Extending storage life of mango (*Mangifera indica* L.) using a new edible wax formulation incorporated with hexanal and cinnamon bark oil

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Two formulations of bees wax-based edible coatings with added anti-ripening and antifungal compounds, C5 (hexanal and cinnamon bark oil) and C6 (cinnamon bark oil only), were developed and tested on mangoes stored at low temperature (13.5 °C ± 2 °C) for quality attributes including internal CO_2 accumulation and marketability. The particle size distribution of the waxes and the surface morphology of the coating were also assessed. Our results demonstrate a low rate of disease incidence with higher marketability in wax-treated fruits after two weeks of storage at the low temperature compared to untreated controls ($p < .05$). Internal CO_2 accumulation in the wax-coated mangoes was high compared to un-waxed controls indicating the formation of a semi-permeable coating around the fruit. No significant differences ($p < .05$) in other quality parameters such as fruit colour, fruit firmness, and pH were observed in wax-treated fruits compared to controls. However, significantly higher ($p < .05$) fruit acidity with lower total soluble solid content was observed in wax-coated fruits after one week of storage indicating a delay in the ripening process. No off-flavours were reported for the wax-coated fruits by the sensory panellists.

Keywords: Hexanal, cinnamon bark oil, edible wax, mango, storage life, post-harvest loss

Mango (*Mangifera indica* L.) is a nutritious tropical fruit with distinct flavour characteristics. Mango variety, Karthakolumban, is widely grown in Sri Lanka. The fruits are of commercial importance in the domestic market and have the potential for export to countries where mango is an exotic fruit. However, post-harvest losses due to diseases, such as anthracnose and stem end rot, and physical damage during transportation and storage contribute to severe quality loss rendering fruits unmarketable and undesirable for consumption. Preventing these substantial economic losses may be achieved by maintaining the quality of mangoes in terms of firmness, colour, texture, flavour, and shelf life.

A number of technologies have been developed and are currently in use to prolong shelf life and enhance the quality of fruit and vegetables. Wax coatings are applied to many commodities to delay fruit ripening, control moisture loss, and modify gas exchange and thereby reduce the rate of respiration and extend shelf life (Dhall 2013). These coatings often create a modified atmospheric condition in fruits by modifying their internal gas composition. Wax formulations derived from biological compounds or GRAS (Generally Regarded as Safe) compounds could be considered as bio-waxes and edible coatings. It has been reported that edible coatings are able to carry active ingredients such as anti-browning agents, colorants, flavours, nutrients, spices, and antimicrobial compounds that could extend product shelf life and reduce the risk of pathogen growth on food surfaces (Pranoto et al. 2005; Pena and Torres 1991). Cinnamon bark oil has been reported to be a strong antibacterial and antifungal compound (Fei Lu et al. 2011; Usha et al. 2012) that can be incorporated into wax formulations in order to, hopefully, enhance antifungal properties.

Since ethylene plays a key role in fruit ripening (Carrari and Fernie 2006), functional modifications of the ethylene biosynthetic pathway through inhibition of key enzymes or receptors have been tested for commercial application, such as using aminoethoxyvinylglycine, and exposure to 1-

methylcyclopropene (1-MCP). Phospholipase D (PLD) is the key enzyme that initiates a series of catabolic cascades that lead to the eventual deterioration of the cell membrane. The initial changes of the membrane associated with ripening and senescence affect cellular compartmentalization and accelerate the senescence process (Paliyath and Subramanian 2008; Paliyath et al. 2008). Inhibition of PLD activity could therefore enhance membrane stability and hence increase the firmness of fruits (Cheema et al. 2014). Previous studies have shown that PLD activity may be selectively inhibited by primary alcohols, hexanol, and aldehydes such as hexanal (Paliyath et al. 1999; Tiwari and Paliyath 2011). Hexanal formulations increased fruit firmness, soluble solids, and antioxidant enzyme activity when applied as a pre-harvest spray treatment for tomatoes, fresh cut vegetables, and sweet cherries (Paliyath et al. 2003; Sharma et al. 2010).

In this study, two bio-wax formulations—one with hexanal and cinnamon bark oil and the other with only cinnamon bark oil—were tested as post-harvest dips to enhance shelf life and improve the quality of cold-stored mango.

Materials and methods

Development of edible waxes

A series of water-based wax emulsions using beeswax (purchased locally), Tween 20 (Sigma Aldrich, USA), and stearic acid (BDH, England) were formulated and screened with initial fruit trials. The two best formulations were selected (Sri Lanka patent application no 18030) for further improvements and named as C5 and C6. Hexanal (FCC, Sigma Aldrich, USA) and cinnamon bark oil were incorporated as anti-senescence and antimicrobial agents in wax formulations C5 (0.02% hexanal and 0.02% cinnamon bark oil) and C6 (0.02% cinnamon bark oil only). Physical properties of the wax emulsions and coating formations were evaluated with a particle size analyser (Fritsch Analysette 22, MicroTec Plus, Germany) and a scanning electron microscope (SEM: LEO 1420VP, LEO Electron Microscopy Inc, USA), respectively. Specimens were coated with a thin gold layer using a sputter coater to avoid electrical charge accumulation during SEM examination.

Post-harvest dip treatment of hexanal and cinnamon bark oil-containing waxes

Mango, cv Karthakolumban, harvested from Ellawala Horticulture (Pvt) Ltd, Galkiriyagama, Sri Lanka, were used to test the efficacy of wax treatments. Mature green, blemish-free mangoes of uniform size were harvested at 13 weeks after full bloom, de-sapped, and randomly assigned to coating treatment (C5, C6, and controls). Sets of 30 mangoes were dipped in each wax formulation (C5 and C6), air-dried at room temperature, and transferred to ventilated cardboard boxes lined with shredded paper (six fruits per box with five replicate boxes per treatment). A set of 30 untreated fruits (six fruits per box with five replicate boxes) were used as controls and they were also assigned to ventilated cardboard boxes lined with shredded paper. All cartons containing treated and untreated mango were transported to the laboratory and stored at the optimum temperature of 13.5^{o}C ± 2^{o}C and 90% relative humidity (RH) for 21 days. Quality evaluations of fruits were done at seven day intervals. Samples were brought to room temperature over 18 hours prior to evaluating physico-chemical parameters. The experiment was repeated in three consecutive mango seasons.

