

COMPARISON OF DIFFERENT FRUIT COATINGS TO ENHANCE THE SHELF LIFE OF KINNOW MANDARIN

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'Kinnow' mandarin is an important citrus cultivar, which ranks first among all the fruit crops in Pakistan. Being a non-climacteric fruit, it has low shelflife even in cold storage, may lose its quality because of some physiochemical changes. Wax coating has been proved as an important strategy to maintain the fruit quality under storage. The present study was planned to compare the different types of waxes which include commercial waxes used by the traders and lab. prepared coatings (PHRC wax and benzaldehyde coating) by the scientists of AARI and UAF, respectively. The results revealed that sharine and paraffin wax exhibited minimum fruit rot (2%) with lower weight loss (11.87%) after 90 days of storage and PHRC wax performed statistically at par to commercial waxes regarding weight loss (12%) and fruit rot (3%). The minimum changes in juice weight, TSS/TA ratio, peel/pulp ratio, ascorbic acid and sugar contents were recorded in coated fruits except benzaldehyde coating. Wax coatings also maintained higher levels of total phenolics (240.7 mg GAE 100g⁻¹), antioxidant (63.4%) and enzyme activities of catalase (17.6), peroxidase (0.71), and superoxide dismutase (137.6 U mg⁻¹ protein) during storage. It is concluded that PHRC wax can be recommended for long term storage of citrus fruits as it performed almost at par to commercial waxes and maintained the fruit quality as well as bioactive juice components.

Keywords: Antioxidants, enzymatic activity, Kinnow, phenolics, wax coatings.

INTRODUCTION

Kinnow mandarin (*Citrus nobilis* Lour. × *Citrus deliciosa* Tenora.) was released in the USA in 1935, exported to Pakistan during 1943-44 and planted at Punjab Agriculture and Research Institute Lyallpur, (now University of Agriculture, Faisalabad) climate of Pakistan has been proven best for its excellent production, with better fruit quality (Khalid *et al.*, 2013).

In 2014-2015, Pakistan exported more than 350 thousand tonnes of Kinnow fruit with a value of some US\$ 284 million (Anonymous, 2014; TDAP, 2015). Due to improper postharvest facilities, postharvest losses of citrus fruits are in the range of 23-38% and sometimes may reach up to 40% (FAO, 2006). Similarly, high losses can occur on 'Kinnow' in Pakistan and in some production areas they may reach upto 45% of total production (Ahmed *et al.*, 2015).

The application of wax emulsion is employed to control the weight loss from fruit (especially citrus) and to maintain its appearance and natural gloss (Alam and Paul, 2001). Waxing of citrus is also used to replace natural waxes on the fruit surface that are removed during washing after harvesting. Natural waxes are preferred such as sugar cane wax, carnauba wax, shellac and various resins. The most commonly used waxes in Pakistan are shellac and polyethylene based wax coating emulsions (Bajwa and Anjum, 2007). Wax coatings with lower molecular weight also exhibit antifungal activities

in comparison of commercial fungicide (TBZ) to control the blue and green mould incidence in Murcott tangor (Chein *et al.*, 2007). Initial formation of citrus wax was based on paraffin wax and combination of different waxes like, bees wax or carnauba wax can also be used (Baldwin *et al.*, 1999).

Paraffin wax is categorized under lipid based waxes which are used as protective layer obtained derived from the fraction of crude petroleum and consists of a mixture of solid hydrocarbon resulting from ethylene catalytic polymerization (Bourtoom, 2008). Sharine wax is carnauba wax which is derived from the leaves of carnauba palm mostly contains aliphatic esters, diesters and fatty acid alcohols and they have been successfully used to maintain the postharvest quality of citrus fruits (Ahmad *et al.*, 1979; Hoa *et al.*, 2002; Shahid and Abbasi, 2011). Volatile compounds like benzaldehyde not only comprise aroma component of flavor but they also play an important role in plant pathogen interaction. They are naturally produced in fruits and exhibit antifungal activities (Wilson *et al.*, 1987; Caccioni *et al.*, 1995) by suppressing the growth of fungi and inhibiting spore germination (Barkai-Golan, 2001).

Commercial waxes used in food industry are usually expensive so, there is need to introduce inexpensive and effective wax sources even at the farmer level for local markets. For this purpose Sharine and paraffin wax were studied (as both are being used at commercial level) in comparison of PHRC wax and benzaldehyde fruit coatings

because they were prepared locally and previously no research work is reported regarding their effects on fruit quality of Kinnow mandarin.

MATERIALS AND METHODS

Experimental Material: The fruit of Kinnow mandarin (*Citrus nobilis* Lour. × *Citrus deliciosa* Tenora.) was harvested from Sq. 9, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan. After harvesting, washing and drying, the fruits were transported to the lab of Post-Harvest Research Centre, AARI, Faisalabad. The fruits were dipped in wax solutions for 5 minutes and wax layer was coated thoroughly on all sides of fruit. The treatments used were control, Sharine (3%), Paraffin (3%), PHRC wax (3%) and Benzaldehyde (2%).

