Effects of Multilayer Coating of Chitosan and Polystyrene Sulfonate on Quality of ‘Nam Dok Mai No.4’ Mango

N. Hadthamard, P. Chaumpluk, M. Buanong, P. Boonyaritthongchai, C. Wongs-Aree

Abstract—Ripe ‘Nam Dok Mai’ mango (Mangifera indica L.) is an important exported fruit of Thailand, but rapidly declined in the quality attributes mainly by infection of anthracnose and stem end rot diseases. Multilayer coating is considered as a developed technique to maintain the postharvest quality of mangoes. The utilization of alternated coating by matching oppositely electrostatic charges between 0.1% chitosan and 0.1% polystyrene sulfonate (PSS) was studied. A number of the coating layers (layer by layer) were applied on mature green ‘Nam Dok Mai No.4’ mangoes prior to storage at 25 °C, 65-70% relative humidity (RH). There were significant differences in some quality attributes of mangoes coated by 3½ layers, 4½ layers and 5½ layers. In comparison to coated mangoes, uncoated fruits were higher in weight loss, total soluble solids, respiration rate, ethylene production and disease incidence except the titratable acidity. Coating fruit at 3½ layers exhibited the ripening delay and reducing disease infection without off flavour. On the other hand, fruit coated with 5½ layers comprised the lowest acceptable score, caused by exhibiting disorders from fermentation at the end of storage. As a result, multilayer coating between chitosan and PSS could effectively maintain the postharvest quality of mango, but the number of coating layers should be thoroughly considered.

Keywords—Multilayer, chitosan, polystyrene sulfonate, Nam Dok Mai No.4.

I. INTRODUCTION

Mango (Mangifera indica L.) cv. ‘Nam Dok Mai’ is a popularly exported fruit of Thailand [1]. It is highly perishable and has a short shelf life by only a week at room temperature (25 °C). Although ripening stage is suitable for perishable and has a short shelf life by only a week at room temperature, there were significant problems of the ripe fruit during the transportation and marketing chains.

Anthracnose caused by Colletotrichum gloeosporioides

N. Hadthamard is a Ph.D. student of the Postharvest Technology Program, School of Bioresources and Technology, King Mongkut’s University of Technology Thonburi (Bang Khun Thian), Bangkok, 10150 Thailand and works at the Vegetable Integration Technology Program, Faculty of Science and Technology, Kanchanaburi Rajabhat University, Kanchanaburi, 71190, Thailand (phone: +66-5596-3339; fax: +66-5596-3301; e-mail: namhawan.ar04@gmail.com).

P. Chaumpluk works at the Botany Program, Faculty of Science, Chulalongkorn University, Bangkok, 10330 Thailand (phone: +66-2218-5485; fax: +66-2252-8979; e-mail: pyiasak.cha@gmail.com).

M. Buanong, P. Boonyaritthongchai, and C. Wongs-Aree work at the Postharvest Technology Program, School of Bioresources and Technology, King Mongkut’s University of Technology Thonburi, Bangkok 10150, Thailand, and the Postharvest Technology Innovation Center, Commission on Higher Education, Bangkok 10400, Thailand (phone: +66-2470-7725; fax: +66-2470-7728; e-mail: chalermchai.won@kmutt.ac.th).
sites and high binding capacity [20]. Accordingly, PSS was considered as an anionic material for multilayer coating.

The success of multilayers coated on mango totally depends on factors of film such as type of materials, number of layers, and coating techniques. Therefore, the aim of this research was to optimize the number of multilayers of chitosan and PSS to maintain the quality of ‘Nam Dok Mai No.4’ mango.

II. MATERIALS AND METHODS

A. Preparation of Fruit and Coating Materials

‘Nam Dok Mai No.4’ Mango (Mangifera indica) fruits at 80% maturation (95-100 days after full bloom) were collected from a commercial farm in Phitsanulok province, the Northern of Thailand between 2017 and 2018 and were transported to the Postharvest Technology Laboratory at King Mongkut’s University of Technology Thonburi, Bangkok, Thailand. 300 fruits were sorted for uniformity of size and free from defects. Fruits were then air dried.

