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Efficacy of Selected Indigenous Plant Extracts in Mitigating Post-Harvest Loss of Tomatoes

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Abstract: *The effects of guava leaves and avocado seed extracts on the postharvest shelf life, fruit quality parameters and degradation pattern of fresh tomato fruits as well as the relative preservation efficiencies of the extracts were investigated to ascertain their efficacy in reducing postharvest loss of tomato. Fresh tomato fruits were separately treated with the unenhanced extracts, L-ascorbic acid enhanced extracts, and the synergistic blends of the plant extracts following initial preparation by acidified-ethanolic extraction. The tomato shelf life conferred by each extract was then determined by monitoring the tomato fruits for degradation by soft rot, fungal rot and shrivelling. The study showed that L-Ascorbic acid-enhanced Guava leave extract (LAA-G) conferred both the highest mean shelf life of 63-days with a preservation efficiency of 83% while preserving tomato fruits treated with up to a maximum of 86-days, thus making it the most potent among the extracts in tomato shelf-life elongation. The potency of the extracts is in the order; LAA-G >A > LAA-AG > G > LAA-A > AG. Also, all the extracts possessed some degree of antimicrobial inhibition against Aspergillus, Rhizopus, E. coli and S. aureus but this was dependent on concentration and enhanced by treatment with L-ascorbic acid. The study found that, all extracts of P. guajava leaves and P. americana seeds possess remarkable shelf-life elongation activity, and hence, could mitigate postharvest loss of tomatoes except the heat-treated variant, which showed no shelf-life elongation activity. The marginal differences in the bioactive phytochemical compositions of the extracts suggest that the extracts may be achieving their preservative effect via a heat-labile bioactive compound that is present in all the extracts and further studies are needed to unravel this.*

Keywords: Tomato, postharvest loss, postharvest shelf life, Guava leaves, Avocado seed, L-Ascorbic acid

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INTRODUCTION

Tomato (Solanum esculentum) is among the popular tropical vegetables grown in Nigeria and around the world [1, 2]. It is usually sold fresh or as processed puree and plays an important role in meeting the nutritional food requirements of humans. Tomato contains enormous amounts of vitamin C, and can supply 40 percent of the daily value of vitamin C [3]. Tomato farming creates employment and generates income for both farmers and retailers [1]. In 2022, Nigeria produced about 3.68 million metric tons of tomato and is presently the second-largest tomato producer in Africa, second only to Egypt which produces 6.28 million metric tons [4]. As a result, Nigeria currently ranks 9th in the world in fresh tomato production [5]. However, only about 20% of tomato production in Nigeria is processed, and this has been attributed to lack of modern processing infrastructure [5]. The remaining 80% is either consumed fresh or lost. In 2017, Nigeria lost 40% of its tomato production to postharvest loss causes [6]. By 2023, Tomato postharvest loss in Nigeria had risen to 60% [7].

Very large amounts of tomatoes are transported daily, over long distances [8] to meet the demand of tomato processing industries and other consumers. As with other fruits, in the process of transportation, a substantial quantity of tomatoes gets spoilt [2, 9] This is mostly due to postharvest microbial, enzymatic and mechanical spoilage which occur between the farm and the final consumer. In less severe cases, such degradations significantly reduce their market value [1] but in extreme cases, results in outright loss.

A number of notable research efforts have been directed at mitigating tomato postharvest loss. Cao et al. [10] investigated the effect of ellagic acid (EA) treatment on postharvest tomato fruits and found that EA retards senescence in fresh tomato fruits by preserving their quality characteristics through an enhancement of their antioxidant responses. Utama et al. (2022) investigated the use of chitosan and starfruit leaf extract (SFLE) in compositing edible preservative coatings for tomato fruit [11]. The study found that adding SLFE to chitosan did not enhance its antimicrobial effect or fruit firmness over the effects produced by a separate use of chitosan and SFLE. However, both components improved the shelf life of tomato fruits compared to untreated tomatoes. Ceylan et al. (2023) investigated the effects of rosemary and sage essential oils (EO) on the shelf life and fruit quality of 'Sentino F1' tomatoes [12]. The study found all application groups of sage and rosemary EOs to be more effective in maintaining the quality of tomato fruits compared to the control application. However, studies have been unable to adequately preserve tomatoes up to 20 days even when a much longer duration of preservation is needed to significantly reduce tomato postharvest loss.

The Food and Agricultural Organization (FAO) reports that postharvest loss of tomato fruits in Nigeria is as high as 50% [5], this translates to huge losses in capital, both for farmers and traders as well as an eminent threat to food security. This research explores the efficacy of extracts of guava tree leaves (*Psidium guajava)* and avocado seeds (*Persea americana)* in mitigating

postharvest loss of tomatoes. This is because there are indications that these extracts contain bioactive compounds that might exert activity against commonly found fungal or bacterial pathogens of tomato, hence prolonging their shelf life and reducing their postharvest loss [13].

MATERIALS AND METHOD

Sample collection and preparation

Ten Kilograms of fresh guava (Psidium guajava) leaves harvested in Makurdi, Benue State Nigeria, were thoroughly washed with running tap water, air-dried in the laboratory at room temperature for 168 hours until they became brittle, before grinding into fine powder with a mistral grinder. The resulting powder was weighed and stored in an air-tight Ziplock bag at room temperature until required for extraction.

