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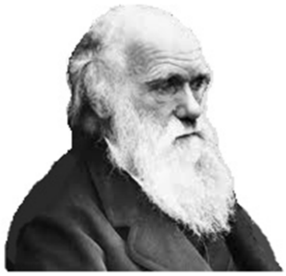

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Investigating the Microbial Safety and Physiochemical Quality of Local vs. Foreign Tomato Pastes: A Study in Rivers State, Nigeria

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ABSTRACT

This study investigates the microbial and physicochemical quality of commonly used tomato paste, assessing 30 local and foreign tomato pastes across three distinct categories and 5 fresh tomato paste serving as a control. Microbial analysis revealed significant variations in total heterotrophic bacteria counts. Local brands (SL), (GL), and (TL) exhibited counts ranging from 2.6×10^3 to 8.2×10^3 CFU/g, while foreign brands (FF), (VF), and (DT) displayed counts from 3.0×10^2 to 7.25×10^3 CFU/g and fresh tomato pastes ranged from 1.8×10^4 to 2.8×10^6 CFU/g. Staphylococcus and coliform counts presented brand-specific disparities. Morphological and biochemical characterization identified thirteen bacterial genera and various fungal species, highlighting the diverse microbial communities present. The frequency of occurrence of bacteria isolates showed *Staphylococcus* spp. 32.0%; *Bacillus* spp. 20%; *Escherichia coli* 22 %; *Klebsiella* spp. 15 %; *Proteus* spp. 13 %; *Pseudomonas* spp. 8% *Citrobacter* 8.0%; *Corynebacterium* 5.0%; *Enterobacter* spp. 5.0%; *Lactobacillus* spp. 4.0%; *Micrococcus* spp. 3.0% and *Salmonella* spp. 4.28%.Fungal species had different occurrences, with: Yeast 22.8%; *Aspergillus niger* 16.9%; *Mucor* 10.1; *Fusarium* 16.9%; Pink Yeast 6.7%; *Aspergillus flavus* 2 %; *Rhizopus stolonifera* 11.8% *Aspergillus fumigatus* 1.0%. *Penicillium* 5.08% *Trichoderma* 1.69% *Candida* 10.0% and *Saccharomyces* 1.09%. Physicochemical analysis demonstrated variations in pH, ascorbic acid content, and moisture levels. Foreign tomato pastes exhibited higher pH values compared to local brands. Ascorbic acid content ranged from 17.59 to 27.80 mg/kg, and moisture content varied among fresh, local and foreign tomato paste. The study recommends conduct long-term studies to monitor trends in microbial safety and quality over time, which can inform future food safety policies and practices. Implementing these recommendations aims to enhance tomato paste quality, ensuring microbial safety and adherence to essential physicochemical quality.

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***Keywords*:** Tomatoes, lycopene, tomato paste, microbial quality, physicochemical qualitys, food safety, *Lycopersicum esculentum*

1. INTRODUCTION

Tomatoes (*Lycopersicum esculentum*) are a critical vegetable crop extensively cultivated for personal consumption and commercial purposes. Their high perishability contributes to significant annual waste, highlighting the need for effective processing methods such as concentration and heat treatment to enhance year-round availability. Nigeria will continue to rely on agriculture to meet its various socio-economic needs, as it plays a vital role in providing food and employment for the nation's ever-increasing population. Tomatoes are among the major vegetables produced in the country and are consumed in various forms (Aditi et al., 2011; Aremu et al., 2016). Nigeria ranks as the 16th largest producer of tomatoes globally and the leading producer in Sub-Saharan Africa, integrating them into daily meals in fresh, cooked, and processed forms such as paste and sauces (Adetoro et al., 2015; Ugonna et al., 2015).

As urban lifestyles evolve, there is a growing demand for convenient and safe ready-to-eat food options. The rise in fast food consumption, driven by time constraints, raises concerns about nutritional quality and health impacts. It is essential for commercially sold tomato paste to retain vital nutrients, such as lycopene and vitamin C, which act as antioxidants and combat oxidative stress (Mellidou et al., 2021). However, the market has seen an influx of adulterated tomato pastes that lack these essential nutrients, leading to significant economic losses and potential health risks.

The economic impact of importing counterfeit tomato products is considerable, with many imports compromised by unethical marketing practices. Substandard products, often containing starch and artificial color additives to mimic the natural deep red hue, proliferate due to insufficient regulatory oversight by the National Agency for Food and Drug Administration and Control (NAFDAC), which prioritizes drug regulation over food safety.

The quality of tomato paste is significantly influenced by both the quality of raw materials and the processing techniques employed, including evaporation methods that concentrate tomato juice (Amón et al., 2015). This study aims to evaluate the microbial and physicochemical quality of commercially available tomato pastes in Nigeria, contributing to a better understanding of their quality and safety for consumer health.

2. MATERIALS AND METHODS

Study Location

Rivers State, located in the southern region of Nigeria, is known for its rich cultural diversity and economic significance, particularly due to its oil and gas industry. The state is characterized by a tropical climate, which supports a variety of agricultural activities, including the cultivation of tomatoes. The capital city, Port Harcourt, serves as a major commercial hub, facilitating the distribution and consumption of various food products, including tomato paste. Rivers State is home to both local and international brands, making it an ideal location for assessing the quality and safety of tomato paste products.

Sample collection

A total of 35 samples were randomly procured using a simple random sampling technique from vendors at Choba, Port Harcourt, Rivers State. This included fifteen (15) local tomato pastes, fifteen (15) foreign tomato pastes, and fifteen (5) samples of fresh tomato paste. The fresh tomato paste was made by purchasing fresh, healthy tomatoes, which were then processed into a paste with no additives.

Media preparation

Plate count agar (PCA), Potato dextrose agar (PDA), Mac Conkey agar, Mannitol salt agar, was prepared according to manufacturer's recommendations and autoclaved at 121 °C for 15 min and medium was allowed to cool to 45-50 °C. For PDA, about 0.1% Hydrogen chloride (HCl) was added to suppress bacterial contaminations. 20ml of the molten PDA was poured into sterile 9 cm glass Petri dishes and were allowed to cool at room temperature before inoculation of the test samples and organisms.