Chitosan (CTS) powder (310-375 kDa) and PSS (70 kDa) (Better Syndicate Co., Ltd., Thailand) were separately prepared at a concentration of 0.1% (w/v). CTS solution was dissolved in 0.5% acetic acid by magnetic stirring for 3 hours and adjusted the pH to 3.0. PSS solution was dissolved in deionized water and adjusted the pH to 7.0.

B. Process of Multilayer Coating on Mango

Mango fruit were coated in 5 different treatments of coating procedures. Each treatment comprised 60 fruits. Fruits were dipped in deionized water for 20 seconds as a control, and in 0.1% CTS as another control treatment. For multilayer coating, fruits were first dipped in 0.1% CTS and then alternately dipped in 0.1% PSS, layer by layer to 3½, 4½, and 5½ layers.

Layer by layer coating was processed by firstly dipping mangoes into CTS solution for 20 seconds and then rinsing fruits with deionized water. Fruits were air dried for 5 minutes. For an additional layer, mangoes were dipped in PSS for 20 seconds and then air dried. Fruits were alternately coated with CTS and PSS until reaching to 3½, 4½, and 5½ layers. All treatments were started and ended up with a CTS layer. Fruit were stored at 25±3 °C, 65-70% RH and measured for the quality every 3 days.

C. Evaluation of Multilayer Coating on Mango

Contact angle of water was used to confirm an alternated deposition of each layer by making a 5 μl water drop on the surface of coated mango skin at room temperature in the dark. Light was horizontally shined to the fruit and the angles of water drop shadow were measured on the left and right sides and averaged [21].

D. Analysis of Mango Quality

For nondestructive parameters of respiration rate, ethylene production, weight loss, peel colour, disease incidence and severity, ten fruits in each treatment were used for continuous determination.

1. Respiration and Ethylene Production Rates

Mango was placed in a closed jar for 2 hours at the storage condition. 1 ml of the head space was withdrawn and injected into a Li-700 CO₂/H₂O Analyzer (Li-700, LI-COR, Inc., U.S.A.) for detecting the concentration of carbon dioxide. For ethylene, the head space was detected by the gas chromatograph (GC-8A, Shimadzu, Japan) connected with a flame ionization detector, using nitrogen as the carrier gas.

2. Weight Loss

Weight loss of fruit was calculated as percentage of fresh weight lost from initial. Each fruit was weighted at the beginning (W₀) and during interval days (Wₙ). Weight loss was calculated from:

\[
\text{Weight loss}_{n} (\%) = \left(\frac{W_{0} - W_{n}}{W_{0}}\right) \times 100
\]

3. Pulp Firmness

Pulp firmness was analysed by a Texture Analyzer (TA.XT Express, Stable Micro Systems Ltd., United Kingdom) in the middle of fruit. Pulp was penetrated by a 6 mm probe with a compression speed of 20 mm/min for 5 mm in distance [22]. The result was reported in Newton.

4. Acetaldehyde and Ethanol Contents

Acetaldehyde and ethanol contents in fruit were measured on day 3 and day 9. 10 ml of mango juice were put into a vial, top sealed, and incubated in a water bath at 50 °C for 15 minutes. 1 ml of the headspace gas was immediately injected into a GC-FID (GC-2014, Shimadzu, Japan) equipped with a 3 mm Porapak-Q 80-100 G-8016. Ultrapure helium as the carrier gas was set for a flowed rate of 30 ml/min and the final temperature of the column was 240 °C for 4.5 minutes [15].

5. Peel and Pulp Colour Changes

Peel and pulp colours at the blossom, the middle, and the stem end region of fruit were detected using a colorimeter (CR-10, Konica Minolta, Japan) and reported in L values (lightness) and hue angles.

