Comparison of Physicochemical, Mineral, and Microbiological Quality of Tomato Paste Produced from Fresh Tomatoes *(Solanum lycoperscum)* Cultivated in Soil-Based and Soilless Farms

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ABSTRACT

Background: *Tomatoes are highly nutritious; there is a long debate over whether soil or soilless cultivation yields better nutrition. Investigating how these methods influence tomato paste nutrients is crucial for optimising dietary health benefits.*
Objective: *The research compared the physicochemical, phytochemical, mineral, and microbiological quality of tomato paste produced from fresh tomatoes (Solanum lycopersicum) grown using soil-based and soilless farming methods.*
Methodology: *Fresh tomatoes were processed into tomato pastes. The physicochemical, phytochemical, and mineral compositions of pastes from soilless and soil-based tomatoes were determined. The microbial assessments of the pastes were carried out for four weeks during storage at ambient (30±2°C).*
Results: *Values for pH, titratable acidity, moisture, and total soluble solids for the tomato pastes ranged from 4.47 to 4.64, 0.37 to 0.41%, 87.37 to 88.32%, and 23.60 to 25.20%, respectively. The colour of soil-based tomato fruit was found more appealing compared to soilless tomato fruit, with a reverse trend in the tomato pastes. The calcium, magnesium, iron, and zinc concentrations were higher in soilless tomato pastes than soil-based. The total aerobic count in tomato pastes increased during the 4-week storage period, with a higher count in soilless tomato paste. There was no mould growth in soil-based tomato pastes throughout the period of storage. Yeast was found on the tomato pastes and increased with the storage period.*
Conclusion: *The tomato pastes from soilless tomato demonstrated better quality in colour and mineral components, while soil-based tomato pastes showed better microbial quality during storage.*

Keywords: Soilless, Soil-based, Physicochemical, *Solanum lycopersicum*, Micronutrients

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INTRODUCTION

Tomatoes (*Solanum lycopersicum*) belong to the family *Solanaceae* and are widely consumed fruits because they are found to be rich in flavour, vitamins, and minerals (1). Fresh tomatoes are highly perishable, and conversion into paste by boiling to reduce moisture content allows extension of shelf life and creates a more concentrated product for various culinary applications (2). The product contains important nutrients such as vitamins A, C, and K, along with minerals like potassium, magnesium, and calcium, all of which are vital to human health (3).

Soil-based farming, which involves growing crops simply in the soil, is the traditional method of crop production. The method relies on the natural ecosystem of the soil for the supply of essential nutrients, water, and oxygen for the growth of plants (4). In recent times, soilless farming has gained popularity in sustainable agriculture practices as a solution to the growing issues of food security, soil-borne diseases, poor soil fertility, and problems associated with soil in greenhouses.

Common soilless components include growing media (like perlite, vermiculite, coco coir, rockwool, and wood fiber) and nutrient solutions that supply essential minerals and elements (5). Local bio-waste is converted into biochar, and its application as a soil amendment is of agronomic and environmental benefits (5). Soilless cultivation techniques are believed to offer promising solutions by minimizing land and water use while maximizing crop yield and quality (6).

According to (4), traditional soil-based farming of tomatoes posed challenges, including soil depletion and the risk of heavy metal contamination from polluted soil. This raises the question of whether tomatoes grown in soilless-based medium systems demonstrate different nutritional and mineral concentrations compared to those grown in soil, and whether these differences affect the final products, such as tomato paste.

Consequently, it is necessary to compare the physicochemical, phytochemical, chemical, mineral composition, and microbial assessment of tomato pastes made from soilless and soil-based tomato farms. This research could assist food safety regulators, farmers, and consumers in making informed choices about tomato farming and consumption for food safety.

MATERIALS AND METHODS

Procurement of Raw Materials

Plum variety (Roma) of fresh tomato was obtained from Soilless Farm Laboratory, Awowo, Ogun State, and the same species of soil-based tomato was also obtained at Awowo close to the Soilless Farm. All reagents used for analyses were Analar® grade.

