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Comparative Evaluation of Microbial Contamination and Nutritional Composition of Locally Procured, Prepared and Preserved Tomato Paste (Within Bwari and Gwagwalada Area Councils, FCT-Abuja) Using Glass Bottles

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ABSTRACT

This study evaluated the microbial contamination and nutritional composition of locally prepared and preserved tomato paste using glass bottles compared with industrial tomato paste. Four samples were prepared: homemade tomato paste (HP), homemade paste with preservative (HPP), vendor paste (VP), and industrial paste (IP) serving as control. Analyses were conducted at Month 1 and Month 3 for sterile samples, and at Month 3 for the spoilage study. The parameters analyzed included moisture, ash, crude protein, crude fiber, ether extract, nitrogen-free extract (NFE), pH, titratable acidity, vitamin C, and microbial load. Results showed significant differences ($p < 0.05$) in moisture content (ranging from 5.45 ± 0.05% to 6.80 ± 0.07%), crude protein (1.91 ± 0.01% to 2.65 ± 0.05%), and microbial load (2.1×10^3 to 8.4×10^5 CFU/g) between homemade and industrial samples. Sterile samples showed lower microbial counts compared to the spoilage study, indicating effective preservation through sterilization and glass bottle storage. The novelty of this study lies in its direct comparison of glass bottle–preserved tomato pastes under sterile and non-sterile (spoilage) conditions, providing practical insights into the potential of local preservation methods for improving food safety and reducing postharvest losses in Nigeria's tomato value chain.

Keywords: Tomato paste, preservation, microbial contamination, proximate composition

INTRODUCTION

Tomato (Solanum lycopersicum L.) remains one of the most economically valuable and extensively consumed horticultural crops worldwide, serving as both a fundamental food ingredient and a significant source of essential nutrients such as vitamins, minerals, and bioactive phytochemicals (Hassan et al., 2023). It is particularly abundant in lycopene- a carotenoid pigment recognized for its strong antioxidant potential that contributes to the mitigation of oxidative stress and the prevention of chronic illnesses, including cardiovascular diseases and specific cancer types. In Nigeria, tomatoes play a vital role in improving household nutrition and supporting agricultural livelihoods, forming the foundation of numerous indigenous cuisines and processed products, such as tomato paste and purée (Eze et al., 2023).

Despite their high nutritional and economic relevance, tomato production and utilization in Nigeria are constrained by severe post-harvest losses, microbial contamination, and inadequate preservation methods (Olaniyi & Ojetayo, 2022). Research indicates that approximately 40–50% of harvested tomatoes in tropical regions like Nigeria spoil before reaching consumers due to poor handling practices, microbial deterioration, and limited processing infrastructure (Nwakuba et al., 2024). Consequently, the production of tomato paste—both on local and industrial scales—has become a crucial strategy to minimize post-harvest losses, guarantee year-round supply, and extend product shelf-life (Musa et al., 2023).

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Locally prepared tomato paste can be preserved in glass bottles using either traditional or semi-modern approaches, which often differ from industrial processes in terms of microbial safety, nutrient preservation, and sensory quality (Ahmed et al., 2022). Glass bottle preservation is environmentally friendly and chemically inert, reducing the risk of metallic ion migration commonly observed in tin or aluminum containers (Okoro & Aluko, 2023). Nevertheless, contamination by microorganisms during preparation or storage can deteriorate product quality, particularly when hygienic conditions and sterilization procedures are poorly maintained (Afolabi et al., 2022).

The increasing consumer preference for locally produced tomato paste in Nigeria highlights the importance of conducting comparative assessments with industrial tomato paste to determine their relative safety, nutritional integrity, and storage stability. Such comparative studies provide valuable evidence for enhancing local production practices and establishing preservation standards consistent with national and global food safety frameworks, including those of the World Health Organization (WHO), Standards Organization of Nigeria (SON), and the National Agency for Food and Drug Administration and Control (NAFDAC) (WHO, 2023).