Samples preparation

10g of tomato samples into 90 ml of diluent/peptone water then homogenized in a stomacher to get the stock solution. Tenfold serial dilution was done from 10^1 to 10^7 them 0.1 ml were inoculated into the petri dishes containing the different media Nutrient agar (NA), Potato dextrose agar (PDA), MacConkey agar, Mannitol salt agar, Plate count agar (PCA), Mannitol salt agar (MSA), and spread plated, this follows incubation.

Microbial analysis

Enumeration of total bacterial count, total staphylococcus count, and total coliform count

Counts from the incubated agar plates were enumerated after 24 hours for bacteria and 72 hours for fungal count.

Determination of Colony Forming Unit per meter cube (CFU/g)

The cfu/g was determined using

Cfu/g = Number of colonies × dilution factor / Volume of culture plate

Identification of isolates

Bacterial isolates were characterized and identified using cultural, morphological and microscopic examinations. The macroscopic examination of the colonies was differentiated based on size, color, pigmentation, elevation surface texture and margin. Different biochemical tests such as Gram staining, Catalase, Coagulase, Methyl-red, Oxidase, Voges-Proskauer and sugar fermentation test were employed to differentiate the bacterial isolates according to the standard microbiological methods.

Fungal Identification

Identification of all fungal isolates was also carried out using standard methods based on macroscopic and microscopic features as described by Lacto-phenol (Cotton blue test). On a clean slide, a drop of methanol was placed and a portion of fungi growth was cut with the aid of surgical blade and tested in the methanol. A drop of lacto-phenol cotton blue was added. A cover slip was placed on it gently and observed under the microscope with X40 objectives.

Physiochemical Analysis

Determination of Moisture Content

Moisture content of the sample was determined using method described by AOAC (2004). 5 g of the tomato paste samples were taken and transferred into a porcelain crucible, after which they were oven dried at a temperature of 105 °C for 1 hr. The difference in the weight of the samples was recorded in percentage as the moisture content**.**

Ascorbic acid

Weigh accurately about 0.1 gm of the sample and dissolve in a mixture of 100 ml freshly boiled and cooled water and 25 ml of 1M sulfuric acid. Immediately Titrate with 0.05M iodine, using the starch solution as indicator until a persistent blue-violet color is obtained as described by (AOAC, 2006).

Determination of pH

The pH value was measured with a pH meter (Mettler Toledo, Switzerland) according to AOAC (2004). 10 g of the sample was homogenized with a blender and strained. 10 mL of the juice was used for pH measurement using Jenway 3310 pH meter which have been previously calibrated with buffers of 4 and 9. (Okafo *et al.*, 2019). (Efiuvwevwere & Atirike, 1998).

Statistical analyses

Analysis of variance (ANOVA) was used to compare means at $p < 0.05$. This analyses were performed to determine if there is significant difference in microbial loads of the different tomato pastes using SPSS (Statistical Package for the Social Sciences), also known as IBM SPSS Statistics, is a software package used for the analysis of statistical data.

3. RESULTS AND DISCUSSION

Total Heterotrophic Bacteria Count of Local Tomato Pastes Studied

The analysis of fifteen local tomato paste brands revealed varying total heterotrophic bacteria counts (THBC) across three specific brands. Brand SL exhibited THBC ranging from 2.6×10^3 to 8.2×10^3 CFU/g. Brand GL showed counts between 1.9×10^3 and 8.0×10^3 CFU/g., Brand TL had counts ranging from 1.0×10^3 to 6.8×10^3 CFU/g.

In contrast, the control group, represented by fresh tomatoes (FT), exhibited a significantly higher THBC, with values ranging from 1.8×10^4 to 2.8×10^6 CFU/g (Fig. 1). These findings indicate variability in microbial loads among the different brands of tomato paste, with the fresh tomato serving as a reference point for comparison.

Further investigation is warranted to assess the implications of these microbial counts on food safety and quality.

Total Heterotrophic Bacteria Count of Foreign Tomato Pastes Studied

The evaluation of fifteen foreign tomato paste brands revealed varying total heterotrophic bacteria counts (THBC) across three specific brands: Brand FF exhibited THBC ranging from 8.0×10^2 to 5.95×10^3 CFU/g., Brand VF showed counts between 5.0×10^2 and 7.25×10^3 CFU/g. Brand DT had counts ranging from 1.5×10^2 to 1.3×10^3 CFU/g. In comparison, the control group, represented by fresh tomatoes (FT), demonstrated a significantly higher THBC, with values ranging from 1.8×10^4 to 2.8×10^6 CFU/g These results highlight the variability in microbial contamination among different brands of foreign tomato paste, emphasizing the need for thorough safety evaluations to ensure product quality and consumer health.

Total Staphylococcus Counts of Local Tomato Pastes Studied

The assessment of total Staphylococcus counts across fifteen local tomato paste brands revealed variability among the three brands studied: Brand SL exhibited Staphylococcus counts ranging from 5.5×10^2 to 1.35×10^3 CFU/g. Notably, no counts were recorded for samples SL1 and SL5.

Brand GL demonstrated counts between 3.5×10^2 and 2.15×10^3 CFU/g, with no counts recorded for GL3 and GL5.Brand TL showed counts ranging from 6.0×10^2 to 1.35×10^3 CFU/g, while samples TL2 and TL5 did not exhibit any Staphylococcus growth. These findings (Fig. 3) highlight the presence of Staphylococcus in local tomato pastes, underscoring the need for monitoring microbial safety to ensure the health of consumers.

Total Staphylococcus Counts of Foreign Tomato Pastes Studied

The evaluation of total Staphylococcus counts among the foreign tomato paste brands revealed limited contamination across the samples: For Brand FF, only two samples, FF3 and FF5, exhibited Staphylococcus counts of 8.0×10^2 CFU/g and 1.45×10^3 CFU/g, respectively. No counts were obtained for samples FF1, FF2, and FF4.In the Brand VF category, only one sample, VF3, was found to be contaminated with Staphylococcus, showing a count of 6.5×10^2 CFU/g.

All other samples tested negative for Staphylococcus. Among the DR brand samples, only DT1 and DT5 demonstrated Staphylococcus counts of 3.0×10^2 CFU/g and 6.0×10^2 CFU/g, respectively, while samples DT2, DT3, and DT4 were negative for Staphylococcus. In contrast, the control fresh tomato paste exhibited the highest Staphylococcus count, recorded at 1.8×10^4 CFU/g (Fig. 4).

These results highlight the variability in Staphylococcus contamination among foreign tomato pastes and raise concerns about food safety, particularly in comparison to fresh tomatoes.

