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Effect of Rice Bran Waxing on Fruit and Vegetable Storage

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ABSTRACT

Sweet peppers and limes were coated with one of three wax emulsions—namely, rice bran wax (RW), carnauba wax (CW) or the two combined (CR). The emulsions were prepared and diluted to four concentrations. After waxing, samples were both physically and chemically examined. The optimum stability formula of RW required 121, 38.4, 24, 56 and 48 g of rice bran wax, oleic acid, triethanolamine, water and paraffin wax, respectively. The quantity of wax emulsion used was varied depending on the formulation and the fruit or vegetable. Sweet peppers and limes used a coated emulsion of 0.9–1.1% by weight. All the emulsions used were effective in retaining chlorophyll color and reducing weight loss. Limes with 10% CR had 22.8% weight loss after 30 d storage, which was similar to the unwaxed samples kept for only 10 d at 30–35 °C. Sweet peppers with 10% RW had only 9% weight loss compared with 18.3% for unwaxed sweet peppers after 7 d at 22 °C. Waxing reduced the changes in firmness, total acidity, pH and juice content.

Keywords: waxing, unwaxed, rice bran wax, carnauba wax, wax emulsion

INTRODUCTION

Proper post-harvest treatment is essential to reduce losses and maintain the freshness of fruits and vegetables. The produce color should be attractive to consumers to increase its value. Cooling during transportation has a negative effect causing over-ripening and reduced quality. Waxing supports chilling or long-life storage of fruits and vegetables by protecting transpiration, and the appearance appeals to consumers. In 1930, melted paraffin wax was used to coat citrus fruits, then in 1950, carnauba wax emulsion was used to coat fresh fruits and vegetables (Kester and Fennema, 1986). Industrial wax emulsion production is dependent on expert decisions. Variations in the amounts of raw materials used as a result of errors in measuring the quantities of ingredients could result in not producing the required emulsion. Preparing ingredients by weight can prevent errors caused by changes in the specific gravity of ingredients. The basis of the prepared emulsion method is that the wax is melted and homogenized together with the other ingredients. The emulsion preparation method requires that the emulsifier is homogenized with water or wax before being mixed with the emulsifier, or some wax is homogenized with water and emulsifier to form an emulsion depending on the variety of the emulsifier and wax emulsion (Fox, 1974 ; Bennett, 1975). Dispersion of wax, wax particles size, stability and the appearance of the emulsion

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depend on the different refractive indices of the two phases and the wax particle size (Allen and Angelo, 1989). Small particles of homogenized wax are produced when the final emulsion is cooled down, which prevents coagulation of the emulsion (Pinporn, 1991). A chitosan–oil coating of sweet pepper stored at 8 °C for 35 d exhibited the best control effect on decay. Sweet peppers treated with coatings maintained good sensory acceptability, whereas the sensory quality of the uncoated control samples became unacceptable and waxing some fruits and vegetables with different varieties and concentrations of wax resulted in differing weight losses (Yage *et al.,* 2011). The water vapor transfer rate and permeability decreased when the thickness of a triglyceride coating increased from 0 to 60 μm (Debeaufort *et al*., 1993). Lime waxing with Candellida emulsion stored at 18–20 °C and 68–85% relative humidity (RH) after 18 d using a 15% concentration reduced the water loss by only half that of non-waxed fruit, while at 20% concentration there was increased water loss (Paredes-Lopez *et al*., 1974). Lime coating with coconut oil emulsion stored at 25–30 °C and 60–70% RH after 18 d significantly ($P \leq 0.05$) reduced the physiological loss in weight and maximized the amount of marketable fruit retained, the total soluble solids, and the ascorbic acid, acidity and juice content of the fruit (Abhay *et al.,* 2011). Commercial sweet pepper waxing reduced withering by 15.7% which was sufficient for efficient wither retardation (Platenius, 1939). A sanitation package can protect against rotten sweet peppers (Johnson, 1968). In general, fully developed fruits have a maximum quantity of organic acids that decreases with storage. The Kreb's cycle in higher plants synthesizes a variety of organic acids (Eskin, 1990). All water soluble and dispersed acids in vacuoles are sources of preserved energy that can be utilized after harvest and produce distinctive taste and odor characteristics (Stanley, 1991). Waxing reduced organic acid changes in lemons in an experiment with wax-and-wrap film where the acid level increased over 2 mth and then decreased (Cohen *et al.,* 1990). The amount of lemon juice in fruit covered with wax-and-wrap film increased over 3 mth and then was stable, whereas, using only waxing resulted in an increase in the lemon juice over 4 mth and then a decrease (Cohen *et al*., 1990). Ripe fruit loses texture from cell wall degradation, resulting in a loss of cohesion between cells. If there is serious degradation, texture is destroyed. The rate of pectin degradation through cell wall composition relates directly to the rate of softening of fruit (Wills *et al.,* 1981; Eskin, 1990). During ripening, fruit loses green color by chlorophyll degradation depending on the amount of organic acid, while yellow color appears clearly (Wills *et al.,* 1981). Waxing could retard the change in color. Higher wax concentrations had higher carbon dioxide and lower oxygen levels that would obstruct oxidation and ethylene production that both use oxygen. Less color change was shown with lime waxing with Pro-long® which is a mixture of sucrose esters which constitute the active ingredient of a fruit coating (Motlagh and Quantick, 1988). Waxing of fruits and vegetables with various wax emulsions has been used in Thailand—for example: Sta-Fresh® which is a concentrated protective wax emulsion for durians, mangoes and pineapples (Siriparn, 1990; Thammaporn, 1991; Siwalak *et al*., 1992); SEMPERFRESH ®which is a sucrose ester coating for pomelos (Anawat *et al*., 1989) and beeswax for pomelos and limes (Erbil and Muftugil, 1986). However, wax emulsion coating is expensive. Rice bran wax is a source of natural wax from rice bran oil refining. It is a waste product and is a pollutant. Purification of rice bran wax from waste for producing emulsion that can be used for waxing fruits and vegetables is a way of adding value to rice which is an economic plant, and reducing the import of wax. The objective of the current project was the production of RW and assessment of the effect of RW waxing on the storage of some fruits and vegetables.

