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HARNESSING *CITRUS SINENSIS* PEEL EXTRACTS: A NOVEL APPROACH TO EXTENDING SHELF-LIFE AND REDUCING POST-HARVEST LOSSES IN TOMATOES

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ABSTRACT

We previously identified bioactive compounds in orange peels with potential for food preservation The present study investigated orange peel extracts as natural preservatives for tomatoes, which are nutritionally important but highly perishable fruits. Orange peel extracts from three sweet orange varieties were obtained using ethanol and hexane as solvents, and applied at different concentrations (0.5%, 1.0%, and 2.0%) to fresh tomatoes stored at ambient temperature. Quality parameters were assessed every 4 days for 16 days. Results showed preservation efficiency was achieved at 1.0% concentration preserving 37.5% of tomatoes until day 16, while untreated tomatoes completely deteriorated by day 8. This suggests Citrus sinensis peel extracts have significant potential as natural food preservatives. Future research will identify the specific bioactive compounds responsible and assess nutritional impacts. These findings contribute to developing eco-friendly, cost-effective strategies for reducing post-harvest food losses and addressing food security concerns.

KEYWORDS: Citrus Peel Extract, Tomato Storage, Postharvest Preservation, Natural Preservative, Food Security, Value Addition

INTRODUCTION

Tomato (*Solanum lycopersicum*), a member of the Solanaceae family, is a nutrient-dense fruit of significant global importance. Its rich composition of carbohydrates, fats, organic acids, water, minerals, vitamins, and pigments contributes to its nutritional value and widespread consumption. According to the Food and Agriculture Organization (FAO), global tomato production reached 189.1 million metric tonnes in 2021, marking a 2% increase from 2020 and a 4% rise from the 2018-2020 average. Nigeria, ranking as the 11th largest producer worldwide and 2nd in Africa, faces substantial challenges with post-harvest losses exceeding 45% annually (PwC, 2020). The perishable nature of tomatoes, characterized by a short shelf-life of 12-72 hours and high moisture content renders tomatoes susceptible to microbial spoilage (Haile, 2018), poses significant challenges in post-harvest management while compromising both nutritional and market value (Onuorah *et al*., 2015). In developing countries like Nigeria, microbial infestation can occur at various stages from harvest to consumer processing. This perishability complicates transportation and storage, leading to substantial decay before reaching processing facilities or high-demand areas where cultivation is not feasible (Irokanulo et al. 2015).

Long-term consequences of tomato post-harvest losses include increased reliance on imported tomato paste, reduced farmer income and welfare, diminished supply to processing industries, and overall underutilization of the fruit. While various preservation methods exist, including freezing and chemical preservatives, many developing nations lack the infrastructure and resources for cold storage facilities (Banjo *et al*., 2022) or address health implications of long-term use of synthetic additives. To circumvent to these challenges, researchers have intensified efforts to explore plant-based preservatives. The use of plant extracts in food preservation offers several advantages, including cost-effectiveness, accessibility, potential for enhancing economic value, and improved consumer acceptance compared to synthetic alternatives (Hosea *et al*., (2017).

Citrus fruits, particularly oranges, present an opportunity in this context. The industrial production of orange juice generates substantial by-products, with peels and segment membranes accounting for up to 50% of the total fruit weight. Unfortunately, only a small fraction of this waste is recycled for essential oil extraction used in the cosmetic, food and pharmaceutical industries (Domínguez *et al*., 2016), while the majority contributes to environmental pollution (Huang *et al*., 2010). This underutilization of citrus by-products, coupled with the 30-35% annual post-harvest losses in orange production (Agnes *et al.*, 2019), underscores the need for innovative approaches to maximize the utility of citrus fruits and their derivatives. A number of studies have reported the efficacy of various plant extracts in extending shelf life of food products. For instance, Ogo et al., (2019) showed that extract of Neem (*Azadirachta indica*) stabilized cooking oil by reducing lipid peroxidation during a 6-month storage period. Similarly, *Vernonia amygdalina* and *Tridax procumbens* (Ijato *et al*., 2011), Sour sop, and Roselle (Banjo *et al*., 2022) have equally shown potential in food preservation, however, there is a notable gap in research regarding the use of orange peel extracts for

the same purpose. Interestingly, we identified some bioactive compounds in three varieties of sweet orange (Ogo et al., 2024) with potential preservative attributes as previously documented. The aim of the present study was to investigate the preservative potential of *Citrus sinensis* peel extracts on fresh tomatoes, with a focus on extending shelf-life and contribute to addressing challenges associated with tomato post-harvest management.

Materials and Methods

Sample collection

Sweet orange (Citrus sinensis)

Three (3) species of sweet orange were procured from a commercial farm in Gboko Local government area of Benue state, Nigeria. The orange samples were identified as *Citrus sinensis "Valencia"*, *Citrus sinensis "Washington Navel"* and *Citrus sinensis "Thomson"* (locally known as Ibadan Sweet) and transported to the laboratory for analysis.

Tomato fruits

Freshly harvested tomatoes (*Solanum lycopersicum*) were obtained from Benue Vegetable and Fruit farm Ltd, a commercial farm located at Apir in Benue State. The tomatoes were carefully harvested between 9 am to 10 am in the morning. The sampled tomatoes comprised of a mixture of breaker and turning tomatoes with almost uniform shape and colour. They were carefully sorted and grouped into batches for the storage studies.

Sample preparation

Preparation of orange peel powder

The orange fruits were thoroughly washed under tap water, then with distilled water to remove dirt after which they were peeled. The orange peels were spread on aluminum foil paper and oven-dried at 40˚C for 72 hours in hot air until they were completely dried. The dried peels were size reduced with a mortar, and then ground into fine powder using an electronic blender. The samples were labeled appropriately and packed in airtight polyethylene bags for further analysis.

