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Research Article

Preservative Potential of Biobased Oils on the Physiochemical Quality of Orange Fruits during Storage

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In recent times, there is an increasing global interest in the consumption of safe, healthy fruits and juices without synthetic materials and preservatives. The objective of the study was to evaluate the physiochemical quality of Valencia, Ibadan sweet, and Washington varieties of sweet orange (*Citrus sinensis L. Osbeck)* fruits in response to eucalyptus leaves, orange peels, and their combination during 30 days of storage at ambient 25°C and 80-85% relative humidity. The experimental design was a 4 × 3 factorial design in a completely randomized design. The results showed that orange fruits coated with the combined oils of eucalyptus leaves and orange peels significantly ($P \leq 0.05$) delayed weight changes, firmness, titratable acidity, total soluble solids concentration, vitamin C content, and higher acceptability with extended shelf life compared to uncoated control fruits. Valencia (V1) exhibited a significant beneficial effect of the biobased oils treatment on weight, firmness, and vitamin C content. In Ibadan sweet (V2) fruits, biobased oils enhanced titratable acidity with relatively better total soluble solids and marketability. Biobased oils are known to reduce fruit weight loss by limiting respiration rate. It was concluded that the combined biobased oil had the best effect on keeping citrus fresh. These findings provide a practical basis for the application of combined biobased oil as an effective preservative to improve the storage quality of citrus fruits.

1. Introduction

The importance of citrus fruits in providing nutrients and medicinal value has been recognized since ancient times. Citrus fruits belong to the genus *Citrus* of the family *Rutaceae*. It is among the most widely produced fruits grown in several countries across the globe. The bioactive compounds such as avanones and anthocyanins of citrus fruits and the Vitamin C obtained from the juice are the most powerful antioxidants that help to quench a variety of reactive oxygen species [1]. Major contributors to citrus fruit losses are often associated with excessive loss of moisture, poor cooling, and temperature abuse during harvest through to consumption. Orange fruit losses that farmers encounter are largely due to physical injury, moisture loss, biological activities, inappropriate storage conditions, and a poor taste of fruits. Africa is well endowed with appropriate ecological and climatic conditions suitable for the production of citrus in commercial quantity. The current global citrus production reported was up to 143,755.6 Mt and oranges accounted for 76, 292.6 Mt of the total production [2]. The production levels of citrus in Nigeria increased over the years resulting in an annual value of 4.1 Mt which generates over 1 Mt of citrus peels [3].

Again, citrus are perishable horticultural commodities that generate heat in packages during transport and storage, resulting in condensation in packages, weight loss, decay, and degradation in total soluble solids. It is important to state that through the application of efficient natural plant technologies, it is possible to optimize the handling and enhance the shelf life of citrus fruits. Aromatic plants are well known for their potential benefits to human health because of their biological, anti-inflammatory and anticancer including antioxidant and antimicrobial properties and because of their organoleptic properties [4, 5]. Plant-based oils also include aromatic substances produced by plants generally belonging to angiospermic families that can be used by several industries for different purposes. Essential oils which are composed of carotenoids, alkaloids, aldehydes, and phenolics have been applied to delay ripening and prevent senescence in fruits during postharvest storage. [6, 7]. The application of essential oils with closer contact between the fruit surface and the oils at similar concentrations promotes the retention of fruits moisture, enhances defense-related enzyme activity, and maintains the commercial quality [8, 9]. The physiological quality in fruits can be maintained with the application of biobased oils. In the current study, the chemical and physical properties of the combined citrus peels and eucalyptus leaf oils relate to the configuration of the constituents of cumarin, tannin, and phenolics. Although some essential oils have been tested on the quality of food products, there has been limited information regarding the combinations of biobased techniques to combine eucalyptus leaves and orange peel oils for the postharvest management of citrus fruits. Foodborne diseases have been reported to increase the healthcare cost of developing nations, and the increased public pressure to deliver healthy and safe fruits has driven research for the development of nonchemical approaches to control postharvest diseases [6, 10] which forms the basis for the current research. The aim of the research was to evaluate the preservative potential to provide a practical basis for the application of biobased oils extracted from eucalyptus leaves and orange peels on three varieties of orange fruits during ambient storage.

2. Materials and Methods

2.1. Plant Material. The experiment was carried out at the Department of Biological Sciences at Benue State University Makurdi, Nigeria. Eucalyptus leaves and orange peels were collected in the Makurdi metropolis. The collected leaves and peels were put in empty fibre board cartons and taken to the laboratory for extraction of the oils. Fresh and healthy orange fruits of three varieties, Washington, Ibadan sweet, and Valencia, were harvested at harvest maturity by hand picking from a local orchard in Makurdi in Nigeria. Fruits were selected based on the consideration that they are similar in size and maturity with no visual symptoms of defects and disease. The fruits were carefully placed in plastic crates and taken to the laboratory for the commencement of the experiment.