MATERIALS AND METHODS

Raw materials

Limes (*Citrus aurantifolia* Swingle) and sweet peppers (*Capsicum annuum* L.) were purchased from a local market. Carnauba wax was purchased from a grocery shop. Rice bran wax was obtained the waste at a rice bran oil factory.

Wax emulsion preparation

The appropriate RW formula has been studied by varying the ratio of trienthanolamine (TEA) to oleic acid (by weight) used in the carnauba wax in the emulsion formula (Warth, 1956). However, in the current study, rice bran wax was substituted for carnauba wax (as both compounds have a similar melting point) and the ratio of TEA (in grams) to oleic acid (in grams) was studied for a range of ratios—namely, TEA 22:oleic acid 30.8, 35.2, 44.0; TEA 24:oleic acid 33.6, 38.4, 53.8; TEA 26:oleic acid 31.4, 36.4, 41.6.

The standard wax emulsion formula (Warth, 1956) was carnauba wax (121 g), oleic acid (37 g), TEA (22 g), distilled water (56 g) and paraffin wax (48 g). The TEA was a viscous liquid, the water was a polar solvent and the benzene provided a non-polar solvent. The wax emulsion was not dangerous to human skin and did not damage clothing. The oleic acid was a liquid and acted as a viscosity modifier. Preparation of the emulsion was reported to be easy but was non-stable and became rancid (Warth, 1956; Fox, 1974). The melting points for rice bran and carnauba wax are 82.5–86 °C and 76–84 °C, respectively, their acid numbers are 0.4 and 2–10, respectively and their saponification numbers are 73 and 78–88, respectively. The rice bran is a brown color and the carnauba wax is yellow. Rice bran wax (121 g) was weighed in a beaker and melted in boiling water using a hotplate. Oleic acid was added at 90–95 °C and stirred with a homogenizer (IKA-Stirring motor RW 20, Germany) at 600 rpm until dark brown. Then, the TEA and 56 g of water were added at 90–95 °C whilst stirring at 1,400 rpm until a brown gel was formed. Next, the melted paraffin wax (48 grams) was added at 90–95 °C followed by hot water (90–95 °C). The water and melted paraffin were stirred at 1,000 rpm. The mixture was made to 20% concentration. RW with the most stable formula from the experiment was selected and prepared by diluting with heated water at 90–95 °C until the wax concentration was 20% and it was then put in a water bath at 20 °C. It was continuously stirred with a stirring rod until the temperature was 45 °C and was then stored at room temperature. The most stable formula had pH and viscosity values near those of the standard formula (pH 8.24 and viscosity 37.5 cp). The viscosity at 20% concentration was 68 cp. The carnauba wax emulsion (CW) formula used was prepared by the method described by Warth (1956). A mixture of rice bran wax and carnauba wax (CR) at a ratio of 50:50 was prepared using the formula and method described by Mane (1991). A rice bran wax emulsion (RW) was prepared. The mixtures of RW and CW were chosen in order to utilize RW produced in Thailand. The three formulas were diluted with water to concentrations of 4, 6, 8 and 10%. Limes and sweet peppers were prepared before waxing by washing with chlorine dioxide at 60 ppm and 20 ppm, respectively. The diluted emulsion, limes and sweet peppers were weighed, immersed in emulsion and dried by fan at 30–35 °C for 6 min. The wax emulsion was weighed after waxing and the loss at each concentration was calculated as a percentage of the lime or sweet pepper weight. The sweet peppers and limes were placed on trays and stored at 22 °C and 40–50% RH, and at 30–35 °C and 50-70% RH, respectively. A 3 × 5 factorial completely randomized design experiment was used, with the factors being the different emulsions (CW, CR and RW) and the concentration of wax emulsion (0%, 4%, 6%, 8% and 10% concentrations). The treatments were composed of non-waxed fruit, 4%, 6%, 8% and 10% waxed fruit respectively. The changes in color and withering of the limes and sweet peppers between non-waxed and waxed fruits at the various concentrations were compared. Each treatment had two replicates, with each replicate consisting of five pieces of the respective fruit. Each lime replicate was weighed every 2–3 d and each pepper replicate was weighed every day until deterioration. Weight loss was determined using Equation 1:

$$\text{Weight loss (\%)} = \frac{\text{Weight before storage} - \text{Weight after storage}}{\text{Weight before storage}} \times 100 \quad (1)$$