Preparation of Tomato Paste

The fresh tomato fruits were washed, and 3 kg from both soil-based and soilless systems were sliced longitudinally and steamed at 60°C for 1 min, followed by manual removal of peel and seeds. The tomato pulp was blended with a Kenwood blender (model ke-2088) and mixed into a smooth paste. The paste was strained through a fine-mesh (2.2 mm) sieve to remove remaining seeds or pulp. The strained puree was transferred into a clean beaker and boiled in a water bath at 95°C and continually mixed to form a thick paste. The tomato paste was filled into clean, sterile glass jars, closed, and boiled in a pot (pasteurization) for 15 min and immediately cooled at room temperature (30±2°C) (7;8). The pastes were stored on the shelf at ambient temperature (30±2°C) for four weeks, and microbial analyses were carried out.

Determination of Physicochemical Properties of Tomato Fruits and Pastes

Ph Determination

The pH of the tomato pastes was measured with a digital pH meter (FE28-Standard, METTLER TOLEDO, America) calibrated using buffer solutions 7.0 and 4.0. The tomato paste (10 g) was blended with 100 mL of distilled water (1:10 w/v), and the glass electrode of the pH meter was inserted into the paste to measure pH (9).

Determination of Moisture Content

The moisture content of the sample was determined using the method described by (9). The sample (5 g) was weighed into a dried and preweighed moisture can. The can with its contents was dried in an oven at a temperature of 105°C for 3 h. It was removed from the oven, cooled in a desiccator, and weighed. It was returned to the oven for another 30 min, cooled and weighed again until constant weight.

Determination of Total Soluble Solid

The total soluble solids (TSS) were determined as described by (10). The calibration for the required range was done with standard sucrose solution (1%, 3%, 5%, 7%, 9% and 11%). The TSS was determined with the use of a refractrometer (Model Misco®) at 20 °C with a range of 0 to 32 °Brix and a resolution of 0.2 °Brix by placing 1 drop of clear paste on the prism and closing with its lid. The TSS value was taken by facing the source of light.

Determination of Total Titratable Acidity

The titratable acidity was determined using the method reported by (11). The sample (25 g) was measured into a 250 mL beaker, mixed with 100 mL of distilled water, and 3 drops of phenolphthalein indicator were added. The sample in the beaker was titrated against 0.1 M NaOH gradually with continuous mixing until the solution changed from colourless to a persistent light pink colour. The spent NaOH volume was recorded, and the citric acid percentage was calculated as % citric acid.

Colour Determination

Colour attributes: lightness (L^*), redness (a^*) and yellowness (b^*) were determined as described by Youssef (12). Tomato fruit and paste were measured (25 g) in a cylindrical sample cup (5-cm diameter×2-cm high) filled to the brim using a Labscan Model LSXE (Hunter Associates Laboratory, Reston, VA, USA). Standard colour plate No. 400 with reflectance values of $L^*=25.70$, $a^*=33.60$, and $b^*=14.70$ was used as a reference. The tomato paste samples were diluted to 12°Brix using distilled water before measuring. The red/yellow ratio (a^*/b^*) was reported to indicate the redness of tomato paste.

Determination of Phytochemical Contents Vitamin C (Ascorbic Acid)

In the determination of vitamin C, tomato paste (5 g) was weighed into an extraction tube and 100 mL of EDTA/TCA at a ratio of 2:1 was added. The mixture was shaken for 30 min, transferred into centrifuge tubes, and centrifuged at 3000 rpm for 20 min. The filtrate was transferred into a 100 mL volumetric flask and made up to the 100 mL mark with the extracting solution. The extract (20 mL) was pipetted into a volumetric flask, and 1% starch indicator was added. This was titrated against 2,6- diichlorophenolindophenol (DCPIP) to get a pink endpoint (13).

Determination of Lycopene

Lycopene was determined by the method of Fish (14). The sample (5 g) was weighed into a centrifuge tube, and hexane, ethanol, and acetone prepared in a ratio of 2:1:1 were respectively added (100 mL). The tube was vortexed and incubated in the dark for 10 min. This was followed by the addition of water (1 mL), mixed, and kept for another 10 min. Absorbance (Abs) was then read using an ultraviolet-visible spectrophotometer (Shimadzu UV-1800/1601/ 1900) at 503 nm. Lycopene content was calculated in mg/kg using the formula below:

$$\text{Lycopene (mg/100g)} = \frac{Abs.@503\ nm\ x\ 537\ x\ 8\ x0.55}{W\ x\ 172}$$

Where 537g /mole is the molecular weight of lycopene; 8 is the volume of the mixed solvent; 0.55 is the volume ratio of the upper layer to the mixed solvent; W is the weight in g of the sample; 172 is the extinction coefficient of lycopene in hexane.