Preparation and analysis of orange peel extracts

The already prepared orange peel powders were extracted with two solvents: ethanol and n-hexane using the Soxhlet extraction method described by Hegazy et al., (2012) and Gotmare et al., (2018) with slight modifications. Exactly 50g of each orange peel powder was extracted with 250 ml of solvent (ethanol or n-hexane) at 40℃ for 5 h. The extracts were filtered through a Whatman No. 2 filter paper to remove any peel particles present. The filtrates were then evaporated to dryness under vacuum at 45°C using a rotary evaporator. The extracts were stored in the refrigerator at 4°C until further use. The orange peel extracts were subjected to GC-MS analysis which identified certain phytochemical constituents, including alkaloids, flavonoids, phenols, saponins, and tannins reputable for preservative properties. Additionally, three different antioxidant assays of the orange peel extracts were previously performed with demonstrable antioxidant capacities as recently reported by Ogo et al. (2024).

Formulation and application of preservatives

The tomato fruits were sorted and washed under running clean water and then with sterile distilled water. The fruits were

subsequently arranged in clusters of eight (8) fruits on a wide work bench labelled according to the number of extract and control. Three different concentrations of 0.5, 1.0 and 2.0% of each of the peel extracts were prepared and applied uniformly but separately on the samples with a hand pump sprayer according to a method previously described (Pilar Hernandez-Munoz et al., 2008). The fruits were then allowed to stand at room temperature (25±2°C) and observed carefully along with untreated samples which were taken as control. All the fruits were stored in an open and safe place free from insects. The storage duration was determined by observing the time taken for deterioration to occur in any group.

Determination of moisture content

The moisture content of the tomato was determined using the method described by AOAC (2005) with slight modifications. Two grams (2 g) of each sample was weighed accurately into a pre-weighed, clean and dry crucible dish. The crucible was oven-dried at 103°C for 4 h after which it was transferred to a desiccator at room temperature to cool for 30 minutes and weighed immediately. The percentage moisture was calculated using the equation (1):

$$\%\, Moisture\ content\ = \frac{W_1 - W_2}{W_1 - W_0} \times 100 \qquad \text{Eqn. (1)}$$

W_0 =Weight of empty crucible (g)
W_1 =Weight of crucible+sample before drying (g)
W_2 =Weight of crucible+sample after drying (g)

Determination of pH

The pH of the tomato samples was carried out by first homogenizing the fruits separately using a ceramic mortar to obtain the fruit juice. A pH meter was used to measure the pH value of the fruit juice according to (Brishti *et al.,* 2013; Islam T. *et al*., 2018). The pH meter was calibrated with deionized water and the electrode was placed in the sample for approximately 1-2 minutes. Readings were taken and the procedure repeated to obtain replicate measurements.

Determination of total soluble solids

Total soluble solids (TSS) content of tomato pulp was estimated using Abbe's refractometer. A drop of tomato juice squeezed from the fruit pulp was placed on the prism of the refractometer and TSS was recorded as °Brix from a direct reading of the instrument (Sinha *et al*., 2019). Temperature corrections were made using the temperature correction chart. Readings were taken in triplicate at every four (4) days interval.

Determination of colour/firmness

The colour and firmness of the fruits were assessed by a panel that consisted of 10 semi-trained members selected randomly from the Department of Chemistry, Benue State University. The tomato fruits were assessed by visual analysis using a colour and firmness scale with each panel member filling a questionnaire to record their observations according to method described by (Brishti *et al*., 2013). The changes in the color of tomato were determined using a numerical rating scale of 1–7, where 1 = green, 2 = breaker, 3 = turning, 4 = pink, 5 = light red, 6 = red, 7 = ripe red (Wills *et al.,* 2004). The firmness of tomato fruit was determined by hand feel using a numerical

rating scale of 1–6, where 1 = hard, 2 = sprung, 3 = between sprung and eating ripe, 4 = eating ripe, 5 = overripe, and 6 = rotten.

Determination of Disease Infestation

Plant disease infestation refers to the number of plant units that are (visibly) diseased, usually relative to the total number assessed (Khandaker *et al*., 2009). In this case, eight (8) tomato fruits from each treatment group were assessed for visible signs of disease after every 4 days throughout the duration of storage. The disease incidence was calculated using equation 2 below:

$$\text{Disease infestation (\%)} = \frac{\text{Number of infected fruits}}{\text{Total number of fruits at every date}} \times 100 \quad \text{Eqn. (2)}$$

Determination of weight loss

Weight loss considered as an indicator of quality of the fruits was also measured every 4- day interval using a digital balance (Brishti et al., 2013). The fruits were stored for 16 days and finally, cumulative weight loss was calculated. The weight loss of fruits was calculated using equation 3.

$$\text{Weight Loss (\%)} = \frac{\text{Weight}_{final} - \text{Weight}_{Initial}}{\text{Weight}_{final}} \times 100 \quad \text{Eqn. (3)}$$

Where, Weight initial = Initial weight of a fruit (g)
Weight final = Weight after 4 days (g)

Statistical analysis

All experiments were performed in triplicate unless otherwise stated. Results of the replicates are expressed as mean ± standard error (SEM). One-way analysis of variance (ANOVA) with Duncan multiple comparisons test were used to evaluate differences between means in each experiment. Data were considered statistically significant with p-value ≤ 0.05.

RESULTS AND DISCUSSION

Effect Citrus sinensis peel extracts of on shelf life of fresh tomatoes

The shelf life of tomato fruits as influenced by post-harvest treatment with extracts from peels of *citrus sinensis* was monitored and calculated by counting the days required to ripen fully with retained optimum marketing and eating qualities. As can be seen in figure 1 below, tomato samples that were not treated with peel extract got deteriorated just 4 days after storage, while treated samples had extended shelf life up to day 16.