6. Total Soluble Solids, Titratable Acidity, and pH Value

Total soluble solids (TSS), titratable acidity (TA), and pH were measured from pulp juice. TSS content was detected by a digital hand held pocket refractometer (PAL-1 3810, Atago, Japan) and reported in degree brix. TA content was analysed using a titration method. 10 ml of mango juice were mixed with 90 ml of distilled water and 1-2 drops of 1% phenolphthalein indicator. The mixed sample was titrated with 0.1 N NaOH until the end point (pink colour) [2], [23].

\[
\text{TA} \% = \frac{\text{(volume of NaOH x 0.1 x 0.07 x 100)}}{10}
\]

pH was measured by a pH meter (FE20-ATC Kit, Mettler Toledo, Switzerland) connected to LE438 electrode probe.
7. Disease Incidence and Severity

Incidence of mango fruit showing disease symptoms was calculated by counting number of infected fruit out of total. The result was reported as mean percentage of disease incidence [2].

Disease severity shown as mean percentage lesion area on the fruit surface was evaluated from visible lesions and decided by scoring: 0 = no disease, 1 = 1-2% disease, 2 = 5% disease, 3 = 10% disease, 4 = 20% disease, 5 = 40% disease, 6 = 60% disease, and 7 = more than 80% disease [2].

8. Degree of Anthracnose and Stem End Rot

Appearance of anthracnose and stem end rot on mangoes was observed from the disease severity scale using visible and decided by using score: 0 = non-development, 1 = less than 0.1 cm², 2 = 2-3 cm², 3 = 3-12 cm², 4 = 12-25 cm², and 5 = more than 25 cm² [6].

9. Total Counts of Yeast and Mold

On the last day of uncoated control fruit, every treatment was analysed for yeast and mold growth. Fruit at 100 g was crushed in a sterile plastic bag containing 500 ml of peptone water. Sample was diluted for 10⁻², 10⁻³, and 10⁻⁴. The total yeast and mold were carried out on potato dextrose agar at 25°C for 5 days and reported in CFU/g [6].

10. Acceptance Scores and Shelf life

The mean of acceptance scores below 3 was used to indicate the end of storage. Acceptance scores from 5 panelists were observed from visual quality rating as followed; 1 = non-development, 2 = edible but not marketable, 3 = poor, 4 = fair, 5 = excellent.

11. Statistical Analysis

All data were statistically analysed by one-way analysis of variance (ANOVA) using SPSS statistical software. Significant differences were regarded when \( p < 0.05 \). Mean separations were performed by employing Duncan’s Multiple Range Test comparison procedure.

III. \textbf{RESULTS AND DISCUSSION}

\textbf{A. Evaluation of Contact Angles of Coating Layers on Mango Fruit}

Fig. 1 shows the angles of water drop on skin of fruit coated with CTS and PSS. The angles were represented as the alternate deposition between CTS and PSS. Water contact angle on CTS hydrophobic surface was higher than PSS hydrophobic surface. The degree of contact angle of CTS coated mango was similar to the multi-coating of CTS combined with pectin on ‘Tommy Atkins’ mango [23]. PSS layer was reported to raise a large number of ion-exchange sites and high binding capacity [20, 24]. Decreased contact angles of hydrophobic fruit skin were changed to hydrophilic surface after the deposition of only few polyelectrolyte layers [25].
There are some reports associated with the utilization of layer by layer coating on fruit softening. Coating with 2% sodium alginate and 0.2% olive oil delayed biochemical changes in cell turgidity and cell wall structure of Ber fruit [31]. Coating ‘Choke Anan’ mangoes with 10% gum Arabic combined with 1% CTS significantly reduced the weight loss and retained the high firmness during storage [22].

2. Acetaldehyde and Ethanol Contents

Acetaldehyde contents in all fruits on day 3 were lower than in ripe fruit on day 9 (Table I). This may be due to the fruit producing energy toward the ripening physiology. On the other hand, an accumulation of ethanol content in uncoated and 5½ layers fruit on day 9 occurred by a conversion of acetaldehyde to ethanol in anaerobic respiration pathway. Uncoated fruit produced high ethanol which could be caused by over ripening and disease infection [27]. Even coating at 5½ layers effectively delayed ripening, but high levels of coating layers produced poor gaseous permeability and started an accumulation of anaerobic metabolites since day 9. Ethanol content was undetectable in fruit coated by 3½ layers. High contents of ethanol in fruit coated by 5½ layers were related with low consumer acceptance scores.

