

Influence of Different Plastic Film Packaging on the Physiological and Sensory Quality of Sweet Oranges (*Citrus Sinensis*) 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 9-week storage at 4°C or ambient (20±2°C). The oranges were seal-packaged with perforated PPE films and BOPP bags, and another group was shrinked-wrapped in films and another as control. Oranges packaged with BOPP bags had the lowest weight loss at both cold storage (4°C) and ambient (20±2°C) relative to other packaged and control, while TA declined with an increase in TSS. Fruit sealed and packaged in plastic films preserved fruit firmness, taste, and flavour compared with control fruit. However, the highest firmness (29.5N), taste score (9.0), and flavour 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 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

INTRODUCTION

Citrus fruits (*Citrus Sinensis*) are one 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 only second 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 mostly consumed varieties for their high vitamin C and for their good flavour. However, fresh orange fruit 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 2,4-D treatments are widely used in the citrus postharvest industry (D'Aquino *et al.*, 2013; Hao *et al.*, 2010). But the 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-keeping quality and with no 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-Arauz *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 0°C) 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-flavour and off-odours 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 are highly susceptible to moisture loss due to the presence of micro-cracks that allow free movement of water from their surface (Khanal *et al.*, 2021). 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 at 8°C storage, and improved the overall quality. In another study, Selcuk and Eckan (2014) reported a prolonged storage period of up to 4 months at 6°C, resulting in decreased total anthocyanin concentration in fruit treated with MAP. Similarly, it has been reported that individual seal packaging has extended shelf-life and reduced water loss, and 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 of orange fruits has been reported (Erkan *et al.*, 2005; Palma *et al.*, 2013; Sajid *et al.*, 2013), while 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-flavours in citrus to the induction of ethanol fermentation metabolism and 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 the 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 flavour acceptability and the accumulation of off-flavour

(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. In this study, film packaging was to delay quality losses and the decay development of sweet oranges stored for 4 or 8 weeks at 4°C, plus seven (7) days at room temperature. 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 fruit were obtained from a commercial supplier. The fruit was immediately transported to the postharvest laboratory of Dr. Hilla Limann Technical University, checked for defects or rind injuries, disinfected with 2% sodium hypochlorite solution, and rinsed with water. The fruit was divided into sets of three replicates of 30 fruit for each replicate. Some of the fruits were seal-packaged with perforated PPE films and BOPP bags while another group was shrinking PPE films. Fruit that was non-sealed or shrink-wrapped was used as a control in the study. The films were purchased from a 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 relative humidity of 75-80% for 4 and 8 weeks and subsequently transferred to shelf life (20±2°C) and 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;

$$\text{Weight loss} = \left(\frac{W_0 - W_1}{W_0} \right) \times 100\%$$

Measurement of fruit firmness

The fruit firmness was evaluated by 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 fruit, and the data was reported in Newton (N).

Evaluation of total soluble solids and titratable acidity

The total soluble solids were determined by using a 0-32% Brix meter refractometer (DFT-HY-DF1-EN-P, China), and data expressed in percentage brix (%brix). The titratable acidity was determined by titrating 10ml of the orange juice with NaOH 0.1 N to pH 8.2, as an endpoint (orange colour) 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 colour changes

The peel colour of fifteen (15) orange fruit were determined by 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 colour 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; $h^\circ = \text{Arctan } b^* / a^*$.

Evaluation of sensory quality

Sensory analysis was conducted at Dr. Hill Limann Technical University Postharvest Technology Laboratory. Organoleptic parameters such as taste test (mouth feel) 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 males and the other 20 females aged 25-40. The consumers' level of sensory evaluation was untrained panelists. Judgments taste tests were made 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 of 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 fruit and were assigned identification numbers. The fruit samples were prepared in a room ($\leq 25^\circ\text{C}$) 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 data was statistically analysed using analyses of variance (ANOVA). A statistical analytical software (SAS) version 9.4, and the comparison of means were conducted by the least significant difference (LSD) test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Weight loss