Total Coliform Counts of Local Tomato Pastes Studied

The analysis of fifteen local tomato paste brands revealed varying coliform counts: Brand SL exhibited total coliform counts ranging from 1.5×10^2 to 2.3×10^2 CFU/g. Brand GL showed counts between 1.1×10^2 and 1.3×10^2 CFU/g. Brand TL demonstrated counts ranging from 1.0×10^2 to 1.3×10^2 CFU/g.

These findings (Fig. 5) indicate variability in coliform contamination among the local tomato paste brands, highlighting the need for ongoing monitoring to ensure food safety and quality

Total Coliform Counts of Foreign Tomato Pastes Studied

The assessment of coliform counts across fifteen foreign tomato paste samples revealed variability among the brands: Brand FF exhibited coliform counts ranging from 1.0×10^1 to 2.3×10^1 CFU/g. Brand VF showed counts between 1.5×10^1 and 1.0×10^1 CFU/g, although samples VF2 and VF5 did not exhibit any coliform growth. Brand DR demonstrated counts ranging from 1.0×10^1 to 1.4×10^2 CFU/g, with samples DT2 and DT4 also showing no coliform presence. In contrast, the control fresh tomato sample exhibited a significantly higher coliform count of 8.45×10^4 CFU/g (Fig. 6). These results indicate varying levels of coliform contamination among foreign tomato pastes, raising concerns about food safety, particularly in comparison to fresh tomatoes.

Total Fungi Counts of Local Tomato Pastes Studied

The evaluation of total fungi counts across local tomato paste brands revealed variability: Brand SL exhibited counts ranging from 5.0×10^1 to 8.5×10^2 CFU/g. Brand GL showed counts between 1.5×10^2 and 4.5×10^2 CFU/g, although one sample, GL3, exhibited no fungal growth . Brand TL had only two samples, TL3 and TL5, with fungal counts of 6.0×10^2 and 2.0×10^2 CFU/g, respectively. The remaining samples GL1, GL2, and GL4 recorded no fungal counts. These findings (Fig. 7) highlight the presence of fungal contamination in local tomato pastes, emphasizing the importance of quality control in food safety.

Total Fungi Counts of Foreign Tomato Pastes Studied

The assessment of fungal counts across fifteen foreign tomato paste samples revealed variability among the brands: Brand FS exhibited fungal counts ranging from 2.0×10^2 to 3.4×10^2 CFU/g. Brand V demonstrated counts between 2.0×10^2 and 8.0×10^2 CFU/g. Brand DR showed higher fungal counts, ranging from 3.0×10^2 to 1.5×10^3 CFU/g. In contrast, the control fresh tomato sample exhibited the highest fungal growth, recorded at 4.0×10^3 CFU/g (Fig. 8). These findings indicate the presence of fungal contamination across foreign tomato pastes, raising concerns regarding food safety and the need for stringent quality control measures.

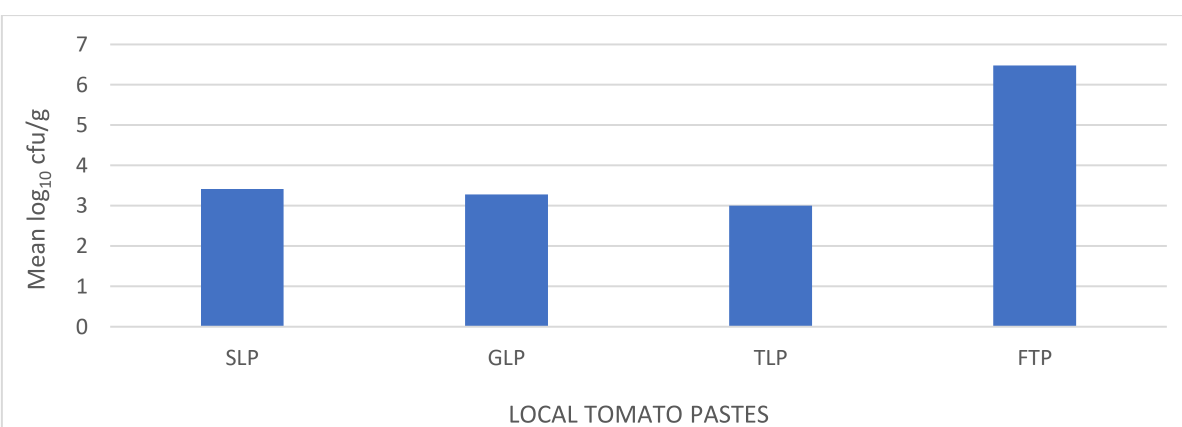

Fig. 1. Total Heterotrophic Bacteria Count of Local Tomato Pastes Studied.
Key: SLP - S Local Tomato Paste, GLP = G local Tomato Paste,
TLP - T Local Tomato Paste, FTP - Fresh Tomato paste.

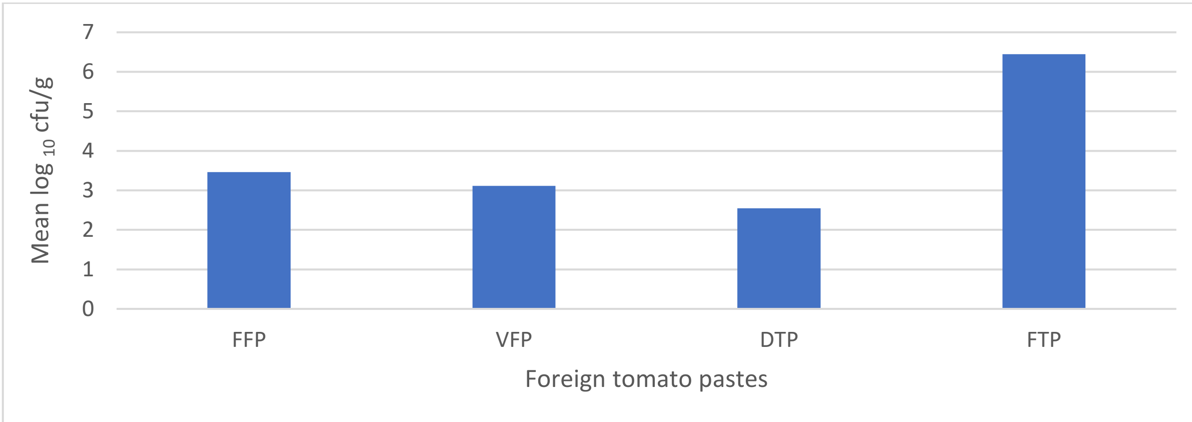

Fig. 2. Total Heterotrophic Bacteria Count of Foreign Tomato Pastes Studied
Key: FFP - F Foreign Tomato Paste, VFP = V Foreign Tomato Paste,
DTP - D Foreign Tomato Paste, FTP - Fresh Tomato Paste