3. Quality Attributes

Changes in fruit colour and taste were used as the index for the ripe mango. When compared with uncoated mangoes, multilayer coating positively retarded the changes in colour and taste of mangoes. A single layer CTS coating showed less effect on delaying the mango ripening. Ripe mango fruit showed increasing L values and decreasing hue angles that present colour changes from green to yellow. Furthermore, the sweetness increased continuously.

The degradation of green colour occurred continuously in every treatment. Loss of green colour of peel was dramatically quick in uncoated fruit. Multilayer coating significantly delayed colour changes of the peel and the pulp during the first 6 days of storage (Table II). The previous research presented the utilization of CTS coating to decrease the...
oxidation of chlorophyll degradation [32] and the ripening process by modification of the internal atmosphere in mango [33] and papaya [34]. Moreover, ratio TSS:TA indicating the sweetness level of ripe mangoes increased rapidly after day 6 and was highest at the end of storage (Table II). Multicoating at 4½ and 5½ layers significantly delayed the sweetness, followed by 3½ layers, and a single CTS coating. The increasing of TSS during the ripening was probably due to a conversion of polysaccharides in tissues to soluble sugars in respiration process and the water loss leading to an increase in sugar concentrations [23]. The relationship between TA content and pH, the decline in TA content and the increase in pH during the ripening may be associated with a reversion of organic acids to such substrates in the respiration process [35]. Thus, the decline of gas and water permeability by fruit multiple coating affected the eating quality of mango.

4. Disease Incidence and Severity

Small black spots on the peel were the starting point of anthracnose and stem end rot. The symptoms of uncoated mangoes started on day 3, whereas coating process retarded anthracnose and stem end (Fig. 4 (a)). When fruit showed the disease symptoms, disease infection was spread out on the fruit and leaded to rapid decay. There was no significant difference in disease incidence and severity between 4½ or 5½ layers of coating (Fig. 4 (b)).

The efficiency of multilayer coating to decrease the disease severity may depend on delayed ripening. CTS and PSS multilayers prevent the diseases by creating modified atmosphere in the fruit which affects microbial metabolisms [19], [36], [37]. Furthermore CTS has been reported to induce plant defensive mechanism [18], while the ionic strength of PSS could obstruct the compatibility of diseases [24]. As a result, the multilayer coating prolonged the disease timing and slowed down the fungal growth about 2 folds.

D. Effects of Multilayer Coating on Qualities’ Acceptance

Table III presents the total yeast and mold counts of all treatments on day 9. The multilayer coating creating antimicrobial films were shown by a dramatic reduction of yeast and mold colony growth, when obviously, the highest counts of yeast and mold were exhibited in uncoated fruit. On day 9, uncoated mango had acceptance scores of 2.2 with high disease appearance. More layers of coating showed better inhibition of disease growth on coated ‘Nam Dok Mai No.4’ mango, especially to stem end rot (Fig. 5). Although 5½ CTS-PSS was shown in the highest scores of visual acceptance (Table III), coated fruit produced high fermented volatiles (Table I).

