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RESEARCH ARTICLE

Influence of different plastic film packaging on the physiological and sensory quality of sweet oranges during cold and ambient storage

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ABSTRACT

The effects of different plastic film packaging on physiological changes and sensory quality of sweet oranges were evaluated during a 9-week storage at 4ºC or ambient (20±2ºC). The oranges were seal-packaged with perforated polyphenylene films and biaxially-oriented polypropylene bags, and another group was shrink-wrapped in films, while another group served as the control. Oranges packaged with BOPP bags had the lowest weight loss at both cold storage (4ºC) and ambient (20±2ºC) compared to the other packaged and control fruits. However, the TA declined with an increase in TSS. Fruit sealed and packaged in plastic films preserved fruit firmness, taste, and flavor compared to the control fruit. However, the highest firmness (29.5N), taste score (9.0), and flavor acceptance (8.0) were observed with fruit sealed with BOPP bags at the end of storage. BOPP films greatly reduced fruit decay to 5%, relative to the control with 25% decay. However, the treatments should be evaluated for a wide range of citrus.

Keywords: Ambient temperature, cold storage, plastic films, sensory quality, sweet oranges, packaging

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INTRODUCTION

Citrus fruits (*Citrus sinensis*) are one of the most important fruits among fresh agricultural fruits in the world, with a total annual production of about 161.8 million tons produced in more than 10.2 million hectares in 2021, second only to plantain and banana fruits combined with a production level of 170.3 million tons (Gonzatto and Santos, 2023). Due to the therapeutic value of citrus fruits and general health awareness, citrus fruit is gaining wider importance, and fresh fruit consumption is likely to increase. Oranges are the most consumed variety due to their high vitamin C content and good flavor. However, fresh oranges are highly perishable, and physiological disorders usually lead to losses (Yeshiwas and Tadele, 2021). To enhance fruit storability and maintain good postharvest quality of oranges, many chemical applications such as fungicides, plant growth regulators, and

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2,4-D treatments are widely used in the citrus postharvest industry (D'Aquino et al., 2013; Hao et al., 2010). But consumers are increasingly concerned about the health risks and environmental threats associated with the use of synthetic chemicals to preserve fruit. Therefore, there is a need for a new approach with the ability to maintain fruit quality without adverse effects as an alternative method to synthetic chemicals (Pham et al., 2023).

One of the major established approaches to maintaining fresh produce is modified atmosphere packaging (MAP) during storage and handling (Ramayya et al., 2012). This method of packaging can retard fruit senescence (ripening) and associated biochemical and physiological changes (Cliffe-Byrne et al., 2007; Guevara-Arauza et al., 2006). Controlling storage temperature is the most effective environmental factor in delaying fruit ripening during postharvest storage. Both ripening and ethylene production rates increase with an increase in temperature (Mayuoni et al., 2011). Storing citrus fruits at a lower temperature (close to 0ºC) can inhibit fruit ripening (Mitalo et al., 2020). MAP can be used as a supplement to proper temperature maintenance to delay ripening and is generally beneficial for all fruits. Reducing oxygen (O2) concentration below 8% and elevating carbon dioxide (CO2) concentration above 1% can retard fruit ripening (Ntsoane et al., 2020). However, studies have established that a 2% O2 level may result in aerobic respiration development of off-flavors and off-odors in fruits (Ramayya et al., 2012). Fruits exposed to such low O2 levels can also lose their ability to attain uniform ripeness upon removal from MAP (Kumar et al., 2017; Mangaraj and Goswani, 2009). It has been reported that storage atmosphere determines the respiration rate of the produce and depends on factors such as film permeability to CO2 and O2 to generate the atmosphere for the produce, temperature and relative humidity, and physiological state of produce (Iqbal et al., 2019). Orange fruit is highly susceptible to moisture loss due to the presence of micro-cracks that allow the free movement of water from their surface (Khanal et al., 2021). Modified atmosphere packaging (MAP), in combination with coating applications, has been applied to delay moisture loss (Caleb et al., 2013). Modification of the atmosphere of fresh horticultural produce can preserve quality by retaining moisture and reducing pathological deterioration and metabolic activities (Caleb et al., 2012). For example, D'Aquino et al. (2010) observed that shrink wrapping, in combination with fludioxonil, reduced weight loss in pomegranate fruit during 12 weeks of 8ºC storage and improved the overall quality. In another study, Selcuk and Eckan (2014) reported a prolonged storage period of up to 4 months at 6ºC, resulting in a decreased total anthocyanin concentration in fruit treated with MAP. Similarly, it has been reported that individual seal packaging has extended the shelf-life and reduced water loss and the severity of surface disorders in citrus fruit (Ben-Yehoshua et al., 1987). Postharvest decay is responsible for most of the losses in fruits (Droby et al., 1993). Decay in orange fruits has been reported (Erkan et al., 2005; Palma et al., 2013; Sajid et al., 2013). Ben-Yehoshua et al. (2001) reduced the development of rind blemishes in 'Shamouti' oranges by providing high humidity conditions using MAP.

