Influence of novel coconut oil and beeswax edible coating and MAP on postharvest shelf life and quality attributes of lemon at low temperature

Taslima Ayesha Aktar Nasrin a,⁎, Most Sadia Arfin a, Md. Atiquir Rahman a, Mohammad Mainuddin Molla b, Ashfak Ahmed Sabuz b, Md Abdul Matin c

⁎ Postharvest technology section, Horticulture Research Centre, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
b Postharvest technology division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh
International Maize and Wheat Improvement Center (CIMMYT), Southern Africa Regional Office, 12.5 KM Peg, Masowe Road, Mount Pleasant, Harare, Zimbabwe

A R T I C L E   I N F O

Key words:
Edible coating
Sensory quality
Respiration rate
Hue angle
Yellowing

A B S T R A C T

Weight loss, turning of peel colour from green to yellow and microbial infections are the major postharvest problems of lemon. Lipid-based edible coatings and modified atmospheric packaging (MAP) are effective techniques in maintaining postharvest quality of fruits for long-term storage. With this view, an investigation was conducted for the preservation of green lemon using coconut oil and beeswax edible coating and MAP during storage at low temperature. Physiologically matured lemons were collected and washed with potable water; fruit surface water was removed and then coated with coconut oil-beeswax (90:10) or only coconut oil. After coating, lemons were packaged in MAP or kept in open crates and stored at 12±1 °C and 85±5% relative humidity (RH) for 8 weeks and a week interval, the sampling was conducted. The results revealed that coconut oil-beeswax coating had immense effect on retaining shiny green colour, reducing respiration, weight loss, shrivelling and preserving firmness and ascorbic acid of lemon throughout the storage. On the other hand, MAP mainly helped to retain moisture & firmness and reduce shrivelling. Uncoated lemons kept open lost the highest amount of ascorbic acid and retained only 13.7 mg/100 g that is significantly (p < 0.05) less than the lemons of all other treatments at 8th week of storage period. While lemons coated with coconut oil-beeswax and packaged in MAP was preserved the highest amount (24.2 mg/100 g) of ascorbic acid and there was no significant difference (p < 0.05) with the amount of ascorbic acid content of lemons coated with only coconut oil and packaged in MAP at the last week (8th week) of storage. Hue angle value was 93.4 in uncoated lemons packaged in MAP while it was 113.67 in coconut oil-beeswax coated lemon kept open and 112.64 in lemon coated with coconut oil-beeswax and packaged in MAP at 8th week of storage. Based on all sensory, physical and chemical parameters uncoated lemons kept open was acceptable up to 1 week, coconut oil-beeswax coated lemon kept open was 6 weeks and coconut oil-beeswax coated lemon packaged in MAP was 8 weeks with good quality and shiny green colour.

1. Introduction

Lemon (Citrus limon L.) is one of the most widely consumed citrus all over the world for their unique flavour, acidity, medicinal and nutritional benefits [1,2].

Lemons contain a high amount of vitamin C, soluble fibre, phenolic compounds and flavonoids that may aid weight loss and reduce risk of heart disease, high blood pressure, hypertension, digestive issues, and cancer [3]. Though lemon is non-climacteric fruit and does not experience major softening or compositional changes after harvest, its postharvest loss is about 18–25% [4]. The major problems that limit postharvest life of lemon are weight loss and yellowing of peel colour. This weight loss occurs mainly due to transpiration and respiration [5].

