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RESEARCH ARTICLE

EFFICACY OF SALT, LEMON JUICE AND OIL AS BIOPRESERVATIVES: IMPACT ON THE NUTRITIONAL AND MICROBIOLOGICAL QUALITY OF TRADITIONAL TOMATO PASTE

OULAI Sylvie Florence*, Zan Bi Toma Eugène, OUATTARA Gninfanni Silvere and
FAGBOHOUN Jean- Bedel

Laboratory of Biotechnology and Agro-Food Valorization (Labo BiVA), Faculty of Biological Sciences, Peleforo
GON COULIBALY University of Korhogo, P.O. Box 1328, Korhogo, Côte d'Ivoire

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*Corresponding author:

OULAI Sylvie Florence

ABSTRACT

The tomato (*Solanum lycopersicum* L.) is a widely consumed yet highly perishable product, necessitating the development of traditional preservation methods accessible to the general population. This study aims to evaluate the effect of local preservatives on the nutritional and microbiological quality of tomato paste. Following production, the paste was divided into four batches: those treated with salt (TPSP), lemon (TPLP) or oil (TPOP) and a control group with no preservative (TPNP). Nutritional and microbiological characteristics were determined using standardized methods. Analysis of the results revealed that salt, lemon and oil influenced biochemical compounds in varying ways. These preservatives also affected levels of polyphenols (3.35 to 4.91 mg GAE/100g), flavonoids (0.48 to 1.42 mg QE/100g), vitamin A (1.33 to 3.10 mg/100g), tannins (1.41 to 2.55 mg TAE/100g) and lycopene (1.61 to 4.85 mg/100g). Antioxidant activity was also influenced by the treatments applied. From a microbiological perspective, the preservatives inhibited microorganism growth compared to the control. These results demonstrate that local preservatives contribute to improving the quality and shelf life of traditional tomato paste.

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INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is one of the major crops belonging to the Solanaceae family (Ifitkhar et al., 2021). The tomato is the most widely cultivated and consumed crop in the world, as it is used daily in the human diet. The tomato is a species of herbaceous plant, widely consumed as a vegetable, even though botanically it is a fruit (Abekoon et al., 2024). Tomatoes contain numerous compounds that are beneficial to health and can be easily incorporated as a nutrient into a balanced diet (Dzakhmisheva et al., 2021), such as micronutrients (Gholami et al., 2021), sugars, vitamins and numerous organic acids (Yan et al., 2021). Tomato pulp is also an essential source of antioxidants such as phenols, flavonoids, chlorophyll, carotenoids, lycopene and lutein (Vitucci et al., 2021). Global production stood at over 189 million tonnes in 2021 (FAOSTAT, 2021). In Côte d'Ivoire, domestic production accounts for only 47,283 tonnes, or 45 % of total consumption. The remainder (55 %) is met by imports (FAOSTAT, 2022). Tomatoes are produced in abundance during the rainy seasons by nearly 60 % women and young people in urban and peri-urban areas. Given their highly perishable nature, it is therefore necessary to process them into tomato purée with the addition of local preservatives, making

it accessible to the majority of the population. This study forms part of this context, and its main objective is to analyse the impact of local preservatives on the phytochemicals and microbiological quality of tomato purée during storage.

MATERIALS AND METHODS

Collection of raw materials: The materials used in this study consisted of fresh tomatoes. These were sourced from growers based in production areas in Korhogo, in the north of Côte d'Ivoire.

Method

Production of tomato paste: The method described by Rahman et al. (2024), with a few modifications, was used to produce the tomato paste. Approximately (1) kg of fully ripe, dark red tomatoes was thoroughly washed with water to remove unwanted substances such as dust, dirt, pesticides and residues. After washing, the tomatoes were drained on a clean cloth. They were then blanched at 95°C for 5 minutes. After removing the seeds and skins, the tomatoes were blended in a blender.

The resulting tomato pulp was concentrated at 100°C until a Brix value of between 32 and 38°Brix was achieved. The paste was divided into four portions, with salt (TPSP), lemon (TPLP) and oil (TPOP) added to the first three portions, whilst the fourth portion contained no preservatives (TPNP). They were then carefully poured into sealed jars, pasteurised at 90–95 °C for 20 minutes and stored for analysis.