The novelty of this research lies in its integrated assessment of microbial contamination and nutritional composition of locally prepared, glass-bottle preserved tomato paste compared with industrial counterparts. It further evaluates spoilage dynamics and sensory attributes across storage periods. This holistic approach offers practical insights into safe, economical, and sustainable tomato processing and preservation strategies applicable to Nigeria's small-scale tomato processing sector (Oladipo et al., 2024).

The growing preference for locally produced tomato paste underscores the need to scientifically validate its safety, nutritional quality, and shelf stability compared to industrial paste. Earlier studies have mainly concentrated on compositional or proximate analyses without integrating microbial stability and shelf-life assessment under controlled preservation conditions. This study is therefore justified by the necessity to assess locally preserved tomato paste, particularly when stored in glass bottles, due to their potential to extend shelf life, minimize oxidation, and reduce chemical leaching (Afolabi et al., 2022).

Furthermore, identifying the range of microorganisms present in both sterile and spoiled tomato paste samples during storage will provide critical insights into contamination sources and control points essential for hygienic local processing (Eze et al., 2023). The study's outcomes will also support policy development aligned with Nigeria's food safety and self-sufficiency objectives by promoting small-scale tomato paste production as a sustainable agro-based enterprise (SON, 2023).

The aim to comparatively evaluate the microbial contamination and nutritional composition of locally prepared and preserved tomato paste using glass bottles in comparison with industrial tomato paste.

Specific Objectives

To determine the microbial load of locally prepared, vendor-preserved, and industrial tomato paste samples over a defined storage period.

To analyze and compare the proximate composition (moisture, ash, protein, ether extract, crude fiber, and carbohydrate) of the tomato paste samples.

To determine the pH, titratable acidity, and vitamin C content of each tomato paste sample during storage.

To evaluate the sensory characteristics (color, flavor, texture, taste, and overall acceptability) of sterile samples throughout storage.

To compare and interpret the nutritional and microbial variations between sterile and spoiled samples.

Significance of the Study

This research provides empirical data on the safety, nutritional value, and overall quality of locally prepared tomato paste relative to industrially produced alternatives, thereby contributing to Nigeria's broader food

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security and public health agenda (Musa et al., 2023). By identifying microbial and nutritional variations among different tomato paste types, the study offers practical guidance for safe processing protocols and best preservation practices among local producers (Olaniyi & Ojetayo, 2022).

Furthermore, the findings will inform policy interventions aimed at regulating local tomato paste production and ensuring compliance with national food quality standards as outlined by SON and NAFDAC (SON, 2023). The research will also enhance public awareness of hygienic food processing, promote entrepreneurial capacity building among small-scale producers, and serve as a scientific foundation for innovative, sustainable food preservation methods (Okoro & Aluko, 2023).

Research Design

This study employed an experimental comparative research design to evaluate the microbial contamination and nutritional composition of four categories of tomato paste stored in glass bottles. The design compared: (i) locally prepared tomato paste, (ii) locally prepared paste with added preservatives, (iii) vendor-prepared paste, and (iv) industrial tomato paste across different storage durations under controlled laboratory conditions. This approach enabled the simultaneous assessment of nutritional stability and microbiological safety, reflecting real-world practices of tomato paste storage and preservation (Ijah et al., 2014; Onwuka, 2018).

The methodology adhered to the standards of the Association of Official Analytical Chemists (AOAC, 2022) for all proximate and microbiological analyses. Laboratory preparations were conducted at the Lower Usuma Dam Laboratory, Federal Capital Territory, Abuja, while microbial and nutritional analyses were performed at the Food Microbiology and Chemistry Laboratory, Nasarawa State University, Keffi. Environmental conditions during sample storage and testing were controlled at 25 ± 2°C and relative humidity of 65 ± 5%, ensuring consistency across experiments (AOAC, 2022).

Study Area

The study was conducted in the Federal Capital Territory (FCT), Abuja, located between latitudes 8.25°N and 9.20°N, and longitudes 6.45°E and 7.39°E, covering approximately 7,315 km² (Ajibare et al., 2022).