Some studies have attributed the development of off-flavors in citrus to the induction of ethanol fermentation metabolism and the accumulation of high levels of ethanol (Obenland et al., 2011; Shi et al., 2007; Tietel et al., 2010). Fruits of 'Minneola' tangelo wrapped with three plastic films of different permeabilities and stored at 20°C and 60% RH were reported to have delayed changes in characteristics of juice TA, TSS, weight loss, aging, fruit decay, and firmness level (D'Aquino et al., 1998). One of the major problems in maintaining citrus fruit quality after harvest is the decrease in flavor acceptability and the accumulation of off-flavor (Tietel et al., 2011). However, no study reported the impact of MAP on the postharvest keeping qualities such as decay development and sensory attributes of sweet oranges under varied storage conditions. Therefore, this present study aimed to evaluate the impact of three plastic films with similar permeability and temperature conditions in maintaining the sensory qualities and the postharvest quality of sweet orange fruit in Uni-packs with plastic films and held under different storage conditions.

MATERIALS AND METHODS

Plant material and storage conditions

Citrus fruits were obtained from a commercial supplier. The fruits were immediately transported to the postharvest laboratory of Dr. Hilla Limann Technical University checked for defects or rind injuries, disinfected with a 2% sodium hypochlorite solution, and rinsed with water. The fruit was divided into sets of three replicates of 30 fruits for each replicate. Some of the fruits were seal-packaged with perforated polyphenylene (PPE) films and biaxially-oriented polypropylene (BOPP) bags, while another group was shrink-wrapped in PPE films. Fruit that was non-sealed or shrink-wrapped was used as a control in the study. The films were purchased from MELCOM supermarket firm in Ghana. The sealing and shrinking were applied with a plastic heating machine made by Swery Electronics (Petach-Tikva, Israel). The samples were stored at 4°C and a relative humidity of 75-80% for 4 and 8 weeks and subsequently transferred to shelf life (20±2ºC) and a relative humidity of 50-55% for 7 days. The fruit was evaluated for percentage weight loss and decay incidence, fruit firmness, internal quality, external appearance, taste test, and consumer acceptance.

Weight loss

Fruit weight loss was evaluated by taking the initial weight (W0) and on each assessment day (W1). Weight loss was calculated using the following method; Weight loss = − Weight loss = $\left(\frac{W0 - W1}{W0}\right) \times 100\%$

Measurement of fruit firmness

The fruit firmness was evaluated using a handheld FT327 penetrometer (UK) with a capacity of 28 lb x 0.25 lb. The measurement was performed on two sides of the equatorial area of the fruit, and the data was reported in Newton (N).

Evaluation of total soluble solids and titratable acidity

The total soluble solids were determined using a 0-32% Brix meter refractometer (DFT-HY-DF1-EN-P, China), and the data was expressed in percentage brix (%brix). The titratable acidity was determined by titrating 10ml of orange juice with NaOH 0.1 N to pH 8.2, as an endpoint (orange color), with a pH meter (Jenway 351, UK). For both TSS and TA levels, all treatment units in each treatment and storage conditions were evaluated at the end of the storage regime.