Biochemical analyses

Moisture and dry matter content: The moisture content was determined using the AOAC (1990) method. Five (5) grams of sample were weighed into a glass capsule of known mass. The capsule containing the tomato paste was placed in a drying oven (MEMMERT) set at 105°C for 24 hours. After 24 hours, the capsule was removed from the drying oven and cooled in a desiccator. The capsule containing the sample was weighed. The moisture content was expressed as a percentage of the sample mass as follows:

$$MC (\%) = \frac{(M1 - M0)}{Me} \times 100$$

$$DM (\%) = 100 - MC$$

MC: Moisture content percentage

DM: Dry matter percentage

M0: mass (g) of the empty capsule.

M1: mass (g) of the assembly (capsule + tomato).

Me: mass (g) of the sample

Protein content: Crude protein was determined by measuring total nitrogen using the Kjeldahl method (AOAC, 1990). This method comprises a mineralisation stage, followed by a distillation stage and, finally, a titration stage using sulphuric acid. The total protein content was expressed as a percentage by mass using the following formulae:

$$N (\%) = \frac{V(H_2SO_4) \times N(H_2SO_4) \times 14,007 \times 100}{1000 \times Me}$$

N%: Nitrogen content percentage

V(H₂SO₄): Volume in ml of H₂SO₄ required for the titration.

N(H₂SO₄): Normality of the sulphuric acid used for the titration (0.1 N).

Me: Sample weight (g).

14.007: Atomic mass of nitrogen.

Fat content: The fat content was determined using the method described by AFNOR (1986), employing the Soxhlet apparatus. The fat content (FC) was expressed as a percentage by mass as follows:

$$FC (\%) = \frac{(M2 - M1)}{5 \text{ g}} \times 100$$

FC (%) : Fat content percentage

M1: extraction flask, previously tared (M1).

M2: flask, initially tared and containing the oil,

Ash content: The ash content, representing the mineral composition of a sample, was determined using the method described by AOAC (1990), which involved incinerating a sample at 550 °C for 12 in a muffle furnace (PYROLABO). The ash content was expressed as a percentage by mass as follows:

$$AC (\%) = \frac{(M2 - M0)}{(M1 - M0)} \times 100$$

AC (%): Ash content percentage

M0: mass (g) of the empty crucible.

M1: mass (g) of the assembly (crucible + tomato) before incineration.

M2: mass (g) of the assembly (crucible + tomato) after incineration

Determination of fiber content: The fiber analysis was carried out in accordance with the method described by AOAC (2000). To 50 ml of sulphuric acid (0.25 N), 2 g (Me) of tomato paste sample was added. The mixture was brought to the boil and boiled for 30 minutes. Next, 50 ml of NaOH (0.31 N) was added and the mixture was brought back to the boil for a further 30 minutes. After filtration and successive washing with hot water until all alkali had been removed (M1), the resulting residue was dried for 8 hours at 105°C and then ashed at 550°C. The resulting ash was weighed (M0) and the fibre content was determined using the following formula:

$$Fiber (\%) = \frac{(M1 - M0)}{Me} \times 100$$

Determination of total sugar and reducing sugar: The protocol of Reshmi *et al.* (2020) was used to determine the total sugar and reducing sugar in the tomato paste. To determine the total sugar, 1.8 mL of concentrated H₂SO₄ and 0.3 mL of phenol (0.5 %) were mixed with an aliquot of 10 µL of extracted sample in a cuvette. After 20 min of incubation at room temperature, the absorbance of the mixture was measured at 480 nm. The total sugar in the samples was expressed in g of glucose per 100 g of tomato paste sample using the standard curve of glucose. In the case of reducing sugar, 150 µL of the sample was combined with 1 mL of DNS (3–5-dinitro salicylic acid) reagent. Then, the mixture was boiled in a bath of boiling water for 5 min. After cooling, 2 mL of distilled water was added, and measured the absorbance by a spectrophotometer at 540 nm. The sample's reducing sugar was reported as g glucose/100 g tomato paste

Phytochemical analysis

β-Carotene and vitamin A content: The method described by Sass-Kiss *et al.* (2005) was used to determine the levels of β-carotene and vitamin A. A sample of 1 g was mixed with 2.5 mL of 96° ethanol and 0.1 mL of hydroquinone solution (20 g of hydroquinone dissolved in 100 mL of 95° ethanol).

