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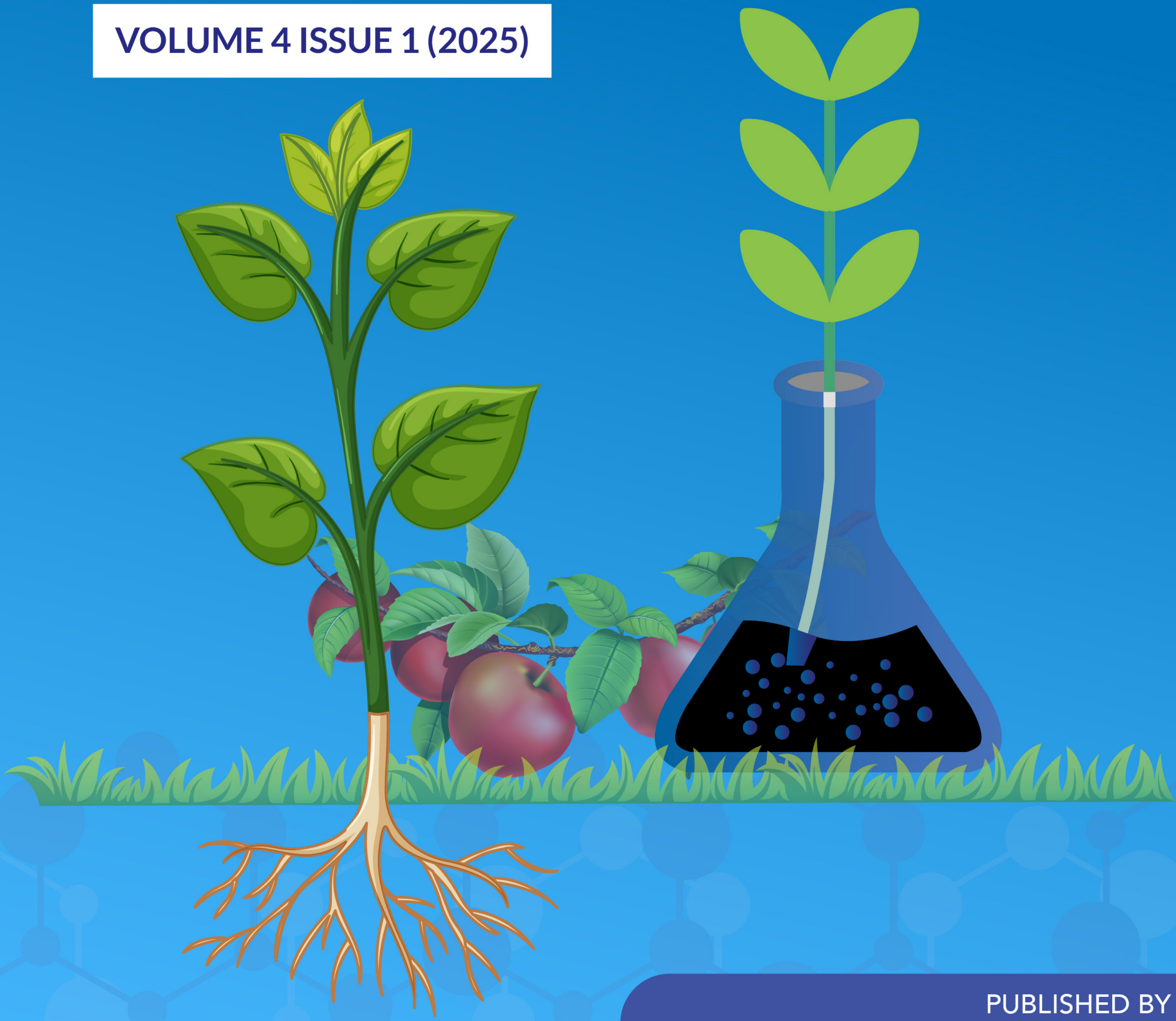

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Improving Tomato Juice Preservation: The Role of Ginger, Garlic, and Lemon Extracts