Measurement of peel color changes

The peel color of fifteen (15) orange fruit was determined using a colorimeter (CR400/4P, Minolta Camera Co., Japan). The measurement was performed on two opposite sides of the equatorial region of the oranges on every assessment day. In the measurement of color changes, a* denotes (green (−) to red (+)), and b* indicates (blue (−) to yellow (+)). The hue angle (h°) of the orange fruit was then calculated by the colorimeter as; $h^\circ = \arctan b^*/a^*$.

Evaluation of sensory quality

Sensory analysis was conducted at Dr. Hill Limann Technical University Postharvest Technology Laboratory. Organoleptic parameters such as taste test (mouthfeel) and consumer acceptability were conducted according to Gomiero (2003). A total of 40 panelists were selected from staff and students of the University comprising 20 untrained males and the other 20 untrained females aged 25-40. The consumers' level of sensory evaluation was untrained panelists. A taste test assessment was performed by rating products on a 9-point Hedonic Scale with corresponding descriptive terms ranging from 9=like extremely to 1=dislike, according to the method described by Meilgaard et al. (2007), to find out the most suitable film's treatment of the fruits. The fruit was peeled, and samples were provided to the tasters as cut-separated segments placed on plates. All samples contained cut segments from at least five different fruits and were assigned identification numbers. The fruit samples were prepared in a room (≤22°C) for the sensory tests. The panelists were provided with water to rinse their mouths in between each taste of samples.

Statistical analysis

The experiment was carried out using a completely randomized design (CRD) with three replicates in each treatment. The test was a three-factorial (film treatment, storage temperature, and time), and the data were statistically analyzed using analyses of variance (ANOVA). Statistical analysis software (SAS) version 9.4 was used, and the comparison of means was conducted by the least significant difference (LSD) test ($p < 0.05$).

RESULTS AND DISCUSSION

Weight loss

The weight loss of fruit increased in all treatments as storage temperatures and times increased. Weight loss was significantly higher in unsealed controlled fruits (Table 1). Fruits packaged in films had reduced weight loss throughout the evaluation period. According to Ben-Yehoshua et al. (1987), individual seal-packaging in plastic films such as HDPE, Cryovac D-950, or Cryovac MPD protected all citrus fruit evaluated (lemons, pomelos, oranges, and grapefruit) from the damage incurred by the high temperatures. In the current study, sweet oranges packaged with BOPP bags and stored in both temperature conditions recorded the lowest weight loss of 1.29% compared with fruits packed with shrink wraps and stored, having a weight loss value of 1.30% on the seventh week of the experiment. At the end of the experiment, the non-wrapped fruits lost 4.19% of their initial weight. While oranges sealed with macro-perforated polyethylene (PPE) bags lost 2.99% of weight. This agreed with the observation of Ben-Yehoshua et al. (1987), where non-sealed 'Shamouti' fruit kept at temperatures ≥30°C for 3 days lost weight rapidly, shrunk, and softened much faster than sealed fruit kept at 17°C or ≥30°C (Ben-Yehoshua et al., 1987). This weight reduction could be directly related to the water vapor transmission rate of the packaging material, which is independent of its gas permeability properties. Weight loss of fruit was significantly higher at shelf life than at 4°C for all treatments. The trend of weight loss for fruit was the same at both storage times and temperatures. But fruit held for four weeks and at 4°C significantly reduced weight loss at the end of storage. However, the highest weight loss was observed in fruit stored for eight weeks and subsequently held at room temperature. This result is similar to the finding that non-sealed fruit kept at 36°C for the first 3 days followed by 35 days at 17°C lost 11% of its original weight, whereas the sealed fruit lost only 1% (Ben-Yehoshua et al., 1987).

Table 1: Weight loss (%) of sweet oranges packaged in plastic films, stored at different times and temperatures. Fruits were packaged with different plastic films at similar thicknesses. The means in the columns and rows in the table that share similar letters indicate insignificant differences.