The firmness of every treatment of sweet pepper was measured. Each treatment had two replicates with each replicate consisting of one piece of fruit. Firmness on two sides was measured at days 2, 4 ,7 , 8 and 10 by a penetrometer (Effigi, Italy) with a diameter of 0.8 cm (the unit used was kilograms). The amount of lime juice was measured for every treatment at days 3, 7, 9, 12 and 15. Each treatment had two replicates, with each replicate consisting of three pieces of fruit. The amount of total soluble solids (TSS) of the juice was measured by hand refractrometer (Atago, Japan). The pH of juice was measured by pH meter (Jenco 6173, China). Total acidity was measured by titrating 10 mL juice with 0.1 N NaOH solution until it reached pH 8.1, and was then determined by the percent of citric acid (Equation 2).

$$\text{Citric acid (\%)} = \frac{\text{standard solution (N) x base solution (mL) x 0.06404}}{\text{Total lime juice (mL)}} \quad (2)$$

The equivalent weight of citric acid = 0.06404.

Statistical differences were determined at the $P < 0.05$ level using Duncan's new multiple range test.

RESULTS

Appropriate formula of rice bran wax emulsion

The appropriate formula for producing RW was tested by changing the quantity and ratio of the emulsifiers TEA and oleic acid. The viscosity, pH, stability and appearance of RW were measured (Table 1). The best ratios of RW were the formulas that had TEA : oleic acid (by weight) of 22:35.2 (1:1.6), 24:38.4 (1:1.6) and 26:31.4 (1:1.2), which had emulsifier amounts of 20.3, 21.7 and 20.3%, respectively. Their appearance was homogenized with a low viscosity that was, however, still higher than the standard (CW). The ratio of 24:38.4 (1:1.6 by weight) had pH 8.21, which was near that of the standard (pH 8.24).

Amount of wax emulsion coating by dipping

The highest amounts of the three wax emulsions used at 4, 6, 8 and 10% concentrations to coat sweet peppers and limes was with CR and RW, respectively. CR had a mean of 1.10% for sweet peppers by weight after coating. RW had a mean of 0.9% for limes by weight after coating. Claypool and King (1941) reported that the paraffin coating on tomatoes could be removed by washing with water as the skin was smooth and a similar result was evident with the smooth surfaces of the limes and sweet peppers.

Effect of waxing on appearance of limes

Non-waxed limes that had been stored for 30 d at 30–35 °C and RH 50–70% turned brown with a hard peel. The weight loss was 23.6% after 10 d, which was similar to the weight losses of 18.0 and 22.5% after 21 d from waxing with 4% and 6% concentrations, respectively. However, RW waxing at 8% and 10% concentrations still had a green-yellow color and was soft after 30 d with weight losses of 26.1 and 31.4%, respectively, while CR waxing still had a green color and was soft with weight losses of 24.3 and 22.8%, respectively, and CW waxing had a yellow color and was soft with weight losses of 25.3 and 22.0%, respectively. The results were similar to those reported by Motlagh and Quantick (1988). The waxed limes retained more chlorophyll when the waxing was with higher concentrations or with no waxing.

Table 1 Ratio and quantity of emulsifier by appearance and property of rice wax (RW) emulsion at 20% concentration with carnauba wax (CW) as the standard.

Variety of wax	Quantity of emulsifier (%)	TEA:Oleic acid (by weight)	pH	Viscosity (centipoise)	Appearance
CW (standard)	20.7	22:37.0 (1:1.7)	8.24	37.5	liquid, homogenized, translucent gray brown, non-separating when kept.
RW	19.0	22:30.8 (1:1.4)	8.72	49.0	liquid, separated when kept 1 wk, upper white turbidity and lower yellow turbidity.
RW	20.3	22:35.2 (1:1.6)	8.52	55.8	homogenized, non-separating when kept 4 wk, more white turbidity.
RW	22.7	22:44.0 (1:2)	8.23	223.2	homogenized, non-separating when kept 4 wk, more white turbidity, much more viscosity.
RW	20.4	24:33.6 (1:1.4)	8.66	53.0	liquid, separating when kept 2 hrs, upper white turbidity and lower yellow liquid.
RW	21.7	24:38.4 (1:1.6)	8.21	68.0	homogenized, non-separating when kept 4 wk, little white turbidity.
RW	25.7	24:53.8 (1:2.2)	8.20	316.8	homogenized, non-separating when kept 4 wk, much greater viscosity and white turbidity.
RW	20.3	26:31.4 (1:1.2)	8.80	85.0	homogenized, non-separating when kept 4 wk, more white turbidity.
RW	21.7	26:36.4 (1:1.4)	8.43	120.0	homogenized, non-separating when kept 4 wk, more viscosity and more white turbidity.
RW	25.7	26:41.8 (1:1.6)	8.47	198.0	homogenized, non-separating when kept 4 wk, more white turbidity.