After homogenisation using a stirrer, the mixture was transferred to beakers and then centrifuged at 3,000 rpm for 20 minutes. The resulting supernatant was collected in test tubes and protected from light using aluminium foil. Next, 4 mL of the supernatant was placed in a cuvette for measurement of the optical density at 450 nm using a T80 UV/VIS Spectrometer, against a blank. At the same time, a β-carotene standard series was prepared from a 10 µg/mL stock solution. For each test, the β-carotene content was determined from the calibration curve obtained. The vitamin A content of the samples was then calculated by dividing the β-carotene content by 6.

$$\beta\text{-Carotene } (\mu\text{g}/100\text{g}) = \frac{Q \times F}{Pe} \times 100$$

$$\text{Vitamin A } (\mu\text{g}/100\text{g}) = \frac{\beta\text{-Carotene}}{6} \times 100$$

F: dilution factor;

Pe: sample volume;

Q: amount of β -carotene in each tube (μg)

Determination of total polyphenols: The polyphenol content was determined using the method described by Singleton *et al.*, (1999). To 1 g of tomato paste, 10 mL of 70 % methanol was added. The resulting mixture was centrifuged at 1,000 rpm for 10 minutes. The pellet was recovered in 10 mL of 70 % methanol and centrifuged again. The two supernatants were combined in a 50 mL flask and made up to volume with distilled water. Next, 1 mL of the methanolic extract was transferred to a tube and added to 1 mL of Folin–Ciocalteu reagent. The tube was left to stand for 3 min, and 1 mL of a 20 % sodium carbonate solution was added. The volume was made up to 10 mL with distilled water. The resulting mixture was kept in the dark for 30 minutes. The optical density (OD) was measured on a spectrophotometer at 725 nm against a blank. Calibration was carried out using gallic acid at 1 mg/mL.

Assay of total flavonoids: The total flavonoid content determine according to Islam *et al.* (2021) method with modifications. 0.5 g of tomato paste was added to 30 mL of 70% methanol. The mixture was centrifuged at 1,000 rpm for 10 minutes. The pellet was resuspended in 30 mL of 70% methanol and centrifuged again at 1,000 rpm for 10 minutes. The two supernatants were combined in a 50 mL flask. 0.3 mL of 5 % NaNO_2 was added to 1 mL of extract mixed with 4 mL of pure water in a centrifuge tube. After the tubes had stood for 5 min, 0.3 mL of 10 % AlCl_3 had been added to the reaction mixture. This time, the tubes had stood for 1 min. Finally, 2.4 mL of distilled water and 2 mL of 1 M NaOH were added and vortexed immediately. The tubes were then stored at room temperature in the dark for 15 min after being centrifuged for 10 min at 4000 rpm. Absorbance was measured on a spectrophotometer at 510 nm against a blank. Calibration was carried out using a quercetin solution at 0.1 mg/mL.

Lycopene determination: Lycopene was determined using the method described by Fish *et al.* (2002). A 1 g sample was homogenised with a mixture of hexane, acetone and ethanol in a ratio of 2:1:1 (v/v/v). After vigorous shaking for several minutes, distilled water was added to promote phase separation. The mixture was then left to stand until two distinct phases were obtained. The upper phase, containing lycopene, was recovered and its absorbance measured at 503 nm using a UV-visible spectrophotometer against a blank prepared under the same conditions. The lycopene content was calculated using the calibration curve equation and is expressed in mg/100 g of sample.

Vitamin C determination: The amount of ascorbic acid was calculated using the method described by Hasan *et al.* (2022). The 10 g sample was extracted for 45 min at room temperature with 10 mL of 1 % metaphosphoric acid before being filtered through the Whatman No. 1 filter paper. After combining 1 mL of the filtrate with 9 mL of 2,6-dichlorophenolindophenol, the absorbance at 515 nm was measured by a spectrophotometer against a blank after 20 min of reaction. The results were expressed as mg of ascorbic acid/100 g of tomato paste using ascorbic acid as standard.

