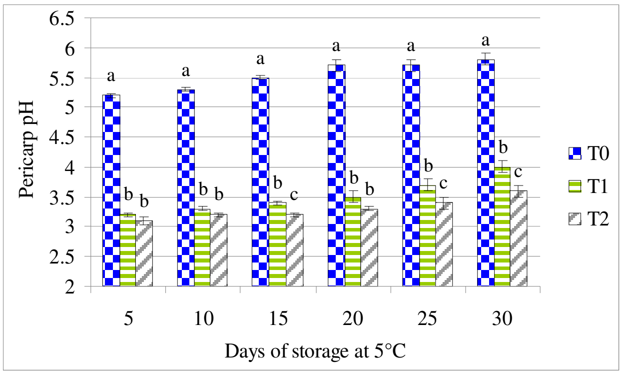

Fig.4. Changes in pericarp pH of treated and control fruits during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

Change in percentage of weight loss

The weight loss of stored longan fruits cv. Long is shown in the Fig. 5. 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. [12] 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 treatment and T_2 treatment 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 [12], [16], [38], and are lower than the findings of [13] 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 [19], [31]. This study shows that high weight loss correlated with high browning index and high pericarp pH (Fig. 1, Fig. 4 and Fig. 5). Weight loss means the amount of water lost from fruits and vegetables [29]. The purpose of the wax coating is to reduce the weight loss in fruits and vegetables [37]. [12] concluded that 6% MW coating has the best effectiveness on reducing the weight loss in longan fruit cv. Long during the storage period. [30] 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 [4]. [29] found that 5% bees wax showed the minimum weight loss in sweet orange fruits cv. Blood red at room temperature storage. [14] 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 [40]. Waxing of Xiang Sui and Pien Pu pears reduced weight loss at all storage temperatures [33]. [8] reported that wax emulsions Fruitex, Britex-561 and SB 65 coated on oranges, kinnow, lemons and grape fruits reduced weight loss.

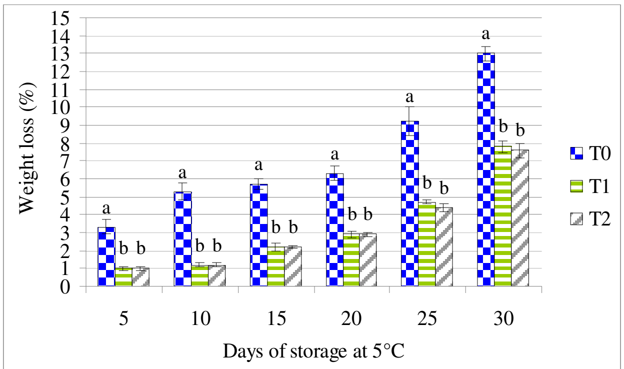

Fig.5. Changes in weight loss of treated and control fruits during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

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%) (Fig. 6). [12] 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 [11]. [1] reported that the control fruits had the highest disease development and flesh rot along with the highest browning index during storage period. Increased decay of longan fruit caused wilt and freshness reduction and resulted in browning on the pericarp [31]. There was little or no disease development during the first 5 days of storage, after that disease incidence increased with increasing of storage time [3]. 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. 6). [12] 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 [11], [38], and are lower than the results of [13] 16]. Longan fruits are very susceptible to postharvest decay as a result of both bacterial and fungal infection, including yeasts [20]. The most important microorganisms in longan fruits are *Botryodiplodia* sp., and yeasts *Saccharomyces* sp. [39]. [39] also 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 [44]. Waxing is primarily done to protect from mold growth in fruits and vegetables [37]. 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 [26]. Waxed fruit had less spoilage than uncoated samples [9]. [4] concluded that the carnauba wax coating reduced fruit decay in mango fruits during storage. Fig 6 shows that there was a marked difference in fruit decay between treated and 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.

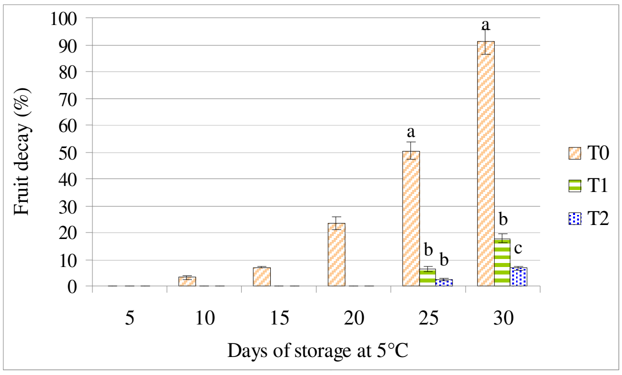

Fig.6. The percentage of fruit decay of treated and control fruits during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