After wax coatings, the fruits were dried with air drier. The fruits were then placed in cold chambers at 5°C for 90 days. Each treatment had 4 replications and experimental unit contained 10 fruits. All the physical, physiological and biochemical parameters described in Exp. 1 were analyzed after every 15 days up to 3 months of storage.

Physical and physiological characteristics: Fruit Rot data were recorded during entire storage period using following formula.

$$\text{Fruit Rot \%} = \frac{\text{Spoiled fruits} \times 100}{\text{Total fruits}}$$

Fruits samples were weighed before storage and after every 10 days interval till the end of storage. The difference between initial and final fruit weight was considered as total weight loss during that storage interval. The calculations were made in terms of percentage on fresh weight basis. The physical fruit parameters were calculated by using following formula.

$$\text{Weight loss \%} = \frac{\text{Initial fruit weight} - \text{final fruit weight}}{\text{Initial fruit weight}} \times 100$$

$$\text{Peel weight \%} = \frac{\text{Average peel weight} \times 100}{\text{Average fruit weight}}$$

$$\text{Juice weight \%} = \frac{\text{Average juice weight} \times 100}{\text{Average fruit weight}}$$

Physiochemical characteristics of juice:

(a) **Total soluble solids (*Brix):** A digital refractometer was used to measure total soluble solids concentration (TSS) of fruit juice and expressed as °Brix at room temperature.

(b) **Titrateable acidity (TA):** The TA of fruit juice was determined by method given by Hortwitz (1960). 10 ml of juice was taken in 100 ml conical flask, diluted up to 50 ml with distilled water and titrated against 0.1 N NaOH, using 2-3 drops of phenolphthalein as an indicator till pink colour end point was achieved. To determine TA calculations were made according to the formula:

$$\text{TA \%} = \frac{0.1 \text{ N NaOH} \times 0.0064 \times 100}{\text{ml juice used}}$$

SSC: TA ratio was calculated in each sample by dividing the percentages of SSC with the corresponding percentages of the TA.

(c) **Ascorbic acid:** Ascorbic acid contents of juice were determined following the described by AOAC (1990). Ten ml of juice was taken in a 100 ml volumetric flask and volume was made by adding 0.4% oxalic acid solution. Out of this, 5 ml filtrated aliquot was taken, and titrated against 2, 6-dichlorophenolindophenol dye, to light pink color end point (persisted for at least 15 seconds). Ascorbic acid was calculated by using formula given below

$$\text{Ascorbic acid (mg100 ml}^{-1}\text{)} = \frac{1 \times R_1 \times V \times 100}{R \times W \times V_1}$$

(d) **Sugar contents:** Sugars in juices were estimated as described by Hortwitz (1960). 10 ml juice was taken in 250 ml volumetric flask in which 100 ml distilled water, 25 ml lead acetate solution (25%) and 10 ml potassium oxalate (20%) solution was added. Then the volume was made with distilled water and was filtered. The filtrate was used for the estimation of the different forms of sugars and the values were calculated using formula.

$$\text{Total sugars (\%)} = 25 \times (X/Z)$$

$$\text{Reducing sugars \%} = 6.25 \times (X/Y)$$

$$\text{Non-reducing sugars (\%)} = 0.95 \times (\text{total sugars\%} - \text{reducing sugars \%})$$

(e) **Total phenolics and total antioxidants:** Total Phenolics (mg GAE 100g⁻¹) the results were recorded using spectrophotometer at wavelength of 765 nm and 517 nm respectively (Ainsworth and Gillespie, 2007).

(f) **Enzymes assay:** Frozen juice was used to estimate the enzymatic activities of POD, CAT and SOD after homogenization using phosphate buffer. The enzyme extracts were prepared and readings were recorded at spectrophotometer at specific wavelengths. The enzyme activity was expressed in Unit mg protein⁻¹ (Liu *et al.*, 2011).

Statistical analysis: The experiment was carried out under Completely Randomized Design (CRD) along with factorial arrangements. The data recorded were analyzed using Analysis of Variance technique with the help of computer run statistical program 8.1 and least significant difference (LSD) was used to compare the treatment means (Steel *et al.*, 1997).

RESULTS

Physical and physiological characteristics:

Fruit rot (%): Fruit rot (%) was recorded on daily basis observations and maximum fruit rot (20%) was observed in control fruits after 90 days followed by the fruits of benzaldehyde coating (12), PHRC wax (3), Sharine and Paraffin wax (2) respectively (Figure 1a). Control fruits had higher incidence of fruit rot (%) after 30 days while treated fruits had maximum decay during 75-90 days which depicted that wax coating maintained their efficacy up to 75 days to control the fruit rot. Both commercial waxes (Sharine and

Paraffin) performed at par to PHRC wax and effectively minimized the fruit rot percentage in stored fruits. However; benzaldehyde coating could not achieve better results to minimize the fruit decay during storage.