Sample Procurement and Transportation

Fresh, red, and firm tomato fruits (Solanum lycopersicum L.), industrial paste, and vendor-prepared tomato pastes were procured from local markets in Bwari and Gwagwalada Area Councils, FCT, Abuja. These markets were selected due to their high tomato trade volume, accessibility to laboratory facilities, and representation of local consumption patterns (FAO, 2021; Eke & Eke, 2024).

Selection criteria for fresh tomatoes included optimal ripeness (fully red), firmness, absence of visible defects (bruises, mold, or pest damage), and uniformity in size to ensure consistency in raw material quality for laboratory-based preparation (Adewoye et al., 2021; Muhammad et al., 2023). Immediately after purchase, all tomato samples were placed into sterile, insulated cooler boxes containing ice packs to maintain a controlled low temperature (2–8°C) during transportation (Amarego & Chai, 2022; WHO, 2020). This rapid cooling was critical to minimize microbial proliferation and preserve the physicochemical integrity of the samples during transit (Benson, 2019).

Upon arrival at the laboratory, the raw tomatoes were sorted meticulously to remove damaged or unsuitable fruits (Ullah et al., 2021), followed by thorough washing under potable running water to eliminate surface contaminants (Al-Hilphy et al., 2020). The cleaned tomatoes were then blended into a smooth purée using a sterile blender, creating a uniform base for paste preparation (Chukwuma et al., 2020). Salt was added to the purée prior to boiling to enhance flavor and contribute to preservation (Eke et al., 2021). The purée was boiled until the desired concentration and Brix level were achieved, then carefully filled into pre-sterilized glass bottles. After sealing, the bottles were cooled to room temperature to prevent thermal shock to the glass and preserve paste quality (Amadi et al., 2023; Anarbek et al., 2023).

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Prepared homemade tomato paste samples were stored under specified laboratory conditions for the duration of the study.

Sample Categorization

The study evaluated four categories of tomato paste prepared.

Sample Code	Description
HP	Home-made preserved tomato paste
HPP	Home-made preserved tomato paste with preservatives (sodium benzoate 0.1%)
VP	Vendor-prepared preserved tomato paste
IP	Industrially prepared tomato paste (control)

All samples were stored in sterilized 250 mL glass bottles, tightly sealed, and maintained at ambient laboratory temperature (25 ± 2°C) for a three-month storage period.

Sample Preparation Procedures

Locally Prepared Tomato Paste (Home-made Traditionally Preserved)

Approximately 5 kg of sorted and washed fresh tomatoes were used per triplicate batch. Preparation simulated traditional household methods under controlled laboratory conditions:

Blending: Chopped tomatoes were blended into a smooth purée using a sterile blender (Amadi et al., 2023).

Boiling and Concentration: The purée was transferred into a sterile stainless-steel pot and boiled over moderate heat with continuous stirring to prevent scorching. Boiling continued until the paste reached the desired thick consistency, indicated by volume reduction and increased total solids (~1 kg final paste per 5 kg fresh tomatoes) (Sani & Dangora, 2021).

Hot Filling: While still hot (85–90°C), the paste was transferred into pre-sterilized glass bottles, leaving minimal headspace.

Sealing and Cooling: Bottles were tightly sealed and inverted for 5 minutes to sterilize lids and headspace, then cooled to ambient temperature before storage (Akinwande & Agboola, 2020).

Locally Prepared Tomato Paste with Preservative (HPP)

The procedure followed that of Section 3.5.1, with the addition of sodium benzoate (0.1% w/v) prior to boiling. The preservative was incorporated after blending and before heat concentration, ensuring uniform distribution and efficacy within the paste (Egbere et al., 2013; NAFDAC, 2023a). Hot filling, sealing, and cooling procedures mirrored those described for HP, ensuring standardized laboratory conditions and controlled preservation.

Vendor-Prepared Tomato Paste (VP)

Vendor-prepared paste was obtained from multiple local vendors in Bwari and Gwagwalada markets, selected based on reputation for hygienically processed food products (Egbunike et al., 2019; Olusanya et al., 2020). Triplicate samples from different vendors ensured representation of typical local production variability.