Determination of Beta-Carotene

Tomato paste (10 g) was mixed with 10 mL of a 1/1/1 volume of ethyl-acetate/methanol/ petroleum solvent mixture for the extraction of beta-carotene content. The extract was evaporated to dryness on a rotary evaporator at low pressure. The sample was redissolved in 1 mL of ethyl acetate, filtered through a 0.45 μm filter, and injected into the High-Performance Liquid Chromatography (Agilent 1200 series HPLC system) for the quantitative determination of beta-carotene (14).

Determination of Mineral Composition of Tomato Pastes

The tomato paste samples were digested using the wet digestion method with concentrated H_2SO_4 and $HClO_4$ at a ratio of 1:1 in a digester (FOSS TECATOR Digester Model 210) at 250℃ for 1 h. The clear solution was used in mineral analysis using an Atomic Absorption Spectrophotometer (Buck 210) (15).

Microbiological Evaluation of Tomato Pastes

The total aerobic bacterial count (TABC), total mould count (TMC) and total yeast count (TYC) were enumerated. Serial dilution was carried out by mixing 1.0 g of tomato paste sample with 9.0 mL of peptone water to obtain a 10^{-1} dilution. Subsequent dilutions were made serially from the stock solution until a 10^{-4} dilution was obtained. About 1.0 mL of the serial dilution was dispensed and mixed with 20 mL each of molten Nutrient agar, de Man Rogosa and Sharpe agar, and potato dextrose agar in a sterile Petri dish for total aerobic, mould, and yeast counts, respectively. For total aerobic count, incubation was at 37°C for 72 h, while plates for mould and yeast count were incubated at 28°C ± 2 for 3 days. The number of colonies on each plate was multiplied by the reciprocal of the dilution factor to obtain the count (16).

Statistical Data Analysis

Duplicate data were subjected to One-Way Analysis of Variance (ANOVA) using Statistical Package for Social Sciences (SPSS) version 16.0. Vertical bar charts were used to compare the means of different treatments. The means were separated using Duncan's New Multiple Range Test (DNMRT) at a 95% confidence level ($P < 0.05$).

RESULTS

Physicochemical Properties of Tomato Fruits from Soil-Based and Soilless-Grown Tomatoes

Figure 1 shows the results of physicochemical properties of tomato fruits from soil-based and soilless farms. Soilless-grown tomatoes were less acidic (pH 4.83) compared to soil-based tomatoes (pH 4.63). The soil-based tomatoes exhibited significantly higher moisture content (94.20%) compared to the soilless-grown tomatoes (90.89 %). The total soluble solids content was similar between the two groups. The titratable acidity value of soilless tomato fruit (1.80%) was less than that of soil-based tomato fruit (2.10%). There were notable differences in the colour parameters. The soil-based tomatoes exhibited a higher L* value (36.54), indicating they were lighter in colour. Conversely, the soilless-grown tomatoes had a lower L* value (24.38), suggesting a darker appearance. The a* value, representing redness, was also higher in soil-based tomatoes (23.24) compared to soilless tomatoes (19.47). The b* value, representing yellowness, was also higher in soil-based tomatoes (31.27) compared to soilless tomatoes (16.25).