2.2. Biobased Oil Extraction. The fresh leaves of eucalyptus (20 kg) and orange peels (15 kg) were collected from Makurdi metropolis, cleaned and dried at room temperature, 32°C for 48hours, and crushed using an electric blender (8010G blender, USA) before extraction. The Soxhlets method of extraction was used as suggested by [11]. A 0.7% and 0.4% of yield per kg of peels and leaves, respectively, was produced. The orange fruits of three varieties which include Valencia (V1), Ibadan sweet (V2), and Washington (V3) were coated with the oil from orange peels, eucalyptus leaves, and their combination at concentrations of 1 : 1 v/v leaves and peels using a soft brush. The fruits after brushing were placed in plastic crates (60 cm × 40 cm × 24 cm) to air dry and kept at room temperature (25°C, RH 80%) for a period of 30 days.

2.3. Experimental Design. The factors in the experiment are as follows: 3 varieties of orange fruits and 4 oils (3 oils plus control). The experimental design was a 4×3 factorial design in a completely randomized design. treatment combinations was $4 \times 3 = 12$. Replications are equal to 3, and total units = $12 \times 3 = 36$ units. Twenty (20) fruits were coated and stored per unit. Total number of fruits was 720.

2.4. Weight Determination. Fruits were regularly weighed, and fruit weight was recorded for each replicate and then calculated as percentages in relation to the weight of the fruit on the first day and repeatedly for every ten days of storage. The following formula suggested by Arnon et al. [12] was used

$$\mathrm{WL}\,(\%) = \frac{W1 - W2}{W1} \times 100. \tag{1}$$

WL is the weight loss percent, where W_1 is the orange fruit weight at day zero and W_2 is the orange fruit weight at subsequent days of storage.

2.5. Fruits Firmness. Fruit firmness was measured as the maximum penetration force (N) reached during tissue breakage using a standard plunger of 11 mm diametre on two opposite sizes of the fruits. The registered force at the penetration of a plunger up to a certain depth (cm) was read as firmness. A handheld fruit pressure tester (model FT 011 standard, Italy) was used to determine the firmness as suggested by Kumar et al. [13].

2.6. Total Soluble Solid. The total soluble solid (TSS) content of the fruits was measured to ascertain the percent level of Brix. This was assessed with the use of a handheld refractometer (model PAL-1, Atago, Italy). Sample fruits from each replicate cut opened on each of the assessment days and juice squeezed and collected in a clean container. The Brix percent was measured by placing a sample of juice on the prism of the refractometer, and readings were taken as suggested by Blanke [14].

2.7. Titratable Acidity. The orange fruits were cut into four slides each, and the juice was squeezed out and collected in a clean plastic container. Ten (10 mL) of sample juice was transferred to a 250 mL beaker. 0.1 g of NaOH was dissolved in 250 mL of distilled water and titrated with 0.1 N NaOH. 0.5 g of phenolphthalein was dissolved in 25 mL of ethyl ether and made up the volume of 50cm^3 with distilled water. Two drops of phenolphthalein indicator were added to the sample juice and titrated with 0.1 N NaOH solution in a burette until the sample turns pink colour. The titratable acidity was calculated using the following formula. The result was expressed as a percent of citric acid [15].

$$\%\text{Titratable acidity} = \left(\frac{[V] \times [N] \times [E]}{W}\right) \times 100. \quad (2)$$

V is the volume of NaOH used, N is the normality of NaOH, E is the milliequivalent factor for citrus (0.064). W is the weight of the sample juice.

2.8. Vitamin C Content. Vitamin C content was determined by the indophenol titration method adapted from the method of [16]. Briefly, 10 mL of orange juice was extracted from the fruits and filtered through two layers of cheesecloth, and 5 mL of metaphosphoric acetic acid solution was then added to the filtered extract. The sample was titrated with 2,6-dichloroindophenol dye solution until the samples turned light rose-pink colour. The quantity of the dye used in the titration was used to calculate the ascorbic content present: mg ascorbic acid/mL = $(X - B) \times (F/E) \times (V/Y)$, where X is the mL for sample juice, B is the average mL for sample blank titration, F is the titer of dye (using 1.0 mL indophenol standard solution), E is the mL assayed (2 mL), V is the volume of initial assay solution, and Y is the volume of sample aliquot titrated.