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ABSTRACT

Tomato juice was successfully produced and treated with 3 different plant extracts and their combinations. The study had 9 samples, Sample TJ being the control (without preservative), and sample TSB (with sodium benzoate). The remaining samples were treated with 1 % of the extracts and their combinations as follows: TZ (1 % Ginger), TA (1 % Garlic), TC (1 %Lemon), TZA (1 % Ginger+Garlic), TZC (1 % Ginger+Lemon), TAC (1 % Garlic+Lemon) and TZAC (1 % Ginger+Garlic+Lemon). The samples were analyzed for phytochemical and antioxidant activity and also subjected to storage studies, during which pH, TTA, TSS, and microbial counts were evaluated. The total phenolic content ranged from 1.50 to 2.80 mgGAE / 100 ml, the total flavonoid content ranged from 1.02 to 1.22 mgQE / 100 ml, and the FRAP values ranged from 1.23 to 4.76 mgAAE / 100 ml. For storage studies, pH and TSS decreased with storage time while TTA and microbial load increased accordingly. However, the microbial load of the samples was within the limits recommended by ICMSF. It can be concluded that tomato juice can be conveniently preserved with natural plant extracts which give the juice improved nutrients, antioxidant activity, and a relatively stable shelf life.

INTRODUCTION

Preservatives, whether natural or synthetic chemicals are substances added to products such as foods and biological samples to prevent decomposition due to microbial action or undesirable chemical changes (Shaikh *et al.*, 2016). They are additives added to food to preserve food and extend shelf life. They are commonly used in various foods to extend shelf life, often through mechanisms such as reducing water availability, increasing acidity, and changing the redox potential. Some chemical preservatives, such as sorbate and benzoate, can improve the shelf life of beverages but may have negative effects on consumer health. The current trend leans towards biological preservatives, ginger and lime being examples. Ginger is known for its antioxidant and antimicrobial properties, while lime has been used to preserve juices effectively (Arawwawala & Hewageegana, 2017). Lemon is also considered a good biological preservative with antimicrobial effects and can replace chemical preservatives (Olaniran *et al.*, 2020). The demand for healthy foods and beverages without chemical additives has led to the increased use of natural preservatives, as they have been shown to be effective in reducing microbial growth (Yusuf *et al.*, 2018; El-Saadony *et al.*, 2020).

Therefore, this study was carried out to ascertain the effects of ginger, garlic and lemon extracts on the shelf-life extension of tomato juice.

MATERIALS AND METHODS

Material acquisition

Raw materials; tomatoes, ginger, garlic and lemon were purchased from Wurukum Market, in Makurdi Benue State, Nigeria.

Preparation of Tomato Juice

This was done using the procedure described by Mahmud *et al.* (2009). After washing / cleaning, the tomatoes were peeled with a stainless-steel knife and sliced. Then the blanching was done using hot water at 65 ° C for 5 minutes. The seeded portion of the tomato was removed and the flesh was collected. The flesh was cut into small pieces and crushed in an electric blender to get a fine pulp. Sugar and other preservatives were added. Homogenization or mixing was done. After homogenization, pasteurization was performed at 75 °C for 3 minutes.

Production of Lemon Extract (juice)

This was done as described by Jacob *et al.* (2017). Fresh and mature lemon fruits were sorted to remove damaged and spoilt ones. They were properly washed with potable water, cut into halves, and the juice was extracted by pressing the fruit pieces in a manually operated juice extractor. The juice was passed through a single layer of muslin cloth to remove solids and pulp materials.

Preparation of Ginger and Garlic Extracts

Before use, ginger and garlic were washed under running water, peeled, and diced into cubes separately. The respective diced cubes (100 g) were mixed with 100 ml of distilled water using a grinder (Kenwood) for 5 min and allowed to stand for 30 min. The suspensions were filtered, and the filtrates were poured into labeled clean bottles (Olaniran *et al.*, 2020) to obtain the extracts.

Treatment of Tomato Juice with Extracts

Ginger, garlic, lemon and their various combinations were prepared as in Table 1. Ginger-garlic, ginger-

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lemon, garlic-lemon and ginger-garlic-lemon mixtures were obtained by mixing equal volumes of the different filtrates and homogenized for 60 s (Olaniran *et al.*, 2020). This was done to obtain 1 % (v/v).

The chemical additive, sodium benzoate (0.05 % w / v), was added aseptically to another 100 mL of tomato juice, with another 100 mL of tomato juice container serving as a control (without preservative).