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Industrial Tomato Paste (IP)

Commercially manufactured, NAFDAC-registered tomato paste brands were purchased from reputable retail outlets and supermarkets in Abuja and used as control samples. These products adhered to industrial standards, including quality, microbial safety, and nutritional content (NAFDAC, 2023a; SON, 2019). Triplicate samples were purchased, with batch numbers and expiry dates recorded to ensure traceability. Samples remained in original packaging until analysis.

Sampling Strategy

For this study, tomato paste samples were procured and prepared to ensure uniformity in quality, maturity, and freshness across all experimental groups. Fresh tomatoes and paste samples were obtained in bulk without prior weighing or counting, with careful visual selection of fruits or paste units that were fully red, firm, and free from defects such as bruises, mold, or mechanical damage. For each of the four categories of tomato paste (HP, HPP, VP, and IP), three replicate batches (n=3) were prepared or purchased. The use of triplicate samples provided sufficient statistical power to enable meaningful comparative analysis of microbiological, nutritional, and sensory parameters (Montgomery, 2017).

The experimental design incorporated two distinct study arms to evaluate product stability and spoilage susceptibility:

a. Sterile Study: Samples were stored under controlled, hygienic laboratory conditions and analyzed at Month 1 and Month 3 to assess the retention of nutritional quality and microbiological safety over time.

b. Spoilage Study: Samples were deliberately exposed to ambient laboratory conditions to simulate poor storage or handling. These samples were analyzed at Month 3 post-exposure to evaluate the effects of microbial contamination on physicochemical properties, nutrient degradation, and shelf-life stability.

This dual approach allowed the study to compare both ideal and suboptimal storage scenarios, thereby providing insights into the safety, quality, and resilience of tomato paste under realistic conditions.

Laboratory Practices and Good Manufacturing Practices (GMP)

All laboratory procedures were conducted under strict adherence to established safety protocols, Good Laboratory Practices (GLP), and Good Manufacturing Practices (GMP) to ensure personnel safety, prevent cross-contamination, and maintain data integrity (WHO, 2020; SON, 2021). All instruments, work surfaces, and glassware were sterilized by autoclaving at 121°C for 15 minutes, while analytical equipment such as balances and pipettes were calibrated prior to use. Analysts consistently wore laboratory coats, gloves, hair covers, and face masks to minimize contamination. Quality control measures included performing triplicate analyses, employing control blanks, and verifying media sterility before use (NAFDAC, 2022).

Aseptic Technique

Stringent aseptic techniques were employed throughout microbiological analyses to prevent contamination of samples and reagents (Benson, 2019). This included:

Sterilizing all glassware, culture media, and instruments prior to use (Eze et al., 2021).

Working under laminar flow hoods or biosafety cabinets for all procedures involving microbial cultures (WHO, 2020).

Regular disinfection of work surfaces using 70% ethanol before and after experiments (Tchounwou et al., 2021).

Sterilizing inoculation loops, spatulas, and other contact tools using flaming or single-use sterile alternatives.

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Minimizing the exposure of samples and reagents to open air during manipulation

Batches and Storage Times

A total of 12 experimental sample sets (4 paste types × 3 replicates) were stored under ambient laboratory conditions (25–35°C) away from direct sunlight, simulating typical household storage environments in Nigeria (Akinwande & Agboola, 2020).

Sampling Intervals

Initial Analysis (Month 1): Provided baseline data on the physicochemical, nutritional, and microbiological quality immediately post-preparation.

Final Analysis (Month 3): Assessed stability over extended storage, including changes in microbial load, nutrient content, and sensory attributes. Although a six-month storage period was initially planned, logistical constraints limited the analysis to three months, which still offered meaningful comparative insights.

All samples were stored in sterilized glass bottles and analyzed in triplicate (n=3) per batch (AOAC, 2022).