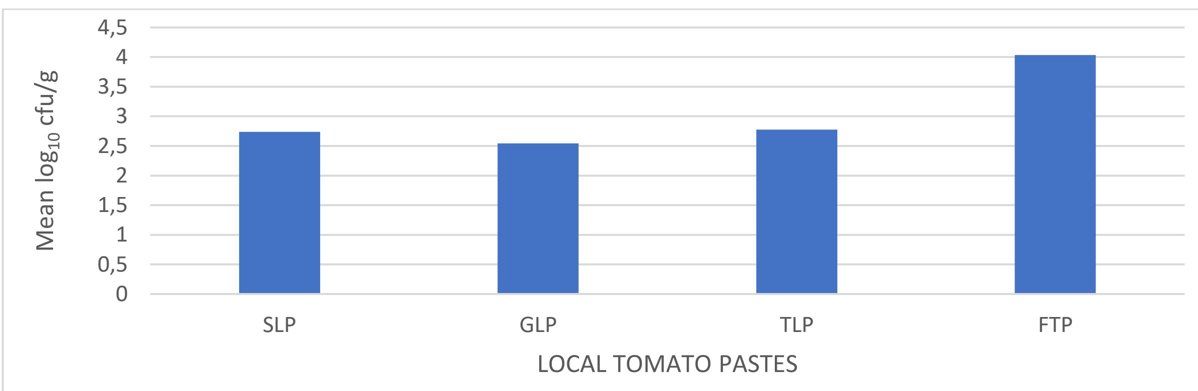

Fig. 3. Total *Staphylococcus* counts of Local Tomato Pastes Studied
Key: SLP - S Local Tomato Paste, GLP = G local Tomato Paste,
TLP - T Local Tomato Paste, FTP - Fresh Tomato Paste

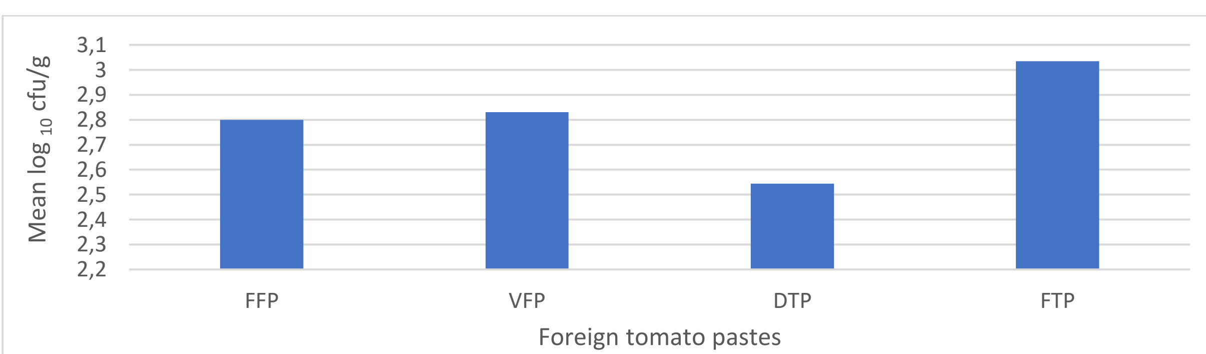

Fig. 4. Total *Staphylococcus* counts of Foreign Tomato Pastes Studied
Key: FFP - F Foreign Tomato Paste, VFP = V Foreign Tomato Paste,
DTP - D Foreign Tomato Paste, FTP - Fresh Tomato Paste

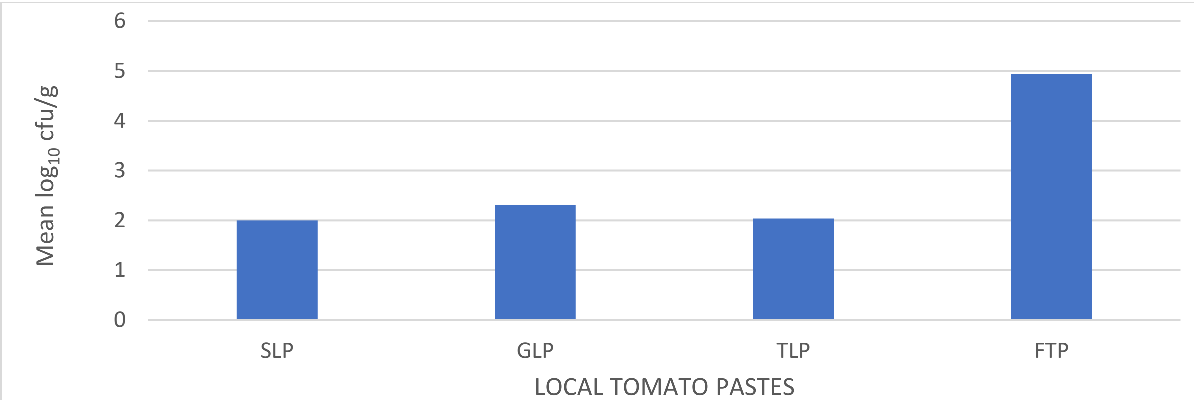

Fig. 5. Total Coliform counts of Local Tomato Pastes Studied
Key: SLP - S Local Tomato Paste, GLP = G local Tomato Paste,
TLP - T Local Tomato Paste, FTP - Fresh Tomato Paste