Ten Kilograms of ripe avocado (Persea americana) seeds were procured from Cross River State, Nigeria. They were thoroughly washed using tap water, allowed to drain and chopped into 2mm chips with a knife. The chips were then air-dried in the laboratory at room temperature for 240 hours until brittle, and ground into fine powder before weighing.

Fifty Kilograms of freshly harvested tomatoes fruits were procured from a local tomato farm in Makurdi, Benue State-Nigeria and conveyed to the laboratory in clean polyethene bags. These were then screened to select fruits that were without mechanical damage, blemish of any sort. These were then rinsed under cold running tap water and allowed to drain completely.

Preparation of plant extracts and their standard solutions

Guava leave extract (G) was prepared by acidified ethanolic extraction [14], where 5.08 Kg of guava leave powder was macerated in 7.4 L absolute ethanol and 100 mL concentrated acetic acid, this was vigorously agitated once every 24 hours for 72 hours and thereafter, filtered using a muslin cloth. The residue was re-macerated and extracted again. The resulting filtrates were combined and concentrated using a rotary evaporator and thereafter evaporated to dryness before grinding to obtain the extract powder. This was then stored in an airtight amber bottle until required. The above process was repeated separately for 6.1 Kg of Avocado seed powder to obtain Avocado seed extract (A) in powder form. The synergistic blend of Avocado seeds and Guava leaves extracts (AG) was prepared by homogenizing 92g of each extract powder in a mistral grinder, wet-mixing with 230 mL of distilled water in a 1000 mL beaker and evenly spreading it out on aluminium foil paper to air-dry at room temperature for 48 hours before grinding into fine powder. A 2 % w/w L-Ascorbic acid-enhanced Avocado seed extract (LAA-A) was prepared by wetting 178.4 g of (A) with 78.9 mM aqueous solution of L-ascorbic acid and the resulting slurry was air-dried at room temperature for 48 hours, before grinding into fine powder. This procedure was repeated for (G) and (AG) to obtain their corresponding L-Ascorbic acid-enhanced variants; (LAA-G) and (LAA-AG) respectively. Thereafter, 0.02, 0.04 and 0.06 g/mL of each plant extract and their modifications

were separately prepared and stored in dark amber bottles by separately dissolving each extract powder in distilled water. Distilled water was used as experimental control (EC) and samples were either dried or evaporated at room temperature to avoid denaturation of heat-labile bioactive compounds.

Determination of effect of plant extracts on postharvest loss of tomato

The efficacy of the prepared plant extracts in mitigating postharvest loss of tomato was assessed by determining the effect of the various extract solutions on the shelf life of fresh tomato fruits. This was done for each extract type by simultaneously steeping 6 freshly harvested tomato fruits each, into each of the standard solutions of the extract and allowing for 5 minutes in order to form a film around the fruit. These were then recovered and allowed to dry on clean filter paper at room temperature before mounting on a display console. The steeping procedure was repeated using distilled water as control. This allowed for each treatment type to have 6 replicates for observation. The shelf life was then monitored at intervals of 2 days for any sign of fungal growth, bacteria soft rot or shrivelling. The onset of any of these degradation pattern marked the end of the shelf life of the fruit. Maximum and minimum shelf life were recorded for each treatment type and their preservation efficiencies were calculated by evaluating (1). Thereafter, the extract solution with the most potency from the shelf-life study was heat-treated by boiling for 10 minutes in an attempt to denature any heat labile-bioactive compound in it before subjecting it to the same treatment as the unheated form of the extract. This is to determine whether the bioactive principle that may have accounted for its potency is an enzyme. The suffix ‘’HT-‘’ was added to the designation for the most potent extract to represent its heat-treated form. The impact of varied concentrations of the heat-treated extract on postharvest shelf life of the tomato fruits was then monitored.

$$Relative\ preservation\ (\%) = \frac{No.\ of\ Intact\ fruits\ on\ Day\ 44}{6} \times 100 \qquad (1)$$

Determination of the effect of the plant extracts on tomato fruit quality parameters

The underlisted fruit quality parameters were determined for all fresh tomato fruits subjected to the following categories of plant extract treatments A, G, AG, LAA-A, LAA-G, LAA-AG, and HT-LAA-G as well as for the two control groups; Baseline control (BC)- tomato fruits obtained directly from the farm in their freshest form solely for characterization on day 1 upon commencement of the study, and Experimental Control (EC) -fresh tomato fruits steeped only in distilled water and subjected to shelf life study.

i. Weight loss (W_L)

Weight loss was determined by evaluating equation (2), where W_i and W_t are the initial and terminal weights of the tomato fruit at the start of the experiment and at the end of its shelf life respectively.

$$W_L = \frac{W_i - W_t}{W_i} \times 100 \qquad (2)$$

ii. Fruit firmness

A penetrometer was gently driven into the fruit sample to be analysed, to a depth of 8 mm set by a stop collar and the maximum force in Newton that was required during the process was recorded from the instrument as a measure of the fruit's firmness [15] hence its resistance to deformation (Maguire, et al., 2018). This was determined in triplicate and the mean recorded. Thereafter, the mean firmness conferred by each extract was calculated and compared using one way-ANOVA for any significant difference.

iii. Total Soluble Solids (TSS)

The fruit sample was ground smoothly using a mistral grinder and strained to obtain a transparent juice. This was then applied to a refractometer prism and the TSS was read and recorded from the instrument in °Brix [16] This procedure was repeated in triplicate for each extract treatment and the mean TSS conferred by each extract was calculated and compared using one way-ANOVA for any significant difference.

iv. Titratable Acidity (TA)

Using a mistral grinder, the fruit sample was ground smoothly and strained to obtain a transparent juice. which was titrated against 0.1 M NaOH using phenolphthalein as indicator. The volume of NaOH required to neutralize the fruit juice was taken as its TA [17] The procedure was repeated in triplicate for each extract treatment and the mean TA conferred by each extract reported. These were then compared statistically using one way-ANOVA for any significant difference.