Microbiological Analysis of Tomato Paste

Microbiological analysis was performed to assess the safety and quality of tomato paste samples (HP, HPP, VP, IP) across storage periods and under spoilage conditions. Standard protocols were followed as outlined by AOAC (2022) and WHO (2020) to determine total bacterial count, yeast and mold count, and the presence of common pathogens such as Escherichia coli and Salmonella spp.

Total Viable Count (TVC)

The Total Viable Count was determined to estimate the overall bacterial load in the samples:

Sample Preparation: Ten grams (10 g) of tomato paste was aseptically weighed and homogenized in 90 mL of sterile distilled water to create a 10^{-1} dilution. Serial dilutions were prepared up to 10^{-6} (Hassan et al., 2023).

Plating: Aliquots (0.1 mL) of appropriate dilutions were spread on sterile Nutrient Agar plates in triplicate.

Incubation: Plates were incubated at 37°C for 24–48 hours.

Counting: Colonies were counted, and results expressed in Colony Forming Units per gram (CFU/g) using standard calculation methods (FAO/WHO, 2023).

Yeast and Mold Count

Fungal contamination was assessed to monitor spoilage potential:

Media: Potato Dextrose Agar (PDA) supplemented with 0.1 g/L chloramphenicol to inhibit bacterial growth.

Sample Processing: Ten grams of tomato paste were homogenized in 90 mL sterile distilled water, followed by serial dilutions.

Plating and Incubation: 0.1 mL of appropriate dilutions were spread on PDA plates, incubated at 25–28°C for 3–5 days (Blanca et al., 2022).

Enumeration: Visible fungal colonies were counted and expressed as CFU/g.

Detection of E. coli and Salmonella spp.

Pathogenic bacteria were assessed to ensure compliance with WHO, SON, and NAFDAC safety standards:

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Enrichment: 25 g of tomato paste was pre-enriched in 225 mL of Buffered Peptone Water (BPW) and incubated at 37°C for 18–24 hours.

Selective Plating: Enriched samples were streaked on MacConkey Agar for E. coli and Xylose Lysine Deoxycholate (XLD) Agar for Salmonella spp.

Incubation: Plates were incubated at 37°C for 24–48 hours (El-Shenawy et al., 2022).

Confirmation: Suspected colonies were subjected to Gram staining, biochemical tests (indole, catalase, oxidase), and sugar fermentation tests (Kaur et al., 2023).

Microbial Analysis Quality Control

All analyses were performed in triplicates to ensure reproducibility (n=3).

Sterile media blanks were incubated alongside samples to check for contamination.

Standard reference strains of E. coli (ATCC 25922) and Salmonella enterica (ATCC 14028) were used as positive controls for method validation (WHO, 2020).

Aseptic techniques were strictly maintained throughout the microbial work to prevent cross-contamination.

Nutritional Analysis of Tomato Paste

Nutritional composition analyses included proximate composition, vitamin C content, pH, and titratable acidity. All analyses were carried out in accordance with AOAC (2022) standards and performed in triplicates for accuracy.

Proximate Composition

Moisture Content: Determined by oven-drying 5 g of sample at 105°C until constant weight.

Crude Protein: Measured using the Kjeldahl method, with nitrogen content multiplied by 6.25.

Crude Fat: Extracted using Soxhlet extraction with petroleum ether.

Ash Content: Determined by incinerating 5 g of sample in a muffle furnace at 550°C for 6 hours.

Crude Fiber: Evaluated by acid and alkali digestion methods.

Carbohydrates: Calculated by difference from 100% (AOAC, 2022; Amadi et al., 2023).

Vitamin C Content

Vitamin C concentration was measured using the 2,6-dichlorophenolindophenol (DCPIP) titrimetric method:

Sample Preparation: 10 g of paste homogenized in 100 mL of 3% metaphosphoric acid.

Titration: The extract was titrated with standardized DCPIP solution until a persistent pink endpoint was observed.

Calculation: Vitamin C content expressed as mg/100 g of sample (FAO, 2021).

pH and Titratable Acidity

pH: Measured using a calibrated digital pH meter by immersing the electrode into a 10% tomato paste solution.