Assay of antioxidant activity: The antioxidant activity of the sauce was measured by DPPH assay. The DPPH scavenging power of sauce was measured by the protocol described by Kabir *et al.* (2021). The 5.126 mg of DPPH was diluted with 100 ml of 80 % methanol followed by ultrasonic for 5 min. The absorbance of a mixture of 50 μL sauce extract and 1.950 mL of DPPH solution was measured at 515 nm with a spectrophotometer (UV 1900i, Shimadzu, Japan) after 30 min of incubation. The results were expressed mg of Trolox /100 g of tomato paste.

Microbiological analysis: The microbial flora was counted using the standard method (deep plating for some samples and spread or streak plating for others). This involved aseptically transferring 10 g of each tomato paste sample into flasks containing 90 mL of sterile saline solution (0.85 % m/v). Decimal dilutions ranging from 10^{-1} to 10^{-5} were prepared using the same diluent and then inoculated into culture media in petri dishes.

Mesophilic aerobic bacterial count (MAB): The mesophilic aerobic bacterial count (MAB) was carried out in accordance with standard NF ISO 4833, following incubation at 30 °C for 72 hours. The method used was double-layer plating on PCA (Plate Count Agar). To this end, 1 mL of the stock suspension and its decimal dilutions were taken and then inoculated into sterile Petri dishes. The PCA medium, which had been previously melted and then cooled in a water bath to 46–47 °C, was then added. Homogenisation was achieved by rotational, vertical and transverse movements. The dishes, kept closed, were left to solidify on the laboratory bench near the Bunsen burner. Once the first layer had solidified, a second layer of 4 to 6 mL of PCA was added and left to solidify. Finally, the dishes were incubated at 30 °C for 72 hours.

Coliform count: The total coliform (TC) count was carried out in accordance with standard NF V08-050, whilst the faecal (thermotolerant) coliform (FC) count was carried out in accordance with standard NF ISO 4832, using Violet Red Bile Lactose (VRBL) agar. To this end, 1 mL (approximately 20 drops) of the stock suspension and its decimal dilutions was added to sterile Petri dishes that had been prepared and numbered in advance. Subsequently, 20 mL of VRBL agar was poured into each dish and then homogenised. The Petri dishes were then incubated for 24 hours at 37 °C for the enumeration of total coliforms and at 44 °C for that of faecal coliforms.

Yeast and mould count: The yeast and mould count was carried out in accordance with standard NF V08-059. To this end, Sabouraud agar containing chloramphenicol was poured into sterile Petri dishes, and 0.1 mL of the samples was inoculated by spreading it over the surface of the medium. The dishes were then incubated at 30 °C for 3 to 5 days. After incubation, the characteristic colonies were counted: yeasts appeared as round, smooth, whitish and creamy colonies, whilst moulds formed downy and rough colonies.

Staphylococcus count: The Staphylococcus count was carried out in accordance with standard NF V08-057-1. The culture medium used was Baird-Parker (BP) agar. The BP agar was first melted and then cooled before being poured into sterile Petri dishes. Once the medium had solidified, 0.1 mL of the stock suspension and decimal dilutions were spread over the surface of the agar using a sterile glass spreader. The dishes were then incubated at 37 °C for 48 hours. The results of all

counts will be expressed in colony-forming units (CFU) per plate; these are then converted to CFU/g using the following formula:

$$N \text{ (UFC/g)} = \frac{\sum \text{colonies}}{(n_1 + 0,1n_2) \times V \times d}$$

Where:

N: number of microorganisms

n1: number of plates in the first dilution under consideration

n2: number of plates in the second dilution under consideration

d: the lowest dilution under consideration

V: volume of the inoculated sample

Statistical analysis: The experimental data obtained were analysed using STATISTICA software (version 7.1). The values were presented as mean $\pm$ standard deviation. To assess the statistical significance of the observed differences, analysis of variance (ANOVA) was used, followed by Turkey's multiple comparison test with a significance level of 5 per cent. Finally, data entry and the creation of graphical representations were carried out using Word and Excel 2016.

