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The Effect of Different Waxing Technologies on Shelf Life of 'Apple' Mango Fruits Stored Under Different Storage Conditions

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Abstract
Beneficial effect of Shellac and Mango wax of different formulations was studied on shelf life of apple mango fruits which were harvested at mature green stage and stored in various storage conditions including ambient (25°C) and simulated commercial cold storage (12°C). Mango wax (one mixed with a fungicide and another without) was obtained from United Phosphorous Limited, while Shellac wax was purchased from a commercial trader in flakes form and dissolved in 0.1N Sodium hydroxide to make two concentrations (3% and 5%). The two waxes were applied by dipping the fruits in a bowl of wax and placing them on wire mesh for air drying using fans. Upon drying the fruits were packed in open cotton boxes and stored in ambient (25°C) and cold storage (12°C). Three fruits from each treatment and different storage conditions were sampled after every 3 and 7 days (ambient and cold storage respectively) for measurement of attributes associated with ripening including weight loss, respiration rate, peel firmness and pulp hue angle. Results indicated that waxing whether with Shellac or Mango wax was effective in extending shelf life of mango fruits for 4 and 6 more days in ambient and cold storage respectively. At the end of observation period, un waxed fruits in ambient and cold storage had lost 12.4% (day10) and 5.5% (day 22) compared to an average of 7.6% (day14) and 3.7% (day 28) for the waxed fruits respectively. Waxed fruits exhibited low respiration peak of 49.39 and 30.38 ml/kg/hr compared to un waxed fruits that had a high peak of 85.09 and 43.15 ml/kg/hr for ambient and cold storage respectively signifying high respiratory activity in the un waxed fruits. Other ripening related parameters had a positive correlation to respiration and water loss. This study shows that coating of mango fruit with wax is effective in delaying ripening thereby extending its postharvest life.
Keywords: Mango wax, Shellac wax, Shelf life, Mango, Postharvest technologies, Storage

1. Introduction

Mango (*Mangifera indica* L.) is regarded as the king of all fruits, but with a short shelf life depending on harvest maturity and storage conditions (Slaughter, 2009). The perishability leads to high postharvest losses that limits its commercial potential. The major contributors of losses in mango include water loss, respiration and postharvest diseases (Zheng *et al*., 2012). Loss of water from perishable commodities such as mango is the major cause of deterioration as it results in both qualitative and quantitative losses. Qualitative losses include the loss of firmness due to softening, loss in gloss due to shriveling and loss in nutritional value such as loss of vitamins. Quantitative losses include loss of salable weight due to transpiration losses and discount selling due poor looking fruits. Various postharvest technologies have been employed to manage the factors that predispose mango fruit to deterioration including low temperature storage (Nair and Singh, 2003), edible coatings (Dhall, 2013), Controlled Atmosphere Storage (CAS) (Meyer *et al*., 2011), Modified Atmospheric Packaging (MAP) (Githiga *et al*., 2012), Evaporative coolers (Dvizama *et al*., 2000), among others. However, most of these are coupled with challenges such as gas injury (Thompson, 2001)), chilling injury (Nair et al., 2004), environmental pollution (MAP bags), among others and are also limited to resource constrained small holder farmers in developing countries. This has led to exploration of alternative technologies that are easy to access, use and affordable. Use of surface coating can be a simple and versatile postharvest technology to prolonging shelf life of perishables such as mangos. Edible coatings have been found to be effective as other materials such as fungicides can be added in the polymer matrix (Dhall, 2013).

The efficacy of waxing to extend shelf life is based on the modification of the internal atmospheric condition of the fruit in storage. The coating is applied by either spraying or dipping the fruits into the solution. The coating is then allowed to dry on the surface forming a thin layer which creates a modified environment around the fruit (Hoa *et al*., 2001). The modified atmosphere is achieved by limiting water vapor loss to the environment by blocking the lenticels, leading to a water saturated internal environment and by regulating gaseous exchange in and out of the fruit (Hagenmaier and Baker, 1993). The low O_2 condition created with waxing affects physiological processes such as respiration. Furthermore, the modified condition created (elevated CO_2 and reduced O_2) also interferes with several enzymatic processes such as the ethylene biosynthesis pathway by limiting the activities of 1-Aminocyclopropane-1-Carboxylic acid (ACC) oxidase (Hoffman *et al*., 1994) the enzyme that catalyses the conversion of ACC to ethylene, reduced activity of enzymes involved in the cell wall degradation such as pectin methylestearse (PME), polygalacturonase (PG), endo-B-1,4-glucanase

(EGase) and pectatelyase activities (Cheng *et al*., 2009) and reduced activity of the chlorophyllase enzyme which is responsible for the degradation of chlorophyll (Persis *et al*., 2002). Many studies have shown beneficial effect of waxing fruits such as citrus and apples coated with carnauba and shellac, tomatoes with mineral oil, mangos with cellulose, apricots with sucrose fatty acid esters (Baldwin, 1994; Baldwin *et al*., 1999) among others.