Weeks at temperatures	Film treatments				Mean
	Control	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	0.0				
4 W at 4ºC	2.07	1.79	0.69	0.72	1.32^{c}
4 W + 1 W at 20ºC	3.30	2.47	0.99	1.08	1.96^{ab}
8 W at 4ºC	2.78	2.68	0.85	0.95	1.82^{bc}
8 W + 1 W at 20ºC	4.21	3.01	1.31	1.34	2.47^{a}
LSD (*p* ≤0.05)	0.62				0.62
Mean	3.09^{a}	2.49^{b}	0.96^{c}	1.02^{c}	

Fruit texture

Fruit texture is one of the most important quality characteristics of citrus fruit, which influences consumers to purchase or otherwise (Habibi et al., 2020). The initial firmness level of the fruits was 32.2N and showed a significant ($p < 0.05$) decrease during the storage period. As expected, fruit kept at 4ºC had less firmness loss when compared with those fruit held at 20±2ºC. There was a decrease in metabolic activity of fruit packaged in plastic films and kept at lower temperatures, leading to a significant delay in softening when compared with fruit stored at elevated temperatures (Table 2). Previous research on tomatoes (Biggs et al., 1988), apples (Klein and Lurie, 1990), and strawberries (García et al., 1996) packaged in a range of plastic films and held at different temperatures showed greater inhibition of texture loss. It would appear that control experienced the greatest decrease in firmness level at the end of storage compared with packaged-in plastic films, probably due to increased moisture loss from the oranges. There is a large space between fruits seal with shrink wrap and had less decrease in firmness during the during period. Please, check shift had less decrease in firmness during the during period up to occupy the space on the paper. Similarly, a study demonstrates that 'Minneola' tangelo wrapped with three plastic films of different permeabilities and stored at 20±2ºC and ≤60% RH was found to delay changes in firmness (D'Aquino et al., 1998). The decrease in texture was significantly ($p < 0.05$) affected by an increase in storage time, which is consistent with the results of Valero and Serrano (2012) reported that fruit softening could be a result of the pectin depolymerization by the activity of cell-wall-degrading enzymes including polygalacturonates, pectin lyase, pectin methyl esterase, and cellulose. Therefore, changes in cell wall composition contributed to texture losses in fresh fruit during storage (Valero and Serrano, 2012), in this current investigation.

Table 2: Fruit texture (N) of Mandarins packaged in plastic films, stored at different times and temperatures. Fruits were packaged with different plastic films at similar thicknesses. The means in the columns and rows in the table that share similar letters indicate insignificant differences.

Weeks at temperatures	Films treatment				Mean
	Control	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	0.0				
4 W at 4ºC	2.07	1.79	0.69	0.72	1.32[c]
4 W + 1 W at 20ºC	3.30	2.47	0.99	1.08	1.96[ab]
8 W at 4ºC	2.78	2.68	0.85	0.95	1.82[bc]
8 W + 1 W at 20ºC	4.21	3.01	1.31	1.34	2.47[a]
LSD (p ≤0.05)	*0.62*				*0.62*
Mean	3.09[a]	2.49[b]	0.96[c]	1.02[c]	

Total soluble solids and titratable acidity

TSS refers to the total amount of soluble constituents of citrus fruit juice. TSS of fresh fruit is an excellent index of the sugar content of citrus fruit, which is roughly 80% sugars (Lado et al., 2014). The TSS contents of the orange juice in this investigation slightly increased as storage progressed but were not significant with the extension of storage time (Table 3). However, there was an interaction effect of the treatments investigated on the TSS of the juice of the oranges. The initial TSS was 10.2% brix for the oranges and increased to 12.4% brix for unsealed fruits on the ninth week of the experimental period. Oranges sealed with micro-perforated PPE bags had a TSS of 12.2% brix at the end of storage (Table 3.4). Fruit sealed with BOPP bags had a slight increase in TSS, but not as compared to those fruit packaged in micro-perforated PPE bags and shrink-wrap fruits, which had a TSS value increased to 1.02% brix at the end of storage. This result agreed with the finding of Habibi et al. (2021), who observed a slightly increased TSS of blood orange cultivars stored at different temperatures due to the reduction in sugars. In this current study, non-packaged orange fruit had the highest TSS contents, which was an indication of maturation, and this could be due to the conversion of organic acids to sugars by glycolytic enzymes (Rapisarda et al., 2008).