Transpiration is a physical process characterized by the evaporation of water from fruit tissues, having as consequence fruits deterioration because of the loss in appearance (wilted and shrivelling), textural (softening) and nutritional quality [6]. Transpiration rate is influenced by rind injuries, maturity stage and environmental factors, such as temperature, relative humidity and air movement. So, the shelf life of citrus can be increased through controlling the rate of transpiration and respiration, skin colour and microbial infection [7]. The application of surface coatings, waxing, and the manipulation of the storage environment (low temperatures, high relative humidity levels and control of air circulation) allow the management of the process. Application of edible coating materials to preserve the postharvest quality of fruit is an environment friendly and economical in comparison with alternate tech-
niques [8]. The edible coating forms a fine film of innate layers on the surface of the fruit. Indeed, it barricades against microbial contamination, moisture loss, preserve textural properties, helping retain colour, volatile flavour compounds and retards respiration as well as transpiration rate in fruits [9]. Lipid-based coatings are prepared by combining different lipid substances such as waxes, oil, acyl monostearoyl glycerol and emulsifying agent [10]. In recent studies, beeswax with Tulsí extract coated pears [11] stored at ambient condition and beeswax coated Kinnow mandarin [10] stored at low temperature exhibited better quality characteristics when compared to other coating materials or uncoated fruits. Even at ambient conditions, the application of beeswax coating exhibited a positive effect on quality maintenance in lemon [12], mango [13] and sweet orange [14]. The beeswax-coconut oil edible coating proved to be a very efficient technique for the minimal processing of strawberries and apricot fruits [15].

Coconut oil is easily available edible oil. It is unique because it contains predominantly medium chain fatty acids of which 45–50 percent is lauric acid that has proven anti-inflammatory and antimicrobial effects. Lauric acid has the additional beneficial function of being formed into monolaurins [16]. The monolaurin investigated as an active component of the coconut oil showed a pronounced antifungal activity which was a very useful characteristic for its potential application in antifungal edible coatings for the preservation of fruits (strawberry, apricots etc.) [15]. Coconut oil coating in Kajzi lime proved to be significantly superior over control and all other treatment followed by castor oil coating and liquid paraffin wax. Because, pure coconut oil has anti- senescence properties that reduce respiration rate, transpiration rate and binding of the ethylene biosynthesis process [17]. Coconut oil coating closed the opening of stomata and lenticels thereby, reducing the transpiration and respiration rate and also reduce microbial activity in pineapple [18].

Citrus commercial coatings are generally known as waxes that based on paraffin wax or a combination of various other waxes such as beeswax or carnauba. Their purpose is to reduce fruit weight loss, shrinkage, incidence of chilling injury and improve appearance [19,20]. Citrus Wax (wood resins18%, Imazalili 0.3%, Thiabendazol 0.5%) coating significantly reduced physiological weight loss, increased shelf life and maintained the quality of lime. Besides this wax coating retained higher levels of vitamin C content, flavour and fruit firmness; prevented disease attack; and improved juice recovery of lime fruits compared with control [21]. However, according to our knowledge, there is very little study about the incorporation of coconut oil as a natural antimicrobial agent in the beeswax or only coconut oil coating in fruits and vegetables to give it a healthy attributes.

MAP is a simple, economical and effective method in prolonging the postharvest life of many horticultural crops [22]. The decreased O2 and increased CO2 inside the package retards the respiration rate, ethylene production, enzymatic activity, chilling injury and decay, resulting in increased postharvest life and quality [23,24]. MAP also prevents weight loss and fruit shrivelling by creating a higher RH in surrounding environment of the produce. MAP for storage and transportation of fruits and vegetables is commonly achieved by packing them in plastic films. Storage in plastic films with different kinds of combinations of materials, perforation and inclusions of chemicals and individual seal packaging are types of modified atmosphere storage [25,26]. A simple technology is needed to develop that will prolong postharvest life of fresh lemon retaining quality. Thus, the objective of this research was to evaluate the performance of edible coating (coconut oil-beeswax coating and only coconut oil) with or without MAP storing at 12±1°C on physical, chemical and sensory quality of fresh lemon.

Materials and methods

Plant material

The fresh, physiologically matured light green, damaged free and uniform size of lemons (Citrus limon var. seedless lemon) were harvested from full grown healthy trees, maintained under homogenous cultural practices from the field of one progressive farmer of Noyarhat village, in Fazilhati union under Delduar upazila, Tangail district, Bangladesh. Recommended dose of fertilizers, irrigation, drainage, pruning etc. were applied and insects, pest & disease were controlled in the lemon field following standard practices. The fruits were washed and graded by density gradation method to select fruits having uniform maturity and only water sinker fruits were used for this study [17]. Chemicals used in this study were chemical grade and the origin of beeswax and coconut oil is India.