Quality evaluation of mango

Physico-chemical analyses

Physico-chemical tests were carried out including fruit firmness (using a Guss FTA-

Fruit Texture Analyzer, Guss Manufacturing (Pty) Ltd., South Africa), peel colour (using a Minolta Colour meter, Model CR-400, Minolta, Japan), total soluble solids (as °Brix using a hand-held prism refractometer, Kruss 0-30, Kruss Optronic GmbH, Germany), titratable acidity (by titration with 0.1 N NaOH with phenolphthalein as an indicator), and pH (HACH, Loveland, USA) and were conducted in accordance with methods described by Ranganna (1977). Weight loss, firmness, and peel colour were determined using 15 fruits from both the treatments and control. Five composite mango samples, each having flesh materials from three mango fruits, were obtained for the determination of total soluble solids, titratable acidity, and pH.

Sugar and organic acid analyses

Sample preparation

For the chromatographic analysis, 5.0 g of flesh material was homogenized in 25.0 mL of distilled water prior to filtration with a 0.45 µm regenerated cellulose filter membrane (Agilent, USA).

HPLC instrumentation and chromatographic conditions – The chromatographic separation of sugars and organic acids was carried out using an Agilent 1260 infinity HPLC system equipped with a quaternary gradient pump, a refractive index detector for sugars, a DAD (λ_{max} = 210 nm for organic acids), and an auto injector. Agilent's OpenLAB Chromatographic Data System software was used to obtain chromatographic data.

Sugar analysis – The separation was achieved on a Zorbax Carbohydrate (NH2) column (250 mm x 4.60 mm x 5 µm, Agilent, USA). The mobile phase consisted of isocratic acetonitrile: water (79: 21, v/v). Each run was completed within 20 minutes with a flow rate of 1.2 mL min^{-1} and an injection volume of 10 µL. The column temperature and detector temperature were maintained at 30^0C. The results were expressed as g/100 g of fresh weight.

Organic acids analysis – The separation was achieved on a SUPELCOSIL LC-18 column (300 mm x 4.00 mm x 5 µm, Supelco, USA). The mobile phase consisted of 97% A (A = dipotassium hydrogen phosphate buffered at pH 2.6 with orthophosphoric acid) and 3% B (B = 100% methanol). Each run was completed within 30 minutes with a flow rate of 0.5 mL min^{-1} and an injection volume of 10 µL. The column temperature and detector temperature were maintained at 30^0C. The detection was carried out at UV 210 nm. The results were expressed as mg/100 g of fresh weight.

Internal gas analysis

A sample of gas was obtained from inside each of the six fruits of the two treatments and the control via a hole bored into the surface of the fruit using a cork-borer (diameter: 5 mm). A glass tube, open at one end and sealed with a Teflon septum on the other end, was inserted into the prepared hole and kept for three hours before taking the sample. A headspace sample of 0.5 mL was drawn from the tube and injected into the gas chromatograph. The CO_2 gas content of the internal gas composition of mangoes was analysed by gas chromatograph (Model 9A Shimadzu Porapack Q column). The column oven temperature, injector port temperature, and thermal conductivity detector (TCD) temperature were maintained at 90^0C, 110^0C, and 200^0C, respectively.

Headspace analysis of volatile compounds

Solid Phase Micro Extraction (SPME) was used to evaluate the volatile aroma compound profile of treated and untreated mango. Six equally-sized mango fruits from each treatment (C5 and C6) and the control were sealed in three separate airtight glass containers, each having two fruits. Sampling

was conducted with Supelco 65 µm polydimethylsiloxane/divinylbenzen, fused silica, 24 Ga SPME fibre assembly, and manual SPME holder (Supelco Park, Bellefonte, PA, USA) for 30 minutes at a room temperature of 30^0C. A Shimadzu 2010 gas chromatographic system equipped with a flame ionization detector and a Supelcowax-10 (30 m x 0.25 mm x 0.2 µm, Sepelco, USA) capillary GC column was used to obtain the volatile profiles. Of the identified volatile compounds, such as pinenes, terpenes, alcohols, and esters described by Macleod and Pieris (1984), variation in ethyl hexanoate, β-ocimene and ethyl octanoate levels were evaluated with respect to treatment and storage period. A GC-MS (a Thermo scientific Trace 1300 GC coupled with an ISQ QD single quadruple mass spectrometer) was used for compound identification (Mass Spectral Database: NIST11).

Disease incidence and marketability

The incidence of disease was rated on a scale of 1 to 10, with 1 meaning no signs of disease and 10 meaning that fruits had entirely succumbed to disease. Fruits that had a rating of 1 or 2 were considered as marketable (Figure 1).

Sensory analysis

A trained sensory panel (as per ISO 8586-1: 1993 guidelines) of nine people analysed the fruits for appearance, colour, odour, texture, taste, and overall acceptability based on a hedonic scale from 1 to 9, where 1 indicated "dislike extremely" and 9 indicated "like extremely", after low temperature storage. Both wax treated and untreated control fruits were removed from storage at the same time intervals for sensory analyses.

Data analysis

Experimental means were subjected to an Analysis of Variance and means were compared with Tukey's tests using the general linear model (GLM) procedure of SPSS software (SPSS, version 16). To compare means of values from treated mangoes with those from control sets, a type I error rate of $p < .05$ was used for all trials.