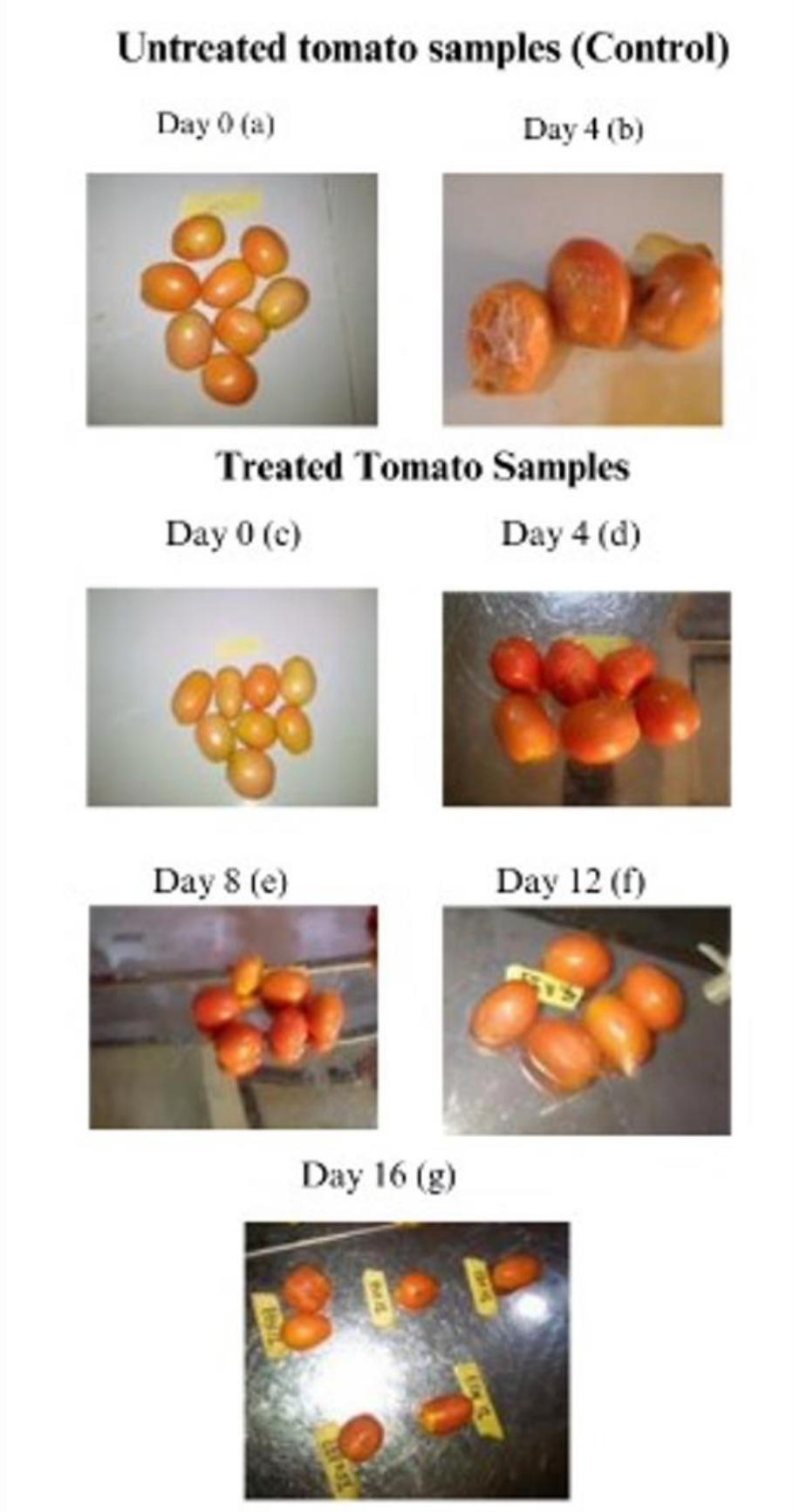


Figure 1: ***Effect of Citrus sinensis extracts on the shelf life of fresh tomatoes.***

Freshly harvested tomatoes were grouped into random clusters of 8 pieces and treated with ethanol and hexane extracts from three varieties of *citrus sinensis* at concentrations of 0.5%, 1.0%, and 2.0%. Both treated and untreated tomatoes were stored at room temperature and observed for signs of deterioration over a period. Untreated samples (control) by day zero were firm and appeared between pink and turning (a) while by day 4, the samples had fully ripened turning red with samples losing firmness and acceptable quality attributes (b). Comparatively, slight signs of deterioration only appeared by day 8 to 12 (d and e) for treated samples where only a single tomato or two were affected with majority lasting up to day 16 and still maintaining some freshness (f). Effective preservative ability was observed for samples treated with ethanol extract at the concentration of 1.0%.

Effect of Citrus sinensis peel extracts on moisture content of stored tomatoes

The result of moisture content of tomato fruits treated with different concentrations of orange peel extracts observed after every 4 days is presented in table 1. The highest moisture content was 97.56% recorded in $EEV_{2.0}$ on day 4 of the storage, whereas the lowest moisture content of 79.83% was measured in $HEW_{2.0}$ on day 12. Generally, the moisture content values of the fresh tomato fruits were consistent with previously documented values of 94.40% recorded by Sohail et al. (2022) and 94.14% by Opadotun et al. (2018). However, the moisture content was higher, but not significantly different ($p > 0.05$) relative to 90% for fresh tomatoes recommended by Adebanwo et al. (2002). Furthermore, the moisture content is observed to steadily increase from day 8-12, and then decrease at day 16. This may be due to release of moisture from the protoplasm of the fruits followed by loss to the surrounding environment since the fruits were exposed.