(IV) Sugar-Acid Ratio

The Sugar-Acid Ratio was obtained by dividing the °Brix value by the TA. The mean Sugar-Acid Ratio conferred by each treatment type were compared using one way-ANOVA for any significant difference.

Phytochemical Screening of the plant types

Plant extract samples; A, G, AG, LAA-A, LAA-G and LAA-AG were screened for phytochemicals using the High-Resolution Accurate Mass Liquid chromatography mass spectrometer (HRAM-LCMS) instrument (HRAM Synapt G2si Waters, UK) and Gas chromatography mass spectrometer (GCMS) following the instrument manufacturer's instructions. Only phytochemicals which have been reported to play a role in tomato fruit preservation were quantitated. The collected GCMS data was compared against multiple NIST and Wiley metabolite databases.

Structural fragmentation data obtained with LCMS HRAM instrument, were combined with the accurate mass and elemental composition information and compared against chemical standards held in the laboratory's inventory. For 'Unknowns' identification, collected mass spectra were compared against phytochemical databases. Extract chromatograms and mass spectra were also compared against the in-house phytochemical library, allowing for the definitive identification of analytes against chemical standards.

Determination of Antimicrobial Activity of extracts.

The antimicrobial activity of each extract was tested against Aspergillus and Rhizopus being the common microbes which cause tomato spoilage in the region and on E. coli and S. aureus because their presence in fresh tomato used in salads can cause food contamination. To this end, antimicrobial activity for each prepared extract was determined at 50, 100 and 200 mg/mL, using the disk diffusion method. In this method, E. coli, S. aureus, Aspergillus, and Rhizopus, were separately cultured on agar. Sterile filter paper disks were soaked in a plant extract solution and allowed to dry before placing on the agar plate inoculated with the test microbe. The entire setup was then incubated at 37 ^{o}C for 48 hours after which the inhibition zones conferred by each extract was measured and compared with that by standard antibiotic. The presence of a clear zone of inhibition around the disk indicates antimicrobial activity and vice versa.

RESULTS AND DISCUSSION

The results obtained for the shelf-life study are as presented in Tables 1, 2 and 3 below. Whereas Figures 1 (a-c) shows groups of tomato fruits treated with their various extracts on Day 0, Figure 2 (a-f) shows the tomato fruits of different extract treatments on the last day of their maximum shelf life.

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Table 1: Effects of Avocado seed and Guava leaves extract on Tomato shelf life, their preservation efficiencies and their degradation pattern

Extract/ Treatment Type	Mean Shelf Life (Days)	Minimum Shelf Life Observed in group (Days)	Maximum Shelf Life Observed in group (Days)	Relative preservation Efficiency on Day 44 (%)	Most prevalent Degradation pattern
EC	17 ± 9^{a}	6	30	N. A	Soft rot = fungal rot
A	53 ± 24^{d}	18	78	50	Shriveling > soft rot
G	40 ± 32^{c}	2	80	33	Soft rot > shriveling
AG	20 ± 18^{a}	4	44	17	Shriveling > soft rot
LAA-A	29 ± 25^{b}	2	78	17	Shriveling = soft rot
LAA-G	63 ± 21^{e}	30	86	83	Shriveling > soft rot
LAA-AG	43 ± 38^{c}	4	80	50	Shriveling = soft rot
HT- LAA-G	14 ± 6^{a}	6	24	N. A	Soft rot = fungal rot

Means with unidentical superscript have a statistically significant difference and vice versa.

In Table 1, there is an apparent appreciable deviation in each of the mean shelf-lives reported, as well as between the maximum and minimum shelve-lives observed within each treatment type, this phenomenon is to be expected in studies of this nature where the removal of experimental replicates almost at the onset of the experiment, produces outliers that must yet be considered as part of the whole. In this instance, the deviations observed could be attributed among other factors to an inability to sufficiently coat the fruit pericarp with the extract's protective film possibly due to inadequate steeping of the tomato fruit in the treatment solution, such that the affected tomato fruits degraded at the very onset of the shelf-life study and had to be removed from the experiment prematurely. However, this phenomenon is compensated for when the observed mean shelf life for each treatment is considered alongside the relative preservation efficiency of each extract

treatment, measured on the day of the highest shelf life attained by the weakest performing extract in the study.