Edible coating formulations

Coconut oil (90 g) and beeswax (10 mL) were put in a beaker and stirred on a low flame in order to obtain a homogenous mass that would become viscous upon cooling. Two types of coating were used such as (a).100% coconut oil, (b). coconut oil and beeswax mixture (90:10). One experiment was conducted on different concentrations of coconut oil and beeswax coatings in lemon at ambient conditions to maintain postharvest quality and found coconut oil-beeswax mixture (90:10) was optimum (as a least amount of bees wax was used) to retain postharvest green life of lemon with quality [12]. Lemons were divided into 3 lots, 1st lot lemons were without coating, 2nd lot lemons were coated with 100% coconut oil and 3rd lot lemons were coated with coconut oil and beeswax mixture (90:10). Half of lemons from each lot were kept in open crates and half were packaged in MAP (0.5% perforated LDPE bag). So, there were 6 treatments and each treatment consisted of 5 replications. The coating was applied carefully on the fruit skin by a soft and clean brush. Lemons packaged into MAP or kept in open crates were stored at 12±1°C and 85±5% RH for 8 weeks. Measurements on various physical, chemical and sensory attributes were done at the day of experiment setting and on each week up to 8 week of storage. From each replication, 10 fruits were kept separately for weight loss and colour change measurement throughout the storage period.

Respiration rate

For the measurement of respiration rate of lemon, five fruits per replication were kept into 1600 mL sealed containers containing septa up to 2 h (incubation time) at ambient condition. Then one mL gas was taken from the container using syringe and examined by gas analyser (CO2/O2 gas analyser, Quantek Instrument, Model No. 902D, USA). Respiration rate was calculated using total gas volume of CO2 in the box, volume and weight of lemon in the container and incubation time [27] and expressed as ml kg⁻¹ h⁻¹ of CO2 evolved using the following equation:

\[
\text{Respiration rate (ml kg}^{-1} \text{h}^{-1}) = \frac{\text{Total amount of CO}_2 \text{ in the box}}{\text{Weight of sample \times incubation time}}
\]

Fruit firmness

Firmness was analysed by Fruit Texture analyser (GUSS, Model Number: GS-25, SA) supported by FTA Win Software. Firmness measurement was taken as the maximum penetration force reached during the tissue breakage and determined with 8 mm diameter stainless steel flathead probe, which penetrates in a normal direction at a cross-head speed of 5 mm per sec. Sample (lemon) was compressed to a depth of 3 mm by the probe. Firmness was measured in the same position (maximum diameter vertically) of each lemon. Lemons (two opposite locations of each lemon) from each replication were analysed and the mean value was used and expressed in Newton (N).

Fruit surface colour

External colour of lemon was measured with a Chroma metre (Model CR-400, Minolta, Japan) based on CIE (L*a*b*). CIE L*a*b* coordinates
were recorded using D65 illuminants and a 10° standard observer as a reference system. L* is lightness, a* (-greenness to +redness) and b* (-blueness to +yellowness) are the chromaticity coordinates. Values of a* and b* were converted to Chroma [C = (a*² + b*²)¹/²] and hue angle \( h = \tan^{-1}(b*/a*) \). Before measurement, the equipment was calibrated against a standard white tile.

**Physiological loss in weight (PLW)**

Initial weight of 10 fruits from each replication was taken after treatment and then a week interval throughout storage time. PLW was measured by using following equation:

\[
\text{PLW} (%) = \frac{\text{Initial fruit weight} - \text{Final fruit weight at indicated period}}{\text{Initial fruit weight}} \times 100
\]

**Juice content**

Juice content was measured by the weight of extracted juice from lemon divided by total weight of fruits and finally expressed in percentage. Juice content was measured by using following equation:

\[
\text{Juice content} (%) = \frac{\text{Juice weight}}{\text{Total fruit weight}} \times 100
\]

**Shrinkage and yellowing**

Fruit shrinkage was measured when at least 10% area of lemon skin became wrinkled or shrunk. Fruit shrinkage was calculated as the number of shrunk or wrinkled lemons divided by total number of fruits. Lemon showing at least 10% area of skin turned into yellow marked as yellow fruit. Yellowing of fruits was calculated as the number of yellow colour lemons divided by total number of lemons [12].

