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Development of Edible Coating using Coconut Oil and Bee Wax to Extend Shelf Life of Lime (*Citrus aurantiifolia*)

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ABSTRACT

Lime (*Citrus aurantiifolia*) is an important horticultural fruit that has a short shelf life due to its perishable nature. The major postharvest limit is weight loss and yellowing of peel color due to transpiration and respiration. An experiment was conducted to assess the influence of coconut oil, bee wax coating, and sealed packaging on post-harvest storage quality and shelf life of lime at cold storage. Limes were harvested at 147 days after fruit setting. Sorted limes were washed and dried using a fan and then coated with coconut oil and bee wax mixture with the respective ratios of 90:10, 80:20, 70:30 and 100:0 percentages. After coating, limes were kept in 17.5 cm x 17.5 cm size with 150 gauge perforated polyethylene bags and sealed polyethylene bags which served as Modified Atmospheric Packaging (MAP) and then stored at cold conditions (6 ^{0}C, RH 40%). The effectiveness of edible coating and sealed bag in extending the shelf life of lime and fruit quality was evaluated by determining weight loss, firmness, surface color, and juice content which were assessed periodically during storage. The results revealed that 100% coconut oil treatment and 90:10 bee wax coating, especially with a sealed bag, had an immense effect on retaining green colour, reducing weight loss and shrivelling and preserving firmness and moisture content of lime performing better storage life for 56 days of storage.

Keywords: Bee wax, Firmness, Lime, Post-harvest, Storage.

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INTRODUCTION

Lime (*Citrus aurantiifolia*) is a non-climacteric horticultural fruit which belongs to the family Rutaceae. It has a unique flavour and acidity. It is a highly seasonal fruit. The peak production falls between mid-April to mid-July (Champa and Gamage, 2020). During this time the price drops which causes lime growers to leave the fruit un-harvested, because the price is not sufficient to recapture the cost of production. However, the price of lime rises during the off-season. Therefore, one aim is to make the product available throughout the year during both peak and off seasons. On the one hand, the market surplus of lime should be overcome and a year-round marketing strategy should be ensured. To achieve this, limes picked in peak season need to have their life increased so that they can be used during off season.

Postharvest quality depends on both pre-harvest and postharvest factors. Lime harvesting time is an important factor. Mature-green limes have a much longer postharvest-life than those picked when they become yellow. There are research evidences indicating correct stage of harvesting time. Lime fruits harvested at 133 days after fruit setting (DAFS) have the longest shelf life of 9 days while stages of 119, 147 and 161 DAFS had shelf life of 6, 7 and 3 days, respectively under ambient storage. This study concludes that the most suitable time for harvesting lime fruits is 133 days after fruit setting (Samaradiwakara *et al*., 2019).

Limes are subjected to weight loss and shrivelling. The shelf life of lime can be increased by controlling the rate of transpiration and respiration (Sonkar *et al*., 2008). Edible coating is a fruitful method to solve this problem. Citrus fruits have a natural waxy layer on the outer surface that is somewhat removed during washing. An extra discontinuous layer of wax applied artificially with sufficient thickness and consistency to prevent anaerobic respiration within the fruit provides the necessary protection against decaying microbes. Beeswax can be used as layers of edible material which can be consumed and provide a barrier to oxygen, microbes of external sources, moisture and solute movement for fruit surface (Nasrin *et al*., 2020). Thus, the application of edible coating may have an effect on prolong storage life of lime which will be the cheaper method of shelf-life extension (Raghav *et al*., 2016).

The aim of this study was to extend the post-harvest life of lime by two months enabling supply during the off-season. Surplus production during the peak season can be treated so that surplus volume will be reduced and the treated fruits will be sold during the off-season. Transferring this technology helps to secure the income of lime farmers while consumers and processors also will get benefits by selling fresh fruits at fair prices during the off-season.

MATERIALS AND METHODS

Location

The experiment was conducted in the Food Science Laboratory, Faculty of Agriculture and Plantation Management, Wayamba University of Sri Lanka from February 2022 to February 2023.

Method

Fresh, yellowish green color and uniformed size of lime fruits were harvested at the proper physiological stage of maturity from the field of one progressive farmer in Malsiripura, Sri Lanka (Low country, Intermediate Zone, Red Yellow Podzolic soil). Harvested limes were brought to the laboratory, in ventilated plastic crates. These fruits were sorted out to remove diseased or bruised ones. The fruits were washed using tap water to remove dirt and dried under a fan. The clean dried fruits were then divided into 5 main lots each containing 1 kg of fruits. Each treatment was replicated three times. Bee wax was collected from a bee yard in Rambukkana, Sri Lanka. Wax is shiny and lustrous in nature. It is insolubility in water. It also has healing and antiinflammatory properties (Saxena *et al.*, 2023).