2.9. Marketability. The marketability was assessed using the following scale adapted earlier suggested by [12] with some modifications. The assessment was based on physical attributes which include the level of visible mold growth, decay, and physical appearance. 1-2.5 is unsalable, 2.6-4.5 is fair: limit of marketability, 4.6-6.5 is good, 6.6-8.5 is very good, and 8.6-9.00 is excellent.

2.10. Assessment of Shelf Life. Shelf life of orange fruits was assessed, and by counting the number of days, orange fruits were still acceptable with retained optimum marketing and eating qualities. It was decided based on a slightly modified procedure on the appearance and spoilage of fruits beyond 50%.[17].

2.11. Organoleptic Assessment. A sensory assessment was carried out by 15 panelists who were made up of students of the Benue State University with an experience in sensory assessment. A 3-point hedonic scale (3 = good, 2 = average, and 1 = fair) was developed and used for taste, while a 9-point scale was used for the overall acceptability (9 = excellent, 7 = very good, 5 = good, 3 = acceptable, and 1 = poor) [18]. The panelist was served with the samples that were coded randomly, and the procedure was explained. Three samples corresponding to the treatments were assessed by each panelist.

2.12. Data Analysis. The data obtained from the study was subjected to an analysis of variance (ANOVA) to test whether there exist any significant differences at $P \leq 0.05$ alpha level between the treatment means. The analysis was performed using the Gentsat Discovery Edition 7 for 2014 VSN International Limited. Mean separation was done using the Fisher least significant difference (FLSD).

3. Results and Discussion

3.1. Weight Loss. The results show a general increase in the percent weight loss of citrus fruits during storage. There was a significant interaction of oil type and the variety ($P \leq 0.05$). As storage progressed, weight loss significantly increased in control fruits than the treated fruits. The least weight loss was observed in V2 (11.09%) in comparison to the highest V3 uncoated fruits (32.26%). Biobased oil treatment resulted in a significant decline of loss in weight among the three varieties of citrus investigated. The reduced weight loss observed was possibly due to the influence of the presence of hydrogen bonds found in the cuticle of the peel and the inside of the coating matrix [19, 20]. The findings demonstrate the protective barrier ability against the movement of solute in V2, which is in broad agreement with previous findings by [21, 22]. The current research demonstrates low weight loss for all treated fruits which confirms the findings of previous research that reported effective post-harvest characteristics of fruits due to coating effect [23, 24]. However, Arnon et al. [19] reported contrary findings that bilayer coating was not effective in reducing the weight loss of citrus fruits during storage.

3.2. Firmness. The results on changes in citrus firmness were influenced significantly by the interaction of oil type and the variety during storage ($P \leq 0.05$). The firmness decreased gradually as storage progressed. Overall the maximum firmness was measured in V1 (7.53 N) treated with combined oil of orange peels and eucalyptus leaves in comparison to all other treatments. At the end of storage, V3 control (2.4 N) showed the least firmness (Table 1). The results demonstrated that biobased oil treatment resulted in a gradual reduction of fruit firmness among the three varieties of citrus. The cell wall structure of fruits degrades due to the physiological activity. In this research, fruits treated with biobased oil from orange peel, eucalyptus, and their combination (1 : 1) resulted in firmer fruits attributed to the external atmosphere formed around the fruits. Biobased oils reduced the cellular hydrolase enzyme activity and eventually maintained the firmness during storage [25, 26]. The higher firmness of fruits may be explained to be the induced resistance of fruits after coating that influences the pectin, methyl esterase, and polygalacturonase activity. Similarly, previous research reported the effects of oil coating on oranges significantly affected the retardation of the biochemical changes and firmness of fruits during storage [7, 27]. The findings collaborate with earlier research conducted on sweet orange that showed treatment indicating a reduction of cell pressure and maximum firmness at storage [28]. Application of a mixture coating material on sweet orange fruits resulted in better firmness relative to control as reported by Ngoc et al. [29].

3.3. Total Soluble Solids. The results show a gradual increase in the total soluble solids (TSS) of citrus during storage and a decline towards the end of storage. The interaction of biobased oil type and variety of citrus used significantly influenced the total soluble solids content during storage

Table 1: Effect of variety and oil type on firmness and weight loss during storage.