RESULTS

Biochemical parameters: The results of the biochemical analyses of four tomato paste formulations are presented in Table 1. Statistical analysis of the results showed that the fat content of TPSP and TPLP is statistically ($p < 0.05$) similar. The fat content ($1.51 \pm 0.01\%$) of the TPOP paste is significantly lower ($p < 0.05$) than that of the other types of paste. The dry matter content of TPSP ($19.25 \pm 0.05b\%$), PTSC ($19.33 \pm 0.03\%$) and TPOP ($18.21 \pm 0.05\%$) are statistically ($p < 0.05$) similar but higher than that of TPLP (12.31 ± 0.01). The ash contents of TPSP (8.78 ± 0.08 per cent) and TPLP ($7.43 \pm 0.30 \%$) are higher than those of the other two. TPNP has the highest protein content ($3.73 \pm 0.03 \%$) and TPLP the lowest ($2.10 \pm 0.10 \%$). However, there is no significant difference between the fibre contents of the four types of tomato paste. The total sugar contents ($3.88 \pm 0.08 \%$) and reducing sugar (0.33 ± 0.03) of TPNP are significantly higher ($p < 0.05$) than those of TPSP, TPLP and TPOP.

Phytochemical parameters: The levels of the various phytochemical parameters in the tomato paste formulations are presented in Table 2. The results show that there is a significant difference between the levels of total tannins, lycopene, total polyphenols, total flavonoids, β -carotene, vitamins A and C, and DPPH. The TPSP paste recorded the highest values for total tannins (2.55 ± 0.55 mg EAT/100) and DPPH (32.62 ± 0.02 mg/100g). TPNP has the highest values for lycopene (8.61 ± 0.01 mg/100 g) and vitamin C (24.79 ± 0.09 mg/100 g). As for TPOP, it has the highest levels of total flavonoids (1.41 ± 0.01 mg EQ/100g), vitamin A (3.11 ± 0.07 mg/100g), β -carotene (18.63 ± 0.94 mg/100g) and total polyphenols (4.91 ± 0.01 EAG/100g).

Microbiological parameters of tomato paste formulations: Figure 1 shows the results of the microbial count for these tomato paste formulations. Mesophilic aerobic bacteria (MAB), total coliforms, and yeasts and moulds were counted in all four types of tomato paste. Generally speaking, staphylococci and faecal coliforms were not detected in any of the tomato pastes during storage.

DISCUSSION

The moisture levels obtained for the various tomato pastes (80.69 to 87.67 %) are broadly consistent with the data available in the scientific literature. Achu *et al.* (2018) indicate that, depending on manufacturing practices and post-production treatments, traditionally produced tomato pastes have moisture contents ranging from 78 to 92 %, which ensures better preservation against spoilage. The high value observed for TPLP may be explained by the hygroscopic nature of citric acid, which is likely to retain free water within the food matrix (Yusuf *et al.*, 2019). The fat contents range from 0.31 to 1.51 %. The high PTCH value (1.51 %) falls within the range reported by Rodríguez-Roque *et al.* (2021). Indeed, these authors observed that the fat contents of tomato paste preserved in olive oil ranged from 1.2 to 2.3 %. The use of oil as a preservative significantly alters the fat profile of the food and may help to protect fat-soluble compounds (Das *et al.*, 2022). The fiber content of tomato paste ranges from 1.38 to 1.53 %. These levels are higher than those obtained by Rahman *et al.* (2024), who studied tomato pulp (0.32 %). The consumption of dietary fiber contributes to digestive wellbeing, disease prevention and good health (Rana *et al.*, 2025). Lycopene concentrations range from 1.61 to 4.85 mg/100g. These values are lower than those observed by Tlili *et al.* (2021) in Tunisian tomato paste (5.2 to 12.8 mg/100g). This difference could be explained by varietal differences and the processing methods used. The marked increase in lycopene in TPLP confirms the findings of Kinsou *et al.* (2021). Indeed, these authors observed an increase in the lycopene content of tomatoes treated with sodium chloride (NaCl). Lycopene is recognised as a powerful antioxidant (Shi and Maguer, 2000). Consequently, tomato consumption could, in particular, contribute to improving endogenous antioxidant status, which is known to reduce the risk and/or incidence of oxidative damage associated with oxidative stress (Baysal *et al.*, 2000). The β -carotene content ranges from 7.97 to 18.63 mg/100g. The high β -carotene content in PTCH (18.63 mg/100g) is thought to be due to the solubilisation of non-polar carotenoids in the lipid phase, according to Malacrida and Jorge (2019). These authors demonstrated that the presence of vegetable oil in a carotenoid-rich food matrix significantly increases the carotenoid content. The β -carotene levels reported in this study are similar to those found by Soyong *et al.* (2021) in several varieties of fresh tomatoes (7.11 to 19.11 mg/100g). β -carotenes are natural fat-soluble pigments and precursors of vitamin A. As antioxidants, they protect cells and tissues from peroxides (He *et al.*, 2017). The vitamin C contents (22.68 to 24.79 mg/100 g) are comparable to the values reported by Osei-Bonsu *et al.* (2021) for Ghanaian tomato paste (18.5 to 26.3 mg/100 g).