**Total soluble solids (TSS), pH, titratable acidity and ascorbic acid determination**

TSS of the lemon juice was determined by the index of refraction by using a refractometer according to AOAC [28] and expressed in °Brix. Ten (10) g of lemon juice were suspended in 100 mL of distilled water and then filtered. The pH of the sample (lemon juice) was assessed using a pH metre (Model pH -211; HANNA Instrument Inc, Italy). Titratable acidity is determined by neutralizing the acid present in ten (10) g of lemon juice using sodium hydroxide (tartar) and phenolphthalein indicator was used to determine the endpoint of titration and expressed in percent.

The ascorbic acid content of lemon juice was determined by using 2-6-dichlorophenol indophenol titration method according to AOAC [28]. The method of estimation involves the reduction of 2, 6-dichlorophenol indophenol dye to a colourless form by ascorbic acid in an alkaline solution. In the procedure followed, the dye solution was first standardized against standard ascorbic acid in order to determine the dye factor. The sample was diluted with 5% metaphosphoric acid and then the phosphoric acid extract of the sample was titrated against the dye solution until a pink colour was obtained which persists for 15 s.

\[
\text{Dye factor} = \frac{0.5}{\text{Titrator volume}}
\]

\[
\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made} \times 100}{(\text{Aliquot of extract taken} \times \text{Weight of sample})}
\]

**Sensory quality**

Sensory quality parameters such as colour, flavour, texture and overall acceptability was evaluated for each treatment. Nine-point unstructured scale ranging from 1 (dislike extremely) to 9 (like extremely) was used to evaluate these sensory parameters. An average score of 4.5 was considered the limit for acceptability. Sensory evaluation was performed by a panel of judges consisting of 10 scientific personnel including both male and female members [29].

**Statistical analysis**

A completely randomized design (CRD) was done with five replication for each experiment and mean ± standard deviation was shown. Analysis of variance (ANOVA) was done according to the procedures of MSTAT-C software. Comparison amongst data was performed using Duncan’s Multiple Range Test (DMRT) (p < 0.05).

**Results and discussion**

**Respiration rate**

Fig. 1 illustrates the effect of edible coating and MAP on the CO₂ production of lemon stored at 12±1 °C. Initial respiration rate of lemon was 20.51 mg.kg⁻¹.h⁻¹ and it was reduced significantly in all treatment. After 1 th week of storage respiration rate was increased sharply and peaked to 27.73 mg.kg⁻¹.h⁻¹ in uncoated lemons kept open at 3 th week of storage and down steadily to 17.10 mg.kg⁻¹.h⁻¹ at 5 th week. On the other hand, coated lemon (coconut oil or coconut oil-beeswax) packaged in MAP maintained low respiration rate (18.1 mg.kg⁻¹.h⁻¹) up to 6 th week and then peaked to 24 mg.kg⁻¹.h⁻¹ at 7 th week of storage.

An important observation was noticed from the graph that respiration rate of all treatments was increased with the change of lemon peel colour from green to yellow during storage period. Coating in combination with MAP helps to produce delay and low respiration peak which also prove that coating helps to retain green colour. Ladaniya [30] reported that respiration rate of fresh lemons (without any treatment) at 25 °C is in the range from 20 to 28 mg.kg⁻¹.h⁻¹. Noichinda [31] illustrated that respiration and ethylene production was higher when lime (without any treatment) became yellow from green during ambient storage. Burg [32] stated that CO₂ production of lime just after harvest was 3.5% (green stage) and it was decreased up to 4 th day of storage and down to 1.4% (green stage) and then again increased up to 3% at 13 th day of storage (yellow stage). Pranamornkith [33] reported that lime stored at 5 °C showed initial respiration of 8 mg.kg⁻¹.h⁻¹ and peaked to 20 mg.kg⁻¹.h⁻¹ at 42 days and then steadily decreased to about 13 mg.kg⁻¹.h⁻¹ at 70 days. Ladaniya [30] also described that wound- ing, rotting and severe shrivelling of citrus fruits stimulates respiration and ethylene production.