The weight loss of fruit increased in all treatments as storage temperatures and times increased. Weight loss was significantly ($p < 0.05$) higher in unsealed fruits (control fruit). 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 lose 2.99% of weight. This agreed with the observation of Ben-Yehoshua *et al.* (1987), where non-sealed 'Shamouti' fruit kept at temperatures $\geq 30^\circ\text{C}$ for 3 days lost weight rapidly, shrunk, and softened much faster than

sealed fruit kept at 17°C or $\geq 30^\circ\text{C}$ (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 3.1. 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	Films treatment				Mean
	Control	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	0.0				
4 W at 4°C	2.07	1.79	0.69	0.72	1.32 ^c
4 W + 1 W at 20°C	3.30	2.47	0.99	1.08	1.96 ^{ab}
8 W at 4°C	2.78	2.68	0.85	0.95	1.82 ^{bc}
8 W + 1 W at 20°C	4.21	3.01	1.31	1.34	2.47 ^a
LSD ($p \leq 0.05$)	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 4°C had less firmness loss when compared with those fruit held at $20 \pm 2^\circ\text{C}$. 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. 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. Fruits sealed with shrink wrap had less decrease in firmness during the storage period. For fruits packaged with BOPP bags, loss in firmness was more than that for fruits packaged with shrink wrap but less than those sealed with micro-perforated bags at the end of the storage period. Similarly, a study demonstrates that ‘Minneola’ tangelo wrapped with three plastic films of different permeabilities and stored at $20 \pm 2^\circ\text{C}$ and $\leq 60\%$ 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 3.3. 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 fruit	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
Day 0	34.5				
4 W at 4°C	26.3	28.6	33.4	30.1	29.6 ^a
4 W + 1 W at 20°C	22.4	26.2	30.5	26.4	26.4 ^b
8 W at 4°C	20.1	24.5	28.7	23.2	24.1 ^c
8 W + 1 W at 20°C	19.4	21.5	25.3	22.5	22.2 ^d
LSD ($p \leq 0.05$)	1.2				1.2
Mean	22.1 ^d	25.2 ^c	29.5 ^a	26.6 ^b	

Total soluble solids and titratable acidity

TSS refers to the total amount of soluble constituents of the citrus fruit juice. TSS of fresh fruit is an excellent index to the sugar content of citrus fruit which is roughly 80% of sugars (Lado *et al.*, 2014). TSS contents of the orange juice in this investigation slightly increased as storage progressed but were not significant with the extension of storage time, however, there was an interaction effect of the treatments investigated on 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 with those fruit packaged in micro-perforated PPE bags and shrink-wrap fruits, which had TSS value increased to 1.02% brix at the end of storage. This result agreed with the finding by 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, although fruit stored at 4°C had a higher TA level in comparison with 20±2°C, 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. 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. 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, in comparison with 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 TA 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 plastic films of different permeabilities and stored at $20\pm 2^{\circ}\text{C}$ and 60% RH were reported to have delayed changes in characteristics of juice TA and TSS (D'Aquino *et al.*, 1998). 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 $20\pm 2^{\circ}\text{C}$ was greater than 4°C , probably due to alcoholic fermentation at a lower temperature (Rapisarda *et al.*, 2008).

Table 3.4. Total soluble solid ($^{\circ}\text{Brix}$) 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 4°C	11.2	11.0	10.3	10.6	10.8 ^c
4 W + 1 W at 20°C	12.3	11.9	10.4	10.5	11.3 ^b
8 W at 4°C	11.5	11.1	10.2	10.9	10.9 ^c
8 W + 1 W at 20°C	12.4	12.2	11.0	11.3	11.7 ^a
LSD ($p \leq 0.05$)	0.4				0.4
Mean	12.7 ^b	13.4 ^a	13.1 ^a	13.3 ^a	

Table 3.5. 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 4°C	1.16	1.03	1.07	1.05	0.99 ^a
4 W + 1 W at 20°C	1.08	0.90	1.05	1.04	1.04 ^a
8 W at 4°C	1.15	1.00	1.06	1.02	1.06 ^a
8 W + 1 W at 20°C	1.12	0.94	1.04	0.97	1.02 ^a
LSD ($p \leq 0.05$)	0.07				0.07
Mean	1.13 ^a	0.99 ^c	1.06 ^b	1.02 ^{bc}	

Fruit peel colour changes

The peel colour 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 peel colour of citrus species and cultivars is the result of three main group pigments which include anthocyanins, chlorophylls, and carotenoids (Rodrigo *et al.*, 2013). The carotenoid group provide yellow colour in mandarins and oranges and is mainly restricted to the flesh (Rodrigo *et al.*, 2013). Therefore, the differential accumulation of these pigments can create colour diversity in citrus

fruit (Rodrigo *et al.*, 2013). In the current study, the h^0 value slightly decreased during storage at both temperatures. Unpacked oranges (control fruit) and packed with the different plastic films and stored at 4°C or 20±2°C. The hue (h^0) angle increased significantly (60 to 64.7°) for control, while fruits packed in macro-perforated PPE bags slightly decreased in value to 63.6° of the oranges evaluated. However, oranges packed with BOPP bags had a significant ($p < 0.05$) increase in the h^0 angle from 60 to 66.7°. There was also an increase in the h^0 angles from 60 to 64° of oranges packaged in shrink wraps on the ninth week of storage (end of storage) as shown in Table 3.7. These increases in h^0 value exhibit actual perceived colour including the orange or green colour and is the primary variable in changes in orange colour. The h^0 is considered the colour index with value ranges of red (0 or 360°), blue (270°), green (180°), and yellow (90°) colours (VanWyk *et al.*, 2009). In our study, h^0 values were between 60 and 67°, and this colour range is orange-yellow to yellow as assessed in all samples. Control and fruit packaged in BOPP bags were found to have the highest and the lowest h^0 values respectively, at both storage temperatures.