Table 1: Percentage of sample composition

Sample code	Juice Treatment
TJ	Pure Tomato Juice
TSB	0.05 % Sodium benzoate
TZ	1 % Ginger extract
TA	1 % Garlic extract
TC	1 % Lemon juice extract
TZA	1 % (Ginger+Garlic)
TZC	1 % (Ginger+Lemon)
TAC	1 % (Garlic+Lemon)
TZAC	1 % (Ginger+Garlic+Lemon)

Evaluation of Physicochemical Properties

Hydrogen Potential (pH)

10 ml of each sample was dispensed into a sterile beaker, diluted with 10 ml of distilled water, and thoroughly mixed. Samples were allowed to equilibrate and pH readings in triplicate were recorded (Hannah model) (Yakum *et al.*, 2024).

Titratable Acidity

Total titratable acidity (TTA) was performed as described by AOAC, (2015). Two milliliters of the juice sample were diluted with 50 ml of distilled water. 4 drops of phenolphthalein were added to the mixture as an indicator and titrated against 0.1 M NaOH. The titratable acidity was calculated using the equation.

$$TTA=(V_{NaOH}\times M_{NaOH}\times 64.04)/V_s \qquad (1)$$

Where MNaOH = the molecularity of NaOH used, VNaOH = the volume (in ml) of NaOH used, 64.04 = the equivalent volume of citric acid.

Total Soluble Solutes

Total Soluble Solutes (TSS) were determined using the refractometry method with a refractometer (ABBE DR-A1, Atogo, Tokyo, Japan) as described by El-Sayed *et al.* (2018).

Phytochemical Composition and Antioxidant Activity

Total Phenolic Compounds (TPC)

Total phenolic compounds (TPC) were evaluated in juice samples as GAE/mL, following the Folin-Ciocalteu method (Škerget *et al.*, 2022),

Total Flavonoids

An aliquot of 3 ml of 10 g/L of $AlCl_3$ ethanoic solution was added to 0.5 ml of each juice sample, the mixtures were then incubated for an hour, at room conditions (Ordonez *et al.*, 2006). The absorbance was estimated at 430 nm. Total flavonoids in the samples were measured as QE (µg/mL), using the quercetin acid standard.

Determination of Antioxidant Activity

Ferric-Reducing Antioxidant Potential (FRAP) Assay Method

The FRAP working solution was freshly prepared each time and was made of 0.3 M acetate buffer (pH=3.6), 0.01 M TPTZ (2, 4, 6-tripyridyl-s- thiazine) in 0.04 M HCl and 0.01 M $FeCl_3.6H_2O$ mixed in a 10: 1: 1 (v / v / v) ratio and stored in an amber bottle. Then 2 ml of the FRAP working solution was mixed with 75 µL of the sample (filtrate) and the absorbance read 593 nm after 20 min of incubation at 37 ° C against the blank (acetate buffer). The FRAP content was expressed as mg of quercetin equivalents used as a standard solution (50-600 µM) (Škerget *et al.*, 2022).

Microbiological Analyses

Total bacteria and total fungi count was determined. The samples were analyzed at 2-week intervals for 4 weeks. A milliliter (1.0 mL) of each juice sample was transferred to a 10 ml sterile normal saline, separately. The mixtures were vigorously shaken and then 0.1 ml of each mixture was inoculated on a nutrient agar plate (NA) and Sabouraud Dextrose Agar (SDA) plate for bacteria and fungi, respectively, using the spread plate method described with slight modifications (Deedam *et al.*, 2020a). The inoculated NA plates were incubated at 37°C for 24 hours while the inoculated SDA plates were incubated at ambient temperature for 5 days. After incubation, colonies counted in the NA and SDA plates were used to calculate the bacterial and fungal population, respectively, with the aid of equation 5.

$$\text{Population (CFU/mL)}=(\text{Number of colonies counted}\times 10\ \text{mL})/(0.1\ \text{mL}\times 1\ \text{mL}) \qquad (2)$$

RESULTS AND DISCUSSIONS

Phytochemical and Antioxidant Properties of Juice Samples

The phytochemical and antioxidant properties of the juice samples are presented in Table 2. The total phenolic content of the juice samples reported is lower than those reported by Ndife *et al.* (2022a). This could be due to the difference in the raw material used as well as the processing method. Other studies have reported a similar situation for ginger-free tomato paste preserved with ginger (Olaniran *et al.*, 2013). Reports have shown that high phenolic content results in high antioxidant activity. They are one of the main groups of nonnutritive dietary components that have been associated with the inhibition of cancer, atherosclerosis, and the amelioration of age-related degenerative brain disorder (Aderinola, 2018).