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Treatment</th>
<th>Peel</th>
<th>Pulp</th>
<th>Taste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L values</td>
<td>Hue angles</td>
<td>L values</td>
<td>Hue angles</td>
</tr>
<tr>
<td>0</td>
<td>Uncoated</td>
<td>71.97</td>
<td>106.24 ab</td>
<td>64.60</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>71.98</td>
<td>107.85 a</td>
<td>64.60</td>
<td>99.86</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>71.95</td>
<td>105.33 b</td>
<td>64.60</td>
<td>99.86</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>71.20</td>
<td>107.03 b</td>
<td>64.60</td>
<td>99.86</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>72.57</td>
<td>104.51 a</td>
<td>68.53 a</td>
<td>95.74 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>73.85 ab</td>
<td>106.06 b</td>
<td>67.73 b</td>
<td>94.73 b</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>73.15 ab</td>
<td>107.11 b</td>
<td>65.53 b</td>
<td>97.86 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>74.04 a</td>
<td>104.94 b</td>
<td>63.90 b</td>
<td>97.43 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>77.49 a</td>
<td>93.12 b</td>
<td>68.59 b</td>
<td>93.68 b</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>75.51 ab</td>
<td>95.21 ab</td>
<td>67.51 ab</td>
<td>94.56 b</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>74.84 ab</td>
<td>95.13 ab</td>
<td>69.48 ab</td>
<td>96.68 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>74.22 ab</td>
<td>97.75 a</td>
<td>67.61 ab</td>
<td>95.65 ab</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>73.26 ab</td>
<td>98.86 a</td>
<td>66.15 a</td>
<td>97.23 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>81.38 a</td>
<td>85.67 b</td>
<td>72.35 a</td>
<td>95.34 b</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>77.92 b</td>
<td>88.78 a</td>
<td>71.79 a</td>
<td>87.26 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>73.54 b</td>
<td>91.94 b</td>
<td>68.05 b</td>
<td>98.38 a</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>74.48 c</td>
<td>90.45 a</td>
<td>69.48 b</td>
<td>88.35 c</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>75.09 ab</td>
<td>89.33 ab</td>
<td>69.63 ab</td>
<td>87.22 ab</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>76.34 ab</td>
<td>87.08 ab</td>
<td>67.89 ab</td>
<td>87.08 ab</td>
</tr>
</tbody>
</table>

**TABLE II**

Changes in Colour and Taste of Mango Fruit Coated with 0.1% CTS and 0.1% PSS at Different Layers and Then Stored at 25±3°C for 12 Days

*The same letters in each column of the mean values were not significantly different at p ≤ 0.05 (n = 10)*
FIG. 4 Disease incidence (a) and disease severity (b) of mango fruit coated by 0.1% CTS and 0.1% PSS at different layers and then stored at 25±3°C for 12 days. Vertical bars represent the SD of means (n = 10).

TABLE III

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yeast &amp; Mold (CFU/g)</th>
<th>Appearance (scores)</th>
<th>Visual Acceptance score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anthracnose</td>
<td>Stem End Rot</td>
<td></td>
</tr>
<tr>
<td>Uncoated</td>
<td>8.49x10⁴</td>
<td>3.88</td>
<td>4.75</td>
</tr>
<tr>
<td>0.1% CTS</td>
<td>3.27x10⁴  b</td>
<td>2.88</td>
<td>3.50</td>
</tr>
<tr>
<td>3½ CTS-PSS</td>
<td>5.54x10³  c</td>
<td>2.6³</td>
<td>3.63</td>
</tr>
<tr>
<td>4½ CTS-PSS</td>
<td>4.18x10³  c</td>
<td>2.6³</td>
<td>3.38</td>
</tr>
<tr>
<td>5½ CTS-PSS</td>
<td>4.36x10³  c</td>
<td>2.38</td>
<td>3.25</td>
</tr>
</tbody>
</table>

*The same letters in each column of the mean values were not significantly different at p ≤ 0.05 (n = 5).

IV. CONCLUSION

Among coating procedures of multilayers between CTS and PSS (0, 1, 3½, 4½, and 5½ layers) on ‘Nam Dok Mai No.4’ mangoes on, coating at 3½ layers was appropriate to maintain the storage quality and decreased anthracnose and stem end rot diseases without off-flavour generation. Although coating at 5½ layers was given in high overall quality and low disease incidence, coated fruit released fermented flavour. These findings suggested that the 3½ layer of CTS combined with PSS was best to prolong the shelf life of mango stores at 25±3°C. Thus, multilayer coating for extending ‘Nam Dok Mai’ mango in retail markets is needed to be further developed.

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REFERENCES