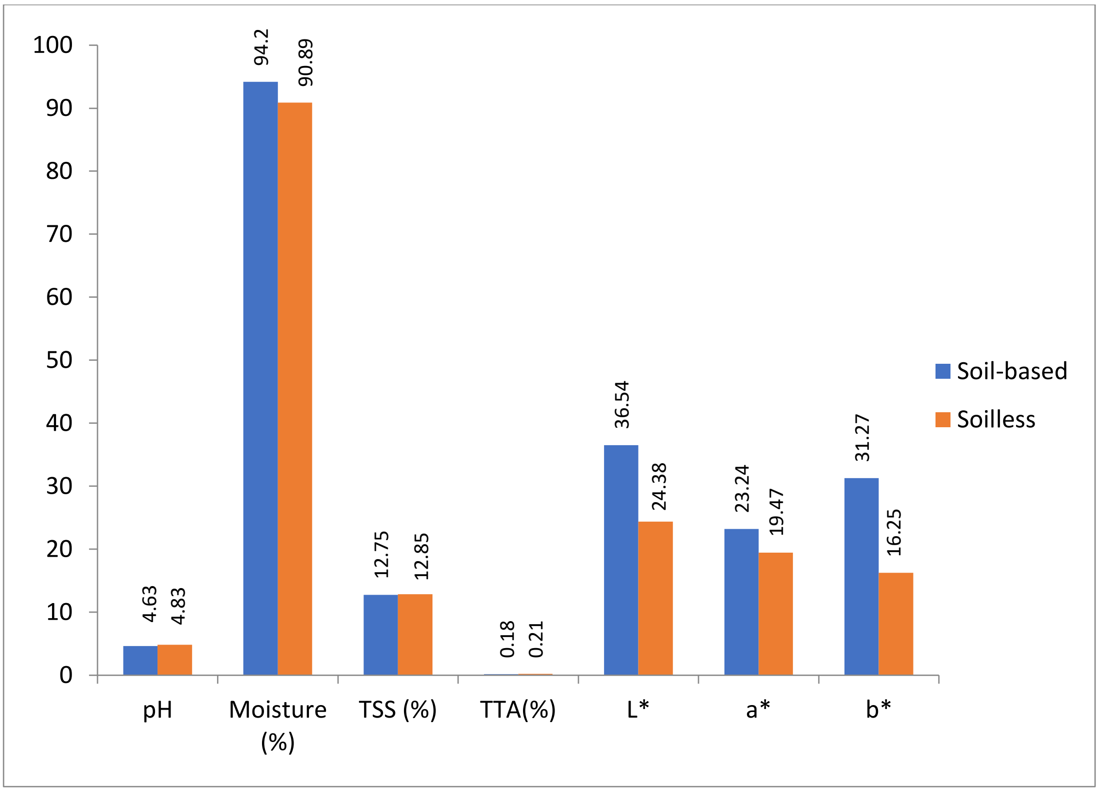

Figure 1: Physicochemical Properties of Tomato Fruits from Soilless and Soil-Based Farms
% Values represent means of duplicate values ± standard deviation

Phytochemical Properties of Tomato Fruits

The results of phytochemicals of tomato fruits are presented (Figure 2). The ascorbic acid contents were similar, at 48.64 and 48.93 mg/100g for Soil-based and Soilless, respectively. The soilless-grown tomatoes showed slightly higher levels of both β-carotene (10.01 mg/100g) and lycopene (8.10 mg/100 g) compared to the soil-based tomatoes (9.86 mg/100g and 7.66 mg/100g, respectively).

Physicochemical Characteristics of Tomato Pastes

In Figure 3, soilless tomato paste had a significantly higher pH (4.64) than soil-based (4.47). Soil-based tomato paste had higher moisture content (88.32%) than soilless (87.37%). The TSS and TTA of soilless tomato paste were higher than those of soil-based tomato paste, from 25.20 to 23.60 and 0.41 to 0.37, respectively. The significantly higher TSS in soilless tomato paste indicates a greater concentration of sugars and other soluble compounds. However, the difference in TTA was not statistically significant at $p<0.05$. Hunter color parameters: lightness (L^*), redness (a^*), and yellowness (b^*) changed significantly ($p<0.05$). The L^* value decreased from 27.32 for the soilless tomato paste to 25.87 (the darkest) for the soil- based tomato paste. The a^* and b* values of 17.02 and 14.99, respectively, showed soilless paste had a better appearance of red colour compared to the soil-based tomato paste.