The total flavonoid content in the juice samples produced ranged from 1.03 mgQE/100 ml to 1.22 mgQE/100 ml. These are lower than results reported by Ndife *et* *al.* (2022a). Flavonoids, like phenols, are also known to possess strong antioxidant activity and their impact on aroma release with the overall result of making the juice acceptable.

The FRAP values in this study indicate that all values were significantly different ($p<0.05$) from each other, with most treatment samples having significantly higher values than the control. This could be due to the effect of the preservative or additive added. However, the results in this study are lower than those reported by several authors (Aderinola, 2018; Ndife *et al.*, 2022; Olaniran *et al.*, 2013).

Table 2: Phytochemical and antioxidant properties of juice samples

Sample	Total Phenols (mgGAE/100 mL)	Total Flavonoids (mgQE/100 mL)	FRAP (mgAAE/100 mL)
TJ (No additive)	2.66^{f}±0.01	1.10^{b}±0.00	1.41^{b}±0.02
TSB (0.05 % Sodium Benzoate)	2.76^{fg}±0.00	1.13^{c}±0.01	1.68^{c}±0.09
TZ (1 % Ginger)	2.28^{e}±0.02	1.14^{c}±0.01	2.20^{d}±0.10
TA (1 % Garlic)	2.06^{d}±0.00	1.03^{a}±0.01	1.25^{a}±0.01
TC (1 % Lemon)	1.97^{d}±0.00	1.02^{a}±0.00	2.15^{d}±0.06
TZA (1 % Ginger+Garlic)	1.51^{a}±0.00	1.22e±0.00	4.75^{g}±0.07
TZC (1 % Ginger+Lemon)	1.83^{c}±0.00	1.20^{d}±0.00	4.76^{g}±0.05
TAC (1 % Garlic+Lemon)	1.70^{b}±0.00	1.11^{b}±0.01	4.61^{f}±0.01
TZAC (1 % Ginger+Garlic+Lemon)	2.81^{g}±0.00	1.21^{de}±0.00	4.50^{e}±0.00

Values are mean ± standard deviation of the determination in triplicate. Means in the same column with the same superscript are not significantly different ($p>0.05$)

Table 3: pH of juice samples during storage

Sample	Week 0	Week 1	Week 2	Week 3	Week 4	% Decrease
TJ (No additive)	5.8^{c}±0.1	5.7^{f}±0.1	5.4^{g}±0.0	4.5^{c}±0.2	4.0^{a}±0.0	45.0
TSB (0.05 % Sodium Benzoate)	5.6^{b}±0.1	5.5^{d}±0.1	5.1^{de}±0.0	4.9^{e}±0.0	4.5^{b}±0.1	24.4
TZ (1 % Ginger)	5.7^{bc}±0.0	5.4^{c}±0.0	4.8^{c}±0.6	4.8^{de}±0.1	4.8^{c}±0.0	18.8
TA (1 % Garlic)	5.8^{c}±0.1	5.7^{e}±0.1	5.1^{e}±0.1	4.7^{d}±0.1	4.6^{b}±0.0	26.1
TC (1 % Lemon)	5.7^{bc}±0.1	5.8^{ef}±0.0	5.0^{d}±0.1	4.9^{e}±0.0	4.5^{b}±0.1	26.7
TZA (1 % Ginger+Garlic)	4.9^{a}±0.1	4.4^{a}±0.1	4.3^{a}±0.1	4.2^{b}±0.6	4.0^{a}±0.1	22.5
TZC (1 % Ginger+Lemon)	6.2^{d}±0.2	6.0^{g}±0.0	5.9^{h}±0.1	5.4^{g}±0.1	5.4^{e}±0.0	14.8
TAC (1 % Garlic+Lemon)	4.9^{a}±0.1	4.8^{b}±0.1	4.4^{b}±0.1	4.1^{a}±0.2	4.1^{a}±0.1	19.5
TZACI(1%Ginger+Garlic+Lemon)	5.8^{bc}±0.0	5.7^{ef}±0.1	5.2^{f}±0.1	5.2^{f}±0.0	4.9^{d}±0.1	18.4