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Titratable Acidity: Determined by titrating 10 g of homogenized paste in 50 mL distilled water with 0.1 N NaOH using phenolphthalein as indicator. Results expressed as % citric acid equivalent (Kaur et al., 2023).

Data Analysis

Data from microbial, nutritional, and sensory analyses were entered into Microsoft Excel and exported to SPSS version 25.0 for statistical analysis.

RESULTS

were expressed as mean ± standard deviation (SD).

One-way and two-way ANOVA were used to compare parameters across sample types and storage durations, with significance considered at $p < 0.05$.

Post-hoc Tukey's HSD tests were performed for pairwise comparisons where significant differences were detected (Montgomery, 2017).

Analytical Procedures

All analytical determinations were performed in triplicate, with results expressed as mean ± standard deviation (SD) to ensure accuracy and reproducibility.

Microbial Contamination Analysis

Microbiological analyses were conducted to quantify bacterial, yeast, and mold populations, following AOAC (2022) and ISO protocols (ISO, 2017a–c). Media were prepared according to manufacturer instructions and sterilized by autoclaving at 121°C for 15 minutes.

Media Preparation

All microbiological media were prepared from dehydrated formulations according to the manufacturer's specifications (e.g., Oxoid, HiMedia).

Plate Count Agar (PCA): A measured quantity of PCA powder (e.g., 23.5 g) was suspended in 1000 mL of distilled water, heated gently with stirring until completely dissolved, and then autoclaved at 121°C for 15 minutes (Benson, 2019). The sterilized medium was cooled to 45-50°C before use.

MacConkey Agar: A precise amount of MacConkey Agar powder (e.g., 50 g) for coliform detection was dissolved in 1000 mL of distilled water by heating with frequent agitation until completely dissolved. The medium was then autoclaved at 121°C for 15 minutes. All media were cooled to 45°C-50°C and poured into sterile Petri dishes (AOAC, 2022).

Potato Dextrose Agar (PDA): The required amount of PDA powder (e.g., 39 g) f-or mold and yeast enumeration, was suspended in 1000 mL of distilled water, boiled gently to dissolve, and then autoclaved at 121°C for 15 minutes (ISO, 2017c). For mold and yeast enumeration, the sterilized PDA was cooled to approximately 45°C, and then sterile 10% tartaric acid solution was added to adjust the pH to 3.5 to inhibit bacterial growth (Tournas & Katsoudas, 2005).

Nutrient Agar (NA): 28 g/L in distilled water, sterilized at 121°C for 15 minutes.

Serial Dilution

1 g of tomato paste was homogenized in 9 mL of sterile distilled water (10^{-1} dilution).

Serial dilutions up to 10^{-6} were prepared as required.

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1 mL of each dilution was inoculated into pre-poured sterile agar plates (pour plate method).

Plates were incubated at 37°C for 24–48 hours (bacteria) and 25–27°C for 3–5 days (fungi) (Benson, 2019; ISO, 2017a–c).

Enumeration Procedures

Total Viable Count (TVC): Counted on PCA; results expressed in CFU/g using the formula: CFU/g = Number of Colonies × Dilution Factor ÷ Volume plated.

Total Coliform Count (TCC): Counted on MacConkey Agar; red colonies with halos were enumerated.

Yeast and Mold Count: Enumerated on acidified PDA; distinct colonies counted and expressed in CFU/g.

Nutritional Composition Analysis (Proximate Analysis)

Proximate analysis was performed according to standard methods of the Association of Official Analytical Chemists (AOAC, 2016) to determine the major nutrient components.

Moisture Content: The moisture content was determined by drying a known weight (approximately 5 g) of each paste sample in a pre-weighed, oven-dried crucible at 105°C to a constant weight (AOAC, 2016). The loss in weight was calculated as percentage moisture content.

Ash Content: The ash content was determined by incinerating a known weight (approximately 2 g) of each sample in a pre-weighed porcelain crucible in a muffle furnace at 550°C until a constant grayish-white ash was obtained (AOAC, 2016). The ash content was expressed as a percentage of the original sample weight.