From Table 1, It can be seen that, the LAA-G treatment conferred the highest mean shelf life (63 days), and the highest number of days of minimum shelf life observed in the study (30 days). Also, the LAA-G treatment produced the highest preservation efficiency (83 %) as well as the longest tomato shelf life (86 days) observed in the study. A tomato fruit treated with LAA-G on Day-0 can be seen in Figure 1 (c) while Figure 2(a) Shows the same fruit on Day-86. All of these make the LAA-G extract, rank highest as the best performing and most effective extract in the study with regard to extending tomato shelf life and the mitigation of postharvest loss of tomato. Also, Table 1 shows there is a statistically significant difference between the mean shelf life observed between the control and all experimental treatments implying that all the plant extracts that were tested against the control had the effect of elongating the shelf life of tomato fruits but to varying degrees. As a result, the extracts can be ranked from the most effective to the least effective thus; LAA-G >A > LAA-AG > G > LAA-A > AG. HT-LAA-G did not produce an elongation of shelf-life. It is noteworthy from this ranking that G which is far less effective than A became the most effective after enhancement with L-ascorbic acid and used as LAA-G. This is congruent with studies reported by Zhoa, et.al [18]. The ranking of AG as the least effective extract clearly shows the complete absence of any synergistic effect between the avocado seed and guava leave extracts in tomato shelf-life extension. Tomatoes treated with HT-LAA-G experienced same fate as those treated with distilled water (EC) seeing as their minimum shelf-life were same and both their mean and maximum shelf-lives are comparable. Also, both the heat- treated LAA-G and control tomatoes completely perished before 44 days (i.e. the maximum shelf life of the weakest extract). These implies that LAA-G lost its preservative effect when heated, this suggests that its potency in tomato shelf-life elongation is likely through an enzyme or heat-labile bioactive principle.

With HT-LAA-G treatment, tomato degradation was only by soft rot and fungal decay, this further confirms that HT-LAA-G had no preservative effect on tomato. However, with the remaining extracts, no fungal degradation was observed. It is noteworthy that, Table 1 shows that shrivelling was the most prevalent degradation pattern observed with all the extract treatments except HT-LAA-G, this further confirms their preservative potency and this is buttressed by the significant elongation of tomato shelf life observed for each of them.

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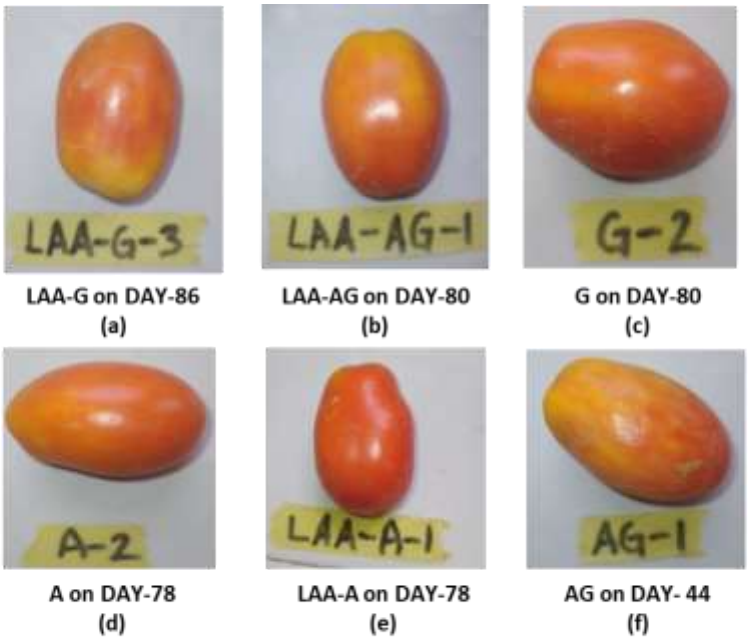
GROUP 1 TOMATOES on DAY 0 (a)

GROUP 2 TOMATOES on DAY-0 (b)

GROUP 3 TOMATOES on DAY-0 (c)

Figure 1: Tomato Fruit at the Start (Day-0) of Treatment



LAA-G on DAY-86 (a)

LAA-AG on DAY-80 (b)

G on DAY-80 (c)

A on DAY-78 (d)

LAA-A on DAY-78 (e)

AG on DAY- 44 (f)

Figure 2: Tomato fruits on the last day of maximum shelf life conferred by extract type

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Table 2: Effect of *Psidium guajava* leaves and *Persea americana* seed extracts on tomato fruit quality parameters

S/N	Extract/Treatment Type	Desiccation (%)	Fruit firmness (N)	Total Soluble Solids (^oB)	Titrable Acidity (10^{-3})	Sugar – Acid Ratio
1.	BC	N. A	6.42 ± 0.65^a	4.40 ± 0.00^b	8.62 ± 2.20^b	528.18 ± 136.91^a
2.	EC	13.2 ± 1.9^a	7.80 ± 1.16^b	4.20 ± 0.35^b	7.25 ± 0.87^b	581.07 ± 21.87^b
3.	A	22.2 ± 5.2^c	8.09 ± 2.11^b	3.96 ± 0.08^e	5.54 ± 1.12^a	745.45 ± 181.16^d
4.	G	16.3 ± 8.1^b	7.05 ± 2.26^a	4.08 ± 0.67^f	6.08 ± 1.32^c	702.33 ± 193.09^d
5.	AG	16.6 ± 9.9^b	6.77 ± 0.89^a	3.96 ± 0.96^e	8.19 ± 4.17^b	568.34 ± 207.44^b
6.	LAA-A	15.6 ± 6.7^b	7.21 ± 0.98^b	3.86 ± 0.30^e	6.66 ± 1.88^c	613.54 ± 156.07^c
7.	LAA-G	21.0 ± 9.6^c	8.18 ± 2.38^b	3.76 ± 0.57^e	5.06 ± 1.03^a	782.32 ± 267.39^d
8.	LAA-AG	18.0 ± 9.1^c	6.94 ± 0.93^a	4.05 ± 0.81^f	6.50 ± 0.75^c	628.98 ± 143.05^c
9.	HT- LAA-G	8.8 ±5.6^a	6.12 ± 2.65^a	3.60 ± 0.52^d	7.79 ± 1.66^b	471.13 ± 70.09^a