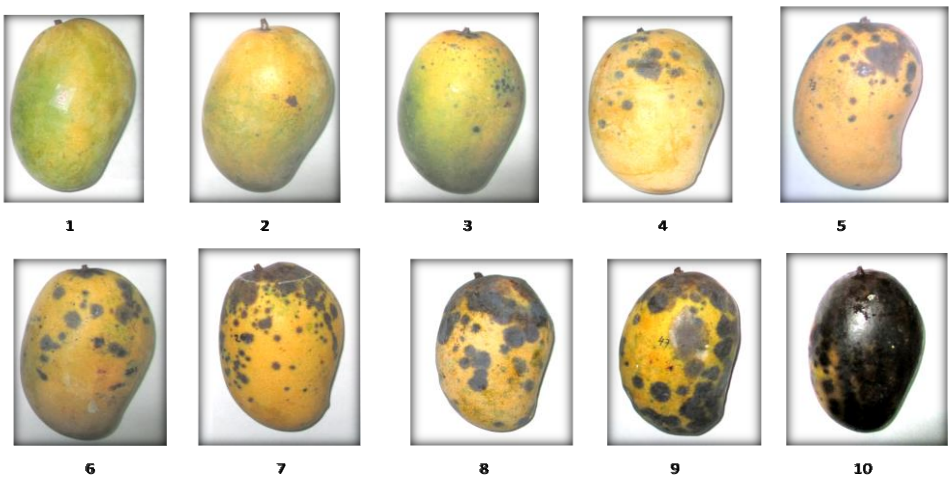


Figure 1: Disease severity index for mango.
1 meaning no signs of disease and 10 meaning that fruits had entirely succumbed to disease. Fruits rated as 1 or 2 were considered marketable.

Results

Particle size distribution and scanning electron microscopy

The cumulative particle size distribution of the wax formulations resembled each other, with C5 and C6 wax emulsions having 90% of the particle sizes falling below 16.7 µm and 16.4 µm, respectively (Figure 2). The SEM images of the surface morphology confirmed that both C5 and C6 waxes formed an even coating and covered the stomata on the fruit surface while stomata of control fruits were observed as remaining uncovered (Figure 3).

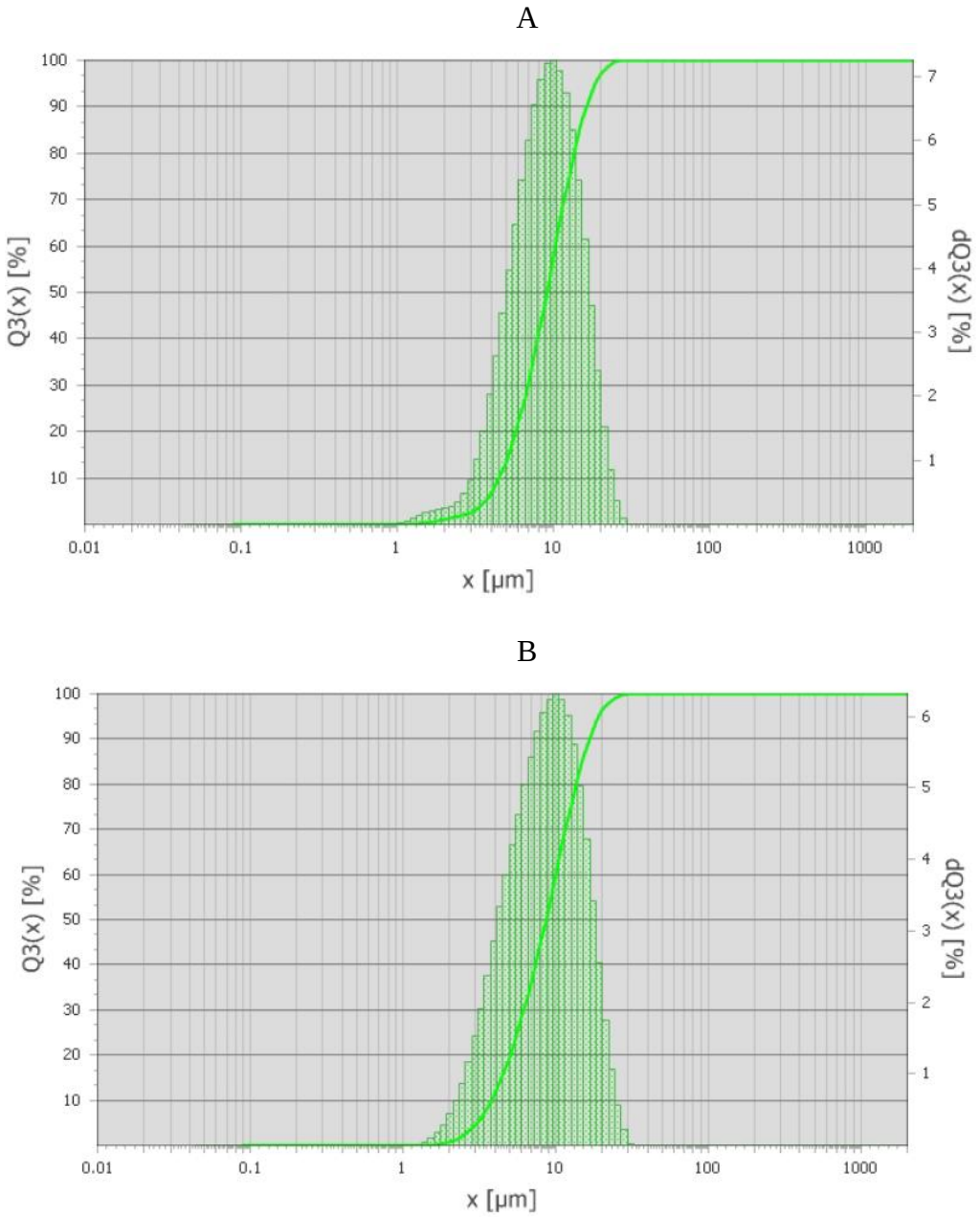


Figure 2: Particle size distributions. *A*, for C5: Q3(x) [90%] = 16.7 µm. *B*, for C6: Q3(x) [90%] = 16.4 µm. Q3(x) is the cumulative distribution of particle size and Q3(x) [90%] means 90% of the particles falls below the given value.