TA gradually decreased for all treatments during storage at both storage temperatures and treatments and control (Table 4). Although fruit stored at 4ºC had a higher TA level compared to 20±2ºC, there was no significant effect of the treatments on the TA of fruit. The TA of fruit decreased during storage in unsealed oranges (control fruit) and those sealed and stored at the same temperature conditions. The TA of fruit on day zero was 1.21% citric acid in the experiment and gradually decreased to 1.12% citric acid on the ninth week for unsealed oranges. The juice of the oranges sealed with micro-perforated PPE had the lowest TA. The mean values of this treatment decreased significantly ($p < 0.05$) from about 1.21% citric acid at the beginning of the experiment to about 0.94% citric acid, compared to those oranges sealed with BOPP bags which had an average TA of 1.04% citric acid. TA of oranges sealed with shrink-wrap films was lower than non-wrap oranges held at the same conditions of storage at the close of the experiment. However, it was observed that storage conditions had no significant effect on the TA of sweet oranges. Fruits of 'Minneola' tangelo wrapped with three '' permeabilities and stored at 20±2°C and 60% RH were reported to have delayed changes in characteristics of juice TA and TSS (D'Aquino et al., 1998).'' The TA level of fruit relates to the concentrations of organic acids, which are important components of citrus fruit juice, and their amount is different among species and cultivars of citrus fruit (Duarte et al., 2012). It has been shown that senescence of citrus fruit at prolonged storage is attributed to the reduction of organic acids (Summo and De Angelis, 2022). In this study, the reduction of TA of fruit at 20±2ºC was greater than at 4ºC, probably due to alcoholic fermentation at a lower temperature (Rapisarda et al., 2008).

Table 3: Total soluble solid (ºBrix) of Mandarins packaged in plastic films, stored at different times and temperatures. Fruits were packaged with different plastic films at similar thicknesses. The means in the columns and rows in the table that share similar letters indicate insignificant differences.

Weeks at temperatures	Films treatments				Mean
	Control fruit	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	10.2				
4 W at 4ºC	11.2	11.0	10.3	10.6	10.8[c]
4 W + 1 W at 20ºC	12.3	11.9	10.4	10.5	11.3[b]
8 W at 4ºC	11.5	11.1	10.2	10.9	10.9[c]
8 W + 1 W at 20ºC	12.4	12.2	11.0	11.3	11.7[a]
LSD (p ≤0.05)	*0.4*				*0.4*
Mean	12.7[b]	13.4[a]	13.1[a]	13.3[a]	

Table 4: Titratable acidity (% citric acid) of Mandarins packaged in plastic films, stored at different times and temperatures. Fruits were packaged with different plastic films at similar thicknesses. The means in the columns and rows in the table that share similar letters indicate insignificant differences.

Weeks at temperatures	Films Treatment				Mean
	Control fruit	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	1.21				
4 W at 4ºC	1.16	1.03	1.07	1.05	0.99[a]
4 W + 1 W at 20ºC	1.08	0.90	1.05	1.04	1.04[a]
8 W at 4ºC	1.15	1.00	1.06	1.02	1.06[a]
8 W + 1 W at 20ºC	1.12	0.94	1.04	0.97	1.02[a]
LSD (p ≤0.05)	*0.07*				*0.07*
Mean	1.13[a]	0.99[c]	1.06[b]	1.02[bc]	

Fruit peel colour changes

The peel color of citrus fruit is one of the most important key quality attributes that influence consumer acceptance in the citrus industry. It has been reported that the peel color of citrus species and cultivars is the result of three main groups of pigments, which include anthocyanins, chlorophylls, and carotenoids (Rodrigo et al., 2013). The carotenoid group provides yellow color in mandarins and oranges and is mainly restricted to the flesh (Rodrigo et al., 2013). Therefore, the differential accumulation of these pigments can create color diversity in citrus fruit (Rodrigo et al., 2013). In the current study, the hº value slightly decreased during storage at both temperatures. Oranges were unpacked (control fruit) and packed with different plastic films and stored at 4ºC or 20±2ºC. The hue (hº) angle increased significantly (60 to 64.7º) for the control, while fruits packed in macro-perforated PPE bags slightly decreased in value to 63.6º of the oranges evaluated (Table 5). However, oranges packed with BOPP bags had a significant ($p < 0.05$) increase in the hº angle from 60 to 66.7º. There was also an increase in the hº angles from 60 to 64º of oranges packaged in shrink wraps on the ninth week of storage (end of storage) as shown in Table 5. These increases in hº value exhibit actual perceived color, including the orange or green color, and are the primary variables in changes in orange color. The hº is considered the color index with value ranges of red (0 or 360º), blue (270º), green (180º), and yellow (90º) colors (VanWyk et al., 2009). In our study, hº values were between 60 and 67º, and this color range is orange-yellow to yellow as assessed in all samples. The control and fruit packaged in BOPP bags were found to have the highest and the lowest hº values, respectively, at both storage temperatures.