Then it was coated with coconut oil and bee wax mixture at 90:10 (T3), 80:20 (T4), 70:30 (T5), only coconut oil (T2), and one lot was kept as a control sample (T1) without coconut oil and bee wax. According to concentration, the mixture was heated up to 70 °C and limes were dipped in treatments at 60 ^{0}C. All lots of fruits were packed in perforated poly bags (P.B) (B1 treatment) and in sealed bags (B2 treatment) and stored at refrigerator (temperature 6 ^{0}C) in the existing laboratory for two months (Figure 1).

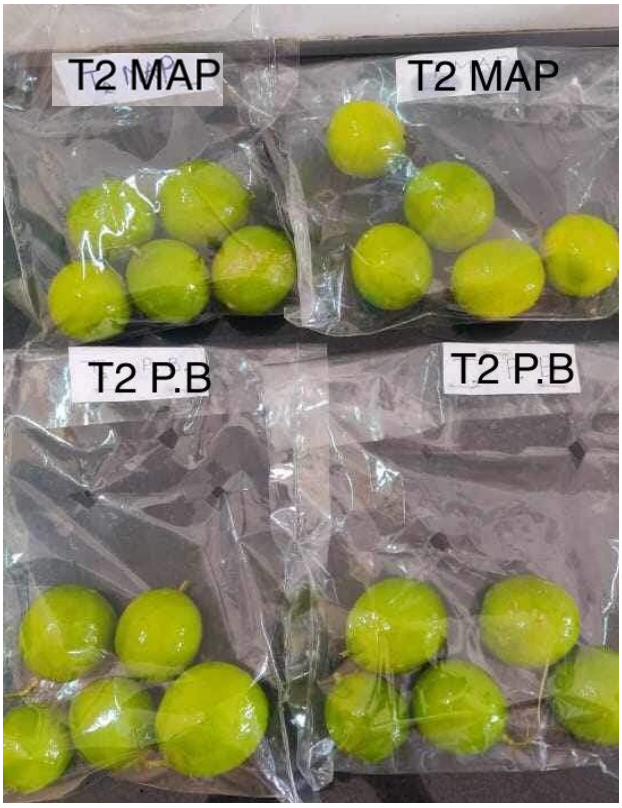

Figure 1. Perforated bag (P.B) vs sealed bag (MAP).

Data collection

Data on randomly selected fruits in each treatment per replication were recorded at 14-day interval during the experiment on weight loss measurement, surface color, juice content and firmness as parameters. Surface colour was measured by colorimeter (Model No: PCE-CSM 2) based on CIE (L*a*b*). The L* is lightness whereas a* and b* values were transformed to chroma (c) and hue angle (h^0). The a* value was represented minus greenness to plus redness and b* value was represented minus blueness to plus yellowness. Before measurement, calibration was done using supplied white plate and black plate. Then lime external color reading was taken by colorimeter.

Firmness was measured by using a penetrometer. For this, needle of instrument was inserted into a depth of 3 mm into lime and the reading was noted on the meter in kilograms per square centimetre (Kg/ cm^2). Two opposite locations for each lime were measured and the mean value was used. Juice content was measured by the volume of juice extracted from each fruit measured by using measuring cylinder. Fruit weight was measured by top loading balance and percentage weight loss was calculated using the following formula 1.

$$PWL = \frac{W2-W1}{W1} X100 \qquad (1)$$

W1 = Weight of fresh weight
W2 = Weight after interval
PWL = Percentage weight loss

Experimental Design

Completely Randomized Design was used as the experimental design for the experiment with five treatments and three replicates. Analysis of variance (ANOVA) was used to analyze the data using R studio (version 4.2.1).