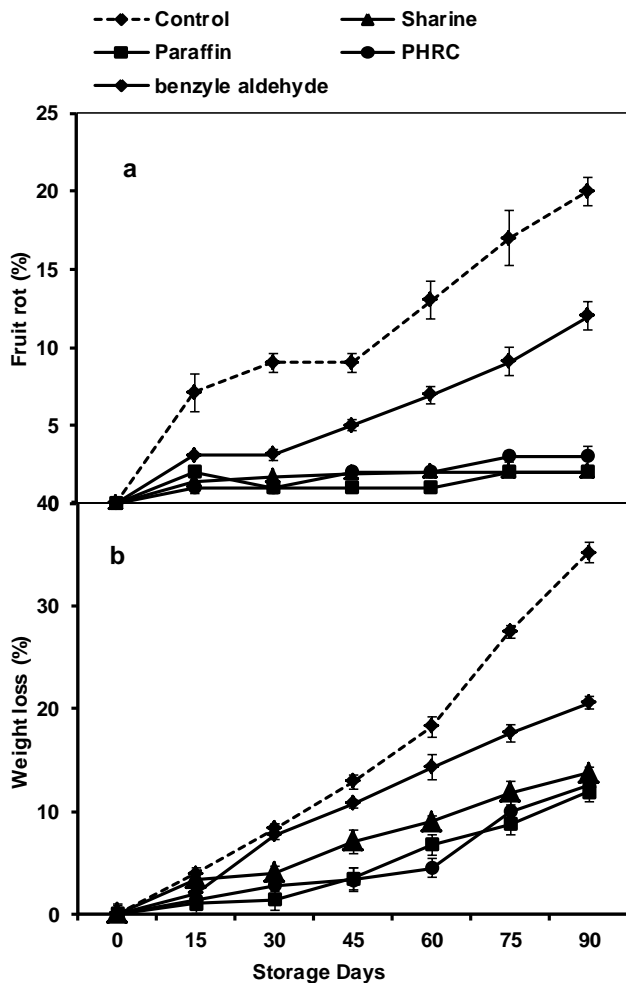


Figure 1. Effect of different wax types on fruit rot and weight loss (%) during storage.

Weight loss (%): Minimum weight loss (11.87%) was found in fruits those were treated with 'Paraffin' (11.86%) followed by 'PHRC' wax, 'Sharine' and benzaldehyde coatings with the weight loss 12.47, 13.68 and 20.52% respectively whereas; maximum loss in weight (35.10%) was recorded in untreated fruits after 90 days of storage (Figure 1b). 'Paraffin' and 'PHRC' wax performed almost at par to control the weight loss in stored fruits. Overall results suggest that weight loss increased with the increase in storage period, however; control fruits had maximum weight loss during storage due to higher metabolic activities.

Peel weight (g): All types of wax coating performed well to maintain peel weight during storage, Maximum peel weight (42.5) was recorded in the fruits those were treated with

PHRC wax followed by the fruits coated with Paraffin (41.9), Sharine (38.33), benzaldehyde (28.82) and control (27.83) respectively after 90 days of storage (Figure 2a). Fruits treated with Paraffin wax retained maximum peel weight from 0-60 days while PHRC and Sharine wax performed at par to minimize weight loss from fruit peel by avoiding direct exposure of fruit skin to environment. In contrast, control fruits had a rapid decline in peel weight during 15-90 days.

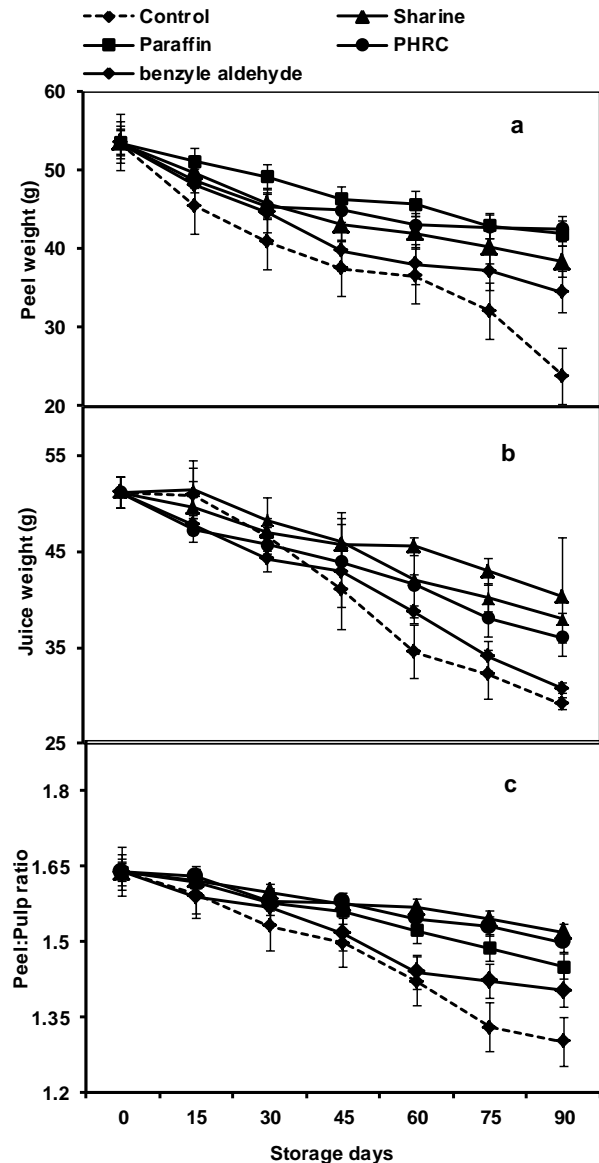


Figure 2. Effect of different wax types on peel weight, juice weight (%) and peel: pulp ratio during storage.