N.A. = Not applicable
Means with identical superscript within a column are not significantly different

The result in Table 2 shows that desiccation was most severe among tomato fruits treated with; A, LAA-G, and LAA-AG which were the extracts that notably conferred some of the longest shelf lives and the highest preservation efficiencies observed in Table 1. Under conditions that promote prolonged shelf life, such desiccations in tomato have been reported to bolster fruit firmness but may negatively impact fruit appearance [19], by causing shrivelling in some cases, especially when the shelf life becomes prolonged for upward of 40 days as seen with the results obtained for firmness conferred by LAA-G and A treatments in Table 2. By this, the extracts have demonstrated potency in conferring a higher degree of resistance to deformation by elongated shelf-life and this may be speculated as one of the mechanisms by which *Psidium guajava leave* and *Persea americana* seed extracts could mitigate postharvest tomato loss. However, this observation is at variance with Nunes, et al. 2008, where such desiccations were associated with shelf-life reduction, although this was linked to fungal degradation [20]. In this study however, fungal rot was only observed with HT-LAA-G treated tomatoes, while shrivelling was the most prevalent degradation observed for the remaining extracts. Hence the observations in Table 2 are to be expected when

shelf life is significantly elongated in fresh vegetables and fruits, because it allows them to experience more desiccation [21-24].

From Table 2, the relative potency of the extract treatments to retard fruit ripening from the most efficacious to the least efficacious is; HT- LAA-G > LAA-G > LAA-A >A=AG> LAA-AG >G. Studies have shown that, the higher the TSS, the riper the fruit will be and vice versa [19, 25]. The results in Table 2 shows that the TSS of tomatoes in both BC and EC groups are higher than the TSS conferred on tomato fruits in all extract treatments. This confirms the potency of all extract treatments in the study including HT-LAA-G to retard the fruit ripening process in tomato and by so doing, extend their shelf life. However, it is clear that this retardation of the ripening process alone is unable to bring about an elongation of shelf life as observed with tomatoes treated with HT-LAA-G and this may be because, this extract had lost its antimicrobial abilities during the heating process. This corroborates the observations reported by [26]. Also, it can be seen that, the extracts which conferred the longest shelf lives and which had the highest preservation efficiencies (namely; LAA-G and LAA-A) from Table 1, are among those with remarkable abilities to retard the ripening process in Table 2, and this suggests that they may have synergised this ability to retard fruit ripening with bioactive properties to elongate shelf life of tomatoes treated with them.

From the results in Table 2, Titrable acidity from most acidic to the least acidic is in the order BC > AG > HT-LAA-G > EC > LAA-A > LAA-AG > G > A> LAA-G. This gradation of the extract appears to produce a complete reversal of the order of grading of the extracts from most potent in shelf life extension to the least potent as earlier discussed for Table 1 (i.e. LAA-G >A > LAA-AG > G > LAA-A > AG > HT-LAA-G) and because a high TA often indicates a less ripen stage, it might appear from the above TA gradation that LAA-G , A , LAA-AG and G -the most potent extracts in shelf life elongation, are least effective in retarding the tomato ripening process, when in fact the results from their desiccation, fruit firmness and TSS parameters show the opposite. The relatively lower TA observed with the LAA-G, A, LAA-AG and G treatments are because the tomato fruits in these treatments attained the longest shelf lives thus allowing enough time for some of their titrable acids to be converted into free sugars and other metabolites associated with delayed ripening [27-30]. Conversely, the relatively higher TA's observed with tomatoes in the BC, AG, HT-LAA-G, EC and LAA-A Treatments were because they were each analysed for TA much sooner due to their short shelf lives. In this regard also, tomatoes in the baseline control, the experimental control, and HT-LAA-G where relatively in their freshest states when they were analysed seeing as they had the shortest shelf life and thus were nearer the fresh state in which they were when they were just harvested and had had undergone little or no postharvest ripening.

In Table 2, the order of the sugar to acid ratio from highest to lowest is; LAA-G >A > G > LAA-AG > LAA-A > EC > AG > BC > HT-LAA-G. The higher the sugar to acid ratio, the greater the ripeness of a fruit and vice versa [11, 29, 32]. The above gradation is similar to the gradation of the extracts based on their respective mean shelf life and preservation efficiency going from most

effective to the least effective even more so as there was no significant statistical difference between the mean shelf lives of the least effective extract (AG), the experimental control and the extract with lost activity (HT-LAA-G). The implication is that tomatoes treated with LAA-G, A, G, LAA-AG and LAA-A had a higher sugar to acid ratio only because they had been preserved for much longer by significantly elongated shelf lives for much longer than the controls and HT-LAA-G (the extract with lost activity), during which time, their acids were converted into more free sugars. Tomatoes in the latter category perished too soon before they could accumulate such amounts of sugar from ripening hence their relatively lower sugar to acid ratio. By implication, the above gradation of the extracts/treatments based on their sugar to acid ratio shows that the extracts which conferred the longest shelf lives on tomato in Table 1, have also produced in the tomatoes treated with them in Table 2, the highest sugar to acid ratios at the end of their shelf lives, but this is only because these tomatoes have been preserved the longest and so have undergone the most postharvest ripening, hence they have the most amount of sugar and the least amount of acid.