Table 5: Effect of plastic films, storage time, and temperatures on the hue⁰ on mandarins during long-term storage. Fruits were packaged with different plastic films at similar thicknesses. The means in the columns and rows in the table that share similar letters indicate insignificant differences.

Weeks at temperatures	Control fruit	Films treatment			Mean
		Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	60				
4 W at 4ºC	64.2	63.3	62.4	63.2	63.3[b]
4 W + 1 W at 20ºC	65.0	64.2	63.5	63.7	64.1[a]
8 W at 4ºC	64.5	63.4	62.6	63.5	63.9[ab]
8 W + 1 W at 20ºC	64.7	63.6	64.1	63.4	64.0[a]
LSD (p ≤0.05)	*0.7*				*0.7*
Mean	64.6[a]	63.6[b]	63.2[b]	63.5[b]	

Rot incidence

Oranges packaged with plastic films prevented fruit decay under both temperature conditions compared to non-sealed oranges for the storage regime. Packaging with BOPP films significantly ($p < 0.05$) reduced the decay of fruit to 5% for 9 weeks, while control fruit had 25% rot incidence (Fig. 1). Decay is caused by *P. digitatum*, and rarely, other pathogens such as *P. italicum* (Palou et al., 2008). Inhibition of decay incidence with fruit with shrink wrap was also very drastic but not as significant as for BOPP films. However, the rot incidence of untreated fruit was significantly high at all storage conditions. This is inconsistent with the reports by Ben-Yehoshua et al. (1987), who showed that about 10% decay occurred for untreated fruit kept at 17°C for a month. Studies have shown that citrus fruit in sealed plastics and kept at higher temperatures delayed fungal development (Baudoin and Eckert, 1985). Moreover, Ben-Yehoshua et al. (1987) demonstrated that sealing oranges with either film of HDPE, Cryovac D-950, or Cryovac MPD inhibited the development of *Penicillium* decay, even at 17°C. But in a side experiment, non-sealed lemons cured at 30°C developed more decay (up to 72%) than the non-cured fruit (Ben-Yehoshua et al., 1987), which is in agreement with the result of this present study, where the percentage decayed of sealed and non-sealed fruit held at 20±2°C was more than fruit at lower storage temperatures. In contrast, fruits of 'Minneola' tangelo wrapped with three plastic films of different permeabilities and stored at 20°C and ≤60% RH were reported to have delayed fruit decay (D'Aquino et al., 1998). Although not enough data are yet available to explain the mode of action of film packaging in reducing decay, two factors can be mentioned. First, seal-packaging as well as a water-saturated atmosphere have demonstrated to delay senescence and maintain the integrity of cellular membranes (Ben-Yehoshua et al., 1983). Furthermore, sealing citrus fruit with films as well as a water-saturated atmosphere accelerated the healing of minor peel injuries (Golomb et al., 1984) and reduced peel blemishes (Ben-Yehoshua et al., 1982).

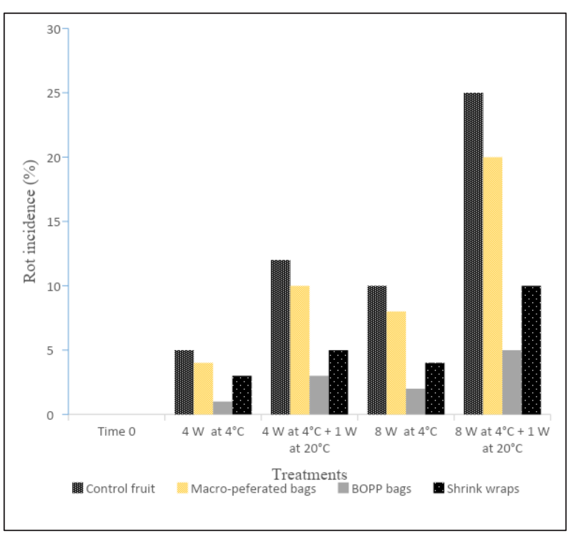

Fig. 1: Effect of plastic films, storage time, and temperatures on the taste of Mandarins during long-term storage. Fruits were packaged with different plastic films at similar thicknesses and stored at 4ºC or 20±2ºC from 4 to 9 weeks.