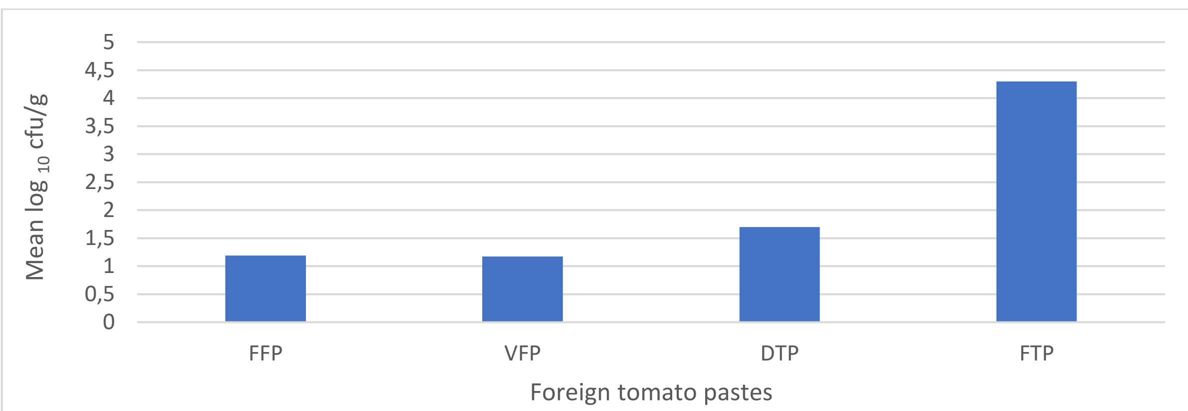

Fig. 6. Total Coliform counts of Foreign Tomato Pastes Studied
Key: FFP - F Foreign Tomato Paste, VFP = V Foreign Tomato Paste,
DTP - D Foreign Tomato Paste, FTP - Fresh Tomato Paste

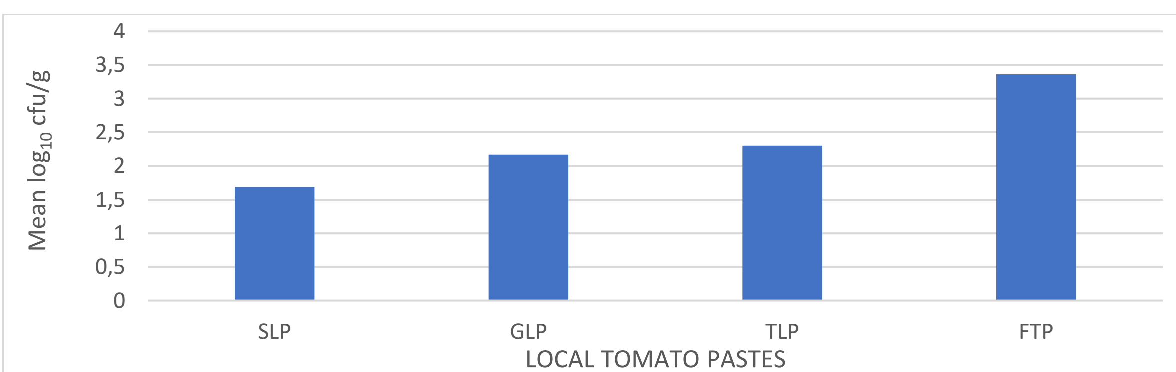

Fig. 7. Total Fungi counts of Local Tomato Pastes Studied
Key: SLP - S Local Tomato Paste, GLP = G local Tomato Paste,
TLP - T Local Tomato Paste, FTP - Fresh Tomato Paste

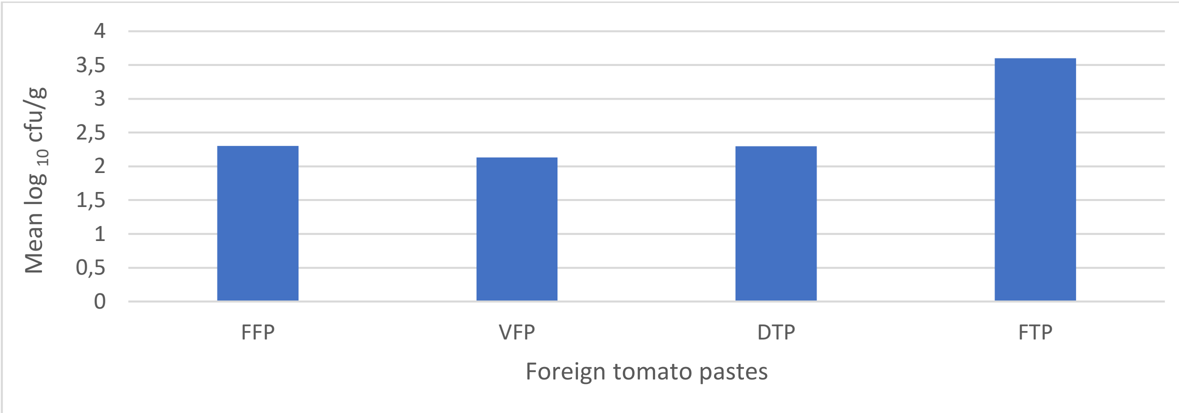

Fig. 8. Total Fungi counts of Foreign Tomato Pastes Studied
Key: FFP - F Foreign Tomato Paste, VFP = V Foreign Tomato Paste,
DTP- D Foreign Tomato Paste, FTP - Fresh Tomato Paste

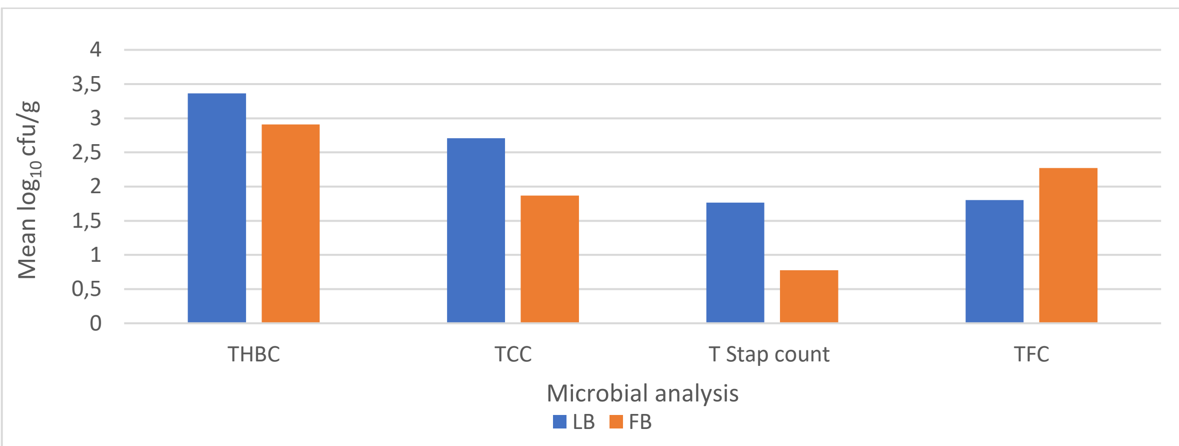

Fig. 9. Microbial Count of local and Foreign Tomatoes Brand
Key: LB - Local Brand, FB = Foreign Brand, THBC = Total Heterotrophic Bacteria Count,
TCC = Total Coliform Count, TSC = Total Staphylococcus Count,
TFC = Total Fungi Count