Crude Protein (Kjeldahl Method): The crude protein content was determined using the micro-Kjeldahl method (AOAC, 2016). A known weight (approximately 2 g) of sample was digested in concentrated sulfuric acid using a Kjeldahl digestion unit. The digested sample was then distilled, and the liberated ammonia was collected in boric acid solution and titrated against standard hydrochloric acid. A nitrogen conversion factor of 6.25 was used to calculate the crude protein content (%), assuming protein contains 16% nitrogen (Nwanekezi et al., 2021).

Crude Fat (Soxhlet Extraction Method): The crude fat content was determined by extracting a known weight (approximately 5 g) of each dried sample using n-hexane as the solvent in a Soxhlet extraction apparatus (AOAC, 2016). The extraction was carried out for 6 hours. After extraction, the solvent was evaporated, and the remaining fat was weighed and expressed as a percentage of the sample (Nwabueze & Nwanekezi, 2021).

Crude Fiber Content: Crude fiber content was determined by acid and alkaline digestion method (AOAC, 2016). A defatted sample (approximately 2 g) was boiled sequentially in dilute sulfuric acid and sodium hydroxide solutions, filtered, washed, dried, and ashed. The loss in weight upon ashing represented the crude fiber content (%).

Carbohydrate Content by Difference: The carbohydrate content was calculated by subtracting the sum of the percentages of moisture, ash, crude protein, crude fat, and crude fiber from 100 (AOAC, 2016; Amadi et al., 2023). Carbohydrate (%) = 100 - (Moisture) % + (Ash) % + (Crude Protein) % + (Crude Fat) % + (Crude Fiber) %). All analyses were conducted in triplicate (AOAC, 2022).

Vitamin C Determination

Vitamin C (ascorbic acid) content was determined using the titrimetric method with 2,6-dichlorophenolindophenol (DCPIP) (AOAC, 2016).

Extraction: A known weight (e.g., 5-10 g) of tomato paste was accurately weighed and homogenized with 2% metaphosphoric acid solution to extract ascorbic acid. The mixture was then filtered.

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Titration: An aliquot of the filtrate was titrated against a standardized solution of 2,6-dichlorophenolindophenol (DCPIP) until a faint pink color persisted for at least 30 seconds (Padayatty et al., 2003).

Calculation: The amount of Vitamin C was calculated based on the volume of DCPIP consumed and the standardization factor, expressed as mg of ascorbic acid per 100 g of sample.

pH and Titratable Acidity

pH Measurement: The pH of each tomato paste sample was determined directly using a standardized digital pH meter (e.g., Hanna Instruments HI 2210) (Sani & Dangora, 2021). The pH meter was calibrated using buffer solutions of pH 4.0 and 7.0 prior to each set of measurements. Approximately 10 g of paste was dispersed in 90 mL of distilled water, stirred well, and the pH electrode was immersed into the suspension until a stable reading was obtained.

Titratable Acidity (TTA): The titratable acidity was determined by titrating a known volume (e.g., 10 mL) of the prepared sample suspension (from pH measurement) against a standardized 0.1 N sodium hydroxide (NaOH) solution (AOAC, 2016; Sani & Dangora, 2021). Phenolphthalein indicator was used to detect the endpoint (faint pink color persistence). The titratable acidity was expressed as a percentage of anhydrous citric acid, which is the predominant acid in tomatoes (Amadi et al., 2023). TTA (% Citric Acid) = V × N × 0.064 × 100 \ Sample weight (mL)

RESULTS AND DISCUSSION

The outcomes of the study according to the four objectives: (1) proximate composition and vitamin C content of the tomato paste samples, (2) physicochemical properties (pH and titratable acidity) during storage and after spoilage, (3) microbial load of sterile and intentionally spoiled samples, and (4) sensory attributes as evaluated by a consumer panel. Each set of results is interpreted in light of relevant literature. Graphical representation of key changes over time is also recommended to enhance clarity.