Changes in weight loss, lime juice, total acidity and TSS

The weight loss of limes coated by dipping and stored at 30–35 °C increased over storage time. Non-waxed limes lost more weight (23.6%) in 10 d than samples treated with different concentrations of wax. Fruit coated with RW at 4, 6 and 10% concentrations lost much more weight than at a concentration of 8%. The least weight loss for the three emulsions, was 26.1% for RW at 8% concentration, while it was 22.8 and 22.0% weight loss after 30 d, at 10% concentration for CR and CW, respectively (Figure 1). There was a significant difference between the weight loss of non-waxed lime and waxed limes at 4, 6, 8 and 10% concentrations but no significant differences among the three formulas of wax emulsion (Table 2). Fruit coated with RW lost more weight than fruit coated with CR and CW. RW did not coat the total surface well and did not stick because of the poor stability of the emulsion. The CR and CW emulsions accumulated on the cuticle and stomata, and so protected against greater water loss. The CR 10% was selected to utilize rice bran wax produced in Thailand. The amount of juice in non-coated and coated limes using the three formulas stored at 30–35 °C increased over the storage time; the level of juice from non-waxed limes increased from 36.4 to 41.9% in 9 d, which was more than for the coated limes, and then decreased to 40.4% after 15 d (Figure 2). The peel on the non-waxed limes at the beginning was soft from digested cell wall enzymes, so much more juice could be squeezed. As water was lost, the lime peel became very hard and the amount of juice was reduced. The digested cell wall enzyme of coated limes had less activity (Kader, 1986), so the lime peel was not soft and had less juice. This result was similar to the report from Cohen *et al* (1990) who found that the amount of juice from waxed and high density polyethylene (HDPE) film wrapped lemons increased from 30 to 37% and was then stable. Juice from non-wrapped lemons increased from 30 to 47.5% and then decreased to 34%—a similar amount to that in the wrapped lemons. The 10% RW showed the lowest increase from 36.4% to 41.8% in 15 d. The amount of juice increased in fruits coated with CR at all concentrations, with

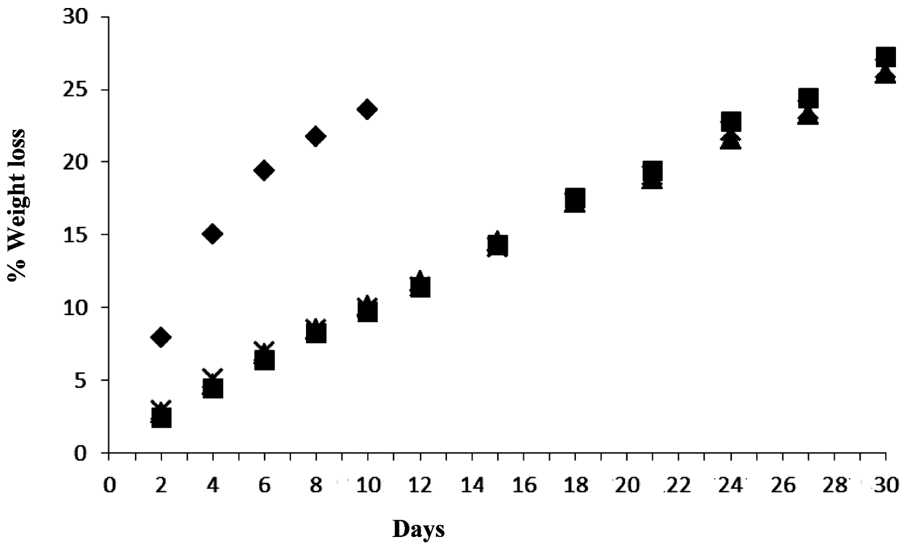

Figure 1 Comparison of least weight loss of three emulsion formulas using rice bran wax (RW), carnauba wax (CW) or the two combined (CR) to coat limes at various concentrations at 30–35 °C and 50–70% RH. ◆ Control; ■ 8%RW; ▲ 10%CR × 10%CW.

the 10% CR showing the lowest increase from 36.4 to 40.8% in 15 d. Fruits coated with CW at all concentrations showed an initial increase in juice and then a decrease. The 10% CW showed the lowest increase over 3, 7 and 9 d from 36.4 to 39.3, 38.2 and 34.8%, respectively (Figure 2). For the three emulsions, the lowest increase in juice in 15 d was for CR at 10% concentration (Figure 2). The total acidity of the non-waxed limes was 7.9% after 15 d, which was more than at the beginning (7.1 %) and more than for any of the three formulas of coated limes at all concentrations. The total acidity of limes coated with CW of 4%, 6% and 8% also increased and then fell to near the beginning

Table 2 Weight loss, pH, total acidity, juice and total soluble solids of limes at 30–35 °C coated with rice bran wax (RW), carnauba wax (CW) or the two combined (CR).