Variety	Oil type	Firmness (N) 0	10	20	30	Weight loss (%) 0	10	20	30 (days)
V1	Orange	11.50^a	9.13^ab	7.23^abc	5.76^ab	*	11.42^b	19.00^bc	18.87^c
	Eucalyptus	11.50^a	8.483^abc	7.02^bc	5.55^abc	*	8.39^c	18.08^bc	18.49^c
	Orange+eucalyptus	11.50^a	10.41^a	9.00^a	7.53^a	*	5.00^d	8.17^d	11.83^d
	Control	11.50^a	7.28^bc	5.00^de	3.53^cde	*	11.63^b	20.97^b	22.81^b
V2	Orange	11.00^a	7.58^bc	4.80^e	3.29^de	*	11.44^b	20.87^b	18.79^c
	Eucalyptus	11.00^a	8.94^abc	7.15^abc	5.77^ab	*	12.46^b	19.73^b	19.82^bc
	Orange+eucalyptus	11.00^a	10.00^a	8.26^ab	6.88^a	*	5.43^d	8.53^d	11.09^d
	Control	11.00^a	6.38^cd	4.67^e	3.00^de	*	16.88^a	25.60^a	31.18^a
V3	Orange	10.70^ab	8.10^abc	5.78^cde	3.19^de	*	8.00^c	15.53^c	19.81^bc
	Eucalyptus	10.70^ab	8.034^abc	6.80^bcd	4.21^bcde	*	9.67^c	14.17^c	18.75^c
	Orange+eucalyptus	10.70^ab	9.71^ab	8.26^ab	4.78^bcd	*	5.27^d	8.23^d	12.41^d
	Control	10.70^ab	6.75^cd	4.38^e	2.24^e	*	17.40^a	25.94^a	32.26^a
F-LSD (0.05)		NS	NS	1.11	1.20		2.20	3.73	3.61

NS: no significant difference; V1: Valencia; V2: Ibadan sweet; V3: Washington; *percent weight loss not computed on day 0. Means in each column followed by the same letter are not significantly different ($P \leq 0.05$) according to the ANOVA and F-LSD test.

($P \leq 0.05$). Generally, the total soluble solid content of the fruits gradually increased as storage progressed up to 20 days and declined, thereafter, for all treatments (Table 2). Total soluble solid content of V3 (9.16%) treated with combined orange peel and eucalyptus oil was significantly higher than all other treatment and the least TSS value of V2 control (4.73%). Biobased oil treatment resulted in a gradual increase in total soluble solids among the three varieties of citrus investigated. The gradual reduction of TSS found in the biobased oils was possibly due to the layer uniformity of the fruit surface and the chemistry of the structural integrity of the oils. The current research findings confirmed previous research that reported that the application of lemon oil coating of mandarin [30] and thyme and tarragon essential oils [31] competed favourably in maintaining TSS values during storage. However, studies on the coating effect contradict the current results that the application of citral-incorporated wax did not influence the TSS content of sweet oranges [32]. The slow increase in the TSS content of the treated fruits could be due to the restriction of the accelerated starch conversion and decomposition of organic acids. The results are in agreement with previous studies that reported significantly different TSS contents of coated and control fruits [33]. It was observed that fruits treated with biobased oils continued to increase for 20 days and declined, thereafter, with the least TSS of 4.73%. On the contrary, related studies reported that 9% TSS was found on oil-treated Valencia orange, which did not show a significant effect compared with the control [34].

3.4. Titratable Acid. The results show a continuous decrease in titratable acidity (TA) percent during storage. The interaction of biobased oil type and variety of citrus significantly influenced the titratable acidity content ($P \leq 0.05$). Titratable acidity for V2 fruits treated with combined orange peel and eucalyptus oils slightly decreased from 2.35% to 2.33% in comparison to all the other treatments (Table 2). The least titratable acidity of V3 control decreased from 1.90% to 0.28% which was significantly lower than all the other treatments. The results of the biobased oil treatment exhibited a gradual reduction in titratable acidity among the three varieties. The decline in TA content could be attributed to the metabolic changes in fruits resulting from the use of organic acids in the respiratory process. The results confirmed the research findings reported previously that primary substrates such as citric and malic acids used for respiration with better titratable acidity reduction in titratable acidity than the control [8, 35]. Orange peel, eucalyptus, and composite (1 : 1 v/v) were beneficial that possibly elevated CO_2 concentration and reduced O_2 which delayed the degradation of TA content of all three varieties. The current results agreed with previous research that reported a slow decline in TA content in citrus fruits treated with composite coatings [15, 36]. Biobased oil-coated fruits possibly delayed the use of organic acid as a source of energy and respiration, thereby retaining the acidity percentage better than the control [37]. Similarly, incorporating orange peel oils in the pectin-based composite coating maintained TA content better than the control [38]. In contrast, Xu et al. [39] reported that composite coating demonstrated that TA contents of coated tangerine fruits using chitosan and montmorillonite showed sharp rises and reached higher values at the first stage of storage and decline towards the end of storage.