Table 3.6. 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	Films treatment				Mean
	Control fruit	Macro-perforated PPE bags	BOPP bags	Shrink wraps	
0 day	60				
4 W at 4°C	64.2	63.3	62.4	63.2	63.3b
4 W + 1 W at 20°C	65.0	64.2	63.5	63.7	64.1a
8 W at 4°C	64.5	63.4	62.6	63.5	63.9ab
8 W + 1 W at 20°C	64.7	63.6	64.1	63.4	64.0a
LSD ($p \leq 0.05$)	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 with 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 also was 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 in this experiment that about 10% decay occurred for untreated fruit kept at 17°C for a month. Studies have shown that citrus fruit in seal plastics and kept at higher temperatures delayed fungal development (Baudoin and Eckert, 1985). Moreover, Ben-Yehoshua *et al.* (1987) demonstrated that sealing oranges with whether 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 were 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).

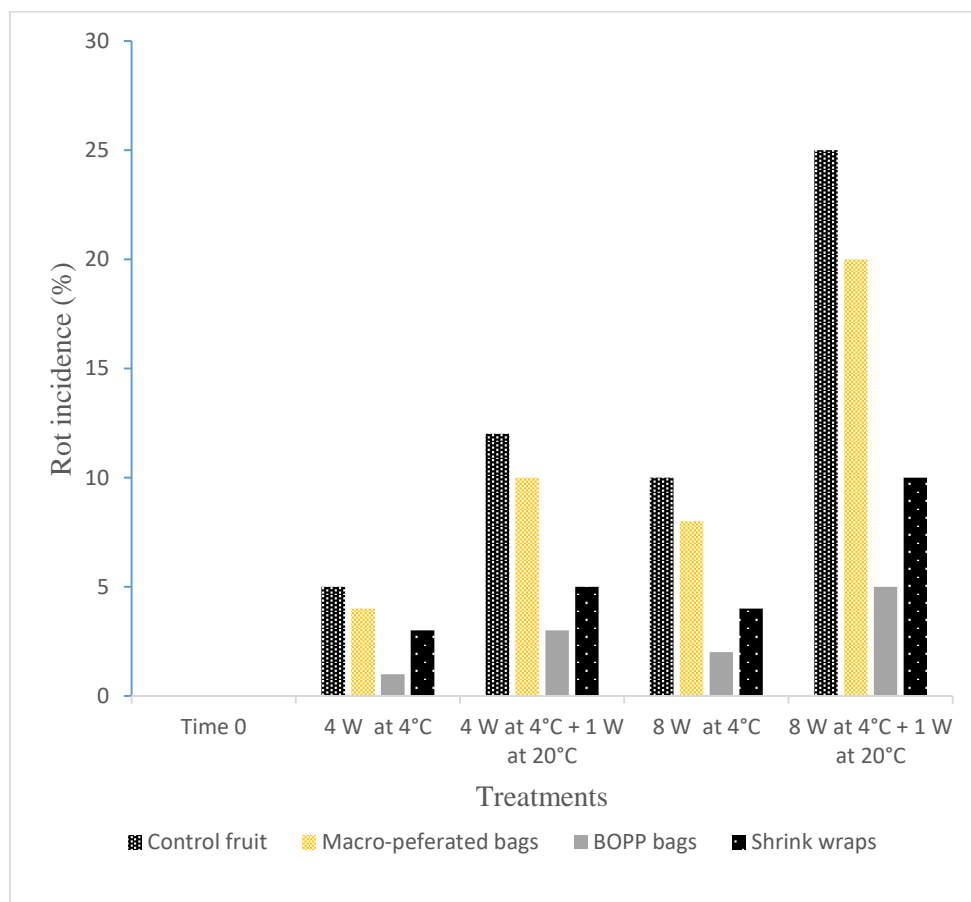


Figure 1. Effect of plastic films, storage time, and temperatures on the taste of Mandarins during long-term storage. Fruits were packaged with different plastic films at similar thicknesses, and stored at 4°C or 20±2°C from 4 to 9 weeks.