Table 1: Moisture content of tomato fruits stored from Day 4-16 post treatment

Sample	**Moisture Content (%)**			
	Day 4	**Day 8**	**Day 12**	**Day 16**
$EEV_{0.5}$	$92.37^{c}\pm0.24$	$95.35^{b}\pm0.02$	$96.20^{f}\pm0.10$	$95.75^{c}\pm0.05$
$EEV_{1.0}$	$95.26^{e}\pm1.30$	$94.11^{a}\pm0.01$	$95.63^{f}\pm0.62$	$95.35^{b}\pm0.05$
$EEV_{2.0}$	$97.56^{f}\pm2.02$	$95.87^{c}\pm0.73$	$95.59^{f}\pm0.06$	$94.40^{a}\pm0.15$
$EEW_{0.5}$	$95.62^{e}\pm0.44$	$95.68^{c}\pm0.01$	$95.03^{d}\pm0.08$	$95.49^{b}\pm0.02$
$EEW_{1.0}$	$83.34^{a}\pm2.96$	$95.70^{c}\pm0.03$	$95.40^{d}\pm0.03$	$95.03^{b}\pm0.06$
$EEW_{2.0}$	$93.48^{d}\pm5.97$	$96.23^{c}\pm0.03$	$96.17^{f}\pm0.04$	$95.11^{b}\pm0.05$
$EEI_{0.5}$	$92.07^{a}\pm3.61$	$96.33^{c}\pm0.01$	$91.52^{b}\pm5.76$	$95.83^{c}\pm0.07$
$EEI_{1.0}$	$92.18^{c}\pm1.43$	$95.94^{c}\pm0.02$	$95.38^{d}\pm0.04$	$95.26^{b}\pm0.07$
$EEI_{2.0}$	$85.62^{a}\pm3.54$	$95.01^{b}\pm0.70$	$95.30^{d}\pm0.07$	$96.76^{d}\pm0.01$
$HEV_{0.5}$	$96.63^{f}\pm0.44$	$95.76^{c}\pm0.02$	$95.08^{d}\pm0.06$	$95.29^{b}\pm0.02$
$HEV_{1.0}$	$93.75^{d}\pm2.18$	$95.09^{b}\pm0.03$	$95.07^{d}\pm0.98$	$94.26^{a}\pm1.44$
$HEV_{2.0}$	$88.34^{a}\pm0.76$	$95.27^{b}\pm0.36$	$96.47^{f}\pm0.06$	$93.91^{a}\pm0.77$
$HEW_{0.5}$	$94.39^{d}\pm5.08$	$96.07^{c}\pm0.10$	$95.26^{d}\pm0.04$	$94.21^{a}\pm0.24$

$HEW_{1.0}$	94.89^{de}±2.27	93.92^{a}±2.84	95.72^{f}±0.02	94.84^{b}±1.19
$HEW_{2.0}$	90.27^{b}±4.87	96.81^{d}±0.37	79.83^{a}±0.01	94.85^{b}±0.01
$HEI_{0.5}$	86.33^{a}±2.40	94.67^{b}±0.03	96.36^{f}±0.01	96.40^{c}±0.01
$HEI_{1.0}$	85.08^{a}±2.84	95.17^{b}±0.05	93.74^{c}±0.02	96.20^{c}±0.06
$HEI_{2.0}$	90.65^{b}±8.33	97.29^{d}±0.03	96.24^{f}±0.04	96.07^{c}±0.03
Control	90.54^{b}±0.44	96.13^{b}±0.01	-	-

Values within the same column with the same superscript are not significantly different at $p > 0.05$.
Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5 = Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI2.0= Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

Effect of *Citrus sinensis* peel extracts on pH of stored tomatoes

The pH values of treated tomato samples as shown in table 2 ranged from 5.23 to 6.77 from day 4 to day 16 of storage. The result showed a significant increase ($p < 0.05$) during the 16-day storage period in the untreated fruits; however, no significant difference ($p > 0.05$) was observed among treated groups. This finding agrees with previous observations by García et al., 2014 and Mai Al-Dairi et al., 2021 who found pH of tomatoes in acidic region although the values in the present study are slightly higher than those obtained in the aforementioned studies. The difference may be as a result of a number of factors such as ripening/respiration of the tomato fruits, environmental temperature and number of days of storage. This assertion may be collaborated by the report of Abera *et al*., 2013 who observed that tomatoes stored at 22℃ and above had higher pH values compared to those stored at lower temperatures. Furthermore, effect of oxygen increments according to Dhital *et al*., 2018 may also be responsible for high values in pH during storage of fresh tomatoes.

Table 2: pH of tomato fruits at different days of storage

Sample	**pH**			
	Day 4	**Day 8**	**Day 12**	**Day 16**
$EEV_{0.5}$	5.87^{cd}±0.06	5.80^{b}±0.10	6.20^{a}±0.17	6.47^{b}±0.06
$EEV_{1.0}$	5.63^{cd}±0.06	6.00^{b}±0.10	6.57^{b}±0.06	6.20^{a}±0.00
E $EV_{2.0}$	5.73^{cd}±0.15	5.83^{b}±0.06	6.20a±0.00	6.20^{a}±0.00
$EEW_{0.5}$	5.60^{cd}±0.10	6.23^{b}±0.06	6.10^{a}±0.00	6.57^{b}±0.12
$EEW_{1.0}$	5.80^{cd}±0.00	5.90^{b}±0.00	6.20^{a}±0.00	6.47^{b}±0.06
$EEW_{2.0}$	5.23^{a}±0.06	6.03^{b}±0.12	6.40^{a}±0.00	6.50^{b}±0.10
$EEI_{0.5}$	5.73^{cd}±0.06	5.60^{b}±0.00	6.10^{a}±0.00	6.57^{b}±0.06
$EEI_{1.0}$	5.73^{cd}±0.06	6.03^{b}±0.06	6.30^{a}±0.00	6.43^{b}±0.15
$EEI_{2.0}$	5.63^{cd}±0.06	5.97^{b}±0.06	6.30^{a}±0.17	6.63^{b}±0.06
$HEV_{0.5}$	5.73^{cd}±0.06	5.87^{b}±0.06	5.97^{a}±0.06	6.33^{a}±0.06
$HEV_{1.0}$	5.77^{cd}±0.06	5.90^{b}±0.00	6.17^{a}±0.06	6.13^{a}±0.06

$HEV_{2.0}$	5.70^{cd}±0.00	5.37^{a}±0.06	6.70^{a}±0.10	6.70^{b}±0.10
$HEW_{0.5}$	5.47^{b}±0.06	5.73^{b}±0.06	6.47^{b}±0.06	6.50^{b}±0.00
$HEW_{1.0}$	5.63^{cd}±0.06	5.90^{b}±0.00	6.43^{b}±0.06	6.63^{b}±0.12
$HEW_{2.0}$	5.60^{cd}±0.10	5.77^{b}±0.06	6.80^{c}±0.00	6.63^{b}±0.15
$HEI_{0.5}$	5.80^{cd}±0.00	5.90^{b}±0.00	6.90^{c}±0.10	6.53^{b}±0.06
$HEI_{1.0}$	5.63^{cd}±0.06	5.80^{b}±0.10	6.37^{a}±0.29	6.13^{a}±0.06
$HEI_{2.0}$	5.53^{b}±0.06	5.93^{b}±0.06	6.37^{a}±0.29	6.63^{b}±0.06
Control	5.70^{cd}±0.01	6.77^{c}±0.33	-	-

Values within the same column with the same superscript are not significantly different at $p < 0.05$.

Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5= Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI 2.0 = Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

Effect of Citrus sinensis peel extracts on Total Soluble Solids (TSS) of stored tomatoes

The result of total soluble solids (TSS) in tomato samples are as reported in table 3. It was observed that TSS increased significantly ($p < 0.05$) from 2.70 on day 4 to 9.03 °Brix on day 12 of storage. However, the TSS values of the tomato fruits decreased considerably on day 16 of storage. The TSS content of tomatoes measured in degree Brix is an indicator of the taste and flavour of the fruits. Tomato flavour is generally related to the relative concentrations of sugars and acids in the fruit, mainly fructose, glucose and citric acid. The best, most flavoursome combination is a high sugar and high acid content (Yara *et al*., 2023) indicating that the lower the pH, the more sour the fruit and the higher the TSS, the sweeter the tomato fruit. The increase in TSS during the duration of storage of the tomato fruits can be attributed to ripening and conversion of carbohydrates to sugars (Mai Al-Dairi *et al*., 2021). The increase in total soluble solids can be caused by the breaking of long chain carbohydrate compounds into soluble sugar compounds (Astuti *et al*., 2018). High temperatures induce the breaking of long chains of carbohydrate compounds into dissolved sugar compounds, so that the sugar content of tomato fruits increases. Ripening during storage also contributes to the degradation of pectin substances into simple sugar resulting in increasing TSS over time (Munhuewyi, 2012). The results in our study are consistent with those obtained by Tigist et al., 2013) who reported significant changes in TSS of tomato at room temperature as a result of carbohydrate conversion and water loss during a 32- day storage period. Similarly, previous report by Gol *et al*., 2013 suggest that high values of TSS are associated with pleasant flavour of tomotoes, thus the increased values of TSS occasioned by treatment with peel extract may be advantageous to consumers.

Table 3: Total soluble solids of treated tomatoes at different days of storage

Sample	Total Soluble Solids (°Brix)			
	Day 4	**Day 8**	**Day 12**	**Day 16**
$EEV_{0.5}$	4.23±0.15	4.40^{c}±0.10	5.93^{b}±0.15	5.07^{a}±0.51
$EEV_{1.0}$	3.10^{a}±0.00	3.30^{b}±0.27	4.97^{a}±2.15	5.93^{b}±0.21
$EEV_{2.0}$	3.46^{b}±0.12	3.07^{b}±0.06	7.57^{d}±0.12	5.07^{a}±0.06
$EEW_{0.5}$	3.57^{b}±0.06	3.13^{b}±0.23	5.83^{b}±0.06	5.87^{b}±0.59
$EEW_{1.0}$	3.70^{b}±0.17	2.77^{b}±0.25	8.07^{d}±0.06	5.40^{a}±0.53
$EEW_{2.0}$	3.30^{a}±0.63	3.77^{c}±0.65	7.23^{c}±0.25	5.37^{a}±0.25
$EEI_{0.5}$	2.83^{a}±0.50	2.80^{b}±1.04	6.27^{b}±0.15	6.07^{b}±0.49
$EEI_{1.0}$	3.60^{b}±0.79	2.77^{b}±1.07	5.93^{b}±0.21	5.73^{b}±0.49
$EEI_{2.0}$	3.98^{c}±0.45	3.23^{b}±0.32	7.23^{c}±0.25	5.60^{b}±0.00
$HEV_{0.5}$	3.27^{a}±0.29	4.40^{c}±0.87	6.90^{c}±0.79	5.50^{b}±0.20
$HEV_{1.0}$	3.63^{b}±0.06	4.03^{c}±0.58	7.00^{c}±0.92	5.73^{b}±0.12
$HEV_{2.0}$	3.57^{b}±0.06	4.27^{c}±0.31	7.87^{d}±0.12	5.97^{b}±0.38
$HEW_{0.5}$	2.70^{a}±0.78	4.07^{c}±0.21	8.40^{e}±0.63	6.53^{c}±0.06
$HEW_{1.0}$	2.80^{a}±0.27	3.57^{c}±0.40	9.03^{f}±0.15	7.43^{d}±0.40
$HEW_{2.0}$	2.70^{a}±0.44	3.10^{b}±0.76	8.33^{e}±0.42	7.27^{d}±0.31
$HEI_{0.5}$	3.23^{a}±0.21	2.43^{a}±0.06	5.87^{b}±0.32	6.50^{c}±0.70
$HEI_{1.0}$	3.23^{a}±0.32	3.00^{b}±0.00	9.27^{f}±0.21	6.43^{c}±0.47
$HEI_{2.0}$	3.33^{a}±0.06	2.73^{b}±029	7.60^{d}±0.44	6.27^{c}±0.47
Control	3.15^{a}±0.07	2.30^{a}±0.00	-	-

Values within the same column with the same superscript are not significantly different at $p< 0.05$.
Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5= Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI2.0= Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

Effect of Citrus sinensis peel extracts on colour and firmness of stored tomatoes

Colour and firmness of tomato fruits are very key parameters considered when assessing consumer acceptability of fresh tomato fruits. The result of colour experiment shown in table 4 revealed that samples had low score for colour in the early days of storage recording 2.30 for $EEV_{0.5}$ while the highest score was observed in $HEV_{1.0}$ to be 3.50. The colour scores for the early days of storage showed that the samples were between the breaker and turning stages. The lowest firmness score was observed in sample $HEI_{1.0}$ with value of 1.20 and the highest was observed in $HEW_{0.5}$ recording 2.00 on the variation scale. This shows that the tomato fruits were either hard or sprung when the treatment was introduced. On day 16, the lowest colour score was observed in $EEW_{2.0}$ (6.60) and the highest score of 7.00 in $EEI_{2.0}$, $HWE_{0.5}$, $HEW_{2.0}$ and $HEI_{2.0}$ which indicates that the tomato fruits became fully mature and ripened in the course of storage. The firmness scores also presented in table 4 were also high with the lowest score in $EEI_{1.0}$

(4.89) and the highest in $EEI_{0.5}$ (5.50). These scores show that the tomato fruits were between eating ripe and overripe by day 16 of storage.