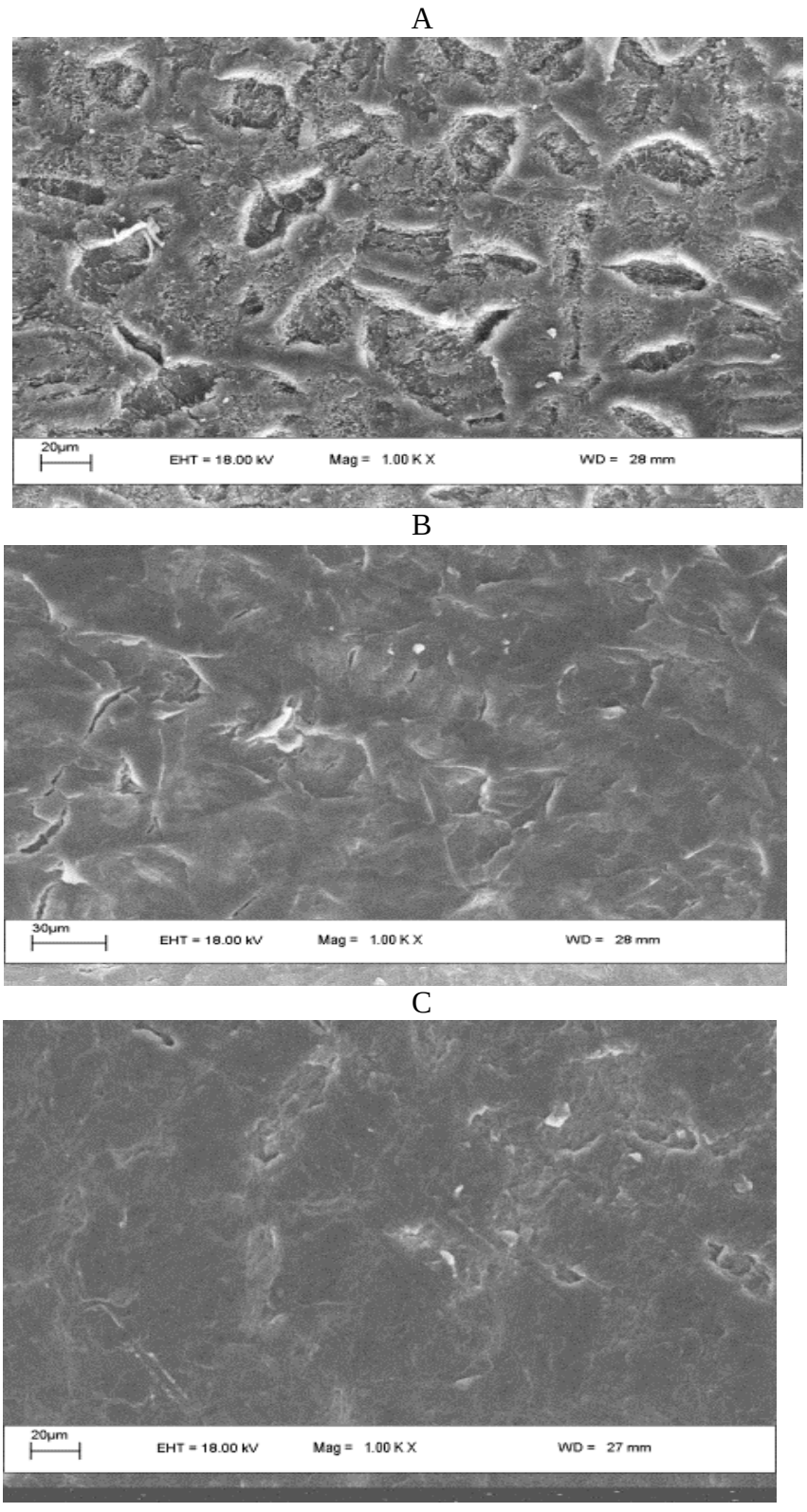


Figure 3: Surface morphology of mango fruit peel, SEM x 1k. *A*, uncoated. *B*, C5 wax coated. *C*, C6 wax coated.

Quality evaluation of mango

Physico-chemical analyses

No significant difference in skin colour (Hue angle), fruit firmness, weight loss, and pH of mangoes was observed, irrespective of the treatment applied and storage duration (Tables 1, 2, 3, and 4). However, significantly lower total soluble solid (TSS) content with higher titratable acidity (TA) was observed in mangoes dipped in wax C5 and C6 formulations compared to the untreated controls indicating a delay in ripening in the first week of storage. However, no significant difference in TSS contents was observed between the treatments and control after 14 and 21 days storage (Tables 5 and 6). The results of the sugar profile and acid profile analysis confirmed the above findings. A significantly higher content of fructose and glucose were observed in control fruits compared to wax treatments. The sucrose content did not show any significant change with the treatment applied (Table 7). In the acid profile, the citric acid content in wax treated fruits was significantly higher compared to control fruits with respect to the storage duration over 7 to 21 days (Table 8).