To realize the beneficial effect of coating, it is critical to match the commodity characteristics with those of the coating. Furthermore, the efficacy of the coating can be realized by addition of antimicrobial compounds that preserves freshness and prevent spoilage, increasing shelf life (Omry, 2011). Mango wax and Shellac wax were identified for this study because Mango wax is a newly introduced product in Kenya and its effectiveness can only be validated through research. Shellac wax on the other hand has been shown to be effective on apples and citrus, but less studies have been done on other fruits such as mango (Baldwin, 1994), and its efficacy on shelf life extension of Kenyan mangos can only be realized through research.

Therefore, the objective of this study was to evaluate the effect of wax with different formulation on shelf life of apple mango under ambient storage conditions and simulated commercial cold storage.

2. Materials and Methods

2.1 Materials

Fruits for the study were obtained from a commercial farm in Machakos County, Eastern Kenya. A survey was conducted to identify trees that were between age 6 to 10 years from which mature green fruits were carefully handpicked, packed in plastic crates containing wetted paper which acted as a cushion against mechanical injury and to lower respiration.

Shellac wax (insect wax of the resin group, obtained from secretion of the insect Laccifer lacca) was obtained from a commercial trader in flakes form and dissolved in 0.1N Sodium Hydroxide to make two concentrations (3% and 5%). Mango wax, Mango wax+Prochloraz (fungicide), Decco clear (food brush sanitizer) and Decco spark (Calcium Chloride) were obtained from United Phosphorus Limited (UPL).

2.2 Method

Upon delivery to the postharvest laboratory, the fruits were sorted for uniformity and washed with water containing 0.018% Calcium Chloride to disinfect. The fruits were then gently brushed with a fine brush dipped in Decco clear solution (50% diluted in water), dipped in hot water (45-55ºC) for 10 seconds, removed and placed on wire mesh to air dry.

The fruits were then randomly batched into five groups for the different treatments. These included Untreated (control), two levels of Shellac wax (3 and 5%), Mango wax and Mango wax+Prochloraz. Waxing was applied by bowl dipping the fruits and placing them on wire mesh to air dry. Upon drying, the fruits were packed in open cotton boxes and stored in ambient (25ºC) and cold storage (12ºC) conditions for normal ripening.

Three fruits from each treatment and storage conditions were randomly sampled for evaluation of changes associated with ripening which included weight loss, loss in firmness, change in hue angle and respiration rates. Completely Randomized Design (CRD) with a factorial arrangement was used as the study design. The factors were storage conditions, treatment and sampling time.

2.3 Assessment of postharvest shelf life

2.3.1 Cumulative weight loss

Mass loss was taken and recorded using a digital balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). The initial weight (W1) of each fruit (marked) at day 0 and the new weight of the same (W2) was taken for the subsequent days. The formula;

Cumulative weight loss (%) = (W1 -W2)/W1 X100

2.3.2 Respiration rate

Mass loss for five individual fruits from each treatment and storage condition was taken and recorded using a digital balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). These fruits were then separately incubated for 2 hours in air tight jars fitted with a CO_2 gas sensor (Model **CM-0187 Cozir AMB, UK**). Gas sample from the headspace was read by the CO_2 sensor and a graph drawn from which the slope was used to calculate the amount of CO_2 in ml per Kg Hour. The following formula was used to calculate CO_2 produced:

Respiration=G*Volume of vessel/Time*M

Where G- slope of the curve

M-mass of fruits in kilograms

2.3.3 Peel firmness

Fruits randomly selected were sampled and an average of three measurements of firmness along the equator recorded. A penetrometer (CR_100D, Sun Scientific Co. Ltd, Japan) having a 5 mm probe was used to puncture the fruits and the force used recorded to determine the firmness. Firmness was expressed as Newton (N) (Jiang *et* *al*., 2001).