Variety of wax	Weight loss (%)[1]	pH[1]	Total acidity (%)[1]	Total soluble solids (°Brix)[1]
RW	12.85 ^{a}	2.13 ^{a}	7.91 ^{a}	8.84^{a}
CR	12.92 ^{a}	2.14 ^{a}	7.60 ^{b}	8.80^{a}
CW	12.89 ^{a}	2.14 ^{a}	7.52 ^{b}	8.62^{a}
Wax concentration (%)				
Non-waxed	23.55^{a}	2.09 ^{d}	7.53^{c}	8.80^{abc}
4	11.80^{b}	2.14 ^{c}	8.03 ^{a}	8.97^{a}
6	10.06 ^{c}	2.15^{b}	7.76^{bc}	8.83^{ab}
8	9.34 ^{c}	2.15^{b}	7.79^{b}	8.63^{bc}
10	9.68 ^{c}	2.17 ^{a}	7.28 ^{d}	8.53^{c}

[1] Different superscript letters in a column show statistically significant differences ($P < 0.05$) using Duncan's new multiple range test.

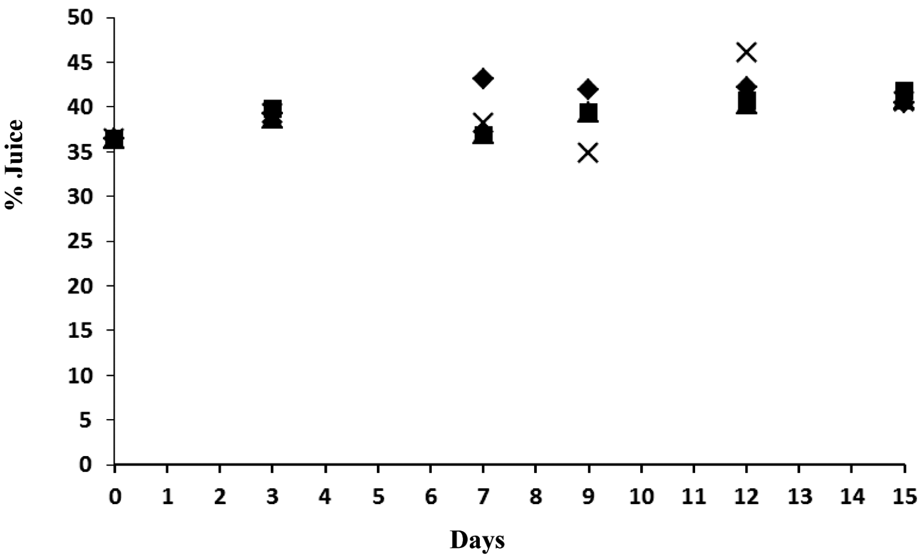

Figure 2 Comparison of three emulsion formulas using rice bran wax (RW), carnauba wax (CW) or the two combined (CR) for coating limes at concentration that had the least change of juice at 30–35 °C and 50–70% RH. ▲ Control; ◆ 10%RW; ■ 10% CR; × 10%CW.

value around 7.1%. The 6% concentration had the lowest acidity after 15 d (7.0%). This was similar to the results of Cohen *et al*. (1990) who found that waxed and HDPE-wrapped lemon acidity increased and then decreased to less than at the beginning or after harvesting, while non-wrapped lemon acidity increased throughout the storage time. The water loss in non-waxed limes also affected the acidity. Coated limes had much more water to dilute the acidity and made the total acidity decrease (Ting and Attaway, 1971). The pH of non-waxed and waxed limes with the three formulas at all concentrations reduced and then increased until it was close to the value at the beginning (2.2). Most pH values had stabilized after 15 d compared to the initial value. The curves varied according to the different harvesting times of the limes. The change in pH was similar to the trend in the total acidity of the coated RW and CR limes at all concentrations (showing an initial increase and then a decrease). The coated limes using the 10% concentration reached total acidity of 7.6%, which then decreased to 7.0% after 15 d to a value similar to that at the beginning. The TSS of waxed and non-waxed limes did not change much during the storage period. Lime is a non-climacteric fruit and the TSS (citric acid) is not used much (Wills *et al*., 1981).

Effect of waxing on appearance of sweet peppers

Sweet peppers waxed with RW at different concentrations and stored at 22 °C and 40–50% RH for 7 d retained their green color, while non-waxed peppers turned orange-red. The result was similar to that reported by Wang (1977) that chlorophyll degradation and red coloring were delayed under controlled atmosphere conditions compared to non-controlled atmosphere conditions. Non-waxed peppers withered and lost 18.3% of their weight over 7 d, while waxing at higher concentrations reduced withering. Peppers waxed with 4, 6, 8 and 10% concentrations lost 12.4, 10.9, 10.0 and 9.0% of their weight, respectively. CR and RW waxing produced the same results.

Weight loss of sweet peppers

The weight loss of non-waxed and waxed peppers stored at 22 °C increased progressively. Non-waxed peppers lost more weight (18.3% in 7 d) than waxed peppers at all concentrations. Increasing the RW concentration resulted in less weight loss, while waxing with CR emulsion at concentrations of 4 and 6% led to much more weight loss than at 8 and 10%. The fruit coated with CW at concentrations of 4, 6 and 10% had much greater weight loss than at 8%. The 10% RW had the least weight loss of 9.0% followed by CR and CW at 8% concentration with weight losses of 10.7% and 10.8%, respectively, after 7 d. Fruit coated with CR and CW lost much more weight than RW. Therefore, the 10% RW concentration was chosen (Figure 3) because it had the least weight loss. There was a significant difference between non-waxed and waxed peppers and also between those waxed at 4% compared to 8% and 10%. In addition, the three wax emulsions did not produce significant differences in weight loss (Table 3).