3.5. Vitamin C Content. The results show a general increase in the vitamin C content of citrus fruits which declines towards the end of storage. There was a significant interaction of oil type and the variety ($P \leq 0.05$). At the end of

Table 2: Effect of variety and oil type on total soluble solid and titratable acidity during storage.

Variety	Oil type	Total soluble solids (%)				Titratable acidity (%)			
		0	10	20	30	0	10	20	30 (days)
V1	Orange	5.34^{b}	5.37^{cd}	7.47^{c}	6.32^{bc}	2.35^{a}	2.16^{ab}	2.00^{ab}	1.70^{ab}
	Eucalyptus	5.92^{abc}	5.94^{c}	8.05^{bc}	6.89^{bc}	1.77^{ab}	1.30^{c}	1.15^{bc}	0.85^{c}
	Orange+eucalyptus	6.75^{ab}	6.78^{b}	8.88^{b}	7.72^{b}	1.80^{ab}	1.92^{b}	1.77^{b}	1.57^{b}
	Control	6.48^{ab}	6.49^{bc}	8.60^{b}	7.44^{b}	1.78^{ab}	1.21^{c}	1.05^{bc}	0.76^{cd}
V2	Orange	6.09^{abc}	6.76^{b}	8.87^{b}	7.71^{b}	2.35^{a}	1.67^{bc}	1.51^{bc}	1.31^{c}
	Eucalyptus	4.68^{b}	3.87^{de}	5.97^{d}	4.82^{d}	2.35^{a}	1.28^{c}	1.12^{bc}	0.83^{c}
	Orange+eucalyptus	5.24^{b}	4.58^{d}	6.68^{cd}	5.52^{cd}	2.35^{a}	2.84^{a}	2.68^{a}	2.33^{a}
	Control	4.28^{c}	3.79^{de}	5.89^{d}	4.73^{d}	2.35^{a}	1.47^{bc}	1.31^{bc}	1.02^{c}
V3	Orange	5.84^{abc}	7.04^{b}	9.15^{b}	7.99^{ab}	1.90^{ab}	0.97^{cd}	0.82^{c}	0.64^{d}
	Eucalyptus	7.62^{a}	7.64^{ab}	9.75^{ab}	8.59^{ab}	1.90^{ab}	1.99^{ab}	1.83^{b}	1.54^{bc}
	Orange+eucalyptus	7.65^{a}	8.22^{a}	10.32^{a}	9.16^{a}	1.90^{ab}	1.16^{c}	1.00^{bc}	0.71^{cd}
	Control	4.72^{b}	4.49^{d}	6.59^{cd}	5.43^{cd}	1.90^{ab}	0.55^{d}	0.39^{cd}	0.28^{de}
F-LSD (0.05)		NS	1.67	1.90	1.89	NS	1.02	1.03	0.91

NS: no significant difference; V1: Valencia; V2: Ibadan sweet; V3: Washington. Means in each column followed by the same letter are not significantly different ($P \leq 0.05$) according to the ANOVA and F-LSD test.

the storage period, the least vitamin C content was observed in the V1 control with 2.01 (mg/100mLs) in comparison to V3 uncoated fruits 4.58 (mg/100 mL) as the highest which was significantly different from all other treatments (Table 3). The results of the biobased oil treatment exhibited higher retention of vitamin C content among the three varieties of citrus. The higher retention of vitamin C at all stages of storage of the treated fruits was due to the increasing percentage of acidity and the slow metabolic changes that change vitamin C to dehydroascorbic acid resulting from ascorbic acid oxidase. The results collaborate with the findings of [40] on citrus and Ramezanian et al. [41] on Washington who reported higher retention of vitamin C in coated fruits. A gradual reduction in vitamin C content was attributed to the reduced autoxidation. Similarly, previous research confirmed that vitamin C content was higher in coated Valencia fruits with essential oils than untreated by providing several antioxidants [20, 42]. It was established that a combination of coating substances on citrus at a temperature of 25°C inhibited ascorbic acid oxidation and maintained higher ascorbic acid content [43] which confirmed the current findings. Biobased oil retained the highest vitamin C content possibly due to the long polymeric chain which decreases the water sensitivity of the coating material. Saberi et al. [44] reported that biocomposite coating material provides low water sensitivity sufficient for fruit quality.