2.3.4 Pulp color

The color change of the fruits was measured at 2 different spots along the equator using Minolta color meter (Model CR-200, Osaka, Japan) which had been calibrated on a white and black standard tile. To access the pulp, the fruit were cut open longitudinally. The L*, a* and b* values were recorded and used to calculate the hue angle (H) according to Mclellan *et al* (1995). Where

Hue angle (H) = $Hue\ angle\ (H0) = \arctan\left(\frac{b}{a}\right) for + and + b\ values$

$$= \arctan\left(\frac{b}{a}\right) + 180\ for - a\ and + b\ values$$

$$= \arctan\left(\frac{b}{a}\right) + 180\ for - a\ and - b\ values$$

3. Results

3.1Weight loss

All fruits gradually lost weight during storage but the cumulative weight loss for the untreated was significantly ($p<0.05$) high compared to the waxed fruits. Fruits in cold storage had significantly ($p<0.05\%$) lower weight loss each sampling day compared to the ambient stored. Further, a combination of cold storage and waxing reduced the weight loss by almost half when compared with waxed-ambient stored fruits. In ambient storage conditions, the untreated fruits lost 12.4% of the initial weight (day 10) as compared to an average of 9% for the treated fruits 4 days later. No significant difference was observed between the different waxing options in ambient storage conditions. For the cold stored fruits, untreated control lost 5.5% of its initial weight by end of storage period (day 22) compared to an average of 3.9% for the treated fruits 6 days later.

3.2 Changes in respiration

The rate of Carbon dioxide production is an indicator of the metabolic activity which gives a signal on the possible shelf life of a given produce. As ripening progressed, CO_2 concentration increased in all fruits during the storage period. Cold stored fruits had a significantly ($p<0.05\%$) lower respiration rate compared to ambient stored on each sampling time. A combination of cold storage and waxing further reduced the rate of respiration. Waxing had a significant effect ($p<0.05$) on the rate of respiration with waxed fruits exhibiting significantly low respiration rates compared to the untreated control fruits throughout the storage period. Under ambient storage conditions, untreated control fruit's CO_2 concentration increased drastically to a peak of 85.09 ml/kg/hr that occurred on day 7 and then declined to 73.69 ml/kg/hr by end of storage (day10) whereas the significantly smaller respiratory peak (49.39 ml/kg/hr) for the treated fruits occurred at day 3 after which it remained fairly constant throughout the storage period. Although there was no significant difference between the different waxing options, the rate of respiration was suppressed more by Shellac wax in ambient storage.

The respiratory trend for the fruits stored in cold storage was not different from those in ambient storage conditions. Uncoated fruit's respiration peak (43.15 ml/kg/hr) occurred on day 15 and declined to 34.16 ml/kg/hr by end of storage period (day 22) compared to a small average peak of 30.38 ml/kg/hr for the treated fruits which remained fairly constant throughout the storage period.

3.3 Changes in peel firmness

Changes in firmness of fruits during storage, is an indication of ripening. Peel firmness for all fruits decreased gradually with ripening. Cold storage reduced the rate of firmness loss compared to ambient storage, and the effect was more with wax treatment. Waxed fruits retained higher peel firmness compared to untreated fruits throughout the storage period, but there was no significant ($p<0.05$) difference between the waxing options (Figure 3 A and B). Under ambient storage conditions, the untreated mango's firmness decreased from an initial115.78N to 14.46N by end of storage period (day 10) as compared to the treated fruits whose firmness decreased gradually to an average of 20.70N by day 14. Under cold storage, untreated fruit's peel firmness decreased to 18.77N (day 22) compared to an average of 29.05N for the waxed fruits by day 28.

3.4 Pulp Hue angle

Ripening inhibition in fruits can be determined by color development. In this study, there was a general decrease in pulp Hue angle of the fruits as ripening progressed in all storage conditions. However, the cold stored fruits had a reduced rate of color development compared to ambient stored fruits. Waxing delayed development of yellow/orange color of the pulp compared to the untreated in both storage conditions. The pulp hue angle of untreated fruits stored in ambient conditions, decreased from an initial 91.47° to 69.17° by day 10 compared to an average of 67.9° for the treated fruits 4 days later. For the fruits stored in cold storage, changes in pulp hue angle was gradual. The untreated fruits pulp hue angle decreased to 70.49° (day 22) compared to the treated fruit's hue angle that decreased to an average of 70.85° 6 days later.