**Firmness**

Texture or firmness is an important quality parameter of fresh fruits for consumer preference. Degradation of insoluble protopectin to the more soluble pectic acid and pectin contribute to a decrease of firmness in many fruits. These changes occur relatively slowly and are less pronounced to citrus fruits as compared to climacteric fruits [34]. However, some softening of fruits also occurs due to the change of turgor pressure and or respiratory loss of dry matters during growth development and senescence. Fig. 2 demonstrates the effect of edible coating and MAP during storage at 12±1 °C on the firmness of lemon. Initially the firmness value of lemon was 6.63 N and it was decreased gradually with time but rate was different across all treatments. amongst the treatment, lemons packaged in MAP retained their firmness effectively throughout the storage period. Uncoated lemon packaged in MAP and coconut oil-beeswax coated lemons kept open had lost 26% and 24% firmness respectively at 4 th week of storage. On the other hand, uncoated lemons kept open had lost 64.25% firmness while coated (only coconut oil or coconut oil-beeswax) lemon packaged in MAP had lost only 7% at 4 th week of storage. Uncoated lemons kept open had lost their firmness sharply up to 4 th week after that it was increased again. It may happen due to excessive water loss made them harder.
Nasrin et al. [12] reported that the firmness value of fresh lemon was 5.43 N and uncoated lemons kept open stored at ambient condition had lost 62.62% firmness at 6th day of storage while lemon packaged in MAP was as firm as initial up to 12th day during storage. So, these results are similar with the findings of current study. The beeswax edible coatings not only prevented the moisture loss but also improved the texture and the general appearance of sweet orange [14] for a long (21 days) period of storage.

**Physiological loss in weight (PLW)**

Fig. 3 elucidates the effect of edible coating and MAP on PLW of lemon during storage at 12±1 °C. PLW of fruits, in general, increased with the advancement in storage period. Maximum PLW around 33% occurred in uncoated lemon kept open whereas it was only 4% in coated (only coconut oil or coconut oil-beeswax) lemon packaged in MAP at 6th week of storage at 12±1 °C. On the other hand, lemon coated with coconut oil-beeswax and kept open had lost 5.96% weight at 4th week of storage period. Fresh lemons kept open lost their weight 27.22% whereas even less than 5% weight was lost by the lemon uncoated or beeswax coated packaged in MAP at 18th day of storage at ambient condition (21±2 °C) [12]. Shahid and Abbassim [14] speculated that the beeswax coatings decreased the respiration rate of the fruits, thus reducing the PLW and increasing the shelf life of sweet orange.

PLW is a consequence of fruit dehydration due to changes in surface transfer resistance to water vapour, in respiration rate, and the occurrence of small fissures connecting the internal and external atmospheres [35]. Coating on fruits and MAP creates a barrier between fruit skin and outer atmosphere which controls movement of O₂, CO₂, moisture, and solute movement, thereby reducing respiration, water loss, and oxidation rates. Sweet orange treated with the solution of (150 ppm GA3+500 ppm bavistin) and wrapping with LDPE resulted in lowest
PLW (3.9%) as against 25.7% in the fruits dipped in plain water (control) during storage at ambient condition (27±2 °C) for 24 days [36].

External fruit colour

Colour is an important factor to determine fruit quality. Fig. 4 (a) and (b) explains the changes in surface colour of lemons influenced by edible coating and MAP during storage at 12±1 °C in terms of hue angle and lightness. Initial hue angle value of lemon was 124.51 and this value proved that lemons were shiny green colours. It is clear from the Fig. 4(a) that hue angle value is decreasing gradually with storage period as lemons turned from green to yellow skin colour with storage period. The reason is there, after this period, ethylene production and respiration rate was increased that stimulated to degree lemons. Fig. 4(a) shows that changes of colour (from green to yellow) was less in coated lemons especially in coconut oil-beeswax coated lemons throughout the storage period. Hue angle value was 93.4 in uncoated lemons packaged in MAP while, it was around 113 in coconut oil-beeswax coated lemons kept open or packaged in MAP and 111.10 in coconut oil coated lemon packaged in MAP at 8th week of storage. So it is evident that coconut oil or mixture of coconut oil with beeswax had a great effect to retain green colour of lemon during storage.