Change of firmness of sweet peppers

In general, fresh sweet peppers should be crisp with a low firmness of about 2.9 kg. With the onset of withering, the fruit became very tough, so the firmness as measured by the Effegi value increased. Thus, sweet peppers that maintained firmness the best would have some slight increased firmness before a subsequent decrease. The non-waxed sweet peppers had low firmness after 4 d (4.0 kg) before increasing to a maximum at 7 d. The firmness of the fruit coated with RW 10% concentration was 4.0 kg after 7 d. The firmness of the fruit coated with CR 6% concentration was 5.0 kg after 7 d and with CW 8% was 4.1 kg after 4 d. Waxed peppers had greater firmness than non-waxed ones. The result was similar to that reported by Ben-Yehoshua *et al.* (1983) that plastic film-wrapped sweet peppers had more firmness than unwrapped ones stored at 17 °C and 85% RH for 4 wk. The three emulsions that maintained firmness the best were RW 10%, CR 6% and CW 8%. The peppers using RW were more firm than the other two formulas (Figure 4). The results were similar for peppers coated with RW 10% that also had the least weight loss. The firmness increased as a result of less transmission of water because of increased sweet pepper cell tension (Pantastico, 1975).There was a significant difference between

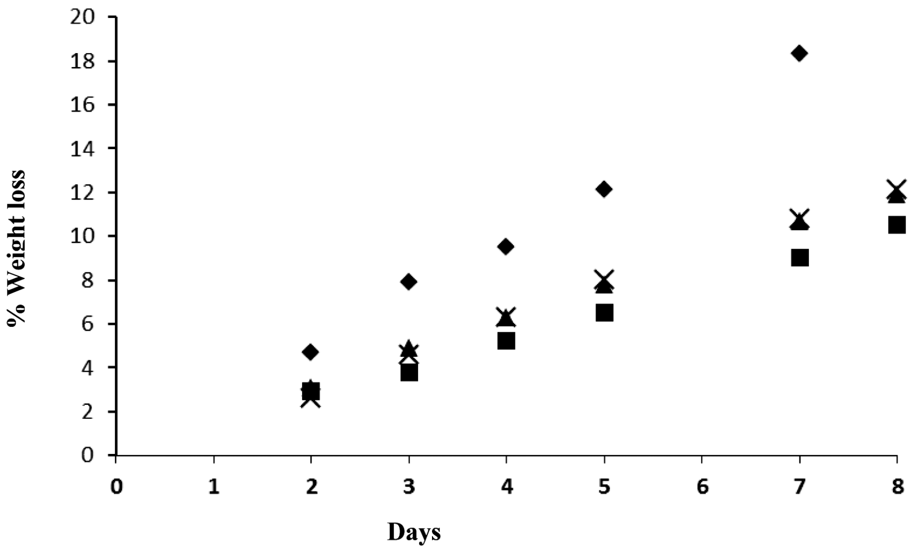

Figure 3 Comparison of three emulsion formulas using rice bran wax (RW), carnauba wax (CW) or the two combined (CR) for coating sweet peppers at concentrations that had the least weight loss at 22 °C and 40–50% RH. ◆ Control; ■ 10%RW; ▲ 8%CR; × 8%CW.

Table 3 Weight loss and firmness of sweet peppers at 22 °C coated with rice bran wax (RW), carnauba wax (CW) or the two combined (CR).

Variety of wax	Weight loss (%)	Firmness (kg)
RW	12.10^{a}	5.25^{a}
CR	12.91^{a}	5.29^{a}
CW	12.68^{a}	5.07^{a}
Wax concentration (%)		
Non-waxed	18.25^{a}	6.01^{a}
4	11.94^{b}	5.44^{b}
6	11.57^{bc}	4.83^{c}
8	10.48^{c}	4.92^{c}
10	10.57^{c}	4.82^{c}

Different superscript letters in a column show statistically significant differences ($P < 0.05$) using Duncan's new multiple range test.

non-waxed and waxed peppers at 4, 6, 8 and 10% concentrations, but the three emulsion formulas were not significantly different (Table 3).

DISCUSSION

The rice bran wax emulsion formulas had much more oleic acid than TEAwhich was consistent with the data of Fox (1974) that showed additional oleic acid reduced emulsion pH, but the viscosity, turbidity and stability increased. An increased amount of oleic acid would have the same effect as increasing the amount of emulsifier, so stability and viscosity were increased. Additional quantities of emulsifier at the same ratios (1:1.4 and 1:1.6) increased the viscosity of the emulsion. The weight loss of coated limes showed that the lower concentrations (4 and 6%) had less thickness to protect from transpiration but the higher concentration at 10% had too much wax, which led to more water loss because the wax blocked stomata and affected the transmission of oxygen and carbon dioxide (Platenius, 1939). This resulted in anaerobic conditions and accumulated carbon dioxide which then produced acetaldehyde and ethanol together with a reduced amount of juice (Paul and Russell, 1973; Smagula and William, 1977), which increased the weight loss. Limes coated with CR and CW at increased concentrations decreased the weight loss.