Sensory and flavour acceptability

The results showed a significant effect ($p < 0.05$) of plastic film packaging and storage time and temperature on the organoleptic value of the taste of fruit fruits. 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 with the other treatments and control fruit. Unsealed fruit stored at increased temperature 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 did adversely affect the altered

internal atmosphere of fruit and resulted in low flavour 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-flavours of fruits, which is in agreement with the report that increased storage temperature reduced the orange-like flavour of oranges and increased the presence of off-flavours over storage, thus impacting adversely on the sensorial quality of in Valencia Late Frost oranges stored at temperatures $\leq 25^{\circ}\text{C}$ for 4 weeks of storage (Marcilla *et al.*, 2006). Our result, however, is in contrast with the observation of 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 to able to differentiate between sweetness, and sourness as separate tastes despite both flavours may interact with each other. The flavour-acceptance score of oranges at day zero was 9 on a scale of 1 to 9, and it decreased to 5 at 8 W at 4°C plus 1 W at $20\pm 2^{\circ}\text{C}$ of storage for BOPP bags fruit, which is the best-performed plastic film package. For control fruit, it declined from 9 to 2 at 8 W at 4°C plus 1 W at $20\pm 2^{\circ}\text{C}$ of storage (Fig. 3). It was only after 4 weeks of storage, we that observed a significant decrease in flavour 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 W at 4°C + 1 W at $20\pm 2^{\circ}\text{C}$). This result demonstrates that increased storage temperature in the present study reduced the orange-like flavour of the oranges and increased the presence of off-flavours over storage, thus tasters scored fruit stored under those conditions low. This decline agreed with the result of a reported study in Valencia Late Frost oranges stored at a temperature $\leq 25^{\circ}\text{C}$ 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 best flavour compared with 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 flavour and by extension consumer acceptance.