3.6. Marketability. The results show an initial increase which declines towards the end of storage except for a few treatments that increased. The interaction of biobased oil type and variety of citrus used significantly influenced the marketability during storage ($P \leq 0.05$). Marketability for V1 fruits treated with combined orange peel and eucalyptus oils slightly increased from 5.33 to 5.48 in comparison to all the other treatments (Table 3). The least marketability of V2 control decreased from 5.33% to 1.38% which was significantly lower than all the other treatments. Biobased oil treatment initially resulted in significant marketability among the three varieties of citrus investigated and declined towards the end of the storage. The higher acceptable marketability observed for treated fruits with biobased oils was possibly due to the better extrinsic gloss and appearance of the citrus fruits. The most important factor for a consumer in the admission of marketable quality is colour, which was exhibited by the biobased oil from orange peels, eucalyptus, and their combination. Similarly, Valencia fruit coatings with Aloe vera gel delayed the extrinsic colour and improved appearance with higher scores of superior marketability [45]. Treated fruits were higher in colour appearance and marketability due to the stability of anthocyanins present in the oil that prevented the loss of natural colour. The findings of the current research confirmed earlier research on the improvement of fruits' colour and acceptability with a higher score by maintaining the anthocyanins [46]. Rasouli et al. [47] reported lower marketable values of citrus than the results of the current research but confirmed that orange fruits coated with salicylic acid and Aloe vera gel combined produced a higher intention to buy. It has also been established that the application of coating enhanced the fruit peel texture and consumers can purchase fresh fruits with high nutritional value instead of stale products in the market [48].

3.7. Shelf Life. In general, treated fruits showed extended shelf life relative to the control (Figure 1). For the varietal effect, the shelf life of the three varieties was the same at 30 days. For the biobased oil effect, the treated fruits were stored for 30 days which was significantly different from the control. Shelf life of fruits for orange peel, eucalyptus leaves, and the combined orange peels and eucalyptus was significantly higher (30 days) in comparison with control for only half of the total duration of storage. The results of biobased oil treatment from orange peels, eucalyptus, and

Table 3: Effect of variety and oil type on vitamin C and marketability during storage.

Variety	Oil type	Vitamin C (mg/100mLs) 0	10	20	30	Marketability 0	10	20	30 (days)
V1	Orange	5.28^{a}	11.57^{ab}	6.50^{c}	3.99^{ab}	5.33^{a}	6.80^{ab}	7.20^{a}	5.48^{a}
	Eucalyptus	5.41^{a}	8.18^{bc}	10.06^{b}	2.06^{d}	5.33^{a}	7.20^{a}	7.70^{a}	5.00^{a}
	Orange+eucalyptus	5.41^{a}	8.88^{bc}	13.27^{ab}	3.44^{b}	5.33^{a}	7.50^{a}	7.80^{a}	4.51^{ab}
	Control	5.35^{a}	8.11^{bc}	5.15^{d}	2.01^{d}	5.33^{a}	6.50^{ab}	5.60^{bc}	2.50^{d}
V2	Orange	4.84^{ab}	11.37^{ab}	14.09^{a}	2.87^{bc}	5.33^{a}	6.70^{a}	6.80^{ab}	5.22^{a}
	Eucalyptus	4.65^{ab}	10.31^{b}	10.06^{b}	4.05^{ab}	5.33^{a}	6.60^{ab}	6.80^{ab}	3.79^{c}
	Orange+eucalyptus	4.84^{ab}	14.80^{a}	15.97^{a}	4.58^{a}	5.33^{a}	6.60^{ab}	6.80^{ab}	3.79^{c}
	Control	4.59^{ab}	9.06^{bc}	5.86^{d}	2.43^{cd}	5.33^{a}	6.30^{ab}	5.70^{abc}	1.38^{e}
V3	Orange	4.72^{ab}	13.80^{ab}	10.30^{b}	4.33^{a}	5.33^{a}	6.20^{ab}	6.70^{ab}	4.05^{bc}
	Eucalyptus	4.72^{ab}	11.80^{ab}	8.05^{bc}	4.57^{a}	5.33^{a}	6.80^{a}	6.80^{ab}	4.60^{ab}
	Orange+eucalyptus	4.84^{ab}	8.96^{bc}	7.30^{bc}	3.98^{c}	5.33^{a}	6.90^{a}	7.30^{a}	5.17^{a}
	Control	4.72^{ab}	7.17^{c}	6.92^{c}	3.27^{b}	5.33^{a}	6.20^{ab}	5.20^{bc}	1.57^{e}
F-LSD (0.05)		NS	4.48	3.75	0.79	NS	NS	NS	0.79

NS: no significant difference; V1: Valencia; V2: Ibadan sweet; V3: Washington. Means in each column followed by the same letter are not significantly different ($P \leq 0.05$) according to the ANOVA and F-LSD test.