The L* parameter is an indicator of lightening or darkening. Initial lightness value of lemon was 39.87 and it was increasing gradually with storage period as lemons turns from green to yellow skin colour with storage period. Green colour reflects less light than yellow colour. Lightness value was 59.93 in uncoated lemons packaged in MAP while, it was around 51.2 in coconut oil-beeswax coated lemons packaged in MAP at 8th week of storage. Pure coconut oil coating helps to delay ripening of fruits and uniform colour development of Kagzi lime in later period of storage [17]. Obeed and Harhash [37] found the similar results like present findings, initially hue angle value of lime was high (106.57) and it was decreasing with storage period. At 4 weeks of storage, it was 97.45 when lime was treated with hot water containing calcium chloride 2% and stored at 12 °C.

Juice content

Fig. 5 presents juice content of lemon influenced by edible coating and MAP during storage at 12±1 °C. The percentage of juice content was increasing with storage period in all treatments. Juice content of fresh lemon was 30.56%. In lemons coated with only coconut oil or coconut oil-beeswax and packaged in MAP had gained juice gradually up to the last (8) week of storage and reached to 54% at 8th week of storage. On the other hand, in uncoated lemon kept open, juice content was increased to 45.33% at 4th week after that it was downed to 40.63% at 6th week of storage. It may be due to excessive water loss from open lemons.

Similar findings like present study was observed by Nasrin et al. [12] that initial juice content of lemon was 29.58%, in fresh lemon kept open, juice content was increased (48.66%) up to 12th day after that it was declined to 46.3% at 18th day of storage at ambient condition. Obeed and Harhash [37] noticed that juice content in ‘Mexican’ lime was 50% initially, after ten weeks, it was 60%, when lime treated with hot water having calcium chloride (1% or 2%) and stored at 12 °C. Lemons are considered ‘mature’ for export when they contain 28% juice by volume [38], regardless of peel colour. An increase in both juice content and acidity normally occurs during storage in lemons, as well as limes [39], in contrast to other edible citrus cultivars. Besides increasing juice content of lemon or lime is a sign of reaching their physiological maturity.

Shrinkage

Lemons have a relatively high transpiration coefficient and water is lost very quickly from unpacked lemon resulting shrivelling or shrinkage of fruit skin. From the table 1 it is shown that 100% uncoated lemons kept open and 9.67% oil coated lemons kept open were shrivelled or shrunk whereas no significant (p < 0.05) shrinkage was observed in rest of the treatments at 3rd week of storage. So individually coating (especially coconut oil-beeswax) and MAP both has moderate effect to reduce shrivelling but together coating (especially coconut oil-beeswax) with MAP is the best technique to protect water loss or skin shrinkage. No significant (p < 0.05) fruit shrinkage was occurred in coconut oil-beeswax coated lemons packaged in MAP even at the last days 8th week of storage. High-humidity storage was shown to increase lemon storage potential [40], and LDPE or HDPE packaging is able to maintain a high humidity in package to reduce transpiration and skin shrinkage [41].

Yellowing

The major problems limit postharvest life of lemon is weight loss/shrinkage and yellowing of peel colour [5]. From the table 1 it is shown that 43.33% uncoated lemons kept open and 56.67% uncoated lemons packaged in MAP were turned to yellow whereas no significant (p < 0.05) yellowing was occurred in coconut oil-beeswax coated
lemons kept open or packaged in MAP up to 3rd week of storage. Any uncoated lemons kept open and oil coated lemons kept open did not get yellow colour fully even at the last day of storage. The reason may be due to low temperature and open/without packaging condition prevents to turn yellow colour but they were shrivelled/shrunk severely. At 8th week of storage, 100% uncoated lemons packaged in MAP became yellow but only 16.33% and 33.33% lemons became yellow at 5% level of significance when they were coated with coconut oil-beeswax packaged in MAP and only coconut oil coated packaged in MAP respectively. After 9 weeks all lemons coated with only coconut oil packaged in MAP or coconut oil- beeswax packaged in MAP were turned to yellow (data did not show). Coconut oil with beeswax had a great effect to retain green colour in lemon.