Table 1: Variation in flesh colour of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	Colour as Hue angle		
	1 week	2 weeks	3 weeks
Control (untreated)	77.10 ± 1.61^{a}	81.30 ± 0.66^{ab}	84.74 ± 1.01^{a}
Wax C5	81.96 ± 3.88^{a}	78.62 ± 1.58^{ab}	84.94 ± 1.14^{a}
Wax C6	75.60 ± 1.35^{a}	77.46 ± 1.21^{b}	86.94 ± 0.79^{a}

Note: The data shown are mean ± standard error of 15 fruits each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 2: Variation in fruit firmness of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	Firmness of mango (Kpa)		
	1 week	2 weeks	3 weeks
Control (untreated)	3.10 ± 0.96^{a}	2.65 ± 0.72^{a}	1.53 ± 0.34^{a}
Wax C5	3.70 ± 1.68^{a}	3.25 ± 0.17^{a}	1.62 ± 0.66^{a}
Wax C6	3.96 ± 0.74^{a}	2.65 ± 0.27^{a}	2.60 ± 0.50^{a}

Note: The data shown are mean ± standard error of 15 fruits each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 3: Variation in weight loss (g) of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	Weight Loss (g)		
	1 week	2 weeks	3 weeks
Control (untreated)	11.80 ± 0.91^{a}	16.38 ± 0.81^{a}	24.75 ± 1.56^{a}
Wax C5	10.72 ± 0.88^{a}	17.52 ± 2.45^{a}	22.42 ± 2.29^{a}
Wax C6	9.76 ± 0.82^{a}	15.59 ± 1.81^{a}	23.42 ± 2.29^{a}

Note: The data shown are mean ± standard deviation of 15 fruits each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 4: Variation in fruit pH of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	pH		
	1 week	2 weeks	3 weeks
Control (untreated)	3.67 ± 0.03[a]	3.41 ± 0.16[b]	3.52 ± 0.04[a]
Wax C5	3.22 ± 0.29[a]	3.79 ± 0.04[a]	3.71 ± 0.04[a]
Wax C6	3.47 ± 0.14[a]	3.66 ± 0.03[ab]	3.60 ± 0.03[a]

Note: The data shown are mean ± standard error of 5 composite samples each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 5: Variation in total soluble solids (°Brix) of mangoes subjected to post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	Total soluble solids (°Brix)		
	1 week	2 weeks	3 weeks
Control (untreated)	15.33 ± 0.88[a]	17.25 ± 0.48[a]	14.66 ± 0.88[a]
Wax C5	11.00 ± 0.58[b]	16.25 ± 0.52[a]	12.50 ± 2.18[a]
Wax C6	12.66 ± 0.88[ab]	16.50 ± 0.65[a]	15.33 ± 1.67[a]

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 6: Variation in titratable acidity (as % citric acid) in mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment	Titrable Acidity (as % citric acid)		
	1 week	2 weeks	3 weeks
Control (untreated)	0.17 ± 0.01[a]	0.15 ± 0.02[a]	0.10 ± 0.01[a]
Wax C5	0.61 ± 0.01[b]	0.15 ± 0.02[a]	0.22 ± 0.03[a]
Wax C6	0.31 ± 0.00[a]	0.15 ± 0.02[a]	0.14 ± 0.00[a]

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values ($p < .05$) within columns are designated by different letters

Table 7: Variation in sugar content (sucrose, fructose, and glucose; g/100 g fresh weight) of mangoes subjected to post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment		Sugar content (g/100g fresh weight)		
		1 week	2 weeks	3 weeks
Sucrose	Control (untreated)	6.62 ± 0.89[a]	7.81 ± 0.11[a]	7.32 ± 0.21[a]
	C5 wax	5.83 ± 0.15[a]	7.38 ± 0.48[a]	6.99 ± 0.38[a]
	C6 wax	5.45 ± 0.19[a]	7.18 ± 0.23[a]	7.35 ± 0.04[a]
Fructose	Control (untreated)	1.28 ± 0.03[a]	1.69 ± 0.02[b]	1.92 ± 0.07[a]
	C5 wax	1.60 ± 0.01[b]	1.49 ± 0.03[a]	1.79 ± 0.13[a]
	C6 wax	1.40 ± 0.07[c]	1.56 ± 0.08[a]	1.76 ± 0.03[a]
Glucose	Control (untreated)	1.23 ± 0.04[b]	1.68 ± 0.10[a]	1.82 ± 0.09[a]
	C5 wax	1.01 ± 0.05[a]	1.40 ± 0.17[a]	2.01 ± 0.18[a]
	C6 wax	1.06 ± 0.08[a]	1.63 ± 0.02[a]	1.71 ± 0.06[a]

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values ($p < .05$) within columns are designated by different letters

Internal gas analyses

The internal CO_2 levels of the C5 and C6 wax-treated fruits were observed to be higher compared to control fruits (Figure 4). This may be attributed to the semi-permeable coating formed around the fruits.

Table 8: Variation in citric and malic acid content (mg/100 g fresh weight) of mangoes subjected to post harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 1 week, 2 weeks, and 3 weeks

Treatment		Organic acid content (mg/100g fresh weight)		
		1 week	2 weeks	3 weeks
Citric acid	Control (untreated)	480.79 ± 14.82[a]	366.57 ± 4.92[a]	254.18 ± 11.57[a]
	C5 wax	643.36 ± 20.28[c]	465.55 ± 2.00[c]	347.48 ± 11.31[b]
	C6 wax	557.30 ± 7.36[b]	424.42 ± 8.97[b]	378.37 ± 37.44[b]
Malic acid	Control (untreated)	54.14 ± 1.53[b]	51.35 ± 2.92[b]	27.19 ± 7.75[a]
	C5 wax	43.14 ± 0.01[a]	50.00 ± 0.30[b]	36.58 ± 0.28[a]
	C6 wax	50.93 ± 1.48[b]	38.93 ± 0.46[a]	27.03 ± 5.25[a]

Note: The data shown are mean ± standard deviation of 5 composite samples each. Statistically significant values ($p < .05$) within columns are designated by different letters