4. Discussion

Fruits lose weight due to transpiration process, which depends on the gradient of water vapor pressure between the surrounding atmosphere and the fruit tissues. The slowed rate of weight loss of the waxed fruits could be attributed to the reduced rate of water vapor loss into the atmosphere due to reduced number and or size of lenticels by the coating (Hagenmaier and Baker, 1997). Also, the reduced weight loss could be as a result of reduced respiration rate that lowered loss of metabolic water (Rathore *et al*., 2007). The loss of water/ weight not only leads to loss of saleable weight but also leads to shriveling and wilting of the produce which makes it unappealing to the consumer. In the current study, although all fruits gradually lost weight over time, the loss was more drastic in the untreated control fruits. The effect of coating on weight loss has also been reported in other fruits such as tomato (Ali *et al*., 2010), banana (Maqbool *et al*., 2011) and mango (de S. Medeiros *et al*., 2012).

Reduced respiration rate is an indicator of low metabolic response due to low O_2. Waxing reduces the number and the size of the lenticels and stomates thus regulating gaseous diffusion in and out of the fruits (Hagenmaier and Baker, 1997). Reduction in respiration in turn slows down the ripening metabolic processes within the fruit. Results in the current study concurs with previous studies, where edible films reduced respiration rate in mango fruit (Kittur *et al*., 2001; Moalemiyan *et al*., 2012). In climacteric fruits like mango, quick deterioration occurs when respiration increases up to a peak and then a decline. The low CO_2 levels observed in waxed fruits could be attributed to the reduced gas permeability across the fruit surface. However, gas diffusion should not be completely restricted as this would lead to undesirable effects such as off-flavors (Bender *et al*., 2000b).

High peel firmness for the treated fruits could be attributed to reduced activity of enzymes involved in the cell wall degradation such as pectin methylestearse (PME), polygalacturonase (PG), endo-B-1,4-glucanase (EGase) and pectatelyase activities (Cheng *et al*., 2009). Similar results have been reported where mango and banana coated with chitosan remained firmer for a longer period of time (Moalemiyan *et al*., 2012; Maqbool *et al*., 2011). Ripening of mangos is associated with chlorophyll reduction and synthesis of other pigments such as carotenoids (Medlicott *et al*., 1986). The delayed chlorophyll breakdown in wax treated fruits could be attributed to the reduced activity of the chlorophyllase enzyme which is responsible for the degradation of chlorophyll. Similar findings have been reported in avocado (Hershkovitz *et al*., 2005) and mango (Persis *et al*., 2002).

5. Conclusion

Results of this study indicate that application of Shellac and mango wax delayed fruit ripening and reduced the physiological changes during storage (ambient and cold storage). The two types of waxes reduced weight loss, respiration rate and firmness. Shellac wax was effective in reducing respiration rate while mango wax was more effective in reducing weight loss. This study suggests that wax application could be an effective way of extending shelf life of perishables like mango fruits. Waxing has a potential of doubling shelf life of produce and thus can be used in reducing postharvest deterioration, extending shelf life and maintain postharvest quality of mango fruit in ambient and cold storage.