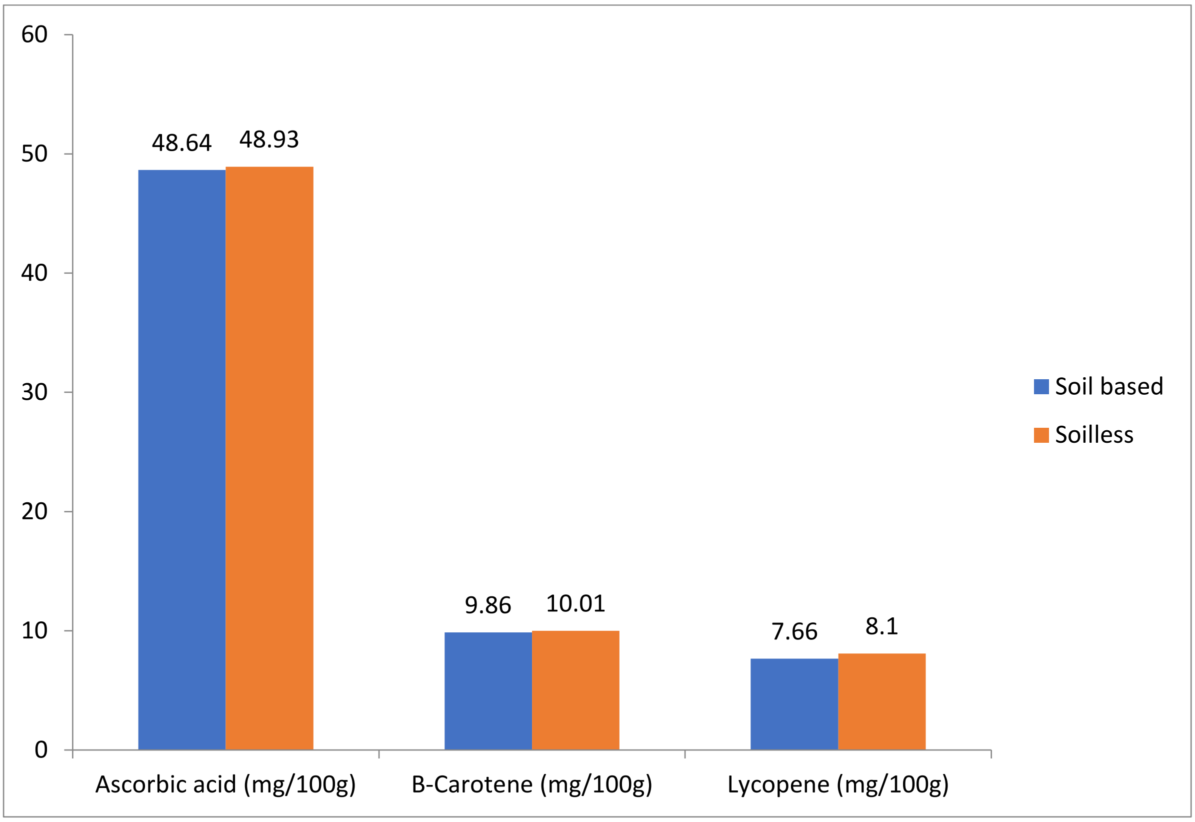

Figure 2: Phytochemical Composition of Tomato Fruits from Soilless and Soil-Based Fresh Tomato

Phytochemical Contents of Tomato Pastes

Figure 4 shows the lycopene, β-carotene, and ascorbic acid contents of tomato pastes. The tomato paste derived from soilless-grown tomatoes exhibited significantly higher lycopene (28.02 mg/100 g), β-carotene (0.98 mg/100 g), and ascorbic acid (63.21 mg/100 g) contents compared to the paste from soil-based tomatoes (61.76 mg/100g).

Mineral Contents of Tomato Pastes

The mineral composition of the tomato pastes is presented in Table 1. The soilless tomato paste exhibited slightly higher levels of both sodium (56.10 mg/kg) and potassium (926.72 mg/kg) compared to the soil-based paste (54.79 mg/kg and 908.67 mg/kg, respectively). These differences were highly significant ($p < 0.001$) for both. The concentrations of iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) were significantly higher in the tomato pastes produced from soilless-grown tomatoes. There was no cadmium (Cd) in either type of paste, but silver (Ag) was detected, showing a higher concentration at $p < 0.001$ in soil-based paste (0.04 mg/kg) compared to the soilless paste (0.03 mg/kg).

Microbial Load of Tomato Paste Samples during Storage

The total aerobic bacterial count (TABC) in both soil-based and soilless tomato paste samples exhibited an increasing trend over the four weeks of storage (Table 2). In the soil-based tomato paste, the TABC ranged from 2.00×10^4 cfu/g in week 1 to 6.00×10^4 cfu/g in week 4. The soilless tomato paste showed a more dramatic increase in TABC; the counts of 10.00×10^4 cfu/g (1.00×10^5 cfu/g) at week 3 and 20.00×10^4 cfu/g (2.00×10^5 cfu/g) at week 4 significantly exceeded the generally accepted limit of 10^5 cfu/g for aerobic bacteria in processed foods, raising significant food safety concerns.

There was no mould growth (ND) throughout the entire four-week storage period in soil-based tomato paste (Table 2). Soiless tomato paste showed no mould growth in week 1 but escalated from 1.50×10^4 cfu/g in week 2 to 10.00×10^4 cfu/g (1.00×10^5 cfu/g) in week 4.