Frequency of Occurrence of Bacteria Isolated Local and Foreign Tomatoes Pastes Studied

The frequency of occurrence of the bacteria isolates were different among the different species of tomatoes studied. The frequencies obtained were: *Staphylococcus* spp. 32.0%; *Bacillus* spp. 20%; *Escherichia coli* 22 %; *Klebsiella* spp. 15 %; *Proteus* spp. 13 %; *Pseudomonas* spp. 8% *Citrobacter* 8.0%; *Corynebacterium* 5.0%; *Enterobacter* spp. 5.0%; *Lactobacillus* spp. 4.0%; *Micrococcus* spp. 3.0% and *Salmonella* spp. 4.28%. (Table 1)

Frequency of Occurrence of Fungi Isolated Local and Foreign Tomatoes Pastes Studied

The frequency of occurrence showed that the most frequent fungal species across all the tomato brands and control samples studied were: Yeast 22.8%; *Aspergillus niger* 16.9%; *Mucor*

10.1; *Fusarium* 16.9%; Pink Yeast 6.7%, *Aspergillus flavus* 2 %; *Rhizopus stolonifera* 11.8% *Aspergillus fumigatus* 1.0%, *Penicillium* 5.08%, *Trichoderma* 1.69%, *Candida* 10.0% and *Saccharomyces* 1.09% (Table 2).

Table 1. Frequency of Occurrence of Bacteria Isolated from Local and Foreign Tomato Pastes Studied.

Bacteria genera	Local Tomato n (%)	Foreign Tomato n (%)	Control (Fresh) n (%)	Total N (%)
Micrococcus spp.	1 (1.89)	2 (5.0)	0	**3 (2.14)**
Staphylococcus spp.	12 (22.6)	7 (17.5)	13 (27.6)	**32 (22.8)**
Bacillus spp.	`8 (15.1)	11 (27.5)	1 (2.12)	**20 (14.28)**
Corynebacterium spp.	3 (5.6)	2 (5.0)	0 ()	**5 (3.57)**
Escherichia coli	7 (13.2)	3 (7.5)	11 (23.40)	**22 (15.7)**
Klebsiella spp.	5 (9.4)	3 (7.5)	7 (14.8)	**15 (10.71)**
Pseudomonas spp.	5 (9.4)	3 (7.5)	0	**8 (5.71)**
Lactobacillus spp.	2 (3.8)	2 (5.0)	0	**4 (2.85)**
Enterobacter spp.	2 (3.8)	3 (7.5)	0	**5 (3.57)**
Salmonella spp.	0	0	6 (12.7)	**6 (4.28)**
Citrobacter spp.	3 (5.6)	1 (2.5)	4 (8.5)	**8 (5.71)**
Proteus spp.	5 (9.4)	3(7.5)	5 (10.6)	**13 (9.2)**
Total	**53 (100)**	**40 (100)**	**47 (100)**	**140 (100)**

Table 2. Frequency of Occurrence of Fungi Isolated from Local and Foreign Tomato Pastes Studied

Fungi Identity	Local Tomato n (%)	Foreign Tomato n (%)	Control (Fresh) n (%)	Total N (%)
Aspergillus niger	2 (11.76)	1 (6.25)	7 (26.9)	**10 (16.9)**
Aspergillus flavus	0	2 (11.76)	0	**2 (3.38)**
Fusarium spp.	5 (29.4)	4 (23.5)	1 (3.8)	**10 (16.9)**
Yeast	6 (35.2)	2 (11.76)	0	**8 (13.5)**

Pink Yeast	2 (11.76)	2 (12.5)	0 ()	**4 (6.7)**
Rhizopus stolonifer	0	1 (6.25)	6 (23.1)	**7 (11.8)**
Saccharomyces spp.	0	0	1 (3.8)	**1 (1.69)**
Candida spp.	0	0	6 (23.1)	**6 (10.1)**
Mucor spp.	2 (11.76)	3 (18.75)	1 (3.8)	**6 (10.1)**
Aspergillus fumigates	0	0	1 (12.5)	**1 (1.69)**
Trichoderma spp.	0	1 (6.25)	0 ()	**1 (1.69)**
Penicillium spp.	0	0	3 (3.8)	**3 (5.08)**
Total	**17 (100)**	**16 (100)**	**26 (100)**	**59 (100)**

pH, Ascorbic Acid and Moisture Contents of Local and Foreign Tomato Paste Brands Studied

The analysis indicates notable differences in the physiochemical properties between local and foreign tomato pastes when compared to fresh tomato paste .

Foreign tomato pastes had higher pH values, ranging from 4.62 to 6.0., Local tomato pastes showed a lower pH range of 4.53 to 4.94, Fresh tomato had a pH value of 4.7, which is closer to the local tomato paste range. Local tomato pastes had higher ascorbic acid content, ranging from 24.5 mg/Kg to 27.8 mg/Kg, Foreign tomato pastes showed lower ascorbic acid levels, between 19.96 mg/Kg and 22.88 mg/Kg, Fresh tomato had a significantly higher ascorbic acid content of 93.05 mg/Kg, Local tomato pastes had moisture content ranging from 20.91% to 28.8%. Foreign tomato pastes had a lower range, from 17.9% to 24.03%. Fresh tomato exhibited the highest moisture content at 79.0%.

These findings suggest that local tomato pastes are more similar to fresh tomatoes in terms of pH and ascorbic acid content, while foreign tomato pastes show higher pH and lower ascorbic acid and moisture content. The differences could affect the nutritional quality and taste profiles of the tomato pastes.

Table 3. Mean pH, Ascorbic Acid and Moisture Contents of Local and Foreign Tomato Paste Brands Studied.