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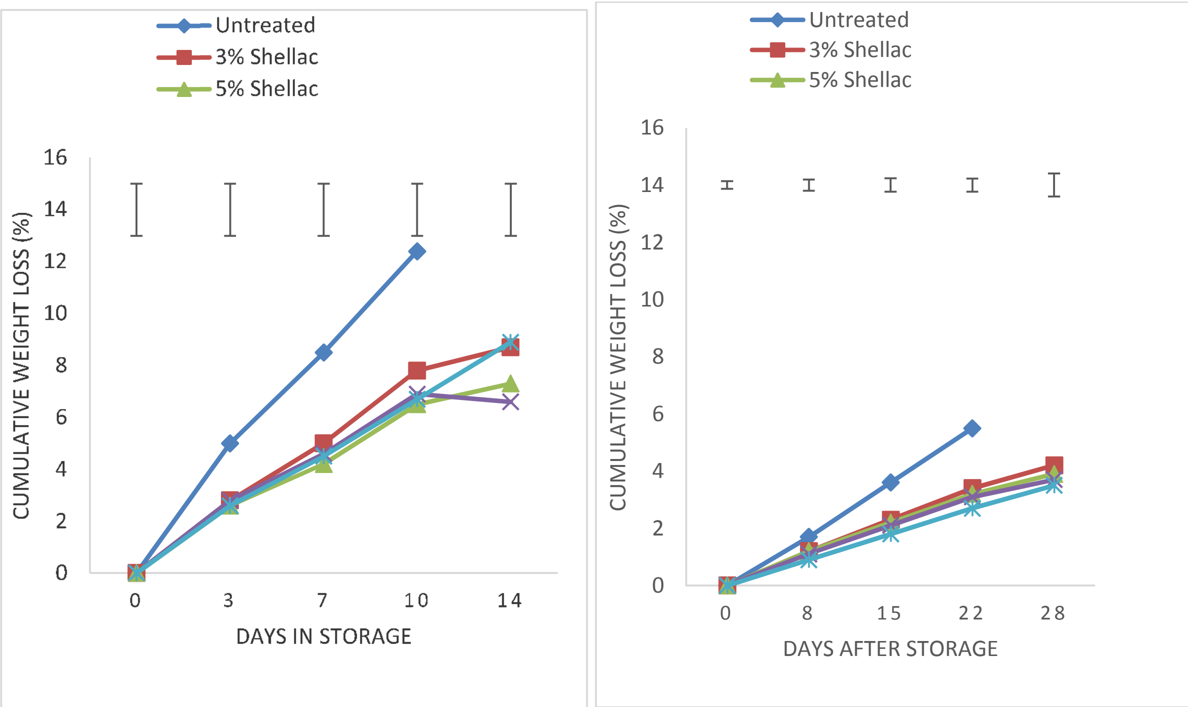

Figure 1: Effect of Shellac wax (3% and 5%), Mango wax and Mango wax+prochloraz on % cumulative weight Loss in mango fruits stored in ambient (A) and cold storage(B) conditions.

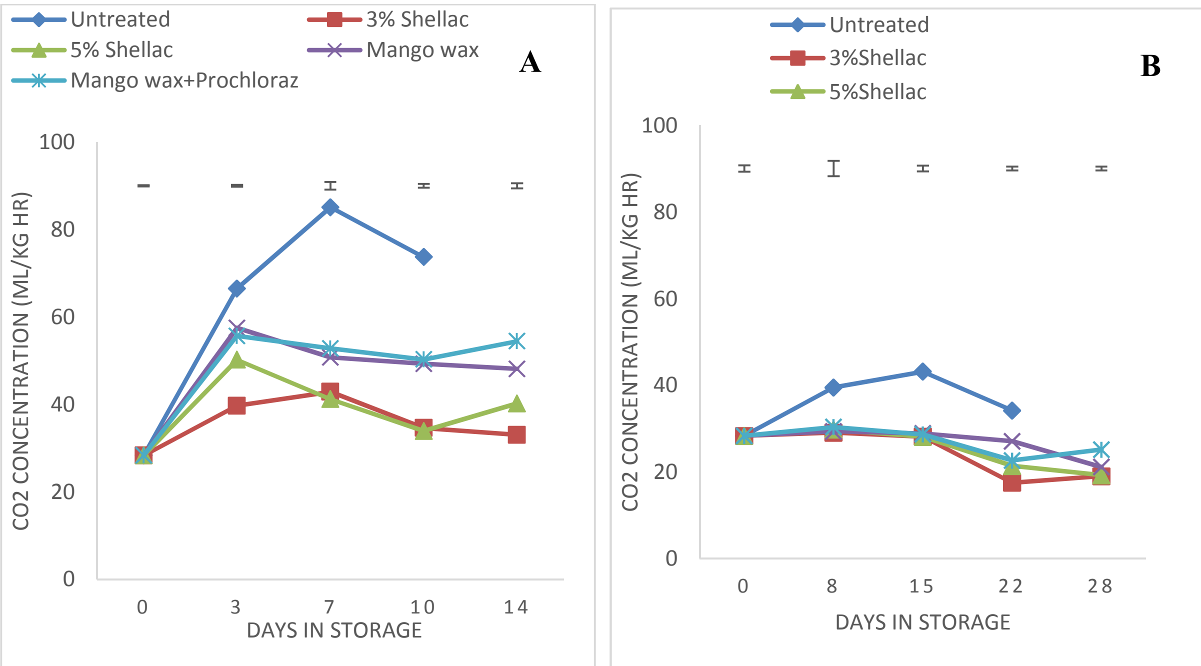

Figure 2: Effect of Shellac wax (3% and 5%), Mango wax and Mango wax+prochloraz on apple mango CO_2 production rates (mL/kg Hr) in ambient (A) and cold storage(B) conditions.

