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Research Article

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Physicochemical Responses of 'Kinnow' Mandarins to Wax and Polyethylene Covering During Cold Storage

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Abstract: This study aimed to evaluate the influence of wax, polyethylene film (19 µm thickness) and storage time on the quantitative and qualitative characteristics and shelf life of 'Kinnow' mandarin fruit (*Citrus reticulata* Blanco cv. 'Kinnow') stored at 5°C for 90 days. The mandarins were analyzed for physicochemical characters such as weight loss, weight of fruit, flesh, pulp, juice and peel, as well as total soluble solids (TSS) content, titratable acidity (TA), and pH. Polyethylene film wrapping reduced fresh weight loss and resulted in the highest fruit weight at the end of the 90-day cold storage period. No significant differences were found among coating treatments in pH, TSS, TA content and TSS/TA. The results revealed an increasing trend in TSS and TSS/TA during storage. It is recommended to use polyethylene coating on 'Kinnow' mandarins to prevent weight loss and preserve quality during storage at low temperature (5°C) up to 90 days.

Keywords: Citrus, Wax coating, Polyethylene film, Shelf life, Fruit weight

1 Introduction

Iran is a major producer of fruits, and in some cases is considered among the top ten producers. Citrus is one of the most important fruits grown in the world and is produced in Iran as an export crop, but approximately 28-31% of citrus fruit goes to waste. Major losses (15-18%) in quality and quantity occur during storage due to unsuitable storage of products after harvest and improper packaging (Miri et al. 2017; Mollapur et al. 2016; Shahedi Baghkhandan 2006).

Fruit is highly perishable as it contains 80–90% water by weight. Also, during the washing process of fruit preparation, most of the natural wax on fruit skin is removed. Therefore, if the fruit is left untouched, the water will quickly begin to evaporate, resulting in poor product shelf life. In addition, contamination of fruit flesh can occur from the skin, which increases fruit spoilage, causes biochemical deterioration such as browning, off-flavor development and texture breakdown, impairs fruit quality and exposes consumers to harmful pathogenic microorganisms (Ali et al. 2015; Dhall 2013). Post-harvest treatment plays a significant role in extending the shelf life of fruit (Rokaya et al. 2016).

Various viable technologies have been used to increase the post-harvest shelf life of fruit in past decades; examples include the use of fungicides, cold storage, controlled or modified atmosphere storage, antitranspirants, wax-coating, growth retardants, irradiation and different types of packaging materials (Miri et al. 2013; Rokaya et al. 2016).

Edible coating on fresh fruit can provide an alternative to modified atmosphere storage by reducing changes in quality and losses in quantity through modification and control of the internal atmosphere of the individual fruit (Dhall 2013). It is useful for controlling ripeness by reducing oxygen penetration into the fruit, thus reducing metabolic activity and softening (Šuput et al. 2015). Waxes are the most efficient edible compounds used to prevent weight loss (retain moisture), inhibit microorganisms, slow down aerobic respiration, and improve appearance by providing gloss (Dhall 2013; Šuput et al. 2015).

Further, to avoid shriveling and to increase fruit shelf-life, proper packaging is very important. Proper packaging protects fruit from physical (firmness), physiological (weight) and pathological (decay) deterioration. Out of various packaging materials, plastic films are commonly used in fruit packaging (Patel et al. 2009).

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Mandarins are cherished around the globe due to their nutritional value, physicochemical properties, natural antioxidants and sensory attributes (Ahmad et al. 2013). Since mandarin is a non-climacteric and perishable fruit, it cannot be kept for a long time during transportation and storage (Bhattarai et al. 2013). One of the well-known mandarins is 'Kinnow' (King × Willow leaf), an oblate-shaped fruit flattened at the base and apex, with adherent and smooth peel, deep orange color, seeded, juicy and highly flavorsome (Ladaniya 2008).