Juice weight (%): It was observed that juice weight of fruit in all the treatments was also decreased with increased storage time however; decrease rate was minimized after wax

coatings. Wax coated fruits had minimum decline during initial 45 days of storage while a rapid loss in juice weight was recorded during 60-90 days. Maximum juice weight (42.87) was observed in fruits those were treated with Sharine wax followed by the fruits coated with Paraffin (40.11), PHRC (38), protector (54.21) and control (32.29) respectively after 90 days of storage (Fig. 2b). During entire storage, Paraffin and PHRC wax performed at par to minimize the weight loss (%) from the juice.

Peel pulp ratio: Peel: pulp ratio is an important factor to determine the water loss in mandarin during storage. After 90 days, maximum peel and pulp ratio (1.51) was recorded in the fruits coated with Paraffin wax followed by PHRC, Sharine, benzaldehyde and control in which ratio was calculated as (1.49), (1.44), (1.40) and (1.3) respectively (Fig. 2c). Coated fruits had non-significant changes during initial 15 days while control fruits had rapid decline during 15-90 days of storage.

Bio-chemical characteristics:

Total soluble solids (*Brix): Soluble solid contents in Kinnow juice were increased with the advanced storage however; this increase rate was minimized by the application of skin coatings. After 90 days, maximum TSS (13.23) was recorded in control fruits followed by protector (12.9), PHRC wax (11.9), Paraffin (11.2) and Sharine (11.1) respectively (Figure 3a). A rapid increase in fruit TSS was observed after 60 days of storage however; wax coated fruits exhibited maximum increase during 75-90 days of storage.

Titrateable acidity (%): Higher titrateable acidity was found in 'PHRC' wax (1.23) followed by 'Sharine' (1.19%), 'Foema' (1.18) and 'protector' (1.1) after 90 days of storage. Control fruits had lower acidity (0.78%) than all other treatments at the end of storage. A clear decline in titrateable acidity in stored fruits was observed with the increase in storage period (Figure 3b).

TSS/ Acid ratio: All the treatments with wax coatings had minor changes in TSS: TA ratio of Kinnow juice during initial 15 days while control and benzaldehyde coated fruits had sharp increase in ratio from 15-90 days of storage. After 90 days, maximum ratio (13.50) was observed in control fruits followed by benzaldehyde (10.93), Paraffin (9.49), Sharine (9.32) and PHRC wax (9.26). PHRC wax performed statistically at par to both commercial waxes to maintain the TSS/TA ratio in optimum range (Figure 3c).

Sugar contents (%): A positive correlation was recorded between sugar contents and storage period and all the three wax types (Sharine Paraffin and PHRC) performed at par to each other and maintained the sugar contents of juice. Control fruits had a rapid increase in total sugars after 60 days while the fruits treated with PHRC wax showed a considerable increase during 45-60 days of storage. Interaction between treatments and storage exhibited that Paraffin and PHRC wax performed at par to each other during entire storage

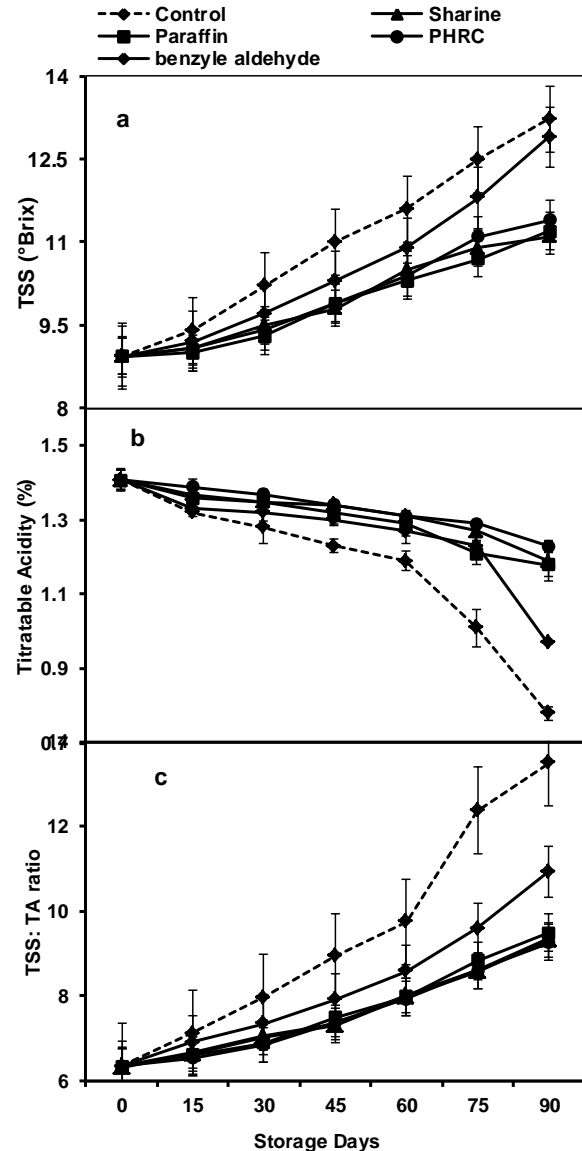


Figure 3. Effect of different wax types on TSS, TA and TSS: TA ratio during storage.