Total aerobic bacteria on fruit surface

There was markedly different total aerobic bacteria on the fruit surface of treated and control fruits during the storage period ($P \leq 0.05$). The control fruits had a total aerobic bacteria much higher than treated fruits, which greatly increased from 5.9 x 10^5 to 47.8 x 10^5, to 56.1 x 10^5 $CFUg^{-1}$ by day 5, 25, and 30 respectively (Fig. 7). The total aerobic bacteria of T_1 and T_2 treatments was not different after the first 25 days, but there was significant difference by day 30 in storage ($P \leq 0.05$). The total aerobic bacteria of T_1 and T_2 treatments also increased from 0.4 x 10^5 and 0.3 x 10^5 to 3.9 x 10^5 and 1.9 x 10^5, 6.5 x 10^5 and 3.1 x 10^5 $CFUg^{-1}$ by day 5, 25 and 30 in storage respectively (Fig. 7). [43] found that microorganism populations on the longan fruit surface reduced from 24 x 10^7 to 11 x 10^7, 10 x 10^7, 0.6 x 10^7 and 0.4 x 10^7 $CFUml^{-1}$ by ozone exposure for 15, 30, 60 and 120 min respectively, but populations markedly increased after 3 days in storage. About 36 species of bacteria have been isolated from longan fruit, and major postharvest pathogens of bacteria in longan fruit were *Enterobacter srtohrnrd*, and *Acinetobacte* sp. [23]. [43] suggested that the pathogens are deeply embedded in the rough surface of longan pericarp. Oxalic acid's main applications include cleaning or bleaching [44]. [4] reported that waxing establishes a barrier against the entrance of bacterial pathogens into the product. Waxing creates a hydrophobic (non-water compatible) surface which is not conducive to pathogen growth and development [26]. This study shows that high total aerobic bacteria correlated with high percentage of fruit decay and high browning index (Fig. 1, Fig. 6 and Fig. 7). As shown in the Fig. 7, the T_2 treatment had the lowest total aerobic bacteria during the storage period. This result demonstrates that the concentration of 7.5% OA in association with 6% MW coating significantly reduced the development of aerobic bacteria on the longan fruit surface cv. Long.

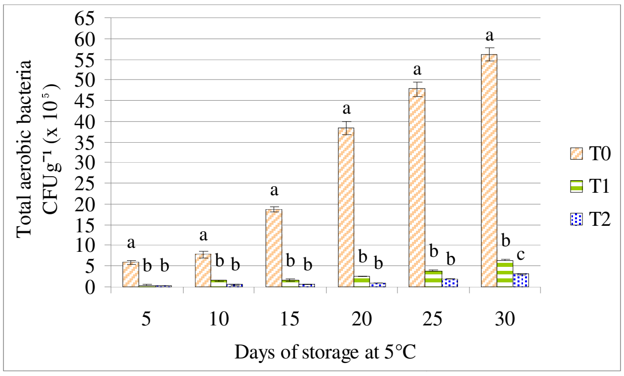

Fig.7. The total aerobic bacteria of treated and control fruits during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

Change in total soluble solids content (TSS content)

The changes in TSS content of 'Long' longan fruits during the storage period were measured and results are shown in the Fig. 8. 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 [12] 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 [1], [3], [10], [11], [13], [16], [36], [41]. By day 25 and 30 in storage, the TSS content ranged from 20.5 to 23.5%, and control fruits had TSS content higher than treated fruits (Fig. 8). The Fig. 8 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%). [11] and [12] found that the treated fruits had TSS contents which were 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. [11], [12], [13] 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 content 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. [3], [11], [12] also assumed that the increase of TSS content in longan fruits during the storage period was due to dehydration.

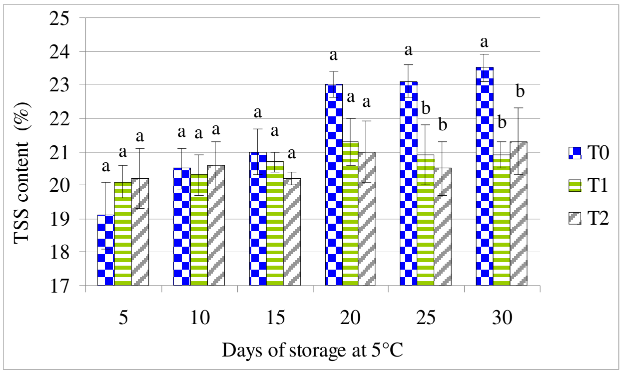

Fig.8. Changes in TSS content of treated and control fruits during the storage period at 5ºC. Vertical bars represent standard errors. Columns with different letters of each storage period indicate significantly different ($P \leq 0.05$).

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 1).

Table 1: The storage life of longan fruits

Treatment	Storage life (days)	Cause of limitation when extend storage time
T_0	5	BI above 2.0
T_1	20	BI above 2.0
T_2	25	BI above 2.0

(BI: *Browning Index*)

IV. Conclusion

Use of 7.5% oxalic acid in association with 6% bees-carnauba mixed wax, (instead of sulphur compounds or carbendazim application) seems to provide an interesting technological alternative method for the prevention of pericarp browning and the maintenance of postharvest quality in longan fruit 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.

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