In the southern regions of Iran, 'Kinnow' mandarins are ready to harvest in mid-winter. Huge harvests of fruit during the peak harvesting season creates a glut, and the growers are compelled to sell at the local markets. Because citrus fruits are mostly consumed as fresh products, they need packaging to preserve their natural qualities during storage (Miri et al. 2017; Pippal 2011). Therefore, the objective of this study was to investigate the effects of wax and polyethylene covering on prolonging the shelf life of 'Kinnow' mandarins during cold storage.

2 Materials and Methods

2.1 Plant material and treatments

Fully ripe and healthy 'Kinnow' mandarins were harvested in early February from the experimental field of Jiroft and Kahnooj Agricultural Research Center, Jiroft, Iran (28°67′ N., 57°73′ E.) (Miri et al. 2017) and graded according to uniformity of size. Experimental groups included untreated fruit (control), wax coating (18% wax, 2% Imazalil, and 5% Thiabendazole) and polyethylene film (19 µm thickness) packaging.

2.2 Storage conditions

Fruit were air-dried in the shade, after which they were kept dry at room temperature for about three hours before being placed inside plastic baskets and stored at 5 ± 1°C with 80-90% relative humidity for 90 days.

2.3 Physicochemical analysis

Observations on physicochemical properties were recorded at 30 day intervals for three months. Fruit was weighed using digital scales, after which they were peeled to weigh their flesh and peel. Juice was extracted from the flesh by squeezing, to record the weight of the juice and pulp. The physiological loss in the weight of fruit was calculated on the basis of the initial and final weight of the fruit and was expressed in percent.

Total soluble solid (TSS) of the juice was determined with a portable digital refractometer (Master-PM, Atago, Japan), corrected at 20°C. Titratable acidity (TA) was measured by direct titration to pH 8.1 with 0.1 N NaOH standardized solution, and the results were expressed in g citric acid per 100 mL juice. The pH value of juice was measured with a pH-meter (Sartorius PB-11, USA). TSS/TA ratio was calculated by dividing the TSS value by the TA value.

2.4 Statistical analysis

The experiment was carried out in a completely randomized design with three replicates (three mandarins per replication). The Analysis of Variance was conducted using SPSS Version 22 and means were compared by Duncan's test at $P \leq 0.05$. Relationships among the variables were determined using the bivariate Pearson's correlations coefficient test at $P \leq 0.01$.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results

3.1 Physicochemical evaluation

This study investigated the influence of wax and polyethylene film packaging on the shelf-life and quality of 'Kinnow' mandarin fruit during cold storage. Analysis of Variance showed that coating type × storage time influenced only the measured physical properties of the fruit, while chemical properties (pH, TSS, TA, and TSS/TA) were not affected. On the other hand, storage time had a significant effect on all traits.

3.2 Fruit, flesh, pulp, juice and peel weight

At the end of storage, fruit packaged in polyethylene film resulted in the highest average fruit weight with a mean of 104.6 g, and untreated fruit (control) had the lowest weight (80.2 g) (Table 1). Fruit weight exhibited a significant positive correlation with flesh ($r = 0.96$), pulp ($r = 0.90$), juice ($r = 0.92$) and peel ($r = 0.93$) weight (Table 2).

The weight of fruit, flesh, pulp, and peel did not differ

Table 1: Effect of wax coating and polyethylene packaging on fruit quantitative traits during 90 days of cold storage

Treatment	Storage period (d)	Fruit weight (g)	Flesh weight (g)	Pulp weight (g)	Juice weight (g)	Peel weight (g)	Fruit weight loss (%)
-	0	109.2 a	83.9 a	43.0 a	38.8 a	28.9 a	-
control	30	103.9 ab	80.1 a	45.5 a	35.5 ab	26.8 ab	4.7 cd
	60	87.2 abc	66.9 ab	36.8 ab	30.0 ab	22.1 bc	20.0 ab
	90	80.2 c	62.5 b	34.7 b	27.8 ab	17.5 c	26.4 a
wax	30	102.6 ab	77.6 ab	42.0 ab	35.6 ab	24.9 ab	5.9 c
	60	97.9 abc	71.5 ab	40.6 ab	30.9 ab	26.2 ab	10.2 bc
	90	85.7 bc	62.8 b	33.6 b	27.4 b	22.8 abc	21.4 ab
polyethylene film	30	107.1 a	82.5 a	42.3 ab	38.2 a	28.4 a	1.8 d
	60	105.6 ab	79.3 a	45.2 a	34.1 ab	28.2 ab	3.2 d
	90	104.6 ab	78.7 a	41.0 ab	37.7 a	26.0 ab	4.1 d