Interestingly, treated samples tomatoes with various concentrations of orange peel extract resulted in delayed ripening and softening contributing to increased shelf-life of the tomatoes. Phytochemicals present in the extracts may have caused retardation of ethylene production slowed down ripening, chlorophyll degradation and carotenoid synthesis thus, ultimately delaying color change of the tomato fruits (Islam *et al*., 2018). In comparison with treated samples, control samples ripened and softened fully by day 8 with 100% disease incidence which caused rotting thereby compromising its acceptability by consumers. Similarly, firmness of samples was observed at the early stage of storage when the tomatoes were between hard and sprung but lost their firmness gradually during the storage period. The loss of firmness during the storage period is characteristic of fruits during the maturation occasioned by increase in the ethylene concentration that promotes the synthesis of polygalacturonase, the enzyme responsible for softening (Ramírez *et al*., 2004)., the treatments gave rise to fruit with higher firmness values than untreated fruit. Results of the present study is in agreement with García et al. (2014) who found that aloe vera coatings exerted a beneficial effect on fruit firmness in a 17-day storage period study. Thus, it can be inferred that the peel extracts had a significant effect on the shelf life of the tomato fruits by delaying colour development and softening of the fruits giving rise to an overall improvement in the shelf life of the treated tomato fruits.

Table 4: Colour and Firmness of tomatoes at different days of storage

Sample	Colour **Day 0**	**Firmness Day 0**	**Colour Day 4**	**Firmness Day 4**	**Colour Day 8**	**Firmness Day 8**	**Colour Day 12**	**Firmness Day 12**	**Colour Day 16**	**Firmness Day 16**
	2.30^{a}±									
		1.70^{b}±	4.10^{a}±	3.10^{a}±	6.10^{b}±	4.10^{a}±	5.90^{a}±	4.30^{a}±	6.70^{a}±	5.00^{a}±
$EEV_{0.5}$	0.68	0.68	0.57	0.57	0.74	0.57	0.74	0.48	0.48	0.00
	3.20^{b}±	1.60^{b}±	4.50^{b}±	3.60^{b}±	5.40^{a}±	4.80^{b}±	6.00^{a}±	4.00^{a}±	6.70^{a}±	5.20^{a}±
$EEV_{1.0}$	0.79	0.70	0.53	0.52	1.27	1.03	0.94	0.47	0.48	0.42
	3.70^{c}±	1.60^{b}±	4.90^{b}±	3.40^{a}±	6.30^{b}±	4.70^{b}±	6.40^{a}±	4.70^{b}±	6.90^{a}±	5.00^{a}±
$EEV_{2.0}$	0.48	0.52	0.88	0.52	0.82	0.68	0.70	0.48	0.32	0.47
	3.20^{b}±	1.70^{b}±	4.50^{b}±	3.20^{a}±	5.90^{b}±	4.30^{a}±	6.10^{a}±	4.50^{b}±	6.60^{a}±	5.30^{a}±
$EEW_{0.5}$	0.92	0.82	0.71	0.42	0.74	0.82	0.88	0.53	0.52	0.48
	3.10^{b}±	1.80^{b}±	4.80^{b}±	3.30^{a}±	6.00^{b}±	3.90^{a}±	6.30^{a}±	4.40^{a}±	6.80^{a}±	5.20^{a}±
$EEW_{1.0}$	0.74	0.63	0.42	0.48	0.82	0.74	0.95	0.52	0.42	0.42
	2.90^{b}±	1.40^{a}±	4.60^{b}±	3.50^{b}±	6.70^{c}±	4.70^{b}±	6.50^{b}±	4.50^{b}±	6.60^{a}±	5.20^{a}±
$EEW_{2.0}$	1.37	0.52	0.70	0.71	0.68	0.48	0.71	0.53	0.52	0.42
	3.40c±	1.30^{a}±	4.70^{b}±	3.40^{a}±	6.20^{b}±	4.10^{a}±	5.80^{a}±	4.40^{a}±	6.90^{a}±	5.50^{b}±
$EEI_{0.5}$	0.70	0.48	0.68	0.52	0.79	0.57	1.23	1.08	0.32	0.53
	3.33^{b}±	1.78^{b}±	4.56^{b}±	3.33^{a}±	6.11^{b}±	4.22^{a}±	6.44^{b}±	4.56^{b}±	6.89^{a}±	4.89^{a}±
$EEI_{1.0}$	0.87	0.67	0.53	0.50	0.78	0.67	0.73	0.53	0.33	0.33
	2.90^{b}±	1.40^{a}±	4.40±	3.40^{a}±	5.80^{b}±	4.60^{b}±	5.60^{a}±	4.20^{a}±	7.00^{a}±	4.90^{a}±
$EEI_{2.0}$	0.99	0.52	0.70	0.70	0.92	0.84	1.35	1.23	0.00	0.32
	3.30^{b}±	1.40^{a}±	4.20^{a}±	3.20^{a}±	6.30^{b}±	4.00^{a}±	6.10^{a}±	4.50^{b}±	6.90^{a}±	5.30^{a}±
$HEV_{0.5}$	0.68	0.52	0.42	0.42	0.83	0.00	0.57	0.53	0.32	0.48
$HEV_{1.0}$	3.50^{c}±	1.60^{b}±	4.80^{b}±	3.40^{a}±	5.90^{b}±	4.80^{b}±	6.20^{a}±	4.80^{b}±	6.90^{a}±	5.20^{a}±