Ascorbic acid, TSS, titratable acidity and pH

Ascorbic acid content of fresh lemon was 31.3 mg/100 g as shown in Table 2. Uncoated lemons kept open lost the highest amount of ascorbic acid and retained only 13.7 mg/100 g that is significantly (p < 0.05) less than lemons of all other treatments at 8th week of storage. While lemons coated with coconut oil-beeswax and packaged in MAP was preserved the highest amount (24.2 mg/100 g) of ascorbic acid and there was no significant difference (p < 0.05) with the value of ascorbic acid content of lemons coated with only coconut oil and packaged in MAP at the last week (8 week) of storage. Initially TSS content in lemon was 6.1° Brix and increased gradually during the storage period. The maximum (7.9° Brix) TSS was observed in uncoated lemon kept open but there were no
Table 1
Shrinkage and yellowing percentage of lemon influenced by edible coating and MAP stored at 12±1 °C for 8 weeks.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Shrinkage (%)</th>
<th>Yellowng (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 week</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Nocoat-open</td>
<td>0</td>
<td>100a</td>
</tr>
<tr>
<td></td>
<td>(86.82)</td>
<td>(86.82)</td>
</tr>
<tr>
<td>Oil-open</td>
<td>0</td>
<td>9.67b</td>
</tr>
<tr>
<td></td>
<td>(17.48)</td>
<td>(86.82)</td>
</tr>
<tr>
<td>Oil &amp; Wax-open</td>
<td>0</td>
<td>0c</td>
</tr>
<tr>
<td></td>
<td>(3.91)</td>
<td>(27.86)</td>
</tr>
<tr>
<td>Nocoat-MAP</td>
<td>0</td>
<td>0c</td>
</tr>
<tr>
<td></td>
<td>(3.91)</td>
<td>(22.99)</td>
</tr>
<tr>
<td>Oil-MAP</td>
<td>0</td>
<td>0c</td>
</tr>
<tr>
<td></td>
<td>(3.91)</td>
<td>(3.91)</td>
</tr>
<tr>
<td>Oil &amp; Wax-MAP</td>
<td>0</td>
<td>0c</td>
</tr>
<tr>
<td></td>
<td>(3.91)</td>
<td>(3.91)</td>
</tr>
</tbody>
</table>

Nocoat-open=Uncoated & kept open, Oil-open=Coconut oil coated & kept open, Oil & Wax-open=Coconut oil and beeswax (90:10) coated & kept open, Nocoat-MAP=Uncoated & packaged in MAP, Oil-MAP=Coconut oil coated & packaged in MAP, Oil & Wax-MAP=Coconut oil and beeswax (90:10) coated & packaged in MAP. For each sample, means with different letters within each column are significantly different (p < 0.05).

Table 2
Ascorbic acid and TSS content of lemon influenced by edible coating and MAP stored at 12±1 °C for 8 weeks.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ascorbic acid (mg/100 g)</th>
<th>TSS ('Brix)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 week</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Nocoat-open</td>
<td>31.3a</td>
<td>19.8d</td>
</tr>
<tr>
<td>Oil-open</td>
<td>31.3a</td>
<td>22.8c</td>
</tr>
<tr>
<td>Oil &amp; Wax-open</td>
<td>31.3a</td>
<td>25.9b</td>
</tr>
<tr>
<td>Nocoat-MAP</td>
<td>31.3a</td>
<td>23.3c</td>
</tr>
<tr>
<td>Oil-MAP</td>
<td>31.3a</td>
<td>28.3a</td>
</tr>
<tr>
<td>Oil &amp; Wax-MAP</td>
<td>31.3a</td>
<td>29.6a</td>
</tr>
</tbody>
</table>

Nocoat-open=Uncoated & kept open, Oil-open=Coconut oil coated & kept open, Oil & Wax-open=Coconut oil and beeswax (90:10) coated & kept open, Nocoat-MAP=Uncoated & packaged in MAP, Oil-MAP=Coconut oil coated & packaged in MAP, Oil & Wax-MAP=Coconut oil and beeswax (90:10) coated & packaged in MAP. For each sample, means with different letters within each column are significantly different (p < 0.05).

significant differences (p < 0.05) amongst the treatments at 8 week of storage.