After 90 days, maximum total sugars (19) were observed in control fruits followed while minimum (13.5) were observed in fruits treated with Sharine wax (Figure 4a, 4b).

In contrast of total and reducing sugars, non-reducing sugars were decreased with the advanced storage and after 90 days, maximum (7.2) was observed in the fruits coated with Paraffin wax while control fruits exhibited minimum (6) contents of non-reducing sugars. Control fruits had a clear decline after 45 days however; maximum decline in coated fruits was observed during last 30 days of storage (Figure 4c).

Ascorbic acid ($\text{mg } 100 \text{ g}^{-1}$): It was observed that maximum vit.C contents were recorded in fruits treated with Sharine wax followed by the fruits of PHRC wax (55.99), Paraffin

wax (54.57) benzaldehyde coating (42.9) and control (26.98) after 90 days respectively (Figure 5a). Vit.C contents were increased in all the treatments during 0-60 days depending upon the treatment applied. However; control fruits had gradual decrease after 30 days while wax coated fruits had higher rates of decline during 75-90 days. Highest value of vit.C contents (72.78) was recorded in the fruits coated with Paraffin wax after 60 days of storage which depicts an increase in ascorbic acid during storage, while control fruits had minimum (44.72) when analyzed at the same day. Moreover; Paraffin and PHRC wax performed statistically at par to maintain maximum ascorbic acid contents during entire storage.

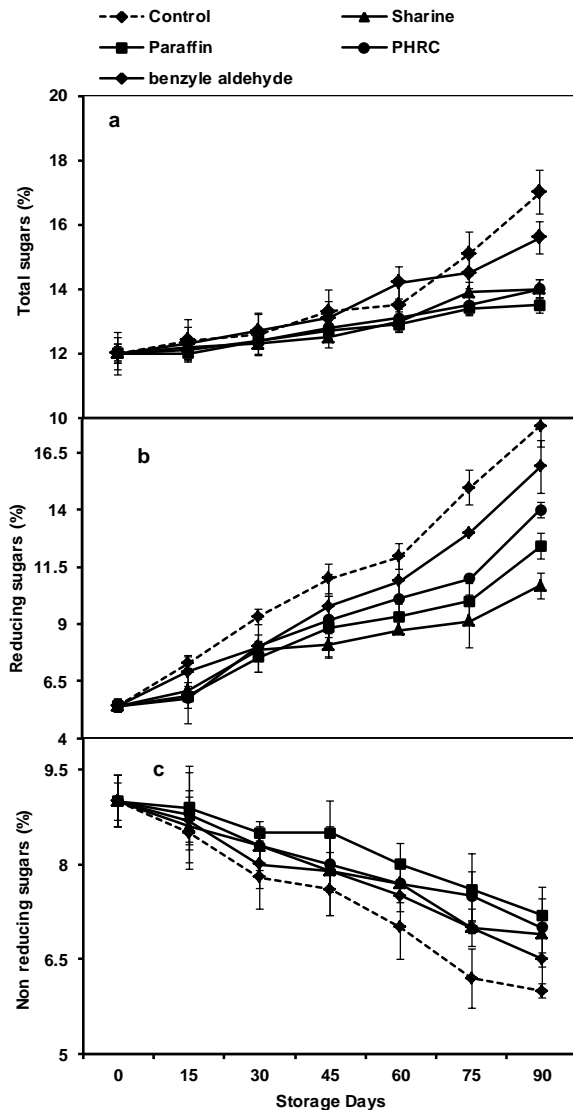


Figure 4. Effect of different wax types on total, reducing and non-reducing sugars (%) during storage.