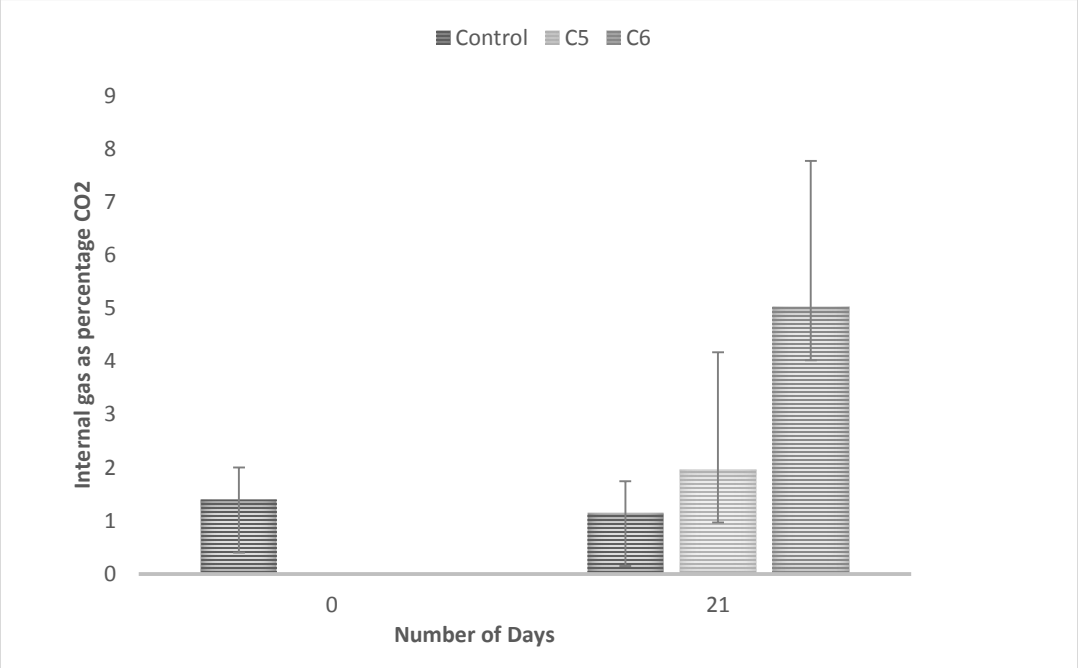


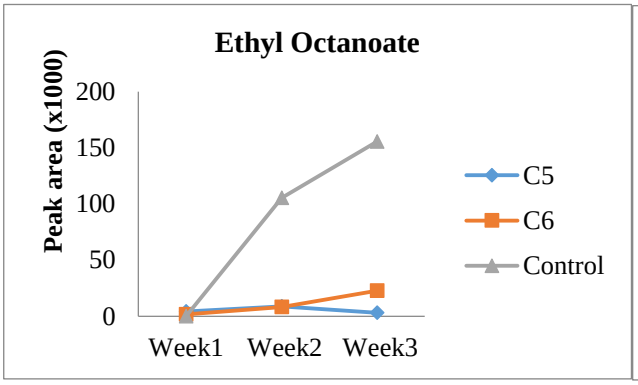
Figure 4: The internal gas composition (as percentage CO_2) of mangoes subjected to the post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C for 21 days.

Headspace analysis of volatile compounds

The levels of ethyl hexanoate, β-ocimene did not change with respect to treatment or storage time, the level of ethyl octanoate was observed to be markedly higher in the control fruits after two and three weeks, respectively (Figure 5).

Disease incidence and marketability

The percentages marketability of fruits treated with wax C6 and C5 and the control after 14 days storage at low temperature were 96% and 90%, and 93% respectively, indicating a higher disease resistance capacity in wax C6. After 21 days of low temperature storage, the percentages of marketability for C5 and C6 were lower (63% and 66%, respectively). This was, however, still higher than the 40% marketable fruits observed in the untreated controls after low temperature storage at 13.5 °C ± 2 °C (Figure 6).



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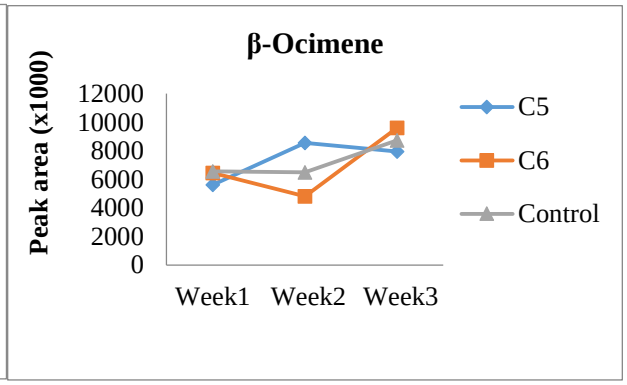

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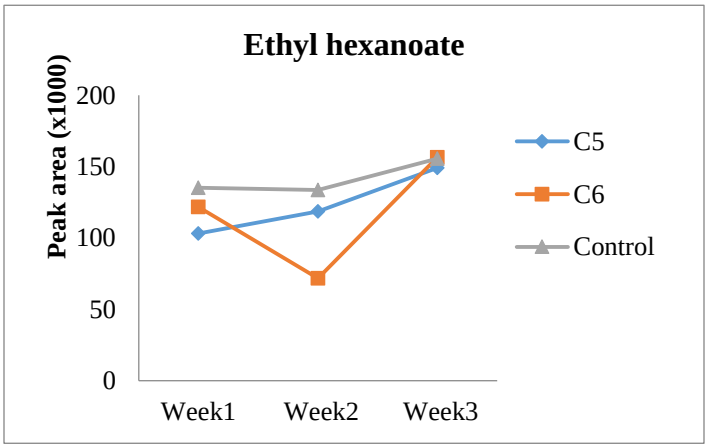

C

Figure 5: The SPME-headspace analysis of selected volatile compounds of mango subjected to the post-harvest wax treatments (C5 and C6) and controls after low temperature storage at 13.5 °C ± 2 °C for 3 weeks. [*A*, ethyleoctanoate. *B*, β-ocimeme. *C*, ethyl hexanoate].