However, there was no detectable yeast count in week 1 for both pastes, but an increase in yeast count was observed in both samples from week 2 (Table 2). The soil-based tomato paste had yeast counts ranging from 1.00×10^4 cfu/g in week 2 to 2.50 x 10^4 cfu/g in week 4. Similarly, the soilless tomato paste showed yeast counts ranging from 1.50 x 10^4 cfu/g in week 2 to 2.00 x 10^4 cfu/g in week 3, and decreased slightly to 1.00 x10^4 cfu/g in week 4.

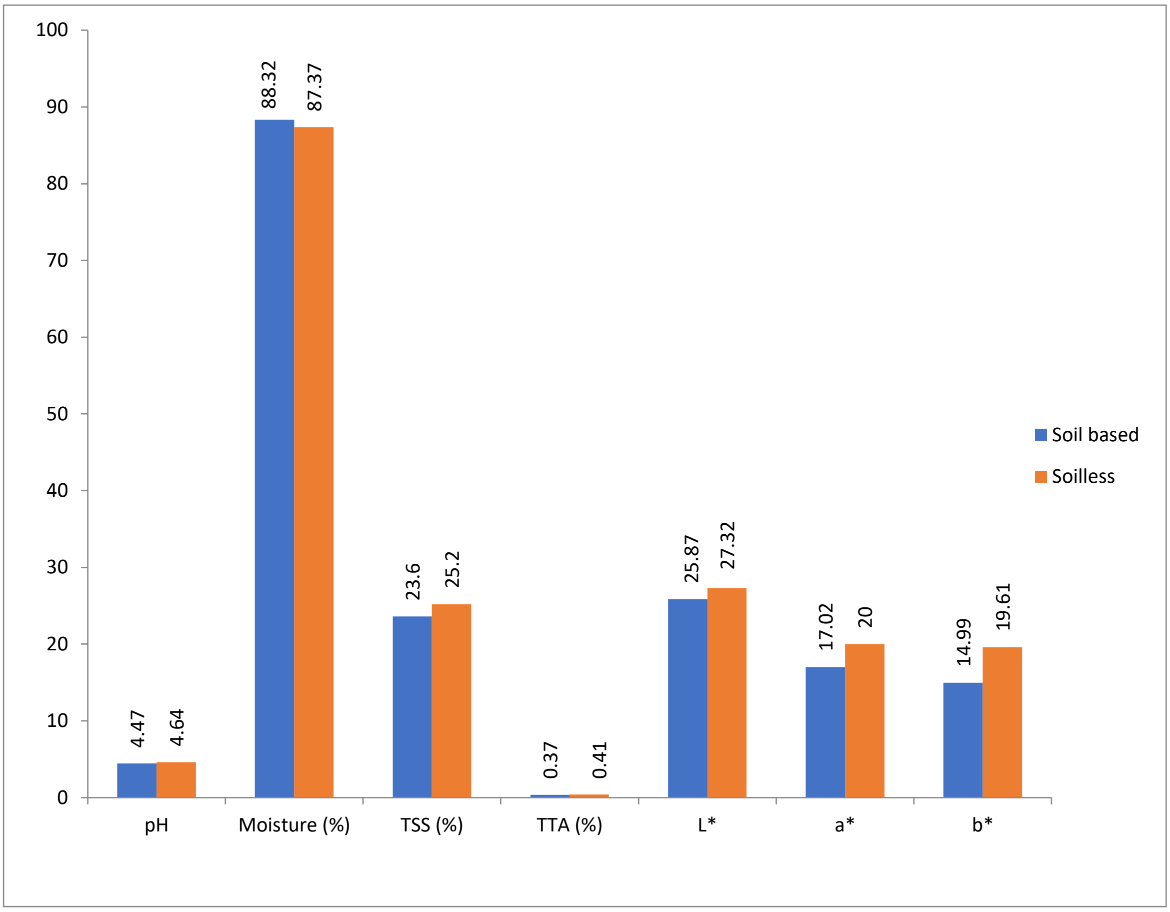

Figure 3: Physicochemical Composition of Tomato Pastes from Soilless and Soil-Based Tomatoes