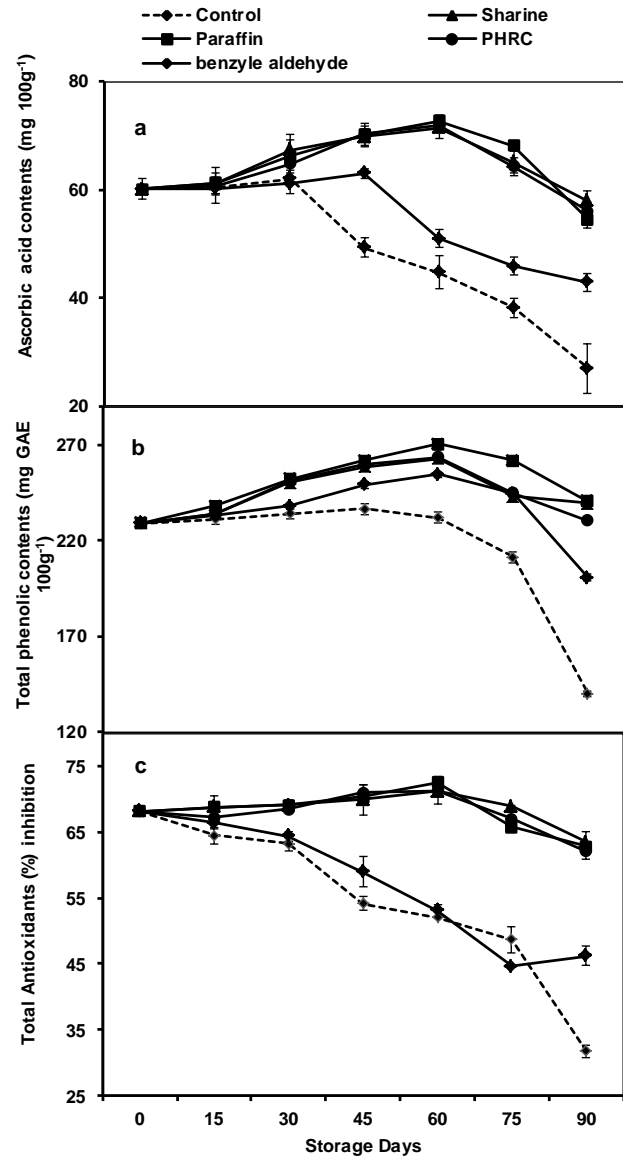


Figure 5. Effect of different wax types on vit. C, total phenolic contents and fruit during storage.

Total phenolic contents (mg GAE 100 g⁻¹): Paraffin wax maintained maximum level (240.78) of TPC up to 90 days followed by the fruits of Sharine (239.69), PHRC wax (230.62), benzaldehyde coating (200.83) and control (140.16) respectively (Figure 5b). A significant increase in total phenolic contents was recorded in all the wax coated fruits from 0-60 days depending upon the treatment applied. A slight increase was also observed in control fruits but it was declined after 30 days of storage however; maximum decline in coated fruits was observed during 75-90 days. Maximum TPC (270.55) were recorded in the fruits coated with paraffin

wax after 60 days while they were minimum (232.1) in control fruits at the same day.

Total antioxidants (% inhibition): Maximum antioxidant activity (63.46) was recorded in Sharine wax, while; minimum was exhibited by the fruits of control (31.73) at the end of storage. All the three wax coatings (commercial and local) performed at par to maintain maximum total antioxidant activity in stored fruits (Figure 5c). Like ascorbic acid and total phenolic contents, antioxidant activity of fruit was also increased in all the treatments from 0-60 days but decreased gradually up to 90 days. PHRC wax and both types of commercial waxes coatings were equally helpful to retain antioxidant activities for maximum time period.

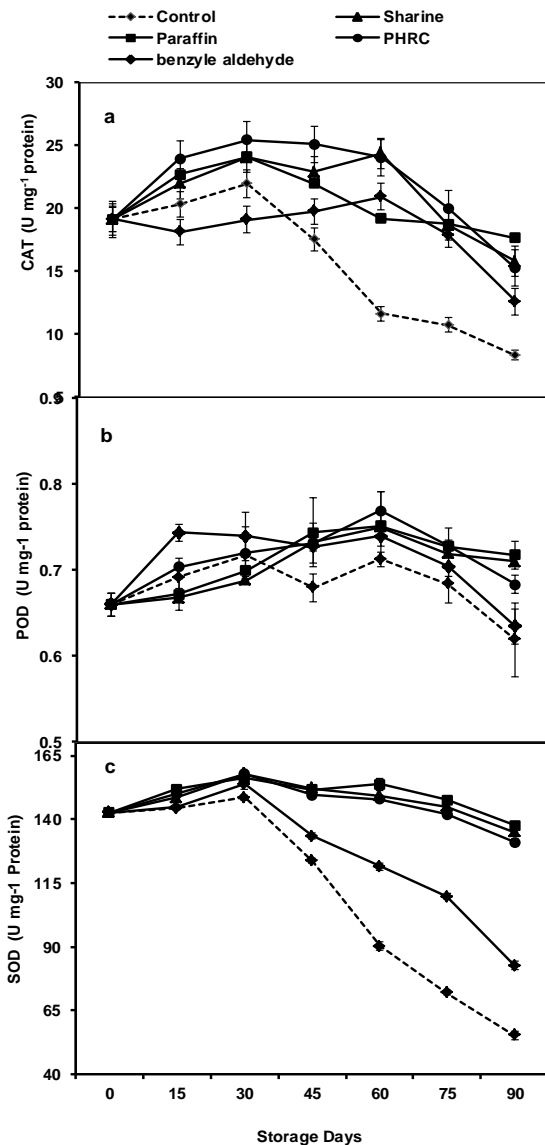


Figure 6. Effect of different wax types on catalase, peroxidase and superoxide dismutase activities in fruit during storage.