Sensory and flavour acceptability

The results showed a significant effect ($p < 0.05$) of plastic film packaging, storage time, and temperature on the organoleptic value of fruit taste. The taste decreased in both fruits packaged in plastic films and control fruit as the storage period prolonged. Fruits sealed-packaged with BOPP film and held at 4°C for four weeks were scored highest by the panelists compared to the other treatments and control fruit. Unsealed fruit stored at increased temperatures was rated lower by tasters at the end of storage (Fig. 2). As expected, the combined effect of sealing and exposure to relatively high temperatures adversely affected the altered internal atmosphere of fruit and resulted in a lower flavor rating of fruit to a larger extent. The combination effects of sealing and storage at high temperatures for extended periods caused both injury and off-flavors of fruit, which is in agreement with the report that increased storage temperature reduced the orange-like flavor of oranges and increased the presence of off-flavors over storage, thus adversely impacting the sensorial quality of Valencia Late Frost oranges stored at temperatures ≤25ºC for 4 weeks of storage (Marcilla et al., 2006). However, our result is in contrast with the observation by Ben-Yehoshua et al. (1986), who demonstrated that seal packaging has less effect in impeding internal gas exchange during prolonged storage of a range of citrus fruit.

In our study, the panelists were untrained and unable to differentiate between sweetness and sourness as separate tastes, despite both flavors potentially interacting with each other. The flavor-acceptance score of oranges at day zero was 9 on a scale of 1 to 9, and it decreased to 5 at 8 weeks at 4ºC plus 1 week at 20±2ºC of storage for BOPP bags fruit, which is the best-performing plastic film package. For control fruit, it declined from 9 to 2 at 8 weeks at 4ºC plus 1 week at 20±2ºC of storage (Fig. 3). It was only after 4 weeks of storage that we observed a significant decrease in flavor acceptability, only in control fruit and Macro-perforated bags, but more pronounced when fruit was moved from cold storage to ambient storage for another week (4 weeks at 4ºC + 1 week at 20±2ºC). This result demonstrates that increased storage temperature in the present study reduced the orange-like flavor of oranges and increased the presence of off-flavors over storage, thus tasters scored fruit stored under those conditions low. This decline agreed with the results of a reported study in Valencia Late Frost oranges stored at a temperature ≤25ºC for 4 weeks of storage (Marcilla et al., 2006). In this investigation, thirty (30) of the tasters representing 75% highly rated oranges packaged with BOPP bags as the fruit with the best flavor compared to the citrus packaged with other films and stored under the same conditions, as demonstrated in Figure 3. It is interesting that the combined effect of sealing and exposure to relatively high temperatures did not adversely alter the internal atmosphere of fruit and affect the flavor and, by extension, consumer acceptance.