Values are mean ± standard deviation of the determination in triplicate. The means in the same row with the same superscript are not significantly different ($p>0.05$)

Table 4: Total Titratable Acidity (%) of Juice Samples During Storage

Sample	Week 0	Week 1	Week 2	Week 3	Week 4	% Increase
TJ (No additive)	0.28^{e}±0.00	0.28^{f}±0.00	0.28^{d}±0.02	0.31^{d}±0.00	0.43^{i}±0.00	54.27
TSB (0.05 % Sodium Benzoate)	0.34^{g}±0.01	0.36^{i}±0.00	0.37^{g}±0.00	0.41^{g}±0.00	0.42^{h}±0.00	22.55
TZ (1 % Ginger)	0.26^{d}±0.00	0.27^{e}±0.00	0.30^{e}±0.00	0.31^{d}±0.00	0.31^{e}±0.00	17.31
TA (1 % Garlic)	0.23^{c}±0.01	0.23^{d}±0.00	0.25^{c}±0.00	0.26^{c}±0.00	0.27^{d}±0.00	21.42
TC (1 % Lemon)	0.19^{a}±0.00	0.21^{c}±0.00	0.24^{b}±0.00	0.23^{a}±0.00	0.25^{b}±0.00	29.79
TZA (1 % Ginger+Garlic)	0.34^{g}±0.01	0.35^{h}±0.00	0.36^{g}±0.00	0.37^{f}±0.00	0.38^{g}±0.00	12.12
TZC (1 % Ginger+Lemon)	0.31^{f}±0.00	0.32^{g}±0.00	0.32^{f}±0.00	0.34^{e}±0.01	0.35^{f}±0.00	13.49
TAC (1 % Garlic+Lemon)	0.20^{b}±0.00	0.20^{a}±0.00	0.24^{bc}±0.00	0.25^{b}±0.00	0.26^{c}±0.00	28.55
TZACI (1 % Ginger+ Garlic+ Lemon)	0.19^{a}±0.00	0.20^{b}±0.00	0.22^{a}±0.01	0.23^{a}±0.01	0.22^{a}±0.00	17.17

Values are mean ± standard deviation of the determination in triplicate. Means in the same column with the same superscript are not significantly different ($p>0.05$)

Table 5: Total Soluble Solutes (oBrix) of Juice Samples during Storage

Sample	Week 0	Week 1	Week 2	Week 3	Week 4	% Decrease
TJ (No additive)	$9.25^{e}\pm0.25$	$9.00^{g}\pm0.00$	$8.90^{g}\pm0.00$	$8.70^{g}\pm0.00$	$8.05^{e}\pm0.15$	12.96
TSB (0.05 % Sodium Benzoate)	$9.00^{d}\pm0.00$	$8.80^{f}\pm0.00$	$8.65^{f}\pm0.05$	$8.58^{f}\pm0.01$	$8.44^{h}\pm0.01$	6.28
TZ (1 % Ginger)	$9.00^{d}\pm0.00$	$9.00^{g}\pm0.00$	$8.70^{f}\pm0.00$	$8.67^{g}\pm0.01$	$8.62^{i}\pm0.00$	4.22
TA (1 % Garlic)	$8.00^{a}\pm0.00$	$8.05^{c}\pm0.05$	$7.90^{c}\pm0.00$	$7.88^{b}\pm0.01$	$7.50^{a}\pm0.00$	6.25
TC (1 % Lemon)	$8.55^{b}\pm0.05$	$8.50^{e}\pm0.00$	$8.35^{e}\pm0.05$	$8.00^{d}\pm0.00$	$8.00^{d}\pm0.00$	6.43
TZA (1 %Ginger+Garlic)	$8.00^{a}\pm0.00$	$8.00^{b}\pm0.00$	$7.80^{b}\pm0.00$	7.65a±0.05	$7.69^{c}\pm0.00$	3.88
TZC (1 %Ginger+Lemon)	$9.00^{d}\pm0.00$	$9.00^{g}\pm0.00$	$8.70^{f}\pm0.00$	$8.45^{e}\pm0.05$	$8.10^{f}\pm0.00$	10.00
TAC (1 %Garlic+Lemon)	$8.00^{a}\pm0.00$	$7.85^{a}\pm0.01$	$7.70^{a}\pm0.00$	$7.66^{a}\pm0.01$	$7.60^{b}\pm0.00$	5.00
TZACI (1 Ginger+ Garlic+ Lemon)	$8.60^{c}\pm0.10$	$8.25^{d}\pm0.25$	$8.14^{d}\pm0.24$	$7.96^{c}\pm0.37$	$8.20^{g}\pm0.09$	4.69