RESULTS AND DISCUSSION

Weight Loss Measurement

The effect of bee wax on weight loss was non-significant between all treatments in 14 days and 42 days after storage although there were significant differences among treatments ($p < 0.05$) 28 days and 56 days after storage. Control treatment showed the highest weight loss until 42 days after storage and it may be due to the high rate of transpiration and respiration. Treatment two (T2B2) and three (T3B2) which were kept in sealed bag and treatment 5 which was kept in perforated bag (T5B1) exhibited minimum weight loss in 14 days and 28 days after storage, respectively. After 42 days of storage, treatment 3 stored in perforated bag (T3B1) showed minimum weight loss while after 56 days of storage, treatment 3 stored in sealed bag (T3B2) showed minimum weight loss. This reduction in weight loss was probably due to the effects of the edible coating as a semi-permeable barrier against O_2, CO_2, moisture, and solute movement, thereby reducing respiration, water loss, and oxidation reaction rates as explained by Thai *et al*., (2001). In Treatment 5 sample, weight loss increased after 56 days of storage (Table 1). The primary reason for weight loss in this treatment may be that wax concentration is high in the treatment 5 sample (70:30). High wax thickness might have created physiological disorders in limes. That might be created a barrier for respiration, therefore, shrivelling was high and moisture loss was increased. Proving our results, Al-Juhaimi *et al*., (2012), have stated that thickly coated limes might generate heat and production of end products from anaerobic fermentation.

Measurement of Fruit Firmness

Bee wax gives gloss to the lime fruits because it is a surface finisher by reducing evaporation and also reducing the wrinkling in fruits, also it reduces the movement of water molecules from cell structure. Because the ratio of unbound water with the bound water in the cells maintains the firmness of fruits. (Shahid and Abbasi, 2011). Application of bee wax coated treatment 4 (T4B1) retained maximum firmness than other treatments throughout the storage period. The maximum score on the first day might be due to the increased activity of pectic enzymes. Furthermore, due to bee wax coatings, there was a reduction in cell wall loosening and respiration rate which in turn increased the cell integrity. All these factors might have increased the firmness of limes. Bee wax retained the firmness of the fruits and acted as a barrier against nutrients and water loss. At 28 days after storage, bee wax treated sample (T4B1, T4B2, T5B2, T3B1, T3B2) showed constant firmness with time. In treatment 2 and T1B1 treatments after 28 days of storage, firmness slightly increased and then at the end of storage firmness declined again (Table 1). The softening of lime fruit is due to deterioration in the cell wall composition, cell structure, and intracellular materials. The minimum score in firmness might be due to the increased storage period because pectic enzymes must be degraded which in turn reduces the firmness of fruit.

Table 1. Percentage weight loss and firmness of lime treated with bee wax.

Treatment	Weight loss %				Firmness kg/cm²			
	14d	**28d**	**42d**	**56d**	**14d**	**28d**	**42d**	**56d**
T1B1	2.100a	5.475a	5.790a	3.655c	2.60a	2.45a	2.45a	2.45a
T1B2	3.000a	3.895abc	2.615a	7.595ab	2.35ab	2.50a	2.40a	2.45a
T2B1	1.320a	2.005abc	1.300a	3.130c	2.35ab	2.60a	2.25a	2.25a
T2B2	0.785a	0.155c	5.745a	4.030bc	2.55ab	2.65a	2.30a	2.20a
T3B1	1.645a	1.98abc	1.025a	3.025c	2.45ab	2.20ab	2.10a	2.10a
T3B2	0.785a	1.37bc	4.075a	2.185c	2.40ab	1.70b	1.50b	1.50b
T4B1	1.001a	1.550bc	2.760a	3.895c	2.35ab	2.50a	2.50a	2.50a
T4B2	2.825a	4.985ab	3.220a	5.26abc	2.65a	2.45a	2.30a	2.30a
T5B1	0.470a	0.895c	1.430a	8.170a	2.50ab	2.35ab	2.20a	2.20a
T5B2	0.800a	1.680abc	3.830a	8.48a	2.25b	2.45a	2.20a	2.20a

T1B1 = Uncoated and kept in perforated bag, T1B2 = Uncoated and kept in sealed bag, T2B1= Coconut oil coating and kept in perforated bag, T2B2 = Coconut oil coating and kept in sealed bag, T3B1 = Coconut oil and bee wax (90:10) coated and kept in Perforated bag. T3B2 = Coconut oil and bee wax (90:10) coated and kept in sealed bag, T4B1 = Coconut oil and bee wax (80:20) coated and kept in perforated bag, T4B2 = Coconut oil and bee wax (80:20) coated and kept in sealed bag, T5B1 = Coconut oil and bee wax (70:30) coated and kept in perforated bag, T5B2 = Coconut oil and bee wax (70:30) coated and kept in sealed bag. Means with different letters within each column are significantly different ($p < 0.05$).