Samples	pH	Ascorbic Acid (mg/100g)	Moisture Content (%)
(SL)	4.94	26.60	20.91
(GL)	4.53	24.54	28.8
(TL)	4.79	27.80	27.6

(FF)	4.5	17.54	18.34
(VF)	4.62	22.88	17.9
(DF)	6.1	19.96	24.03
(FT)	4.7	93.05	79.0

KEY: SL, GL, TL (LOCAL BRANDS) VF, DF, FT (FOREIGN BRANDS), FF (FRESH TOMATO PASTE)

4. DISCUSSIONS

Microbial Quality of Fresh, Local and Foreign Tomatoes Pastes

This study explores the crucial interplay between microbial and physicochemical characteristics in tomato pastes. By analyzing the microbial composition and physicochemical parameters, the research aims to shed light on the preservation, safety, and overall quality of this popular food product.

The microbial analysis of various tomato paste brands indicates significant differences in total heterotrophic bacteria counts between local and foreign brands, as illustrated in Figures 1 and 2. For the local brand labeled SL, counts ranged from 1.9×10^3 to 8.2×10^3 CFU/g, whereas foreign brands showed counts between 1.5×10^2 and 7.25×10^3 CFU/g. Notably, one foreign brand sample (DT4) exhibited no detectable growth of total heterotrophic bacteria. In contrast, the fresh tomato (FT) paste had the highest count at 2.8×10^6 CFU/g. The differences in bacterial counts among fresh, local, and foreign tomato pastes were statistically significant ($p < 0.05$), highlighting clear distinctions in microbial quality. The elevated bacterial count in fresh tomatoes paste could be due to improper handling at the point of sale, processing methods, inadequate hygiene practices, the quality of raw materials, storage conditions, and natural microflora. Beuchat (1996) and Beuchat et al. (2006).

By comparing the observed microbial counts to established standards, we can assess whether they meet acceptable limits, providing critical insights for consumers and regulatory bodies. It's essential to reference specific microbial standards set by organizations such as the World Health Organization (WHO), which recommends a limit of 10^2 CFU/g. All brands examined exceeded this limit, particularly the fresh tomato paste.

Furthermore, correlating these findings with existing literature on microbial quality in tomato products will enhance our understanding. The heterotrophic counts from this study were notably lower than the range of 6.4×10^2 to 3.6×10^7 CFU/g reported by Dabai et al. (2020) for tomato brands in Katsina State, with local brands showing higher microbial loads compared to foreign ones.

Figures 3 and 4 depict variations in Staphylococcus counts among local brands: SL ranged from 5.5×10^2 to 1.35×10^3 CFU/g, GL from 3.5×10^2 to 2.15×10^3 CFU/g, and TL from 6.0×10^2 to 1.35×10^3 CFU/g. Foreign brands FF and VF displayed limited counts, with FF3 and FF5 reporting counts of 8.0×10^2 and 1.45×10^3 CFU/g, respectively. VF3 had a count of 6.5×10^2 CFU/g, while only DT1 and DT5 from the DR brand had Staphylococcus counts of 3.0×10^2 and 6.0×10^2 CFU/g, respectively. The fresh tomato paste sample recorded the highest Staphylococcus count at 1.8×10^4 CFU/g, significantly exceeding the counts in both local and foreign brands ($p < 0.05$).

Staphylococcus contamination in tomato paste can originate from various sources. Raw ingredients, such as tomatoes and other components, may introduce bacteria if not properly washed or handled before processing. Inadequate hygiene practices during processing, such as insufficient handwashing by workers or the use of unsanitary equipment, can also contribute to contamination. Furthermore, improper processing temperatures or inadequate storage conditions can foster bacterial growth, as Staphylococcus bacteria thrive in warm, moist environments.

Coliform counts for local tomato paste brands SL, GL, and TL ranged from 3.5×10^2 to 2.35×10^3 CFU/g, 8.5×10^2 to 4.0×10^3 CFU/g, and 1.0×10^3 to 5.0×10^2 CFU/g, respectively. In contrast, foreign brands FF, VF, and DT showed coliform counts ranging from 5.0×10^2 to 3.3×10^3 CFU/g, 1.5×10^2 to 1.9×10^3 CFU/g, and 5.0×10^1 to 1.5×10^2 CFU/g, as illustrated in Figures 5 and 6. The fresh tomato paste exhibited a significantly higher coliform count of 8.45×10^4 CFU/g compared to both local and foreign brands ($p < 0.05$).

Coliform contamination can occur at various stages, starting with the tomatoes themselves. During cultivation, factors such as unhygienic farming practices, the use of contaminated water, or contact with polluted soil or fecal matter can introduce bacteria. During processing, inadequate sanitation of equipment or processing environments can lead to cross-contamination from previous batches or environmental sources. Additionally, water used for washing or diluting the tomato paste can introduce coliform bacteria if not adequately treated or sourced from contaminated supplies. The coliform counts in fresh tomato paste exceeded the WHO recommended limit of 1.0×10^1 CFU/g (2015), raising significant public health concerns. Fungal counts among local brands varied, with SL showing a range of 5.0×10^1 to 8.5×10^2 CFU/g, GL from 1.5×10^2 to 4.5×10^2 CFU/g, and TL showing counts only in two samples, TL3 and TL5, at 6.0×10^2 and 2.0×10^2 CFU/g, respectively. In contrast, foreign brands FF, VF, and DT showed fungal counts ranging from 2.0×10^2 to 3.4×10^2 CFU/g, 2.0×10^2 to 8.0×10^2 CFU/g, and 3.0×10^2 to 1.5×10^3 CFU/g, respectively, as shown in Figures 7 and 8. These results can be compared with fungal counts reported by Dabai et al. (2020), which ranged from 2.1×10^2 to 7.0×10^5 CFU/g. Notably, the Total Fungal Count (TFC) in all sampled products exceeded the WHO permissible limit of 0 CFU/g.

Fungal contamination can occur at multiple stages, including during the growth, harvesting, or transportation of tomatoes. Tomatoes that come into contact with contaminated soil, water, or air may carry fungal spores on their surfaces. Poor sanitation practices in processing facilities can also facilitate fungal growth on equipment and surfaces, leading to contamination. Furthermore, inadequate storage conditions, such as high humidity or poor temperature control, can promote fungal growth after processing. Once packaging integrity is compromised or if the package is opened, environmental fungal spores may invade and proliferate within the product. The levels of fungal contamination observed in this study indicate a pressing need for improved processing and storage practices to ensure product safety. Morphological and biochemical characterization identified thirteen genera of bacteria and various fungal species across local, foreign, and fresh tomato paste samples.