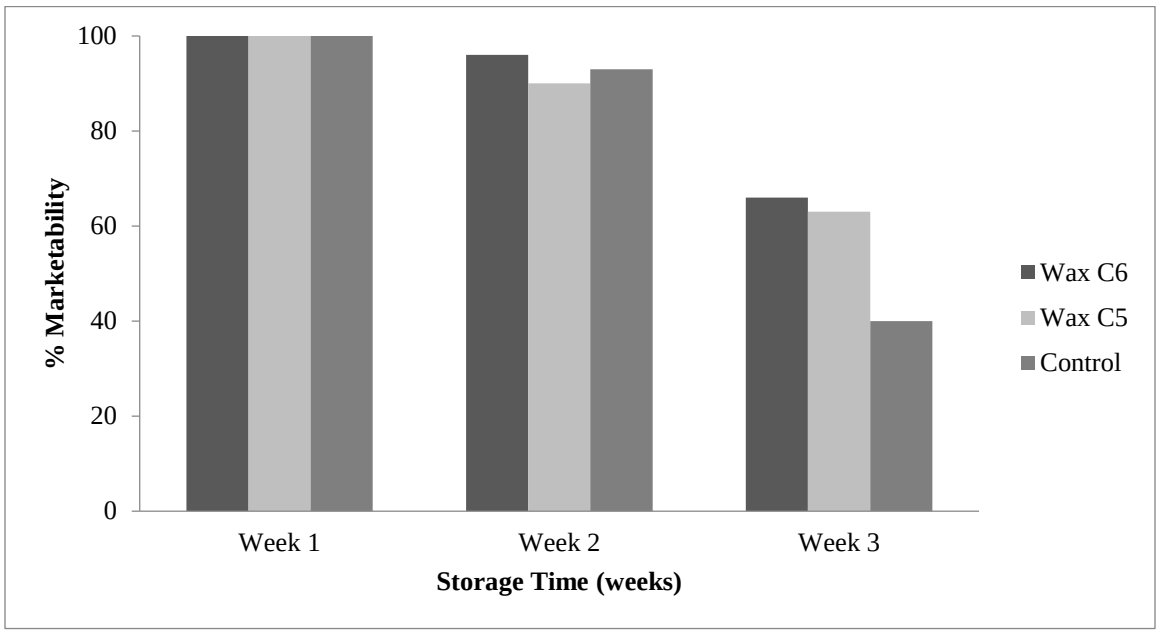

Figure 6: Percentage marketability of mangoes subjected to post-harvest wax treatments (C5 and C6) and the controls after low temperature storage at 13.5 °C ± 2 °C after 1 week, 2 weeks, and 3 weeks.

Sensory analysis

Sensory analysis of mango fruits subjected to the two wax formulations or control treatment and stored at low temperature for 21 days revealed that control fruits had the highest ratings for appearance, aroma, taste, and overall acceptability. As both treatments were evaluated on the same day, this indicates that ripening was delayed in the wax treated fruits. However, no undesirable sensory attributes were perceived in wax treated fruits.

Discussion

Particle size distribution indicates similarity in stability, ease of application and appealing cosmetic appearances of the final wax coating. In order to get the maximum advantage of edible coatings, the coatings should adhere to the fruit surface. However, adhesions of most hydrophilic edible coatings on the hydrophobic whole fruit surfaces are inherently poor due to the differences in the chemical nature of the two surfaces (Lin and Zhao 2007). In addition, non-uniform or sticky surfaces may result, making the product unattractive to consumers (Zhao and McDaniel 2005). According to previous studies, surfactants added to the coating formulations have improved the wettability and surface adhesion of the coating (Choi et al. 2002; Lin and Krochta 2005).

This study attempted to evaluate the application of modified wax coatings with natural anti-senescence and antimicrobial compounds on the keeping quality of mangoes. Although the cosmetic appearance, physico-chemical parameters, and sensory characters can be positively affected in wax-coated fruits, further improvements in effective delivery of these bioactive compounds onto the fruit could potentially enhance the functionality of wax treatments. Significant changes in treated fruits compared to controls was not evident due to the natural diversity of individual fruits and complexity of the fruit ripening process, which involves several biochemical processes

including the breakdown of cell walls and pectin, degradation of membranes, the breakdown of stored carbohydrates into sugars, a reduction in acidity, and an increase of biosynthesis in colour and volatile aroma compounds (Cheema et al. 2014).

Sensory data confirmed that wax C5 and C6 retarded the rate of ripening compared to the control fruits during the study period. Sensory data also revealed no off flavour development after storage when mangoes were coated with either of the two biowax formulations. Hence, these two edible coatings show potential for meeting the challenges associated with minimizing loss while maintaining stable quality and market safety during low temperature storage.

The coatings allow CO_2 exchange through the partially covered stomata, so that fruits maintained an acceptable flavour and did not succumb to anaerobic respiration as a consequence of high levels of CO_2 accumulation within the fruit. This microclimate or modified atmosphere condition created by the wax combined with the antimicrobial compounds helps increase the shelf life of fruit. The gas-barrier function could in turn retard the enzymatic oxidation and protect the fresh produce from browning (i.e. discolouration) and texture softening during storage (Lin and Zhao 2007). Development of undesirable sensory properties on coated fruits is one potential adverse effect of the use of edible coating. Off-flavours could occur due to the existing flavour of coating materials or as the result of anaerobic respiration from excess inhibition of O_2 and too low a rate of CO_2 exchange. Therefore, it is necessary to consider these important sensory attributes when developing an edible coating for fresh and minimally processed produce (Zhao and McDaniel 2005).

It is reported that the aroma profile could change dramatically during the post-harvest life of fresh produce, particularly in climacteric fruits in which the dominant volatile may vary significantly based on the maturity of the fruit (Lin and Zhao 2007). The increase in levels of ethyl octanoate and other esters towards the later stage of ripening in this study are consistent with the previous studies reported (Lalel et al. 2003). Elevated levels of ethyl octanoate in control fruits compared to treatments C5 and C6 during the storage period of three weeks could potentially be used as a marker compound to identify the level of ripening in future studies.