Measurement of Juice Content

The quality of juice was a vital economic feature in beverage industry. About 95% citrus crops are further processed to make different drinks (Samad *et al.*, 2019). Juice content showed an increase in all treatments during storage. In the control treatment, juice content was less than that of other treatments. It may be due to excessive water loss from uncoated open limes. Juice content of treatment 4 and treatment 2 stored in sealed bag was slightly increased and after 28 days it was increased rapidly. Treatment 2 samples stored in perforated bag increased rapidly and after 42 days it slightly increased. Control treatment was constant until 28 days and then it was rapidly increased. Treatment 5 juice content was increased gradually. Treatment 3 stored in sealed bag was slightly increased and after 28 days decreased and finally it was constant after 42 days. According to the above result, perforated bag containing samples' juice content was comparatively larger than the juice content of the samples stored in sealed bag (Table 2). Increasing trend of juice content with the storage period in all treatment might be due to fruit ripening slightly after 28 days. Treatment 3 sample showed better shelf life than other treatments with delayed ripening.

Table 2. Change in juice content of different concentrations of coconut oil and bee wax.

Treatment	Juice content (mL)			
	14d	**28d**	**42d**	**56d**
T1B1	14.45a	14.60c	16.5bcd	17.00abc
T1B2	13.00a	15.25bc	16cd	16.15bc
T2B1	15.00a	16.50ab	18ab	18.25a
T2B2	15.35a	15.75abc	17abcd	17.50ab
T3B1	15.00a	15.00c	16.5bcd	17.0abc
T3B2	15.00a	16.00abc	18abc	15.00c
T4B1	14.75a	16.00abc	18.5a	18.35a
T4B2	15.05a	16.00abc	18.5abc	17.85ab
T5B1	14.85a	15.50abc	16.5bcd	17.50ab
T5B2	14.10a	15.00c	17abcd	17.15ab

T1B1 = Uncoated and kept in perforated bag, T1B2 = Uncoated and kept in sealed bag, T2B1= Coconut oil coating and kept in perforated bag, T2B2 = Coconut oil coating and kept in sealed bag, T3B1 = Coconut oil and bee wax (90:10) coated and kept in perforated bag. T3B2 = Coconut oil and bee wax (90:10) coated and kept in sealed bag, T4B1 = Coconut oil and bee wax (80:20) coated and kept in perforated bag, T4B2 = Coconut oil and bee wax (80:20) coated and kept in sealed bag, T5B1 = Coconut oil and bee wax (70:30) coated and kept in perforated bag, T5B2 = Coconut oil and bee wax (70:30) coated and kept in sealed bag. Means with different letters within each column are significantly different ($p < 0.05$).

Measurement of Surface Colour

Peel color is an important factor in the perception of fruit quality. Kader *et al.*, 1989 noted that slow peel colour development in perforated polyethene cover treatment and it reduced the rate of metabolic reaction of fruit. Initially a* value in all treatments were taken minus values. Minus a* represents the green color and the green color was faded with time. Because minus values turned into positive values with the storage period. Coconut oil coated sample (T2B1) stored with perforated poly bag was taken longer time than other treatments to change into positive values. After 28 days of storage, in the control treatment, green color of the limes faded faster than that of other treatments. In treatments 2, 4, and 5 samples were become fully yellow by 42 days after storage. However, limes in treatment 3 were reduced greenness in 56 days after storage (Table 3).

According to Lightness (L*) value, majority of treatments were constant until 28 days. Until 28 days limes were kept freshly without color variation. Then it was rapidly decreased within the next 14 days. Limes were changed from white to dark color with storage time. The perforated bag included treatment 2 (T2B1) and treatment 3 (T3B1) color did not change rapidly. After 42 days it increases rapidly. Perforated poly bag included treatment 5 samples were rapidly dropped after 28 days. Treatment 3 sample were green colour throughout the storage period as shown in Figure 2.

T1 **T2** **T3** **T4** **T5**

Figure 2. Pictorial views of coated and uncoated limes kept in sealed bags and perforated bags during 56 days after storage at refrigerator (6 ^{0}C and 40% RH).

Table 3. Change of b* value of different concentrations of bee wax and coconut oil.