Table 2: Correlation coefficients of fruit quantitative and qualitative traits during 90 days of cold storage

Trait	Fruit weight	Flesh weight	Pulp weight	Juice weight	Peel weight	Weight loss	pH	TSS	TA
Flesh weight	0.96**								
Pulp weight	0.90**	0.92**							
Juice weight	0.92**	0.96**	0.80**						
Peel weight	0.93**	0.83**	0.81**	0.75*					
Weight loss	-0.99**	-0.97**	-0.93**	-0.92**	-0.90**				
pH	0.17	0.27	0.07	0.39	-0.04	-0.16			
TSS	-0.52	-0.66*	-0.62	-0.62	-0.31	0.75*	-0.56		
TA	0.52	0.63	0.70*	0.50	0.40	-0.85**	0.05	-0.85**	
TSS/TA	-0.54	-0.66*	-0.69*	-0.56	-0.38	0.85**	-0.22	0.93**	-0.98**

*: P≤ 0.05, **: P≤ 0.01

significantly among treatment groups during storage, except for the untreated fruit (Table 1), which experienced a significant reduction on day 90 compared to day 30.

3.3 Fruit weight loss

The physiological loss in the weight of fruit was aggravated during storage in untreated fruit (Table 1). The highest weight loss (4.7-26.4%) was recorded in the controls, which exhibited a sharp increase in the percentage of weight loss on day 60, rendering them almost unacceptable for consumption. The second highest weight loss during storage was recorded for fruit treated with wax (5.9-21.4%), while weight loss was negligible in the polyethylene-packed fruit (1.8-4.1%). Further, weight loss had a significant negative correlation with the weight of fruit (r = -0.99), flesh (r = -0.97), pulp (r = -0.93), juice (r = -0.92) and peel (r = -0.90) (Table 2).

3.4 Acidity (pH)

Between days 30 to 60 of storage, a decreasing trend in pH was observed, which changed into an insignificant increasing trend by the end of the storage period (Figure 1).

3.5 Total soluble solid (TSS)

There was an increase in TSS content during storage. The TSS values at the beginning and the end of the storage period were 10.1 and 11.3, respectively (Fiure. 1).

3.6 Titratable acidity (TA)

The results showed that TA did not significantly change until day 60, but at the end of shelf-life, there was a declining trend from 1.34 % to 1.20 % (Figure 1).

3.7 Total soluble solid/titratable acidity (TSS/TA)

According to the similarity coefficient (Table 2), a significant negative correlation was observed between TA and TSS (r = -0.85). The increase in TSS and the decrease in TA content resulted in an increased TSS/TA ratio, which increased to 9.6 after storage for 90 days (Figure 1). Also, the TSS/TA ratio showed a negative correlation with flesh (r = -0.66) and pulp (r = -0.69) weight and TA (r = -0.98), and a positive correlation with weight loss (r = 0.85) and TSS (r = 0.93) (Table 2).

4 Discussion

Noticeable differences in the post-harvest physiological behavior of ‘Kinnow’ mandarins were found, which were affected by types of coating or packaging materials and cold storage.