Table 3: Effects of varied concentrations of Avocado seed and Guava leaves extract types on Tomato shelf life and their preservation efficiencies

Extract type	Concentration (g/L)	Mean Shelf Life (Days)	Relative preservation efficiency on Day-44 (%)
A	10	47 ± 4.01	100
	20	54 ± 9.79	100
	30	59 ± 26.87	100
G	10	28 ± 16.97	50
	20	40 ± 5.74	50
	30	54 ± 6.76	100
AG	10	43 ± 1.41	100
	20	5 ± 1.41	50
	30	13 ± 12.72	50
LAA-A	10	13 ± 15.55	50
	20	26 ± 2.82	100
	30	48 ± 12.42	100
LAA-G	10	81 ± 7.07	100
	20	53 ± 32.52	100
	30	56 ± 16.97	100

The results in Table 3 shows that, three (A, G and LAA-A) out of the five plant extracts produced increased elongation of shelf life as the applied concentrations of the extracts were increased.

However, with Preservation efficiency, it is not very clear whether an increase in concentration of the plant extracts produces an increase in the preservation efficiency of the extracts. In the case of Extracts A and LAA-G, the preservation efficiency remained same regardless of changes in concentration of the extract used. This suggests that it is either the extracts preservation efficiency is unaffected by the concentration applied or that the concentrations tested though within the ranges used in related literature, were far above the minimum effective concentrations hence the maximum preservation efficiencies recorded on Day-44. These suggests that there may be need to undertake the study at much wider concentration ranges.

Table 4: Phytochemical abundance of avocado seeds and guava leaves extracts by percentage of sample weight

Phytochemical	A (% w/w)	G (% w/w)	AG (% w/w)	LAA-A (% w/w)	LAA-G (% w/w)	LAA-AG (% w/w)
Citric Acid	0.9449	0.5370	0.7004	1.7883	0.9805	1.6418
Quinic Acid	0.4756	0.2515	0.4398	0.5369	0.4205	0.5253
2,3-Dihydroxybenzoic Acid	0.0975	ND	0.0365	ND	ND	0.0678
Epicatechin	0.6073	0.9463	0.7392	0.8997	1.1160	1.1232
Chlorogenic Acid	0.5560	0.0124	0.2925	0.8250	ND	0.4191
Gallic Acid	0.0037	0.0006	0.0014	0.0054	0.2682	0.1873
Cinnamic Acid	ND	ND	ND	ND	ND	ND
Caffeic Acid	0.0038	ND	ND	0.0036	0.0045	ND
Sinapic Acid	0.0005	0.0001	0.0004	ND	ND	0.0009
Quercetin	ND	4.1156	2.9374	ND	0.7705	0.5010

The result in Table 4 shows a unique cocktail of phytochemicals which have all been reported to play different crucial roles in tomato fruit preservation and apart from Cinnamic acid, all of them were found to be present in various amounts in the plant extracts used for tomato preservation in the study. This accounts for the varying degrees of shelf lives, preservation efficiencies and fruit quality conferred by each extract on fresh tomato fruits in the study. Citric acid and 2,3-dihydroxybenzoic acid, lowers pH, thus inhibiting the growth of spoilage organisms and pathogens [33, 34]. Citric acid also acts as an antioxidant and helps maintain the quality of tomatoes during storage, hence preserving flavour and firmness [33]. Fang et al. (2020) demonstrated that Quinic acid enhances the stability of some bioactive compounds in tomatoes, thus contributing to an extended postharvest shelf life [35]. Epicatechin possesses strong antioxidant properties that helps protect tomato tissues from oxidative damage and plays a role in delaying senescence, thus contributing to the extension of tomato shelf life [36]. Chlorogenic acid has been reported to play a role in inhibiting certain fungal pathogens hence demonstrating usefulness in extending tomato shelf life [37] and this likely explains the complete suppression of fungal degradation seen in Table

1 except for the Heat-treated extract (HT-LAA-G), especially since Chlorogenic acid is heat-labile. Gallic and Caffeic acids act as antioxidant and exhibit antibacterial properties [38, 39]. Quercetin, combines antioxidant and anti-inflammatory properties and inhibits the growth of spoilage bacteria and fungi, thereby preserving the freshness and extending the shelf life of tomatoes [40]. The implication is that while it appears that this unique cocktail of phytochemicals present in the extracts probably accounts for the tomato fruit preservation effects demonstrated by each of the extract forms as shown in Table 1, it is instructive to note that there is no significant difference in the levels of each of these phytochemicals in the various extracts yet there is a marked gradation in the degree of potency of each extract type as seen from their relative preservation efficiencies and post-harvest shelf life, that each have conferred on fresh tomato. This phenomenon may be suggestive of another mechanism of action of the extract that is dependent on a heat labile protein especially considering how that the heat-treated extract in Table 1 showed a complete loss of preservative action after it underwent boiling.