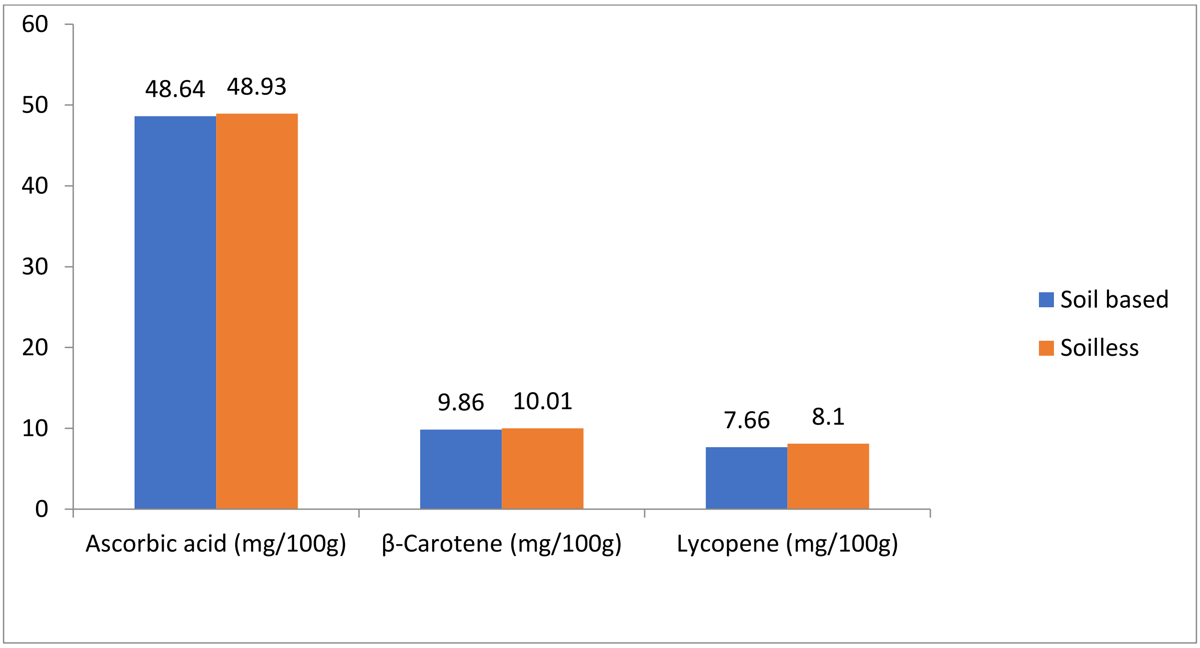

Fig. 4: Phytochemical composition of tomato paste from soilless and soil-based tomatoes

Table 1: Mineral Contents (Mg/Kg) of Tomato Paste from Soil-Based and Soilless-Grown Tomatoes

Parameters	Soil based	Soilless	Sig. P
Na	54.79±0.01	56.10±0.01	0.000
K	908.67±0.02	926.72±0.02	0.000
Fe	3.06±0.00	3.11±0.00	0.003
Mn	0.32±0.00	0.34±0.00	0.011
Cu	0.37±0.00	0.39±0.00	0.012
Zn	0.63 ±0.00	0.65±0.00	0.014
Cd	ND	ND	ND
Ag	0.04±0.00	0.03±0.00	0.020

Values represent means of duplicate values ± standard deviation. ND=Not Determined

Table 2: Total Aerobic Bacteria, Total Mould and Total Yeast Count (Cfu/G) of Tomato Paste Samples during Storage

Storage period (weeks)	TABC		Total mould count		Total yeast count	
	Soil-based	Soil-less	Soil-based	Soil-less	Soil-based	Soil-less
1	2.00×10^4	1.00×10^4	ND	ND	ND	ND
2	4.00×10^4	6.00×10^4	ND	1.50×10^4	1.00×10^4	1.50×10^4
3	5.00×10^4	10.00×10^4	ND	4.50×10^4	2.00×10^4	2.00×10^4
4	6.00×10^4	20.00×10^4	ND	10.00×10^4	2.50×10^4	1.00×10^4

ND-Not Detected; Soil-based – Tomato Pastes from Soil-based; Soil-less - Tomato Pastes from Soil-less