Untreated fruit had the highest weight loss during cold storage. This could be due to lower moisture loss from the fruit surface by retardation of the transpiration and respiration processes (Patel et al. 2009), because the respiration rate of treated fruit was lower than that of unwaxed and polyethylene-packed fruit. These results are in agreement with previous studies (Barakat et al. 2012; Bisen et al. 2012; D’aquino et al. 2001; Rokaya et al. 2016; Roongruangsri et al. 2013; Shein et al. 2008). Hammash and El Assi (2007) noticed that wrapping or waxing of ‘Shamouti’ oranges reduced water loss from the fruit and contributed to maintaining higher fruit albedo firmness throughout the storage period. Ahmad Shah et al. (2015) also showed that carboxymethyl cellulose (CMC) and guargum-based silver nanoparticle coating markedly reduced weight loss in ‘Kinnow’ fruit during storage. Even though the wax reduced gas exchange, it was not as effective as polyethylene film in reducing fruit weight loss percentage. Mota et al. (2003) found that yellow passion fruit (*Passiflora edulis*) packaged in polyolefin film maintained higher fruit and rind fresh matter mass for 21 days after harvesting compared to waxed fruits. They stated that lower efficiency of wax may be due to reduced thickness of the wax layer. On the other hand, greater efficiency occurred because an environment of saturated humidity was formed inside the package due to its lower permeability to water vapor compared to wax, with a reduction in water vapor pressure gradient between fruit and the internal atmosphere of the packaging and, consequently, reducing fruit transpiration. Caron et al. (2015) reported that the combined use of wax coating and plastic film resulted in better post-harvest preservation of acid limes compared with only wax coating.

On the other hand, weight loss was highly correlated with the aesthetical deterioration of fruit (D’aquino et al. 2001). The visual appearance of fruit can be affected by surface dehydration, and wax coating and polyethylene wrapping reduced moisture loss and controlled surface dehydration in fruit by slowing down the evapotranspiration rate, resulting in high glossiness of fruit surfaces (Patel et al. 2009; Seehanam et al. 2010). Boonyakiat et al. (2012) also reported that the visual appearance of tangerine fruit continuously decreased during storage, but the fruit coated with commercial

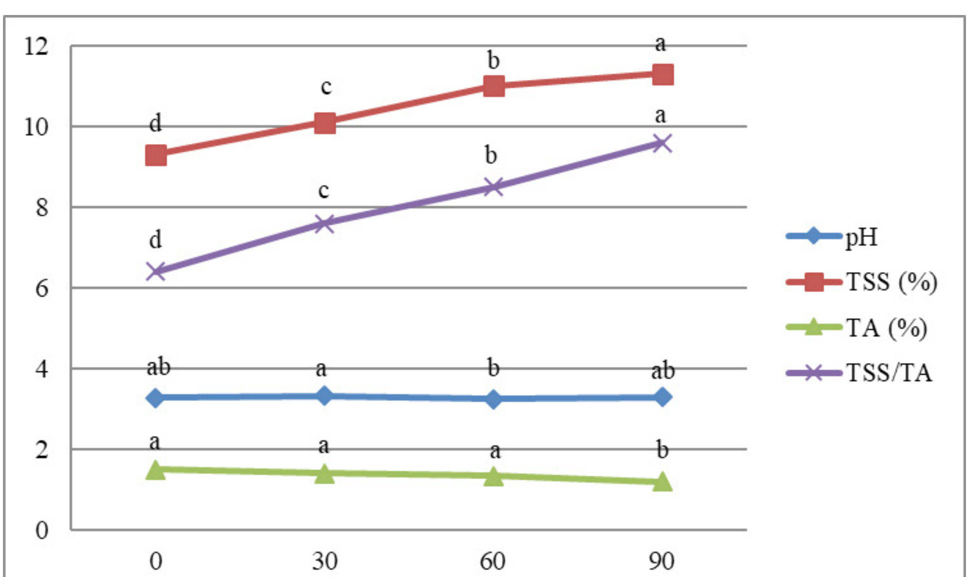

Figure 1: pH, TSS, TA and TSS/TA during 90 days of storage

coating had higher visual appearance scores than the non-coated controls. Juice content remained quite stable during the storage of fruit in all treatments.