CONCLUSION

The RW emulsion was composed of 121 g rice bran wax, 38.4 g oleic acid, 24 g TEA, 56 g water and 48 g paraffin wax. The mean weights of wax coating of sweet peppers and limes by dipping at various concentrations were 1.10% and 0.9%, respectively. Vegetables coated with any of the three formulas noticeably reduced weight loss and withering. The rate of weight loss depended on the wax concentration. Different emulsion formulas did not have significantly different efficiencies. Sweet peppers coated with RW at10% concentration lost 9.0% weight, which was lower than with the other formulas, compared to non-waxed fruit samples

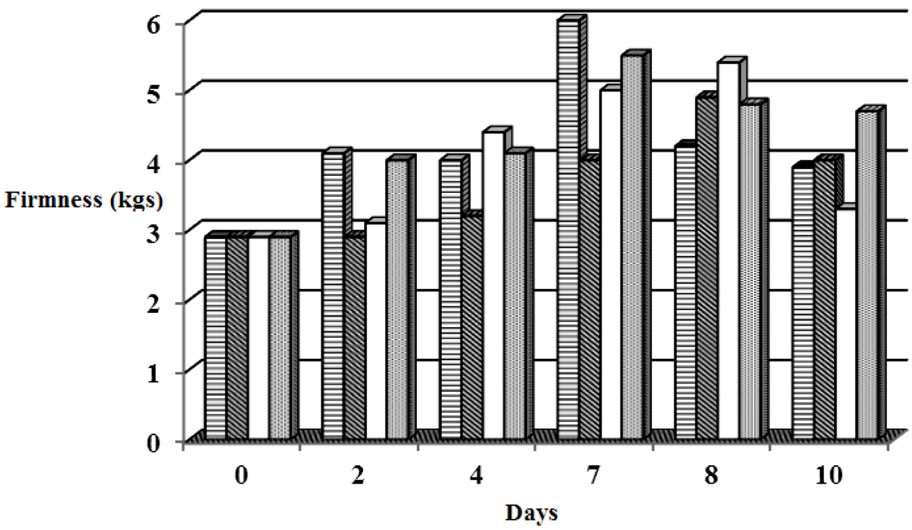

Figure 4 Comparison of three emulsion formulas using rice bran wax (RW), carnauba wax (CW) or the two combined (CR) for coating sweet peppers at concentrations that had the best firmness at 22 °C and 40–50% RH. ⊟ control ▨ 10%RW ☐ 6%CR ▩ 8%CW.

that lost about 51% of their weight in 7 d at 22 °C. Limes coated with CR at 10% concentration had the lowest weight loss of 9.3%. Uncoated limes had a weight loss of 60.6% when stored at 30–35 °C for 10 d. The three emulsion formulas clearly maintained the green color of chlorophyll on the vegetable surface with some variation depending on the wax concentration. The three emulsion formulas maintained vegetable firmness longer than for non-coated samples and this depended on the wax concentration; however, there were no differences among the emulsion formulas. Fresh sweet peppers had firmness of 2.9 kg when stored at 22 °C for 4 d, while the best emulsion coating for sweet peppers was RW 10%, at which the peppers could be stored for 7 d while maintaining equal firmness. The pH, juice and TSS levels of the three emulsion formulas used to coat the limes were not significantly different. Different formulas were appropriate for limes and sweet peppers coated with the three different emulsions. RW should be used for coating sweet peppers, whereas CR should be used for coating limes (the effect of CR and CW was the same).

LITERATURE CITED

Abhay, B., K.P. Sailendra and P. Neha. 2011. Effect of skin coatings on prolonging shelf life of kagzi lime fruits (*Citrus aurantifolia* Swingle). **J. Food Sci. Technol.** 48: 1–7.

Allen, J. and S.T. Angelo. 1989. A brief introduction to food emulsions and emulsifiers, pp. 1–8. *In* C. George and D. George, (eds.). **Food Emulsifiers: Chemistry Technology, Functional Properties and Applications.** Elsevier Science Publishing Company Inc., New York.

Anawat, S., N. Sodsri, C. Agsuma, J. Ari, S. Siriparn and T. Shing Shi. 1989. **Prolonging Shelf-life of Pomeloes by Coating and Low Temperature Storage.** Seminar Course on Coating Material. Thailand Institute of Scientific and Technological Research. Bangkok. 36 pp.

Bennett, H. 1975. **Industrial Waxes.** Vol.1 Chemical Publishing Company, Inc., New York. 336 pp.

Ben-Yehoshua, S., B. Shapiro, Z.E. Chen and S. Lurie. 1983. Mode of action of plastic film in extending life of lemon and bell pepper fruits by alleviation of water stress. **Plant Physiol.** 73: 87–93.