Table 4.3. Anti-microbial activity of P.guajava leaves and P. americana seed extracts

Plant Extract	Microbe Isolate	Inhibition by concentration (mm)			Inhibition by standard (mm)
		200 mg/mL	100 mg/mL	50 mg/mL	
A	*E. coli*	10	N. Z	N. Z	Ciprofloxacin: 19
	S. aureus	12	9	N. Z	Ciprofloxacin: 22
	Aspergillus	N. Z	N. Z	N. Z	Nystatin: 24
	Rhizopus	N. Z	N. Z	N. Z	Nystatin: R
G	*E. coli*	13	9	N. Z	Ciprofloxacin: 22
	S. aureus	16	11	N. Z	Ciprofloxacin: 29
	Aspergillus	11	N. Z	N. Z	Nystatin: 20
	Rhizopus	N. Z	N. Z	N. Z	Nystatin: 17
AG	*E. coli*	14	10	8	Ciprofloxacin: 23
	S. aureus	16	11	8	Ciprofloxacin: 27
	Aspergillus	12	8	N. Z	Nystatin: R
	Rhizopus	N. Z	N. Z	N. Z	Nystatin: 12
LAA-A	*E. coli*	N. Z	N. Z	N. Z	Ciprofloxacin: 19
	S. aureus	12	N. Z	N. Z	Ciprofloxacin: 20
	Aspergillus	N. Z	N. Z	N. Z	Nystatin: 11–13
	Rhizopus	10	8	N. Z	Nystatin: 19
LAA-G	*E. coli*	16	11	9	Ciprofloxacin: 17
	S. aureus	N. Z	N. Z	N. Z	Ciprofloxacin: 28
	Aspergillus	N. Z	N. Z	N. Z	Nystatin: 11

	Rhizopus	9	N. Z	N. Z	Nystatin: R
LAA-AG	*E. coli*	13	N. Z	N. Z	Ciprofloxacin: 27
	S. aureus	11	N. Z	N. Z	Ciprofloxacin: 23
	Aspergillus	N. Z	N. Z	N. Z	Nystatin: R
	Rhizopus	N. Z	N. Z	N. Z	Nystatin: R

The result in Table 5 shows that only G and AG demonstrated activity against Aspergillus. In a similar manner only LAA-A and LAA-G showed activity against Rhizopus. Both these inhibitions were observed at the highest concentration of 200 mg/mL, and no inhibition zones were observed for Aspergillus and Rhizopus at 50 and 100 mg/mL. This implies that; A, G, AG, LAA-A, LAA-G and LAA-AG possessed antifungal property that is dependent on concentration but is enhanced by treatment with L-ascorbic acid. This is consistent with previous reports by many authors [41-45]. Apart from LAA-A which likely required to be used at a higher concentration, all extracts showed inhibition of E. coli and thus implying they have inherent capacity to equally mitigate food contamination by E. coli. With exception of LAA-G, all extracts showed inhibition against S. aureus but it is unclear how L-ascorbic acid enhancement reduces the ability of extracts to inhibit S. aureus.

CONCLUSION

The effects of guava leaves and avocado seed extracts on the postharvest shelf life, fruit quality parameters and degradation pattern of fresh tomato fruits as well as the relative preservation efficiencies of the extracts were investigated to ascertain their efficacy in reducing postharvest loss of tomato. The extracts of avocado seeds and guava leaves proved to be effective in reducing postharvest loss of tomatoes and they achieve this by a combination of actions; shelf-life elongation, retardation of the fruit ripening process and antimicrobial action. The potency of the extracts in mitigating tomato postharvest loss is in the order; LAA-G >A > LAA-AG > G > LAA-A > AG. However, the marginal differences in the preservative phytochemical composition of the various extract forms suggest that the extracts may be achieving this effect via a heart labile bioactive compound present in all the extracts and further studies are needed to unravel this.

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Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

[1]. Obekpa, H.O. (2019). Reducing Post-Harvest Losses in Tomatoes. Feed the Future Innovation Lab for Food Security Policy Research Brief 92, p1-4.
[2]. Arah, I.K., Kumah, E.K., Anku, E.K., Amaglo, H., (2015), An Overview of Post-Harvest Losses in Tomato Production in Africa: Causes and Possible Prevention Strategies. Journal of Biology, Agriculture and Healthcare 5 (16):78-85.
[3]. Bhowmik, D., Kumar, K.P.S., Paswan. S., & Srivastava, S. (2012). Tomato-A Natural Medicine and its Health Benefits. Journal of Pharmacognosy and Phytochemistry, 1(1), 33-43pp.
[4]. FAO (2023). Global tomato production in 2022. Rome, FAO.
[5]. FAOSTAT (2022). Global tomato production in 2021. Rome, FAO.
[6]. SUN Newspaper publication 27/11/2017.
[7]. Business Day Newspaper publication of 26/07/2023.
[8]. Al-Dairi, M., Pankaj, B.P., and Al-Yahyai, R. (2021) Effect of Postharvest Transport and Storage on color and firmness of Quality of. "*Horticulturae*, 7(7): 163-171.
[9]. Zhou, R., Su, S., Yan, L., Li, Y. (2007). Effect of transport Vibration Levels on Mechanical Damage and physiological response of Huanghua pears. Postharvest Biology and Technology. 46,20-28.
[10]. Cao, J., Wang, T., Li, Y., Cao, S., and Fan, T., (2023). Ellagic Acid Treatment Improves Postharvest Quality of Tomato Fruits by Enhancing the Antioxidant Defence System. Journal of FoodBiochemistry, 2023 (8375867): 1-10.
[11]. Utama, N.A., Ernawati, R., Pramesi, P.C. (2022) The improvement of tomato shelf life using chitosan and Star fruit leaf extract as edible coatings. Journal of Horticultural Research 30(1):77- 86.
[12]. Ceylan, A., Unlu, H.O. (2023). Effects of some postharvest essential oils applications on the fruit quality of tomatoes (Solanum lycopersicum) during cold storage. Food Science and Technology 43 (1); 1-10.
[13]. Rodriguez, F., Silva, M. (2022). Enhancing the shel life of fruits using L-ascorbic acid. Journal of food chemistry, 48 (7), 1012-1025.
[14]. Rodríguez-Martínez B., et al., (2022). Potential and prospects for utilization of avocado by-products in integrated biorefineries. Bioresource Technology 364 (2022) 128034.
[15]. McClements, D. J. (Eds.). (2015). Advances in Food and Nutrition Research (1st ed., Vol. 200). Academic Press.
[16]. Bhandari, B. R., & Bansal, N. (Eds.). (2015). Handbook of Food Powders: Processes and Properties. Woodhead Publishing.
[17]. Bhat, R., Karim, A. A., & Liong, M. T. (Eds.). (2015). Natural Food Additives, Ingredients and Flavourings. Woodhead Publishing.
[18]. Zhoa, H., Lius, S., Chen, M., Li, J., Huang, D. and Zhu, S. (2019). Synergistic Effects of Ascorbic acid and plant Derived Ceramide to enhance storability and boost antioxidant systems of postharvest strawberries. J. Sci. Food Agric., 99:6562-6571.