Conclusion

The present study is an attempt to determine the effectiveness of the post-harvest application of waxes containing hexanal and cinnamon bark oil as active ingredients against senescence and microbial infection, and for maintaining quality parameters of *Karuthakolumbaan* mangoes during low temperature storage. Both waxes showed improved physico-chemical, and marketability attributes in the mangoes with no development of off flavours, compared to the untreated control fruits. Effective concentration of hexanal and cinnamon bark oil in the wax emulsion could be a key consideration in the future development of edible waxes.

Acknowledgement

The research was supported by the Canadian International Food Security Research Fund (CIFSRF)-Canada, Global Affairs Canada, and the International Development and Research Centre (IDRC), Canada. The authors would also like to acknowledge Ellawela Horticulture, Galkiriyagama, for providing facilities to conduct field trails. The Sri Lanka Institute of Nanotechnology is also acknowledged for providing their support to conduct the particle size analysis.

References

Carrari, F., and A.R. Fernie. 2006. "Metabolic regulation underlying tomato fruit development." *Journal of Experimental Botany* **57**: 1883-97.

Cheema, A., P. Padmanabhan, J. Subramanian, T. Blom, and G. Paliyath. 2014. "Improving quality of greenhouse tomatoes (*Solanumlycopersicum* L.) by pre and post-harvest applications of hexanal containing formulations." *Postharvest Biology and Technology* **95**:13-19.

Choi, W.Y., H.J. Park, D.J. Ahn, J. Lee, and C.Y. Lee. 2002. "Wettability of chitosan coating solution on 'Fuji' apple skin." *Journal of Food Science* **67**:2668–72.

Dhall, R.K. 2013. "Advances in edible coatings for fresh fruits and vegetables- a review." *Critical Reviews in Food Science and Nutrition* **53**:435-50.

Fei, L.U., D. Yi-cheng, Y.E. Xing-qian, and D. Yu-ting. 2011. "Antibacterial effect of cinnamon oil combined with thyme or clove oil." *Agricultural Sciences in China* **10 (9)**: 1482-87.

Lalel, H.J.D., Z. Singh, S.C. Tan. 2003. "Aroma volatiles production during fruit ripening of 'Kensington Pride' mango." *Postharvest Biology and Technology* **27**:323-36.

Lin, S.Y.D., and J.M. Krochta. 2005. "Whey protein coating efficiency on surfactant-modified hydrophobic surfaces." *Journal of Agricultural and Food Chemistry* **53**:5018–23.

Lin, D., and Y. Zhao. 2007. "Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables." *Comprehensive Reviews in Food Science and Food Safety* **6**:60-75.

MacLeod, A.J., and N.M. Pieris. 1984. "Comparison of the volatile components of some mango cultivars." *Phytochemistry* **23 (2)**: 361–66.

Paliyath, G., and J. Subramanian. 2008. "Phospholipase D inhibition technology for enhancing shelf life and quality." In *Postharvest Biology and Technology of Fruit, Vegetables, and Flowers*, edited by G. Paliyath, D. P. Murr, A. K. Handa, and S. Lurie, 240–45. Hoboken, NJ: Wiley-Blackwell.

Paliyath, G., K. Tiwari, H. Yuan, and B.D. Whitaker. 2008. "Structural deterioration in produce: phospholipase D, membrane deterioration, and senescence." In *Postharvest Biology and Technology of Fruit, Vegetables, and Flowers*, edited by G. Paliyath, D.P. Murr, A.K. Handa, and S. Lurie, 195–239. Hoboken, NJ: Wiley-Blackwell.

Paliyath, G., R.G. Pinhero, R.Y. Yada, and D.P. Murr. 1999. "Effect of Processing Conditions on Phospholipase D Activity of Corn Kernel Subcellular Fractions." *Journal of Agricultural and Food Chemistry* **47(7)**: 2579-88.

Paliyath, G., D.P. Muir, R.Y. Yada, and R.G. Pinhero. 2003. Inhibition of Phospholipase D. US Patent # 6,514,914.

Pena, D.C.R., and J.A. Torres. 1991. "Sorbic acid and potassium sorbate permeability of an edible methylcellulose-palmitic acid film: water activity and pH effects." *Journal of Food Science* **56 (2)**: 497–99.

Pranoto, Y., V.M. Salokhe, and K.A. Rakshit. 2005. "Physical and anti-bacterial properties of alginate-based edible film incorporated with garlic oil." *Food Research International* **38**:267–72.

Ranganna, S. 1977. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*, 2nd edition. New Delhi: Tata McGraw-Hill Publishing.

Sharma, M., J. Jacob, J. Subramanian, G. Paliyath. 2010. "Hexanal and 1-MCP treatments for enhancing the shelf life and quality of sweet cherry (*Prunus avium* L.)." *Scientia Horticulturae* **125**:239–47.

Tiwari, K., and G. Paliyath. 2011. "Microarray analysis of ripening-regulated gene expression and its modulation by 1-MCP and hexanal." *Plant Physiology and Biochemistry* **49(3)**:329-40.

Usha, M., S. Ragini, and S.M.A. Naqvi. 2012. "Antibacterial activity of acetone and ethanol extracts of cinnamon (*Cinnamomum zeylanicum*) and ajowan (*Trachyspermum ammi*) on four food spoilage bacteria." *International Research Journal of Biological Sciences* 1**(4):** 7–11.

Zhao, Y., and M. McDaniel. 2005. "Sensory quality of foods associated with edible film and coating systems and shelf-life extension." In *Innovations in Food Packaging*, edited by J.H. Han, 434–53. San Diego, CA: Elsevier Academic Press