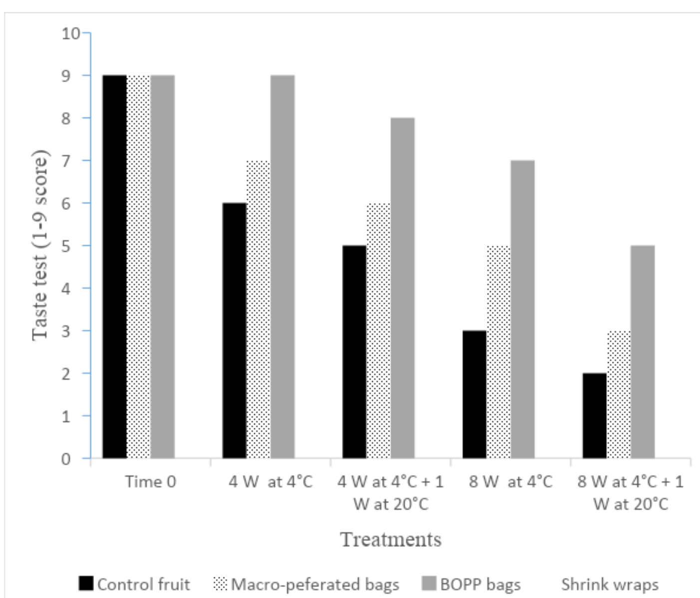

Fig. 2: Effect of plastic films, storage time, and temperatures on the taste of oranges during long-term storage. Fruits were packaged with different plastic films at similar thicknesses and stored at 4ºC or 20±2ºC from 4 to 9 weeks.

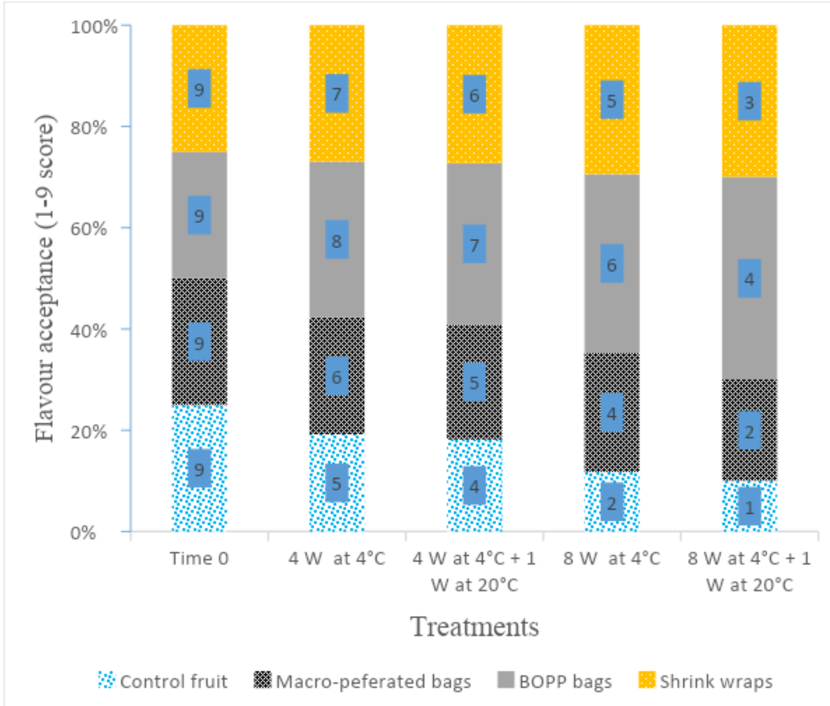

Fig. 3: Effect of plastic films, storage time, and temperatures on flavor acceptance of oranges during long-term storage. The fruits were packaged with different plastic films of similar thickness and stored at 4ºC or 20±2ºC for 4 to 9 weeks.

CONCLUSIONS

Comparative evaluation of the effects of different plastic films and storage conditions on the quality and storage life of oranges, as observed in the present study, reveals that packaging oranges in BOPP plastic films and storing them at low temperatures reduces weight loss and changes in peel color, thus maintaining the external quality of the fruit. The chemical attributes of the juice were better at 4ºC. Additionally, our study developed a variety-specific protocol for selecting the best packaging based on physiochemical attributes for fresh consumption during long-term storage. Oranges sealed and packaged in plastic films maintained better firmness, taste, and aroma acceptance compared to control fruit, but the highest firmness, flavor acceptance score, and taste score were observed in fruit sealed with BOPP bags under both storage conditions. Packaging with BOPP films significantly delayed fruit decay for up to 9 weeks, while control fruit showed significant decay. There was significant variation among all packaged and non-sealed fruits under different storage conditions. Overall, fruit packaged in BOPP bags and kept at 4ºC storage was considered the optimum treatment for sweet oranges.

Author contributions

NA: Conceptualization, methodology, investigation, and writing of the original draft. **AA**: Editing and writing of the final manuscript. **TM:** Data analyses and editing of the manuscript. All authors have read and agreed to the publication of this paper.

Conflict of interest

The authors declare that they have no conflict of interest.

Data availability statement

Data from this research is available within the text of the paper.

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