	0.71	0.52	0.63	0.70	0.74	0.63	0.42	0.42	0.32	0.63
	$2.80^{b}\pm$	$1.40^{a}\pm$	$4.90^{b}\pm$	$3.30^{a}\pm$	$6.00^{b}\pm$	$4.60^{b}\pm$	$6.40^{a}\pm$	$4.50^{b}\pm$	$6.80^{a}\pm$	$4.90^{a}\pm$
$HEV_{2.0}$	0.63	0.52	0.74	0.68	0.67	0.70	0.52	0.53	0.42	0.74
	$2.50^{b}\pm$	$2.00^{b}\pm$	$4.25^{a}\pm$	$3.25^{a}\pm$	$6.00^{b}\pm$	$4.63^{b}\pm$	$6.63^{b}\pm$	$4.63^{b}\pm$	$7.00^{a}\pm$	$5.25^{a}\pm$
$HEW_{0.5}$	0.54	0.76	0.71	0.71	1.31	0.92	1.06	0.52	0.00	0.46
	$3.10^{b}\pm$	$1.70^{b}\pm$	$4.40^{a}\pm$	$3.40^{a}\pm$	$6.20^{b}\pm$	$4.60^{b}\pm$	$6.50^{b}\pm$	$4.60^{b}\pm$	$6.80^{a}\pm$	$5.00^{a}\pm$
$HEW_{1.0}$	0.74	0.48	0.52	0.52	0.63	1.27	0.71	0.52	0.42	0.00
	$3.00^{b}\pm$	$1.70^{b}\pm$	$4.70^{b}\pm$	$3.20^{a}\pm$	$6.30^{b}\pm$	$4.30^{s}\pm$	$6.30^{a}\pm$	$4.30^{a}\pm$	$7.00^{a}\pm$	$5.10^{a}\pm$
$HEW_{2.0}$	0.82	0.68	0.82	0.42	0.48	0.68	0.68	0.48	0.00	0.32
	$3.10^{b}\pm$	$1.40^{a}\pm$	$4.40^{a}\pm$	$3.00^{a}\pm$	$6.10^{b}\pm$	$4.50^{b}\pm$	$6.30^{a}\pm$	$4.60^{b}\pm$	$6.90^{a}\pm$	$5.20^{a}\pm$
$HEI_{0.5}$	0.88	0.52	0.70	0.70	0.88	0.71	0.68	0.52	0.32	0.42
	$3.20^{b}\pm$	$1.20^{a}\pm$	$4.60^{b}\pm$	$3.30^{a}\pm$	$6.00^{b}\pm$	$4.50^{b}\pm$	$6.60^{b}\pm$	$4.80^{b}\pm$	$6.90^{a}\pm$	$5.00^{a}\pm$
$HEI_{1.0}$	0.92	0.42	0.97	0.48	1.05	0.71	0.52	0.42	0.32	0.47
	$2.80^{b}\pm$	$1.70^{b}\pm$	$4.60^{b}\pm$	$3.30^{a}\pm$	$6.10^{b}\pm$	$4.70^{b}\pm$	$6.50^{b}\pm$	$4.90^{b}\pm$	$7.00^{a}\pm$	$4.90^{a}\pm$
$HEI_{2.0}$	0.79	0.68	0.70	0.48	0.74	0.68	0.53	0.32	0.00	0.32
							-	-	-	-
	$3.20^{b}\pm$	$1.60^{b}\pm$ `	$4.70^{b}\pm$	$3.60^{b}\pm$	$6.60^{c}\pm$	$5.50^{c}\pm$				
Control	0.42	0.70	0.68	0.84	0.52	0.53				

*Color score (1= green, 2= breaker, 3= turning, 4= pink, 5= light red, 6 =red, 7= red ripe)
*Firmness scale (1= hard, 2= sprung, 3= between sprung and eating ripe, 4= eating ripe, 5= overripe, 6= rotten)
*Values within the same column with the same superscript are not significantly different at $p< 0.05$
Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5= Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI2.0= Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

Effect of *Citrus sinensis* peel extracts on disease infestation of stored tomatoes

Percentage disease infestation is used to observe the effectiveness of preservatives on tomato fruit samples in retarding disease process. Variation in respect of percent disease incidence was found highly significant between the samples. As presented in table 5, the result of disease incidence increased with the advancement of the storage period across all the samples. However, the level of disease infestation was higher in the control (87.50%) followed majorly by samples of treated with hexane extracts namely $HEV_{0.5}$, $HEV_{2.0}$, $HEW_{2.0}$, $HEI_{0.5}$ and $HEI_{2.0}$ which had disease infestation of 75.00% respectively by day 16 of storage. The least disease infestation was 37.5% observed in three (3) samples treated with ethanolic extracts namely $EEV_{0.5}$, $EEV_{1.0}$ and $EEW_{1.0}$. This shows that the variety of orange used to prepare the peel extracts, the extraction solvent and the concentration of post-harvest treatments had a combined effect on the disease severity in the tomato fruits. A study by Islam et al., (2018) where the preservative ability of chitosan and guava leaf extracts was evaluated by coating on banana, carambola and tomato fruits recorded that percentage disease index increased as the number of storage days increased, however, treatment with extracts exerted antimicrobial effects on the coated fruits by probably decreasing transpiration, delay in maturation and senescence, and maintained the quality of

harvested fruits (Fornes et al., 2005; Mohammed et al., 2017). The efficacy of orange peel extracts was apparent with untreated samples having the highest disease infestation rate at day 8 of storage in comparison with treated samples which were significantly preserved till day 16 of the storage period.

Table 5: Disease Infestation observed in tomato fruits at various days of storage