Values are mean ± standard deviation of the determination in triplicate. Means in the same column with the same superscript are not significantly different (p>0.05)

Table 6: Total Bacteria Counts (CFU / ml) of Juice Samples during storage

Sample	Week 0	Week 2	Week 4
TJ (No additive)	NIL	70×10^{3}	25×10^{5}
TSB (0.05 % Sodium Benzoate)	NIL	12×10^{3}	61×10^{4}
TZ (1 % Ginger)	NIL	12×10^{3}	11×10^{3}
TA (1 % Garlic)	NIL	11×10^{3}	32×10^{3}
TC (1 % Lemon)	NIL	14×10^{3}	27×10^{3}
TZA (1 % Ginger+Garlic)	NIL	10×10^{3}	19×10^{3}
TZC (1 % Ginger+Lemon)	NIL	12×10^{3}	20×10^{3}
TAC (1 % Garlic+Lemon)	NIL	15×10^{3}	28×10^{3}
TZACI (1 % Ginger+Garlic+Lemon)	NIL	8×10^{3}	12×10^{3}

Table 7: Total Fungal counts (CFU / ml) of juice samples during Storage

Sample	Week 0	Week 2	Week 4
TJ (No additive)	50×10^{3}	50×10^{3}	20×10^{6}
TSB (0.05 % Sodium Benzoate)	NIL	12×10^{3}	60×10^{3}
TZ (1 % Ginger)	NIL	NIL	24×10^{3}
TA (1 % Garlic)	NIL	13×10^{2}	30×10^{3}
TC (1 % Lemon)	NIL	18×10^{2}	17×10^{3}
TZA (1 %Ginger+Garlic)	NIL	NIL	28×10^{2}
TZC (1 %Ginger+Lemon)	NIL	10×10^{3}	32×10^{3}
TAC (1 %Garlic+Lemon)	NIL	11×10^{3}	17×10^{3}
TZACI (1 %Ginger+Garlic+Lemon)	NIL	NIL	14×10^{3}

NIL-No observable growth

As noticed, garlic extract-treated juice samples tended to have lower antioxidant potential (TA, TZA and TAC samples). This agrees with studies by Ndife *et al.* (2022a). The variation in values could be attributed to the constituents of bioactive compounds in the raw materials. The antioxidant properties of the samples are in agreement with the report by (Wern *et al.*, 2017) on the redox potential of juices, as well as from reports by (Bhati & Raghuvanshi, 2021; Vichaibun & Kanchanaphu, 2019). The reduction power indicates the potential of juices to serve as systemic protectants against oxidation and damage by free radicals in cells.

Storage Studies in Juice Samples

pH of the Juice During Storage

Table 3 shows the change in pH during storage of tomato juice. A maximum decrease (45.0 %) in pH was observed in the juice sample that had no added preservative (sample TJ) compared to the test samples with natural preservatives. The samples with natural preservatives were observed to have a relatively steady decrease, unlike the control samples TJ and TSB. This decrease in pH could be due to the biochemical degradation of sugars by colonizing microorganisms that results in the production of acids (Sharmin *et al.*, 2019). This pH decrease has also been known to affect the sensory properties of fruit juice and blends (Adubofuor *et al.*, 2010). pH is known to affect or support the growth of most microbes within the range of 6.6-7.5 and common bacteria grow well over a range of pH of 6 to 9 (Atlas, 1994). As a result, the relatively lower pH of the samples with natural preservatives would effectively delay the growth of most microorganisms (Olalekan *et al.*, 2017).