Catalase ($U\ mg^{-1}\ protein$): Catalase (CAT) activity increased with the increased storage in all the treatments, but also decreased after 30-45 days depending upon the treatment. Maximum CAT activity (17.64) was recorded in fruits treated with Paraffin wax followed by the fruits of Sharine, (12.58), PHRC (15.26), benzaldehyde coating (12.58) and control (9.97) respectively after 90 days (Figure 6a). Interaction effect exhibited highest CAT activity (25.46) in the fruits coated with PHRC wax after 30 days of storage while it was minimum (19.11) in the fruits coated with benzaldehyde solution at the same day. Sharine and PHRC wax performed at par to maintain the CAT activity during entire storage.

Peroxidase ($U\ mg^{-1}\ protein$): Maximum peroxidase (POD) activity was recorded in fruits coated with Paraffin (0.71) while control fruits exhibited minimum (0.66) at the end of storage (Figure 6b). Significant interaction between treatments and storage time exhibited highest activity (0.76) in PHRC coated fruits after 60 days of storage while control fruits had minimum (0.71) when analyzed at the same day.

Superoxide dismutase ($U\ mg^{-1}\ protein$): A significant increase in superoxide dismutase (SOD) activity was observed under low temperature, however; wax coatings maintained higher levels upto 90 days by keeping their influence in comparison of benzaldehyde coating and control fruits. Paraffin coated fruits exhibited maximum SOD activity (137.62) followed by the fruits of Sharine (135.15), PHRC wax (131.00), benzaldehyde (82.65) and control (55.15) after 90 days (Figure 6c). Maximum SOD activity (153.87) was observed in fruits treated with Paraffin wax after 60 days while the control fruits had only (90.15) SOD at the same day.

DISCUSSION

Edible coatings in fruits and vegetables are used for many purposes particularly to improve the fruit appearance, skin texture and to minimize the water loss from the fruit surface. In citrus, wax coatings are used to improve skin gloss, to reduce skin shriveling during storage and to replace the natural waxes that are removed during harvesting and postharvest handling (Baldwin, 1994; Chein *et al.*, 2007).

Citrus fruits face serious problems of postharvest decay during storage which is mostly caused by fungal pathogens. *Penicillium digitatum* and *penicillium italicum* are important wound pathogens of citrus which cause green and blue mold in citrus respectively. Lower incidence of fruit decay in wax coated fruits may be due to formation of a protective layer on fruit skin because fungal spores enter the fruit through skin and waxing creates a barrier against fungal and bacterial pathogens into the skin. It also creates a hydrophobic layer on fruit surface which restricts the growth and development of fungi because usually their spores are produced in water loving environment. Some wax coatings i.e., chitosan also exhibit antifungal properties itself and directly inhibit the attack of fungal pathogens during storage (Lam and Deip,

2003; NARI, 2004; Bourtoom, 2008). Our findings are also supported by the previous studies where it has been reported that different types of wax coatings effectively minimized the fruit rot and fungal decay during storage of citrus fruits (Lam and Deip, 2003; Hagenmaier and Shaw, 2002; Shahid, 2007). In present study, increasing trend in weight loss of fruit from peel, pulp and juice was observed among all the treatments however; all the wax coatings including PHRC wax effectively minimized the weight loss (%) during storage. Weight loss in fruits and vegetables is associated with water loss through transpiration and respiration during storage. Water loss from the citrus fruits during storage is the physiological loss which declines the fruit quality of citrus making it unacceptable for consumer. Respiration and transpiration process continue during the storage of horticultural crops leading to reduce moisture contents of fruit and ultimately deteriorate the fruit quality. Water loss from the fruit peel, pulp and juice adversely affects the fruit weight and appearance by causing wilting, shriveling and fruit softening. Moreover; many physiological and rind disorders of citrus are also related to water loss from the fruit (Greirson *et al.*, 2006; Palou *et al.*, 2015). After waxing of citrus fruits, a thin film tightly adheres the fruit skin and the pores of cuticle are blocked which decreases the rate of respiration and transpiration, ultimately leads to reduce the water loss from fruit surface (NARI, 2004; Shahid, 2007; Palou *et al.*, 2015). These results are in agreement with Shahid (2007) and Avina *et al.* (2007) who reported that wax coatings significantly reduce the weight loss from the citrus and tomato respectively.

Application of different types of wax coatings effectively maintained the levels of fruit TSS, total sugars and reducing sugars in comparison of control and protector treatment. Increase in fruit TSS and sugars mostly occurs due to higher rate of physiological changes in fruit, more water loss and higher rates of respiration and transpiration during fruit storage. It has been reported that many processes including glycolytic cycles and Krebs's cycle take place during storage and cause the sugar variation during storage (Taiz and Zeiger, 2003). Sugar contents during storage usually increase due to hydrolysis of starch into sugars within the fruit moreover; most of the physicochemical changes are also correlated with fruit senescence, and respiration rate. Sugar contents of juice also increase with the fluctuation in water contents as the sugars increase with the increase in water loss from the fruit (Hassan *et al.*, 2014). Wax coatings slow down the respiration rate and metabolic activities that ultimately slow down the physicochemical changes including sugar level of juice. Previous studies confirm that wax coatings slow down the physiochemical changes as well as other metabolic activities within the fruit during storage (Boylston *et al.*, 2002). Our results regarding total soluble solids and sugars are in association with Shahid and Abbasi (2011) who reported that wax coated fruits had minimum change in TSS, total sugars,

reducing sugars and non-reducing sugars in sweet orange cultivar blood red.