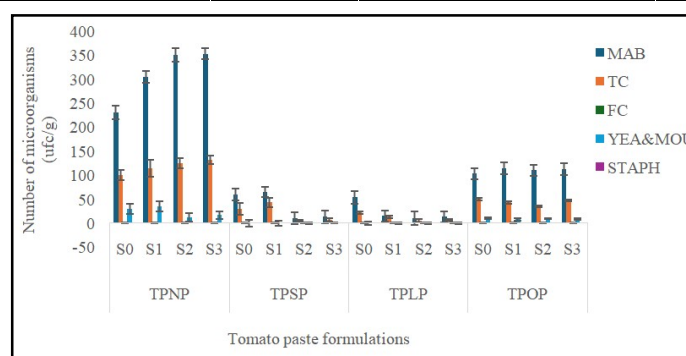
The slight degradation of this vitamin in the TPSP and TPLP formulations is consistent with the findings of Chikweto *et al.* (2023), who confirmed that a pH below 4 accelerates the thermal degradation of ascorbic acid. Total polyphenols, ranging from 3.34 to 4.91 mg EAG/100g, fall within the recommended range for processed tomato products (3 to 15 mg EAG/100g). The finding that TPOP has the highest levels of polyphenols and flavonoids is consistent with the work of Vallverdú-Queralt *et al.* (2018), who demonstrated that the presence of oil in tomato-based foods prevents the oxidation of phenolic compounds by forming a barrier against oxygen. Total tannin contents range from 1.55 to 2.55 mg EAT/100 g.

Tableau 1. Biochemical composition of tomato paste formulations

Parameters (%)	Different types of tomato paste formulations				Value P
	TPNP	TPSP	TPLP	TPOP	
Fat	0.6 ± 0.06 ^b	0.37 ± 0.07 ^c	0.41 ± 0.08 ^c	1.51 ± 0.01 ^a	<0.001
Moisture	80.67 ± 0.06 ^c	80.75 ± 0.04 ^c	87.69 ± 0.08 ^a	81.79 ± 1.08 ^b	<0.001
DM	12.33 ± 0.03 ^b	19.25 ± 0.05 ^a	19.31 ± 0.01 ^a	18.21 ± 0.05 ^a	<0.001
Ash	4.97 ± 0.07 ^c	8.78 ± 0.08 ^a	7.43 ± 0.30 ^b	4.65 ± 0.05 ^c	<0.001
Protein	3.73 ± 0.03 ^a	2.82 ± 0.02 ^b	2.10 ± 0.10 ^c	2.36 ± 0.06 ^c	<0.001
Total Fiber	1.44 ± 0.04 ^a	1.53 ± 0.03 ^a	1.38 ± 0.08 ^a	1.39 ± 0.09 ^a	0.061
Total sugars	3.88 ± 0.08 ^a	0.37 ± 0.07 ^b	0.11 ± 0.002 ^c	0.08 ± 0.02 ^c	<0.001
Reducing sugar	0.33 ± 0.03 ^a	0.18 ± 0.08 ^b	0.01 ± 0.04 ^c	0.01 ± 0.06 ^c	<0.001