However, the loss of fruit weight had a negative correlation with the weight of different parts of the fruit, but since fruit juice content did not change during storage, it seems that the weight loss was mainly caused by transpiration from the peel of the fruit. This may be due to continuous transpiration from the surface of the fruit as a result of more dehydration, and most water lost during storage comes from the peel (Bisen et al. 2012; D'aquino et al. 2001). These findings are supported by the observations of Roongruangsri et al. (2013), who demonstrated that the drying of peel is related to fruit weight loss, and the moisture content of peel gradually decreased in tangerine fruit during storage for 21 days.

A slight increase in pH was noticed up to day 30, which gradually decreased until day 60, after which it reached a plateau until day 90. Seehanam et al. (2010) and Bisen et al. (2012) also reported that acidity of tangerine and lime fruit was increased as storage period was extended to 13 and 18 days, respectively. The increase in acidity during storage was likely due to a slow rate of sugar conversion into acids or transpiration rate, which increased the concentration of acids. The decrease in acidity might be induced by the utilization of available organic acids during respiration (Patel et al. 2009).

TSS content was increased during cold storage in all treatments. Similar results have been obtained for mandarins (Ahmad Shah et al. 2015; Rokaya et al. 2016), tangerines (Roongruangsri et al. 2013) and pomegranates (Miri et al. 2012). It appears that TSS in citrus keeps increasing for a time during post-harvest storage, which can be attributed to a concurrent increase in sucrose content due to hydrolysis of insoluble polysaccharides into sugars (Ahmad et al. 2013).

TA was constant until day 90, but then it started to decline. Roongruangsri et al. (2013) and Rokaya et al. (2016) found that TA of tangerines and mandarins was decreased after storage for two and four weeks, respectively. The decreasing trend of acidity during the storage period was probably due to utilization of acid in tricarboxylic acid cycle in the respiration process (Rokaya et al. 2016), but it seems that this process was postponed by the low temperature of fruit storage.

TSS, TA and their interaction with volatile compounds play a role in orange flavor and can enhance the sensory quality of fresh fruit (Roongruangsri et al. 2013). Consistent with our findings, an increase in TSS/TA ratio along with the storage period has also been observed by Seehanam et al. (2010) and Roongruangsri et al. (2013). The negative correlation between TSS/TA and flesh and pulp weight indicated that fruit that were lighter in weight or underwent more weight loss were sweeter and had less acidity. The increase in TSS/TA ratio influenced taste due to lower acidity and stronger sweetness. During storage of oranges, organic acids decreased faster than sugars, so that fruit was predicted to be slightly sweeter in holding (Roongruangsri et al. 2013).

As previously mentioned, pH, TSS, TA, and TSS/TA of the mandarins was not affected by fruit coating, probably because of the slow rate of respiration and metabolic processes of this non-climacteric fruit. Roongruangsri et al. (2013) suggested that coating treatments did not influence TSS, TA, TSS/TA, and pH values, but there were significant changes during storage. These results are also in agreement with Shein et al. (2008) and Boonyakiat et al. (2012)' studies on 'Sai Nam Peung' mandarins. They reported that wax coating or polyethylene film packing had no effect on chemical composition (TSS, TA, and pH) of the fruit. On the contrary, Ahmad et al. (2013) found that waxed and polyethylene film-packed 'Kinnow' fruit had lower TSS and higher TA than controls. Seehanam et al. (2010) showed that %TSS, TSS/TA, and pH in 'Sai Nam Phueng' tangerines treated with Zivdar were higher than those of Citrashine. However, no significant difference was found in these traits in tangerine fruit coated with Citrosol AK, Supershine-C, or Perfect Shine coating. Also, they found that coating treatments did not affect TA loss.

5 Conclusion

Suitable coating can be a good strategy for the protection of post-harvest properties of fruit and their traits during storage. In this study, polyethylene film (19 µm thickness) reduced fruit weight loss (%) during cold storage compared to wax, but had no effect on the pH, TSS, and TA of fruit juice. The values of TSS and TSS/TA were increased during storage. It can be concluded that the shelf-life of 'Kinnow' mandarin fruit may be extended to 90 days in cold storage (5°C), while maintaining good appearance and better marketing conditions, if they are packaged in polyethylene film.

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Conflict of interest: Authors declare no conflict of interest.

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