The bacterial genera identified included *Staphylococcus, Micrococcus, Bacillus, Corynebacterium*, *Escherichia coli*, *Klebsiella*, *Pseudomonas*, *Lactobacillus, Enterobacter, Salmonella*, *Citrobacter*, and *Proteus*. Predominant fungal species included *Mucor* spp., *Aspergillus flavus*, *Aspergillus niger*, *Rhizopus stolonifer*, *Various yeasts*, *Fusarium* spp., *Trichoderma* spp., *Aspergillus fumigatus*, and *Penicillium* spp. The organisms isolated in this study are consistent with those reported by Ogundipe *et al.* (2012), Wogu and Ofuase (2014), and Bashir *et al.* (2016). The contamination observed in these tomato pastes likely reflects multiple factors, including raw material quality, insufficient processing, pre-processing contamination, and the rigor of production standards, as supported by findings from Ogundipe et al. (2012) which indicated that many bacteria isolated from tomatoes may enter through soil or contaminated water used for washing post-harvest. Cross-contamination from contaminated surfaces, vessels, and hands can further exacerbate these issues (Adebanwo *et al.,* 2002).

The presence of pathogenic organisms in tomato paste raises significant public health concerns, particularly regarding food safety and the risk of foodborne illnesses. Notably, *Staphylococcus species* and *Escherichia coli* were identified as concerning pathogens associated with tomato paste. Staphylococcus aureus, commonly found on human skin and in the environment, can produce heat-stable enterotoxins when present in tomato paste. These toxins are not destroyed by cooking or pasteurization, making contaminated products a potential source of food poisoning, characterized by symptoms such as nausea, vomiting, abdominal cramps, and diarrhea within hours of consumption. Public health measures must emphasize strict hygiene practices during the harvesting, processing, and packaging of tomatoes to prevent Staphylococcus contamination. Effective handwashing, proper sanitation of equipment, and temperature control during storage are critical for minimizing the risk of Staphylococcus-related foodborne illnesses.

Certain strains of *Escherichia coli* are well-known for causing severe gastrointestinal infections. Contamination of tomato paste with *E. coli* can occur through contact with contaminated water, soil, or during processing. There is a risk of contamination during processing and packaging. Pathogens like *E. coli* can enter the product if hygiene standards are not strictly followed.

Consumption of raw or undercooked tomato products contaminated with pathogenic *E. coli* can lead to symptoms such as abdominal cramps, bloody diarrhea, and, in severe cases, kidney failure (hemolytic uremic syndrome). To mitigate the public health risks associated with *E. coli*, it is essential to implement stringent safety measures, including proper washing and sanitizing of raw tomatoes, adherence to good agricultural practices, and rigorous monitoring of food processing environments.

Physiochemical Quality of Fresh, Local and Foreign Tomatoes Pastes

The physicochemical parameters of the tomato paste samples exhibited significant variation across different brands. The pH values for foreign brands ranged from 4.62 to 6.1, which were higher than those of local brands, which ranged from 4.53 to 4.94. The fresh tomato paste had a pH value of 4.5. These pH values are notably higher than those reported by Ndife et al. (2020) and Eke-Ejiofor (2015), who found pH levels between 3.75 and 4.35. The acidic pH not only contributes to the tangy flavor essential in many culinary applications but also inhibits microbial growth, thus extending shelf life. However, the pH levels observed in this study slightly exceeded the Codex Alimentarius Commission's recommended maximum pH of 4.5 for tomato paste (CAC, 2011), indicating a need for enhanced quality control. Except for the fresh tomato paste that was within the maximum range. Exceeding this pH level can increase the likelihood of microbial growth, particularly in processed foods, which may compromise safety. Therefore, adherence to this standard is vital for manufacturers to ensure their tomato paste products are safe for consumption.

The ascorbic acid content in local brands ranged from 24.5 mg/kg to 27.8 mg/kg, while foreign brands had values between 17.59 mg/kg and 22.88 mg/kg. Fresh tomato paste had a significantly higher ascorbic acid content of 93.05 mg/kg, likely influenced by factors such as the ripeness and variety of tomatoes used. The ascorbic acid levels in this study was found to be lower than those reported by Abdulahi et al. (2016) (5.71-10 mg/100g) and were consistent with findings from Ndife et al. (2020). Despite this, all processed tomato paste samples had considerably lower ascorbic acid content compared to fresh tomato paste. The reduction of vitamin C during processing can be attributed to heat exposure, which degrades the nutrient. Although some manufacturers may add ascorbic acid to fortify the paste, these levels still remain below those found in fresh tomatoes.

Moisture content in local brands varied from 20.91% to 28.8%, while foreign brands ranged from 17.9% to 24.03%. In contrast, fresh tomato paste had a much higher moisture content of 79.0%. The moisture levels in processed tomato paste were lower than those reported by Eke-Ejiofor (2015) (69.00-84.85%) and Abdullahi et al. (2016) (71.80-72.40%). The reduced moisture content in processed paste contributes to its thicker consistency and concentrated flavor, as well as lowering the risk of microbial growth, thereby extending shelf life. Conversely, the higher moisture content in fresh tomato paste makes it more perishable, requiring refrigeration to prevent spoilage.

The variations in physicochemical parameters among tomato paste brands highlight differences in processing methods and ingredient quality. Elevated pH values could indicate reduced acidity and a potential risk for microbial growth, while lower moisture content in processed pastes aids in prolonging shelf life. The significant loss of ascorbic acid during processing underscores the necessity for proper fortification and quality control to maintain nutritional quality. Additionally, varietal and environmental factors may affect nutrient content, further contributing to the observed differences across samples. These findings emphasize the importance for manufacturers to adhere to international standards, such as those set by the Codex Alimentarius Commission, to ensure the safety and quality of tomato paste products.

5. CONCLUSION

This comprehensive study provides a detailed analysis of the microbial and physicochemical quality of commonly used tomato paste. The results highlight the variability among local and foreign brands, with insights into bacterial and fungal diversity. The findings emphasize the importance of regular monitoring, adherence to international standards, and continuous efforts to ensure the safety and quality of tomato paste products in the market. Further research and collaboration with industry stakeholders are essential to address potential areas of concern and enhance consumer confidence in these widely consumed food products.

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