Table 2. Levels of phytochemical parameters in tomato paste formulation

Parameters	Different types of tomato paste formulations				Value P-
	TPNP	TPSP	TPLP	TPOP	
Total Tannins (mg EAT/100)	1.55 ± 0.05 ^c	2.55 ± 0.55 ^a	1.83 ± 0.03 ^b	1.41 ± 0.01 ^d	<0.001
Lycopene (mg/100g)	4.85 ± 0.05 ^a	1.61 ± 0.01 ^c	3.88 ± 0.08 ^b	3.84 ± 0.04 ^b	<0.001
Total Polyphenols (EAG/100g)	4.18 ± 0.08 ^c	3.34 ± 0.04 ^d	4.42 ± 0.02 ^b	4.91 ± 0.01 ^a	<0.001
Total Flavonoids (mg EQ/100g)	0.79 ± 0.09 ^b	0.61 ± 0.01 ^c	0.47 ± 0.07 ^d	1.41 ± 0.01 ^a	<0.001
β-Carotene (mg/100g)	7.97 ± 0.03 ^d	15.26 ± 0.02 ^b	9.25 ± 0.07 ^c	18.63 ± 0.94 ^a	<0.001
Vitamin A (mg/100g)	1.33 ± 0.03 ^d	2.54 ± 0.03 ^b	1.54 ± 0.06 ^c	3.11 ± 0.07 ^a	<0.001
Vitamin C (mg/100g)	24.79 ± 0.09 ^a	22.68 ± 0.08 ^b	22.08 ± 0.08 ^b	23.95 ± 0.05 ^a	<0.001
DPPH (mg Trolox /100g)	25.32 ± 0.02 ^c	32.62 ± 0.02 ^a	18.45 ± 0.05 ^d	27.20 ± 0.02 ^b	<0.001

**Figure 1. Evolution of microbial loads of different tomato paste formulations during storage. S0: week 0; S1: week 1; S2: week 2; S3: week 3**

The highest tannin content (2.55 ± 0.55 mg EAT/100 g) in TPSP is thought to be due to a concentration of phenolic compounds caused by the reduction in water activity brought about by the salt. Similar results were reported in studies by Dewanto *et al.* (2002), which showed that certain processing methods can promote the stability of tannins in plant products. The total tannin contents in this study are similar to those reported by Rahman *et al.* (2020) in tomatoes at different stages of ripeness. A previous study revealed that a small amount of tannins (0.15 to 0.2 mg/100g) in food is beneficial to health (Schiafone *et al.*, 2008). However, excessive consumption of tannins could have the opposite effect; that is, tannins could have an anti-nutritional effect (Felix and Mello, 2000).

The antioxidant activity, as assessed by the DPPH test, revealed a higher free radical scavenging capacity in TPSP (32.62 per cent) compared with the other formulations. Ekezie *et al.* (2021) demonstrated that the products generated by the Maillard reaction during salting and drying contribute significantly to the free radical-scavenging activity of high-salt foods. According to Brand-Williams *et al.* (1995), antioxidant activity is generally correlated with the presence of polyphenols, carotenoids and antioxidant vitamins. The microorganisms analysed in this study are mesophilic aerobic bacteria (MAB), total coliforms (TC), faecal coliforms (FC), yeasts and moulds (Yea & Mou) and Staphylococci (Staph). Mesophilic aerobic bacteria gradually increased from 230

CFU/g to 353 CFU/g between S0 and S3, indicating microbial growth in the absence of any inhibitory agents. This trend is consistent with the findings of Matsheka *et al.* (2014), who indicate that unprotected processed plant products create an environment conducive to microbial proliferation due to their water content and nutritional value. The TPSP and TPLP samples showed a significant reduction in microbial load compared with the TPNP control. According to Taormina (2010), the high osmotic pressure caused by sodium chloride prevents the growth of many types of microorganisms. Our results are also consistent with the work of Esra *et al.* (2021), who demonstrated that adding organic acids such as citric acid to foods during processing enhances flavour and inhibits microbial growth. TPOP, oil also showed a reduction in microbial load compared with the control, but its effect was less pronounced than that of lemon. The oil acts primarily by limiting contact with oxygen through the formation of a protective barrier on the surface, thereby reducing the proliferation of aerobic organisms such as moulds and several types of bacteria. Similar observations were reported by Tassou and Nychas (1995) regarding the protective effect of vegetable oils on food preservation.

CONCLUSION

This study aimed to evaluate the effect of local preservatives on the nutritional and microbiological quality of tomato paste. Overall, the three preservation methods helped maintain the

quality of tomato paste, but with different mechanisms of action. Lemon was particularly effective for acidification and microbiological stability, oil for oxidation protection and pigment preservation, while salt mainly provided better microbiological stability by decreasing water activity. These results confirm that the use of natural preservatives constitutes an accessible, economical and suitable alternative to the artisanal preservation of tomato paste, while contributing to the promotion of local products.

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