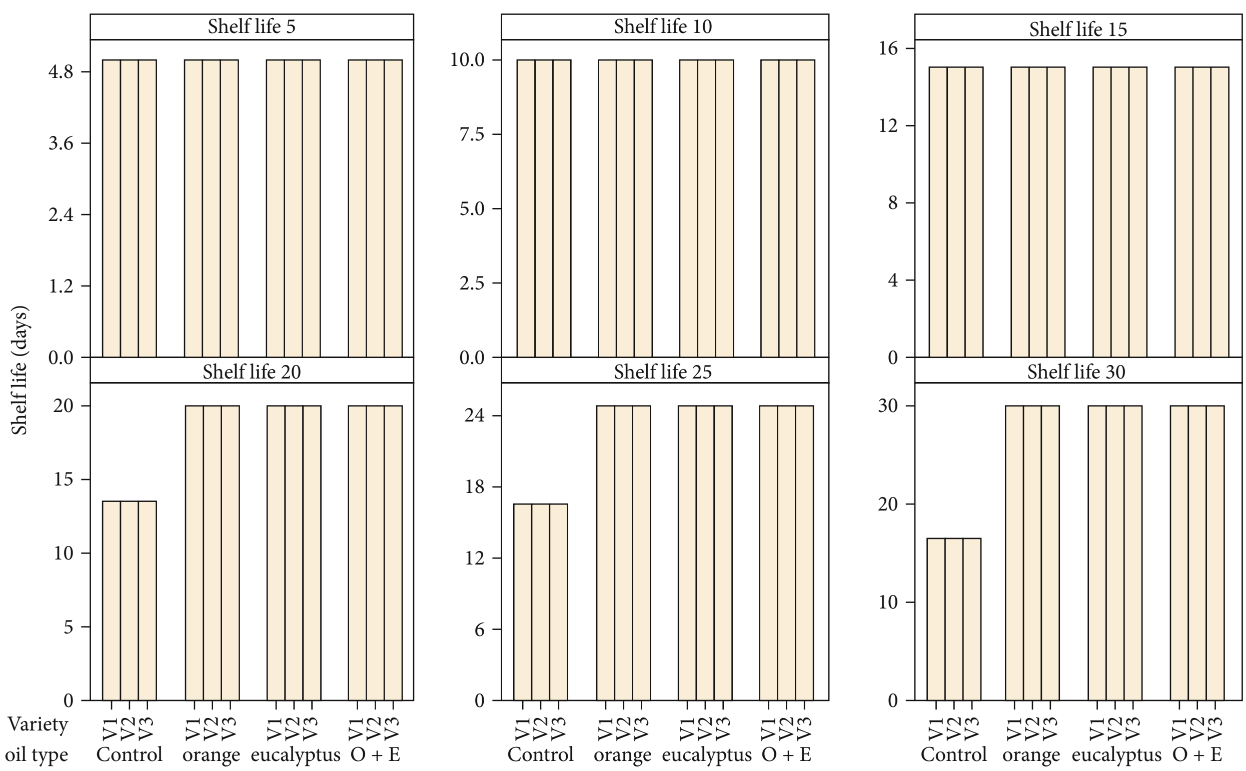

Figure 1: Shelf life of Valencia (V1), Ibadan sweet (V2), and Washington (V3) varieties of citrus treated with orange peel oil (O), eucalyptus leave oil (E), orange peel oil (O) and eucalyptus leave oil (E), and control stored for a duration of 30 days.

their combination enhanced the shelf life of citrus, but the control fruits produced shorter shelf life during storage. The extended shelf life of the treated fruits during storage was possibly due to the optimum performance in reducing weight loss and decay. The results confirmed previous research that reported extended shelf life due to the optimum reduction of respiration, weight loss, and firmness of plant-based coated Valencia orange fruits for a duration of 30 days [20] and 10 days duration of sweet orange fruits [49]. Biobased oils used in the current research delayed senescence and reduced desiccation that resulted in the extended shelf life of all treated fruits relative to the control.