Wax coated fruits showed higher levels of acidity after storage as compared to control fruits which may be due to lower metabolic activities within the fruit. A rapid decline in titratable acidity of control fruits is caused by the conversion of acids into sugars within the fruit while; wax coated fruits exhibit lower changes due to slow metabolic activities during storage resulting in higher acid contents (Bajwa, 2007). Citrus fruits contain different organic acids and they are minimized during storage because fruits use them as energy source (Hassan *et al.*, 2014). The level of TSS: TA ratio was increased among all the treatments however; this increase was more in control fruits which may be due to the higher decline rate of acidity and increase of sugars during the storage. Higher TSS/Acid ratios adversely affect the fruit taste as the mandarin and citrus fruits are liked by their lower TSS/Acid ratio during storage (Arpaia and Kader, 2012). These results are in line with Shahid and Abbasi (2011) who reported that TSS: TA ratio in citrus fruits is minimally affected after different types of wax coatings in comparison of control.

Ascorbic acid is an important part of antioxidant family which is water soluble vitamin and is rapidly oxidized by the effect of temperature, light and ascorbic acid oxidase enzymes. Being an important part of citrus fruit juice which is also considered as quality indicator during storage of citrus fruits (Rapisarda *et al.*, 2008; Silva *et al.*, 2013). Results from present study indicated that wax coated fruits had higher levels of Vit.C after 90 days in comparison of control which may be due to effect of low temperature on metabolism control and lower activities of ascorbic acid degrading enzymes. These results are supported by previous studies where it has been reported that Vit. C contents and acidity decrease during the storage of citrus fruits but wax coatings maintain their levels under cold storage (Bajwa and Anjum, 2007)

In this study, a slight increase in total phenolics was observed during initial storage followed by decline till the end of storage. Control fruits had maximum decline in total phenolics during entire storage in comparison of wax coated fruits. Citrus fruits contain a considerable amount of phytochemicals which are very active in plant defense system and protect the plants against stress and pathogen attack. These phenolic compounds induce resistance against *Penicillium* in citrus fruits and under certain favorable conditions including low temperature storage, the concentration of plant phytochemicals might be enhanced (Zobel, 1997). Increase in phenolic contents during initial days may be in association with low temperature as it affects the initiation of different phenolic compounds and water loss during storage may also cause variation in phenolic contents of juice (Silva *et al.*, 2013). Decrease in phenolics after a defined time period might be due to decrease in antioxidant activity and this degradation is the sign of lower internal

resistance of fruits against pathogen attack. These results are supported by Machado *et al.* (2014) who reported a slight increase in phenolic contents during initial storage followed by a continuous decrease after the application of different coating types on pineapple fruit.

Higher activities of antioxidants were recorded in the wax coated fruits after 90 days as compared to control and benzaldehyde coating. Citrus fruits contain flavonoids which also exhibit antioxidant activity and they may be involved to change the status of total antioxidants within the fruits during storage (Bocco *et al.*, 1998). The initial increase in antioxidant enzymatic activity may be due to environmental stress provided in the form of low temperature as it increases the level of reactive oxygen species (ROS) at the transcript, protein and activity level which ultimately alters the cellular homeostasis (Suzuki and Mittler, 2006). Moreover; vit.C contents may also affect the antioxidant activity of fruits being an important part of their family (Du *et al.*, 2009). In our study, lower antioxidant activity of non coated fruits expressed their low resistance against disease attack and metabolic changes during storage.

Wax coatings effectively maintained the higher activities of antioxidant enzymes as compared to control and benzaldehyde coating. Enzymatic phytochemicals (SOD, CAT and POD) are very important because they are activate the plant defense system against various biotic and a biotic stress. SOD is a ubiquitous defensive enzyme which protects from the superoxide damage to anaerobic organisms. CAT and POD also help to scavenge free radicals which can damage the cells under stress. Initial increase in antioxidant enzymes activities may be due to low temperature exposure and wax coatings which results in accumulation of H₂O₂ (a signal of oxidative stress). Accumulation of H₂O₂ increases the peroxide scavenging system during cold storage and activates the plant defense system. Wax coatings in fruits may cause the production of free redicals which activate the fruit internal defence system by increasing the activities of antioxidant enzymes (Erkan *et al.*, 2008; Shafique *et al.*, 2011; Maharaj, 2015).

Conclusion: PHRC wax effectively minimized the fruit decay during 90 days storage and performed statistically at par to maintain the fruit TSS, sugars, acidity, total phenolics, antioxidants, CAT, POD and SOD activities after storage. Consequently, it can be recommended that PHRC wax can successfully replace the commercial waxes as it performed almost equal to commercial waxes. It will be very cost effective as it has about 50% lower price than commercial waxes.

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