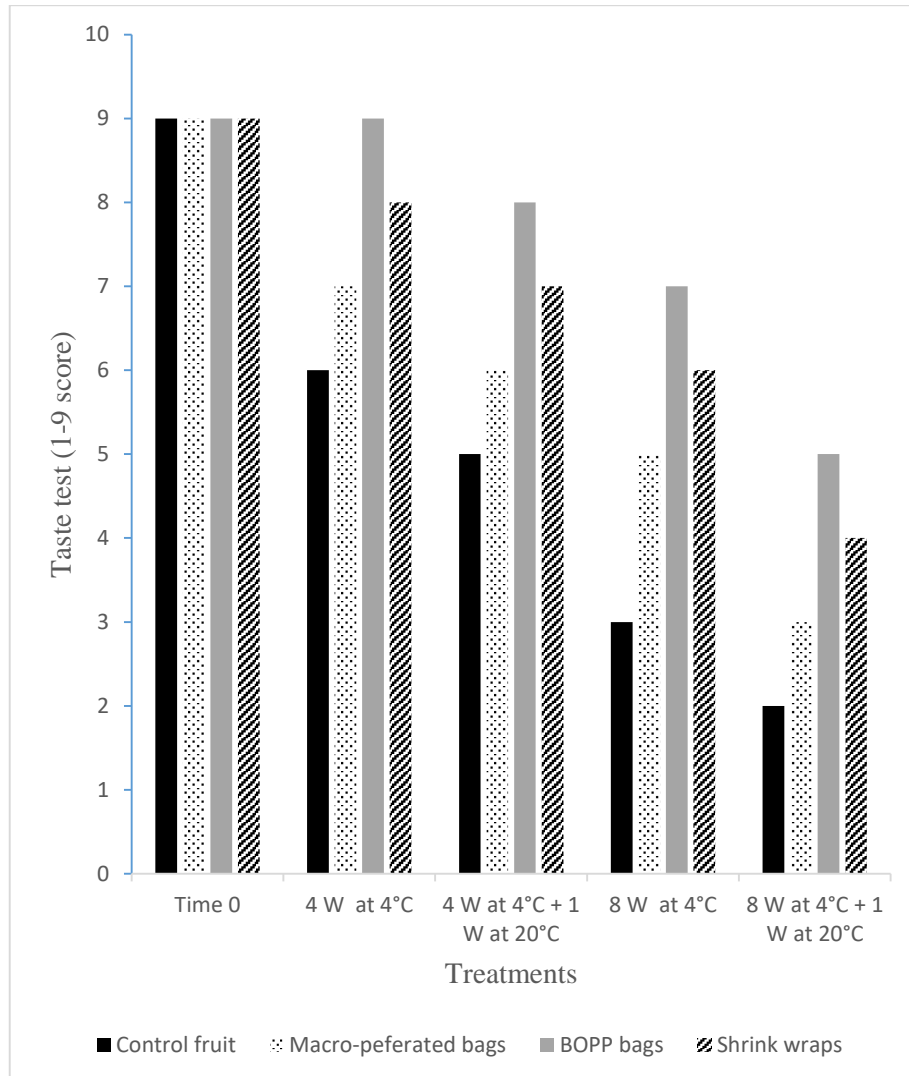


Figure 2. Effect of plastic films, storage time, and temperatures on the taste of oranges during long-term storage. Fruits were packaged with different plastic films at similar thicknesses, and stored at 4°C or 20±2°C from 4 to 9 weeks.

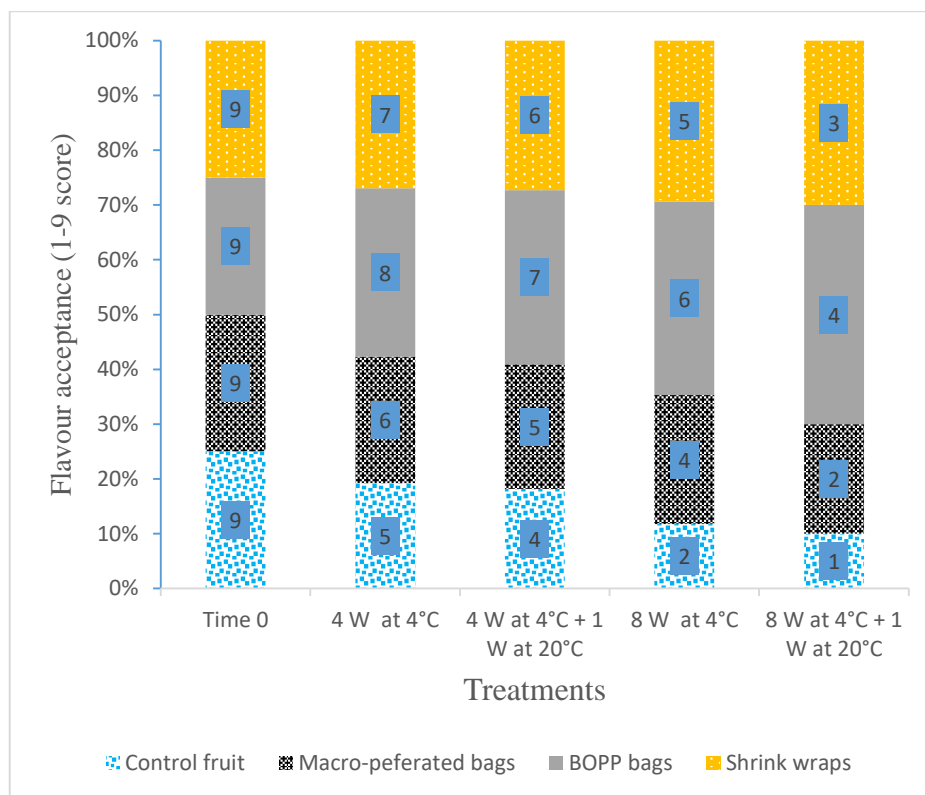


Figure 3. Effect of plastic films, storage time, and temperatures on flavour acceptance on oranges during long-term storage. Fruits were packaged with different plastic films at similar thicknesses, and stored at 4°C or 20±2°C from 4 to 9 weeks.

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 of oranges in BOPP plastic films and storage at low temperatures reduced weight loss and peel colour changes, thus maintain fruit external quality. The chemical attributes of juice were better at 4°C. In addition, our study created a variety-specific protocol for the selection of the best packaging based on physiochemical attributes for fresh consumption during long-term storage. Orange fruit sealed and packaged in plastic films maintained better fruit firmness, taste, and aroma acceptance compared with control fruit, but the highest firmness, flavour acceptance score, and taste score were observed with fruit sealed with BOPP bags at both storage conditions. Packaging with BOPP films greatly delayed the decay incidence of fruit for up to 9 weeks, while control fruit had significant decay. There was a significant variation in all packaged and non-sealed fruits with different storage conditions. Overall, fruit packaged in BOPP bags and kept at 4°C storage was considered as an optimum treatment for the sweet oranges.

AUTHOR CONTRIBUTIONS

N. Alhassan: Conceptualization, methodology, investigation, and writing of the original draft.

A. Abdulai: Editing and writing of the final manuscript. **T. Mohammed:** Data analyses and

editing of the manuscript. All authors reviewed the manuscript to ensure completeness and uniformity with the journal's writing guidelines.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

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

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