Sample	Disease Infestation					
	Day 0	**Day 4**	**Day 8**	**Day 12**	**Day 16**	**Total DI (%)**
$EEV_{0.5}$	8(0)	7(0)	4(2)	4(0)	2(1)	37.50
$EEV_{1.0}$	8(0)	6(1)	5(1)	5(0)	3(1)	37.50
$EEV_{2.0}$	8(0)	7(0)	6(0)	3(3)	2(1)	50.00
$EEW_{0.5}$	8(0)	6(1)	4(2)	3(1)	2(1)	62.50
$EEW_{1.0}$	8(0)	6(1)	5(1)	5(0)	3(1)	37.50
$EEW_{2.0}$	8(0)	6(1)	4(2)	3(1)	2(1)	62.50
$EEI_{0.5}$	8(0)	7(0)	5(2)	3(1)	1(1)	50.00
$EEI_{1.0}$	8(0)	6(1)	3(2)	3(1)	2(1)	62.50
$EEI_{2.0}$	8(0)	5(2)	3(2)	3(0)	1(1)	62.50
$HEV_{0.5}$	8(0)	4(3)	4(0)	3(2)	1(1)	75.00
$HEV_{1.0}$	8(0)	6(1)	5(1)	3(1)	2(1)	50.00
$HEV_{2.0}$	8(0)	4(3)	3(1)	3(1)	2(1)	75.00
$HEW_{0.5}$	8(0)	5(2)	5(0)	4(2)	1(1)	62.50
$HEW_{1.0}$	8(0)	5(2)	3(1)	3(1)	1(1)	62.50
$HEW_{2.0}$	8(0)	4(3)	2(2)	2(0)	1(1)	75.00
$HEI_{0.5}$	8(0)	4(3)	3(1)	3(1)	1(1)	75.00
$HEI_{1.0}$	8(0)	5(2)	5(0)	3(1)	3(2)	62.50
$HEI_{2.0}$	8(0)	4(3)	2(2)	2(1)	1(0)	75.00
Control	8(0)	4(3)	0(4)	-	-	87.50

Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5= Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI2.0= Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

Effect of *Citrus sinensis* peel extracts on weight loss of stored tomatoes

Weight is a very important quality indicator in tomatoes. After 16 days of storage, the cumulative weight loss percentage of the treated samples were lower compared to the control sample. On day 16 of storage, the control sample of the tomato fruits showed the highest weight loss (100%), the sample treated with 0.5% Ibadan Sweet hexane extract, $HEV_{0.5}$ had 91.53% weight loss while the lowest weight loss of 63.18% was observed in the sample treated with 1% Valencia ethanolic extract. It was also observed that the rate of weight loss increased with increase in storage time.

As shown in Table 6, lower weight loss values were recorded on day 4 and 8 while the higher values were seen on day 12 and 16 of the storage which may be due to loss of water from the tomato fruits in the duration of storage. This trend is in agreement with Islam et al., (2018) who observed higher weight loss values on day 12 of storage. Similar studies inferred that storage temperature also has a tangible effect on weight loss of tomato fruits. Increase in temperature is accompanied by increase in physiological and metabolic processes, the opposite is the case for decrease in temperature which is associated with lower respiratory and transpiration processes (Francis et al., 2022; Tigist et al., 2013).

Table 6: Percentage Weight loss of tomato fruits at various days of storage

Sample	**Weight Loss (%)**				
	Day 4	**Day 8**	**Day 12**	**Day 16**	**Total weight loss**
$EEV_{0.5}$	14.05	26.48	36.42	54.06	81.55
$EEV_{1.0}$	13.87	6.94	23.29	40.13	63.18
$EEV_{2.0}$	25.38	23.00	34.28	28.90	79.05
$EEW_{0.5}$	9.33	28.71	37.08	60.30	85.67
$EEW_{1.0}$	28.17	21.35	29.67	36.45	72.59
$EEW_{2.0}$	17.37	4.58	31.04	50.84	74.84
$EEI_{0.5}$	11.39	24.68	67.62	73.53	89.13
$EEI_{1.0}$	16.55	35.11	42.11	43.92	79.99
$EEI_{2.0}$	15.53	20.16	14.54	68.47	81.98
$HEV_{0.5}$	37.86	5.33	30.27	63.93	85.21
$HEV_{1.0}$	28.20	16.28	39.18	42.26	77.86
$HEV_{2.0}$	55.83	5.47	26.56	37.56	73.60
$HEW_{0.5}$	15.36	3.86	28.61	66.96	80.80
$HEW_{1.0}$	8.29	29.18	24.09	65.99	83.23
$HEW_{2.0}$	48.23	9.22	41.66	56.14	86.66
$HEI_{0.5}$	50.02	13.31	35.90	76.18	91.53
$HEI_{1.0}$	26.09	4.05	25.09	78.63	88.65
$HEI_{2.0}$	45.97	15.39	44.62	44.86	86.04
Control	31.83	49.28	-	-	100

Key: EEV0.5, EEW0.5, EEI0.5= Samples treated with 0.5% ethanolic extracts of Valencia, Washington navel and Ibadan sweet. EEV1.0, EEW1.0, EEI0.5= Samples treated with 1.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, EEV2.0, EEW2.0. EEI 2.0= Samples treated with 2.0% ethanolic extracts of Valencia, Washington navel and Ibadan sweet, HEV0.5, HEW0.5, HEI0.5= Samples treated with 0.5% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV1.0, HEW1.0, HEW1.0= Samples treated with 1.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet, HEV2.0, HEW2.0, HEI2.0= Samples treated with 2.0% hexane extracts of Valencia, Washington navel and Ibadan Sweet.

CONCLUSION

This study investigated the effects of orange peel extracts on some key physico-chemical properties and shelf-life of fresh tomatoes. The results demonstrate the efficacy of *Citrus sinensis* peel extracts by significantly extending the shelf-life of tomato samples and maintaining other quality attributes. Over the 16-day storage period at ambient temperature, notable changes were observed in crucial parameters including moisture content, pH, total soluble solids, weight, color, and firmness of the treated tomato fruits. The application of relatively low concentrations of orange peel extracts yielded positive preservative effects, suggesting that optimization of treatment conditions could further enhance potency. These findings indicate plausible evidence in support of the use of sweet orange peel extracts as alternatives to synthetic preservatives, and contribute to minimizing post-harvest losses, a critical issue in tomato production and distribution. The utilization of orange peel extracts represents an opportunity for value addition to both orange and tomato fruits, potentially creating new economic opportunities in the agricultural sector. While these results are encouraging, further research would seek to optimize extraction methods, treatment concentrations, and storage conditions. Additionally, studies on the scalability and economic viability of this approach would be beneficial. Overall, this study contributes to the growing body of knowledge on natural preservatives and offers a potential solution to enhance food security and reduce waste in the fruit and vegetable industry. Given that positive results were obtained at room temperature, further research at lower temperatures may even be more interesting. Additionally, studies on the impact of this approach on nutritional quality is recommended.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The authors confirm that the data supporting the findings in this study are not yet available online. However, raw data sets used for statistical analysis in this research are available from the corresponding author upon request.

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