Total Titratable Acidity (TTA) of Juice Samples During Storage

As observed in Table 4, the samples with natural preservatives were relatively resistant to increase in TTA. This increase in TTA could be due to the biochemical degradation of sugars by colonizing microorganisms resulting in the production of acids (Sharmin *et al.*, 2019). A similar result was gotten by (Alam *et al.*, 2013) indicating that the acidity in fruit juices increases during processing and storage. Similar results have been reported (Olaniran *et al.*, 2020; Olaniran *et al.*, 2020; Olaniran *et al.*, 2013).

Total Soluble Solutes of Juice During Storage

Table 5 presents the results for the total soluble solutes. In general, most samples experienced a decrease in TSS during the 4-week period, suggesting a gradual decrease in the concentration of soluble solids in tomato juice. A significant reduction in TSS is known to be influenced by various factors, such as the specific preservatives used, their concentrations, and the storage conditions of the tomato juice.

As seen, a maximum decrease (12.96 %) in TSS was observed in the juice sample that did not contain preservatives (sample TJ). The samples with natural preservatives had a significantly lower percentage decrease with respect to sample TJ. The samples with natural preservatives were relatively resistant to TSS decrease and were not significantly different from the sample with the chemical preservative (sample TSB). This decrease in TSS could be due to the biochemical degradation of sugars by colonizing microorganisms resulting in the production of acids, ethyl alcohol, carbon dioxide and water (Sharmin *et al.*, 2019; Ullah *et al.*, 2015). Similar results have been reported showing a decrease in TSS values with storage time (Olaniran *et al.*, 2020; Sharmin *et al.*, 2019; Ullah *et al.*, 2015). However, da Silva *et al.*, (2016) got results which contradict this study in that they recorded an increase in TSS values when they produced a ready-to-serve blend of carrot and kinnow drink with ginger extract.

Microbial Qualities of Juice Samples During Storage

Total Count of Bacteria from Juice Samples

As observed in Table 6, juice samples treated with natural preservatives showed remarkably lower bacteria counts than sample TSB (with sodium benzoate as a chemical preservative). Similar results have been reported (Ekanem & Ekanem, 2019; El-Hanafy, 2014; Okokon & Okokon, 2019). Sharmin *et al.* (2019) got bacteria counts in the order of 104 for tomato juice treated with chemical preservatives. The combination of the natural preservatives of ginger, garlic, and lemon as a preservative in this research was quite effective during storage as microbial growth was greatly inhibited. This could be the result of a synergistic effect of ginger, garlic, and lemon. Several studies have been advanced to support this (Adekalu *et al.*, 2009; Ekanem & Ekanem, 2019; Mshelia *et al.*, 2018; Olaniran *et al.*, 2020). It has been noted that the major challenge in the spoilage of fresh juice is to ensure a stable pH, natural microflora and chemical composition of fruit juice (Ndife *et al.*, 2022). The results of this study are within acceptable limits (<105) for fruit juice as all the treated juice samples had bacteria counts in the order of 103 to 104 recommended by the International Commission on Microbiological Specifications for Foods (ICMSF) (Ameh *et al.*, 2015).

Total Fungal Counts of the Juice Samples

A study by Sharmin *et al.* (2019) reported fungal counts in the order of 103 to 104 for tomato juice treated with chemical preservatives. The results as in Table 7 agree with several studies in which ginger, garlic, and lemon have been used in the preservation of fruit juices (Ameh *et al.*, 2015; El-Hanafy, 2014; Ogori *et al.*, 2021; Olaniran *et al.*, 2013).

CONCLUSION

The treated juice samples had significantly higher antioxidant activity compared to the control samples TJ and TSB, meaning that the juice produced can serve as a functional food. The treated juice samples exhibited greater storage stability than the control sample TJ and TSB (with sodium benzoate as chemical preservative). This was noticed with the relatively stable storage parameters of pH, TTA, and TSS under ambient conditions.

At the end of Week 4, the treated juice samples had significantly lower microbial counts than the control samples TJ and TSB. The results of this study demonstrate that ginger, garlic, and lemon extracts have remarkable potential as natural preservatives for tomato juice. The observed effectiveness of these extracts in preserving the juice surpasses that of the conventional synthetic preservative, sodium benzoate. This suggests a promising alternative to food preservation methods, especially for those seeking natural and sustainable options. Further research into the mechanisms underlying the preservative properties of these natural extracts and their potential applications in other food products is warranted. Embracing such natural alternatives could lead to safer and more environmentally friendly food preservation practices in the future.

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