[19]. Kader, A.A. (2002). Post-Harvest Technology of Horticultural Crops. University of California Agriculture and Natural Resources.
[20]. Nunes, M.C.N. (2008). Impact of environmental conditions on fruits and vegetable quality. Stewart Postharvest Review, 4(2), 1-14.
[21]. Shamaila, M. (2020). Desiccation: A novel approach to extend shelf life of fruits and vegetables. Journal of food science and Technology. 57 (2), 538-546.
[22]. Kumar, P. (2019). Desiccation-induced changes in physiological and biochemical characteristics of broccoli. Journal of Food Science, 84(5), S1448-s1456.
[23]. Singh, R. (2018). Effect of desiccation on shelf life and quality of cherry tomatoes. Journal of food processing and preservation, 42(3), e13544.
[24]. Zhang, Y. (2020). Water loss and desiccation-induced changes in postharvest quality of Strawberries. Postharvest Biology and Technology, 163, 111-115.
[25]. Beckles, D.M. (2012). Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit. Post-harvest Biology and Technology, 63 (1), 129-140.
[26]. Salunkhe, V.S (2018) Changes in sugar composition during ripening of mango fruit. Journal of food science and Technology, 55(2),432-438.
[27]. Laurence, P. (2019). Sugar and acid metabolism in fruits. Journal of Food Science, 84(5) S1478-S1486.
[28]. Wang, Y. (2020). Metabolic changes in fruit ripening; A review. Journal of Food Science and Technology, 57(4), 1050-1063.
[29]. Zhang, J. (2019). Changes in sugar and acid composition during ripening of apples. Journal of food Science, 84(2), S388-S395.
[30]. Zhang, J. (2019). Changes in sugar and acid composition during ripening of Peaches. Journal of food Science, 85(2), S388-S395.
[31]. Kumar, P. (2018) Sugar and acid metabolism in mango fruit during ripening. Journal of Food Biochemistry, 42 (1), e12431.
[32]. Saini, C.S., (2019). Sugar-Acid Ratio; A Key Indicator of Fruit Ripeness. Journal of food Science andTechnology 56(4),1050-1063.
[33]. García-Viguera, C., et al. (2019). Citric acid as a natural preservative in postharvest storage. Food Chemistry, 298, 125013.
[34]. Zhang, R., et al. (2020). Evaluation of phenolic compounds for antifungal activity. Frontiers in Microbiology, 11, 492.
[35] Fang, Z., et al. (2020). Analysis of key phytochemicals in tomatoes and their implications for postharvest storage. Food Chemistry, 311, 126079.
[36]. Cai, J., et al. (2021). Roles of flavonoids in postharvest quality and storage of tomatoes. Journal of Agricultural and Food Chemistry, 69(1), 10-23.
[37]. Mansouri, M., et al. (2022). Chlorogenic acid: A review of its effects on fruits and vegetables. Critical Reviews in Food Science and Nutrition, 62(5), 1418-1432.
[38]. Khan, M. I., et al. (2019). Antimicrobial synergism of gallic acid in tomatoes. Journal of Food Science, 84(3), 834-842.

[39]. González-Aguilar, G., et al. (2020). Influence of caffeic acid on the quality of postharvest tomatoes. Postharvest Biology and Technology, 164, 111139.
[40]. Mao, L., et al. (2022). Quercetin as a natural antimicrobial agent for improving the shelf life of tomato. Postharvest Biology and Technology, 188, 111861.
[41]. Martynenko, I. V., & Kolesnik, L. I. (2023). Synergistic Antimicrobial Activity of Essential Oils and Vitamin C. Applied Sciences, 15(8), 4294.
[42]. Molla, R., Sadia, H., & Anisuzzaman, M. (2022). Assessment of Antibacterial and Anti-biofilm Effects of Vitamin C against Uropathogenic E. coli In Vitro. BMC Microbiology, 23(1), 56.
[43]. Das, S., & Mandal, S. (2022). Recent Advancements in Enhancing Antimicrobial Activity of Plant Extracts. Plants, 11(5), 401.
[44]. Rizvi, M., Kumar, S., & Sidhu, G. P. S. (2022). Characterization, Antioxidant, and Antimicrobial Activity of Two Sage Plant Extracts. Food Chemistry, 375, 131775.
[45]. El Amin, S., Hussain, S. K., & Ameer, D. M. (2021). Exogenous Application of Ascorbic Acid Enhances the Antimicrobial Activity of Plant Extracts in Tomato. Journal of Food Science 86(9), 3821-3830.