DISCUSSION

The high moisture content observed in soil-based tomatoes compared to the soilless-grown tomatoes is similar to observations by (17), and this could be attributed to variations in water availability and management in the two systems. The non-significant difference in the total soluble solids suggested that both cultivation methods were effective in producing fruits with comparable sugar levels, a key determinant of sweetness. High total soluble solids (TSS) and low acidity observed in soilless-grown tomato fruit are considered desirable qualities for manufacturers of various processed products from fresh tomatoes (18). Notably, the soil-based tomatoes displayed a lighter and more saturated yellow-red colour. These differences suggest that the cultivation system can influence certain physicochemical attributes of tomato fruits, potentially impacting their nutritional value, appearance, and consumer appeal. According to (19), changes in colour from green to red are influenced by the physiological breakdown of pigments from xanthophylls to lycopene, β-carotene, and γ-carotene in mature fruits. The two methods of cultivation showed comparable levels of ascorbic acid (Vitamin C), and this reflects similar levels of ripening (20). Carotenoids are important antioxidants and contribute to the colour of the fruits (21).

pH is a crucial parameter affecting the stability, microbial safety, and flavour of tomato paste. According to (22), a little change in acidity could be related to the variation in nutrient solutions used in the soilless system compared to the conventional soil's buffering capacity. High moisture content in soil-based tomato paste could influence texture, consistency, and shelf-life. Low moisture is a desirable trait as it contributes to the sweetness and overall flavour intensity of the paste (23). High levels of soluble solids and titratable acidity are desirable for the production of tomato paste, as tomatoes with these attributes require less thermal treatment, thus reducing loss of nutrients (24).

The analytical results of the colour of tomato paste from soilless farms showed better colour compared to soil-based tomato paste. It was reported that a one-unit difference in L^* value of two samples can be detected by the human eye, which in turn affects consumer acceptability (25). Maintaining the natural colour in processed and stored foods has been a major challenge in food processing, and this serves as a major reason colouring additives are usually involved in the production of commercial tomato pastes (26).

Lycopene increment in soilless tomato paste could be attributed to factors in the soilless system that enhance lycopene synthesis during fruit development, which is then preserved in the paste-making process (27). β-carotene is a precursor of Vitamin A and acts as an antioxidant; the choice of cultivation method influences the provitamin A content of the final tomato paste product. Ascorbic acid is a water-soluble vitamin known for its antioxidant properties. While the paste-making process can lead to some degradation of Vitamin C due to heat, these results suggest that tomatoes from soilless systems may have a higher initial concentration, resulting in a final product with a slightly higher content (28).

Soilless cultivation showed slightly higher concentrations of essential macro-minerals (potassium, sodium), which, on average, an adult requires more than 100 mg/day, and micro-minerals (iron, manganese, copper, zinc) less than 100 mg/day (29). The little variations in minerals are crucial for human health and may likely stem from the composition of the nutrient solutions used in the soilless system compared to the mineral availability in the soil (30).

The silver content is within the range of recommended levels in food. Although there is no universally established limit for silver in food, the European Food Safety Authority proposed a restriction of 0.05 mg/kg (31). The inherent characteristics of the soil-based tomatoes derived from the grown soil could be considered effective in inhibiting the growth of microbes, especially mould spores, which are common contaminants of fresh produce (32). However, the presence of mould in soilless tomato paste indicates a potential risk of mycotoxin production, which poses a serious health hazard.

The absence of yeast count in week 1 of storage indicated safety. A general guideline for the permitted yeast limit in processed food products is below 10^2 cfu/g for quality and safety (33). Therefore, the observed yeast levels in both the soil-based and soilless pastes from week 2 to 4 make the paste potentially unsafe for consumption.

Tomatoes basically contain all the nutrients necessary for microbial growth and metabolism, making them susceptible to microbial contamination. However, this could also have been a result of the ambient environment the tomato pastes were kept in during the period of storage (34). Several genera of bacteria and fungal identified as being associated with the spoilage of tomato fruits and tomato paste (35). The presence of fungi may lead to the production of mycotoxins with public health risks (36).

CONCLUSION

This study established that the medium of tomato cultivation influenced physicochemical, mineral, and microbial characteristics of tomato paste. The colour characteristics of fresh soilless tomato were low but gained better quality in tomato paste. The total soluble solids, moisture content, titratable acidity, pH, colour, vitamin C, lycopene, β-caraotene, mineral were enhanced in soilless tomato paste but were susceptible to microbial invasion compared to the soil-based product. Tomato paste producers should consider sourcing tomatoes from soilless farms, especially in regions where soil quality or heavy metal contamination is a concern. This approach offers a more controlled and potentially safer raw material input, reducing the risk of undesirable mineral accumulation in the final product. Further research work on improving the microbial quality of soilless tomato paste is recommended.

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