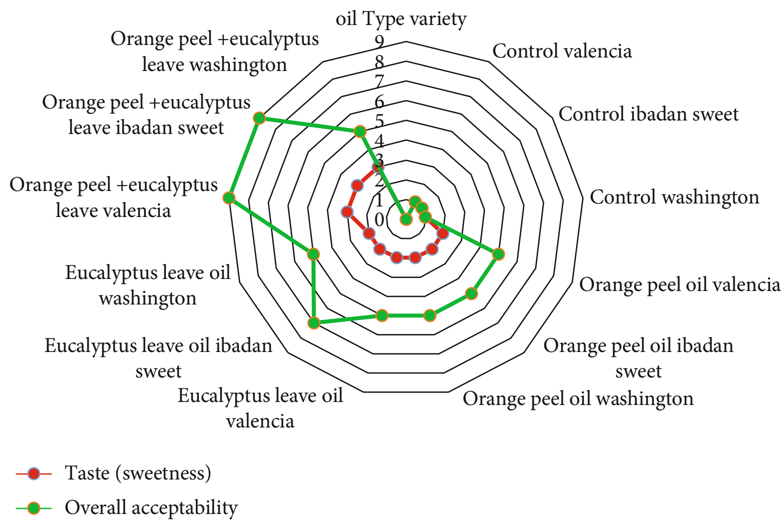

Figure 2: Average taste (sweetness) and overall acceptability scores of Valencia, Ibadan, and Washington varieties of citrus fruits treated with orange peel, eucalyptus leaves, the combined oils, and control. A 3-point scale was used for the taste scores, while a 9-point hedonic scale was used for the overall acceptability.

This was found to be in harmony with previous research that reported delays in the senescence of citrus fruits due to a coating effect with extended shelf life [50].

3.8. Organoleptic Attributes. The results of the sensory evaluation play an important role in the application of edible coatings. In the current study, the sensory analysis reveals significant changes in taste and overall acceptance (Figure 2). The panelists gave the highest scores (3) that showed good taste to the fruits treated with combined peel and leaf oil for all the three varieties tested. The fruits that were treated with only orange peel oil and eucalyptus leaf oil were scored an average taste in comparison to control fruits that were scored (1) described as poor. For overall acceptability, the panelist gave the highest score of (9) described as excellent to Valencia and Ibadan sweet fruits treated combined oils relative to Washington's acceptance rating of (5) described as good. The control samples were all rated (1) which was described as poor (Figure 2). The taste and overall acceptance of fruits during storage were affected by the application of biobased oils. Sensory evaluation results revealed that treated citrus fruits with the biobased oils significantly differed on taste and acceptability. However, biobased oil treatment performed better on sweetness and overall acceptance than the control. The higher ratings for the treated fruits could possibly be attributed to the maintenance of firmness, reduced loss in weight, and a good balance of the acid and total soluble solids. The results confirmed related studies that coating of citrus fruits delayed the degradation of total soluble solid titratable acid, and vitamin C content with higher scores for sensory quality [51, 52]. Biobased oil maintained the cell wall integrity of the citrus fruits against fungal attack and postponed pathogenic infection which improves taste with higher acceptability. The results concurred with the findings of studies of coated fruits against postharvest decay which resulted in higher acceptability of coated fruits better than the control [46, 53].

4. Conclusion

The objective of this study was to ascertain the effects of oils from eucalyptus leaves and orange peels on the shelf life and physiochemical quality of orange fruits during storage. The results of this study demonstrated that the three varieties of citrus fruit coated with combined biobased oil of eucalyptus leaves and citrus peels significantly delay weight changes, firmness, titratable acidity, soluble solids concentration, and ascorbic acid during storage at 25°C as compared to uncoated control fruits. In addition, the study showed that the application of combined biobased oils of eucalyptus leaves and citrus peels maintained the marketability quality with extended shelf life. Valencia (V1) exhibited a significant beneficial effect of the biobased oils treatment on weight, firmness, and marketability. In Ibadan sweet (V) fruits, biobased oils enhanced titratable acidity with relatively better vitamin C content. Biobased oils are known to reduce fruit weight loss by limiting respiration rate. For Washington (V3), a better maintenance of total soluble solids was found. It was safely concluded that the combined biobased oil from eucalyptus and orange peels offers a promise of better physiochemical quality and extends the shelf life of Valencia, Ibadan sweet, and Washington varieties of citrus during storage. The findings provide a practical basis for the application of combined biobased oil as an effective preservative to improve the storage quality of the three varieties of citrus fruits.

Data Availability

Data supporting the findings of the study are part of the article.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

Authors' Contributions

Adams Abdul-Rahaman designed the experiment, data collection, and its analysis; Kortse P. Aloho and Simon V. Irtwange supervised and helped in the design and contributed to the compilation of the manuscript. All authors read and approved the final version of the manuscript.

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