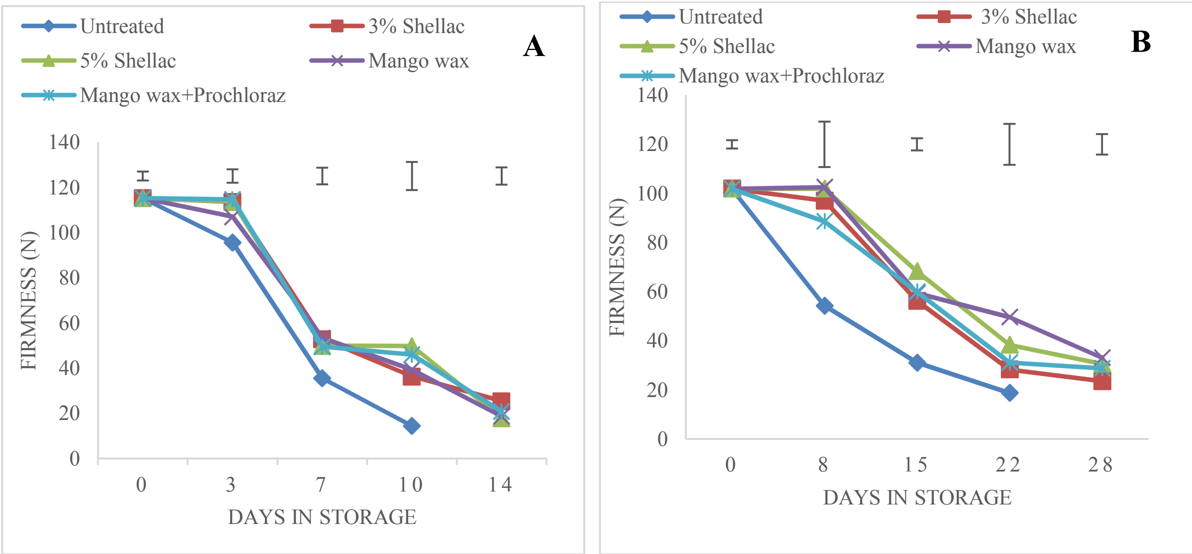

Figure 3: Effect of Shellac wax (3% and 5%), Mango wax and Mango wax+prochloraz on apple mango peel firmness (N) in ambient (A) and cold storage(B) conditions

Table1: Effect of Shellac wax (3% and 5%), Mango wax and Mango wax+prochloraz on apple mango pulp Hue angle (H°) in ambient storage condition

		Days in Storage			
TREATMENT	0	3	7	10	14
Untreated	91.47a	90.4a	70.22a	69.17a	
3 Shellac Wax	91.47a	91.4a	84.83b	71.05a	65.75a
5% Shellac Wax	91.47a	90.7a	74.71c	77.64b	69.59a
Mango Wax	91.47a	90.6a	73.87c	74.59a	68.12a
Mango Wax+Prochloraz	91.47a	90.7a	75.62c	73.24a	68.14a
MEAN	91.47	90.76	75.85	73.14	67.9
LSDs	2.196	3.543	2.844	4.92	3.494

Means within each column followed by different letter differ significantly at ($p<0.05$).

Table 2: Effect of Shellac wax (3% and 5%), Mango wax and Mango wax+prochloraz on apple mango pulp Hue angle (H°) in cold storage condition

		DAYS IN STORAGE			
TREATMENT	0	8	15	22	28
Untreated	91.47a	77.41a	71.86a	70.49a	
3% Shellac Wax	91.47a	89.57b	80.9b	75.13b	70.59a
5% Shellac Wax	91.47a	84.31b	85.11b	76.54b	70.25a
Mango Wax	91.47a	85.54b	76.68a	71.46a	70.85a
Mango Wax+Prochloraz	91.47a	81.15a	86.58b	72.81b	71.7a
MEAN	90.69	83.6	80.23	73.29	70.28
LSDs	1.093	4.264	4.626	1.878	3.329

Means within each column followed by different letter differ significantly at ($p<0.05$).