Table 3 represents the changes of titratable acidity and pH content of lemon throughout the storage period. Initially, titratable acidity of fresh lemon was 7.21% and it was reduced slowly throughout the storage in all treatments. The highest (6.97%) amount of titratable acidity was measured in lemon coated with coconut oil-beeswax and packaged in MAP and the lowest (6.65%) amount was found in uncoated lemons kept open but there were no significant differences (p < 0.05) amongst the treatments at 8 week of storage. pH content of fresh lemon was 2.67. Opposite to titratable acidity, pH was increased slowly throughout storage period. The maximum (2.98) and the minimum (2.85) pH
Fig. 6. Visual appearance of coated and uncoated lemons kept in MAP and open in crates during storage at 12±1 °C for 8 weeks.

Table 3
Titratable acidity and pH content of lemon influenced by edible coating and MAP stored at 12±1 °C for 8 weeks.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Titratable acidity (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 week</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Nocoat-open</td>
<td>7.21a</td>
<td>6.96a</td>
</tr>
<tr>
<td>Oil-open</td>
<td>7.21a</td>
<td>7.08a</td>
</tr>
<tr>
<td>Oil &amp; Wax-open</td>
<td>7.21a</td>
<td>7.05a</td>
</tr>
<tr>
<td>Nocoat-MAP</td>
<td>7.21a</td>
<td>7.03a</td>
</tr>
<tr>
<td>Oil-MAP</td>
<td>7.21a</td>
<td>7.12a</td>
</tr>
<tr>
<td>Oil &amp; Wax-MAP</td>
<td>7.21a</td>
<td>7.15a</td>
</tr>
</tbody>
</table>

Nocoat-open=Uncoated & kept open, Oil-open=Coconut oil coated & kept open, Oil & Wax-open=Coconut oil and beeswax (90:10) coated & kept open, Nocoat-MAP=Uncoated & packaged in MAP, Oil-MAP=Coconut oil coated & packaged in MAP, Oil & Wax-MAP=Coconut oil and beeswax (90:10) coated & packaged in MAP. For each sample, means with different letters within each column are significantly different (p < 0.05).
were found in uncoated lemon kept open and in coconut oil-beeswax coated lemon packaged in MAP respectively and there were no significant differences (p < 0.05) amongst the treatments. In fresh seedless lemon, ascorbic acid, pH, acidity and TSS were 29.4 mg/100 g, 2.5, 6.68 (%) and 5.8 (° Brix) respectively [12]. Porras et al. [42] reported that ascorbic acid content in fresh Verna lemon was 47.2 mg/100 g. After harvest “libson” lemon retained pH 2.55, acidity 7.33 (%) and TSS 6.4 (° Brix) and during storage acidity value was decreased slightly [43].

Sensory quality

Sensory evaluation was done on colour, flavour, texture and overall acceptability of lemon at 3rd, 6th and 8th week of storage as shown in table 4. In case of overall acceptability, only coated oil kept coated open and coconut oil-beeswax coated packaged in MAP secured the highest score (8.8) that was statistically similar (p < 0.05) with the scores of lemons coated with only coconut oil coated and coconut oil-beeswax coated kept open at 3rd week of storage period. At 8th week of storage, maximum score (5.8) was obtained by the coconut oil-beeswax coated lemons packaged in MAP and that score was statistically similar (p < 0.05) with the score of lemons coated with only coconut oil packaged in MAP while uncoated lemon kept open secured the lowest score that is 1.9 only. Both type of coated lemons especially, coconut oil-beeswax coated ones packaged in MAP were greener and shiny in the storage period shown in Fig. 6.

Conclusion

Coconut oil-beeswax or only coconut oil coating and packaged in MAP during storage at 12±1 °C proved to be an effective technique for postharvest storage of lemon by retaining shiny green colour with fresh like appearance, controlling PWL, shrivelling and respiration. This combine technique also helped to preserve firmness, juice content and ascorbic acid content. On the other hand, only edible coating specially the mixture of coconut oil-beeswax had a pronounced effect to retain shiny green colour and to control respiration throughout the storage period. Uncoated lemon kept open was acceptable up to a week whereas coconut oil-beeswax coated lemons packaged in MAP were good even at 8 weeks with shiny green colour and fresh like appearance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This work was supported by the grants from Bangladesh Agricultural Research Institute, Ministry of Agriculture, Government of Bangladesh.

References