Claypool, L.L. and J.R. King. 1941. Fruit waxing in relation to character of cover. **Proc. Amer. Soc. Hort. Sci.** 38: 261–265.

Cohen, E, S. Lurie, B.Shapiro, S. Ben-Yehoshua, Y. Shalom and I. Rosenberger. 1990. Prolonged storage of lemons using individual seal-packaging. **J. Amer. Soc. Hort. Sci.** 115: 251–255.

Debeaufori, F., M. Martin-Polo and A.Voilley. 1993. Polarity, homogeneity and structure affect water vapour permeability of model edible films. **J. of Food Sci.** 58: 426–429.

Erbil, H.Y. and N. Muftugil. 1986. Lengthening the postharvest life of peaches by coating with hydrophobic emulsions. **J. of Food Processing and Preservation** 10: 269–279.

Eskin, N.A.M. 1990. **Biochemistry of Foods,** 2nd ed., Academic Press, Inc., California.

Fox, C. 1974. Cosmetic emulsions, pp. 870–933. *In* K.J. Lissant, (ed.). **Emulsions and Emulsion Technology Part 2.** Vol. 6. Marcel Dekker, Inc., New York.

Johnson, H.B. 1968. Heat and other treatments for cantaloups and pepper, pp. 1–16. *In* A.L. Ryall and J. Lipton, (eds.). **Handling, Transportation and Storage of Fruits and Vegetables,** The AVI Publishing Company, Inc., Westport, CT, USA.

Kader, A.A . 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. **Food Technol.** 40: 99–104.

Kester, J.J. and O.R. Fennema. 1986. Edible films and coatings: A review. **Food Technol.** 40: 47–59.

Motlagh, F.H. and P.C. Quantick.1988. Effect of permeable coatings on the storage life of fruits. I. Pro-long treatment of limes (*Citrus aurantifolia* cv, Persian). **Int. J. Food Sci. Technol.** 23: 99–105.

Mane, S. 1991. **The Use of Useless from Rice Bran Wax Purification.** MSc. thesis, Kasetsart University, Bangkok, Thailand.

Pantastico, Er.B. 1975. Structure of fruits and vegetables, pp. 1–24. *In* E.P. Pantastico, (ed.). **Postharvest Physiology, Handling and Utilization of Tropical and Subtropical Fruits and Vegetables.** AVI Publishing Company, Inc., Westport, Connecticut.

Paredes-Lopez, O., E. Camargo-Rubio and Y. Gallardo-Navarro. 1974. Use of coatings of candelilla wax for the preservation of lime. **J. Sci. Food Agric.** 25: 1207–1210.

Paul, L.D. and H.C. Russell. 1973. Effects of coating on weight loss and ethanol buildup in juice of oranges. **J. Agr. Food Chem.** 21: 455–458.

Pinporn, L. 1991. **Cosmetic Emulsion.** Pharmaceutical Technology Department. Pharmaceutical Faculty. Chiang Mai University. Chiang Mai, Thailand. 258 pp.

Platenius, H. 1939. **Wax Emulsions for Vegetables.** Cornell Univ. Agric. Exp. Sta. Bull. No. 723.

Siriparn, S. 1990. **Effect of Coating on Ripening and Different Varieties of Durian.** MSc. thesis, Kasetsart University Bangkok, Thailand.

Siwalak, P., C. Chusak, K. Yongyuth and T. Bantit. 1992. Design and development on pineapple wax coating machine. **Proceedings of the 30th Kasetsart University.** Annual Conference: Economics and Business Administration, Social Sciences, Education, Humanities, Environment, Home Economics, Agro-Industry, Science, Engineering.

Smagula, J.M. and J.B.William. 1977. Acetadehyde accumulation : Is it a cause of physiological deterioration of fruits? **Hort. Sci.** 12: 200–203.

Stanley, J.K. 1991. **Postharvest Physiology of Perishable Plant Products.** Van Nostrand Reinhold, New York, 532 pp.

Thammaporn, P. 1991. **Effects of Coating and Low Temperature on Quality and Shelf Life of Mango Fruit.** MSc. thesis, Kasetsart University, Bangkok, Thailand.

Ting, S.V. and J.A. Attaway. 1971. Citrus fruits, pp. 120–130. *In* A.C. Hulme, (ed.). **The Biochemistry of Fruits and Their Products.** Vol 2. A. R. C. Food Research Institute, Norwich, Academic Press, London.

Wang, C.Y. 1977. Effect of CO_2 treatment on storage and shelf life of sweet peppers. **J. Amer. Soc. Hort. Sci.** 102: 808–812.

Warth, H.H. 1956. **The Chemistry and Technology of Wax.** 2nd ed. Reinhold Publishing Corporation, New York. 940 pp.

Wills, R.B.H., T.H. Lee, D. Graham, W.B. McGlassom and E.G. Hall. 1981. **Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables.** New South Wales University Press, New South Wales. 101 pp.

Yage, X., L. Xihong, X. Qinglian, Y. Juan, L. Yaqing and Y. Tang. 2011. Effects of chitosan coating enriched with cinnamon oil on qualitative properties of sweet pepper (*Capsicum annuum* L.). **Food Chem.** 124: 1443–1450.