Treatment	b* value			
	14d	**28d**	**42d**	**56d**
T1B1	53.5ab	36.22ab	23.73a	24.03b
T1B2	57.49a	43.85a	24.99a	32.13ab
T2B1	50.33ab	36.61ab	35.43a	35.505ab
T2B2	46.25ab	33.33ab	18.26a	39.065a
T3B1	37.40bc	36.22ab	23.86a	36.09ab
T3B2	50.34ab	32.33ab	14.52a	36.02ab
T4B1	42.9abc	41.34ab	27.48a	36.24ab
T4B2	29.64c	29.185b	28.16a	33.55ab
T5B1	27.995c	25.17b	15.96a	28.67ab
T5B2	28.32c	25.64b	23.73a	36.86ab

According to b* value, treatment 4 (T4B1, T4B2) samples and treatment 3 (T3B1) sample showed constant until 28 days. T5B1 and T3B2 samples slightly decreased until 28 days. b* value was decreased with the time that represents yellow color decreased with time.

The thickness of coatings is an important parameter as it directly affects the functionality of the coatings, typically the permeability of the coatings to water and gases. Coatings exceeding a critical thickness can cause detrimental effects of reduced internal O_2 concentration and increasing CO_2 concentration from anaerobic fermentation (Cisneros-Zevallos and Krochta, 2003).

Applying of sealed bag for the storage of limes has the potential to modify the level of CO_2 and O_2 around the fruit inside the bag. The limitation of perforated poly bags is fruit damage that may occur due to high concentration of CO_2 or low O_2 and condensation of water inside the bag. One approach was decreasing the risk of developing injurious gas concentrations is to make holes in the bag that help to reduce transpiration in limes. It creates modified atmospheric surroundings inside the bag.

A homogeneous coating was produced from the mixture of melted beeswax and coconut oil (90:10) and only coconut oil applied on fresh limes

Table 4. Change of a* value and L* value in different concentrations of coconut oil and bee wax.

Trt	a * value				L* value			
	14d	28d	42d	56d	14d	28d	42d	56d
T1B1	-8.99ab	-7.95ab	-2.16bcd	3.230b	64.015ab	60.82a	30.625c	46.45a
T1B2	-7.28ab	-4.70ab	-2.74bcd	5.710b	68.080a	67.19a	30.29cd	49.025a
T2B1	-9.20ab	-9.33ab	-6.345d	4.680b	59.0bcd	60.62a	52.575a	52.43a
T2B2	-21.34b	-4.090a	0.425abc	3.585b	60.45bc	57.77a	35.35bc	50.64a
T3B1	-1.87ab	-12.16ab	-3.855cd	27.96ab	56.93cd	61.17a	42.005b	49.6a
T3B2	-0.84ab	-10.25ab	-1.8abcd	52.13a	55.64cd	62.42a	28.86cd	52.13a
T4B1	-0.39a	-10.45ab	3.580a	4.615b	56.83cd	58.26a	34.80bc	52.055a
T4B2	-18.25ab	-10.45ab	2.485ab	4.510b	59.95bcd	56.44a	32.36bc	50.53a
T5B1	-13.07ab	-9.380ab	1.015abc	4.51b	59.97bcd	60.95a	20.22d	54.14a
T5B2	-22.26b	-6.195ab	0.020abc	3.845b	58.67bcd	60.36a	33.56bc	55.85a

T1B1 = Uncoated and kept in perforated bag, T1B2 = Uncoated and kept in sealed bag, T2B1= Coconut oil coating and kept in perforated bag, T2B2 = Coconut oil coating and kept in sealed bag, T3B1 = Coconut oil and bee wax (90:10) coated and kept in perforated bag. T3B2 = Coconut oil and bee wax (90:10) coated and kept in sealed bag, T4B1 = Coconut oil and bee wax (80:20) coated and kept in perforated bag, T4B2 = Coconut oil and bee wax (80:20) coated and kept in sealed bag, T5B1 = Coconut oil and bee wax (70:30) coated and kept in perforated bag, T5B2 = Coconut oil and bee wax (70:30) coated and kept in sealed bag. Means with different letters within each column are significantly different (p <0.05).

showed *p*rolonging the postharvest life of limes with quality retaining green color at cold conditions. Coconut oil and 10% bee wax (90:10) coated lime gave a better appearance than other treatments.

CONCLUSION

It can be concluded that bee wax coating significantly influences the post-harvest shelf-life of lime. It was concluded that 10% bee wax in combination with 90% coconut oil was the best treatment and 100% coconut oil treatment proved second best treatment to be effective in improving the overall quality and extending the shelf life of limes for 56 days. Sealed bag performed better storage life, with respect to peel appearance (color), firmness, and physiological weight loss. This technology can be used for commercial purposes for exporting lime fruits in the international market by using refrigerated storage facilities during transportation.

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