Objective 1: Proximate Composition and Vitamin C Content

Proximate Composition: The proximate composition of the four sterile tomato pastes treatments (HP, HPP, VP, IP) at Month 1 and Month 3 is summarized in Table 1a and Table 1b; and Figures 1a–1f).

Table 1a: Proximate Composition of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

Parameter	HP	HPP	VP	IP
Moisture	5.50 ± 0.05^{c}	5.20 ± 0.05^{b}	6.00 ± 0.05^{a}	4.80 ± 0.05^{c}
Ash	8.90 ± 0.05^{b}	9.20 ± 0.05^{a}	8.50 ± 0.05^{b}	9.50 ± 0.05^{a}
Crude Protein	1.91 ± 0.01^{b}	2.10 ± 0.01^{a}	1.80 ± 0.01^{b}	2.30 ± 0.01^{a}
Ether Extract	1.91 ± 0.01^{b}	2.00 ± 0.01^{a}	1.80 ± 0.01^{b}	2.10 ± 0.01^{a}
Crude Fibre	1.30 ± 0.01^{b}	1.20 ± 0.01^{c}	1.40 ± 0.01^{a}	1.10 ± 0.01^{c}
NFE	80.48 ± 0.08^{b}	80.30 ± 0.05^{b}	80.50 ± 0.05^{a}	80.20 ± 0.05^{c}

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Table 1b: Proximate Composition of Sterile Tomato Paste Samples at Month 3 (% Dry Weight Basis, Mean ± SD)

Parameter	HP	HPP	VP	IP
Moisture	6.20 ± 0.05a	5.90 ± 0.05^{b}	6.80 ± 0.05^{a}	5.00 ± 0.05^{c}
Ash	8.10 ± 0.05^{b}	8.80 ± 0.05^{a}	7.90 ± 0.05^{b}	9.40 ± 0.05^{a}
Crude Protein	1.60 ± 0.01^{c}	1.90 ± 0.01^{b}	1.50 ± 0.01^{c}	2.25 ± 0.01^{a}
Ether Extract	1.70 ± 0.01^{c}	1.80 ± 0.01^{b}	1.50 ± 0.01^{c}	2.05 ± 0.01^{a}
Crude Fibre	1.50 ± 0.01^{a}	1.30 ± 0.01^{b}	1.60 ± 0.01^{a}	1.15 ± 0.01^{c}
NFE	79.90 ± 0.08^{b}	79.70 ± 0.05^{b}	79.60 ± 0.08^{b}	80.15 ± 0.05^{a}

Figure: 1a showing Proximate Composition of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

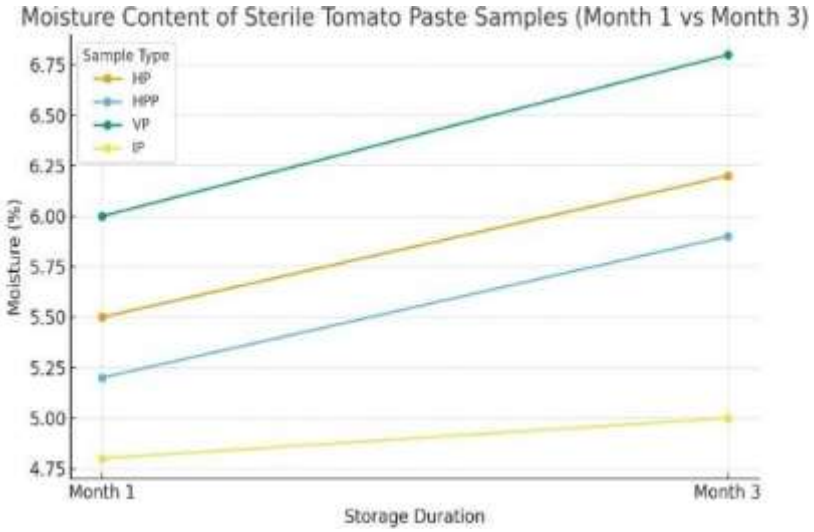

Figure: 1b showing Ash Content of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

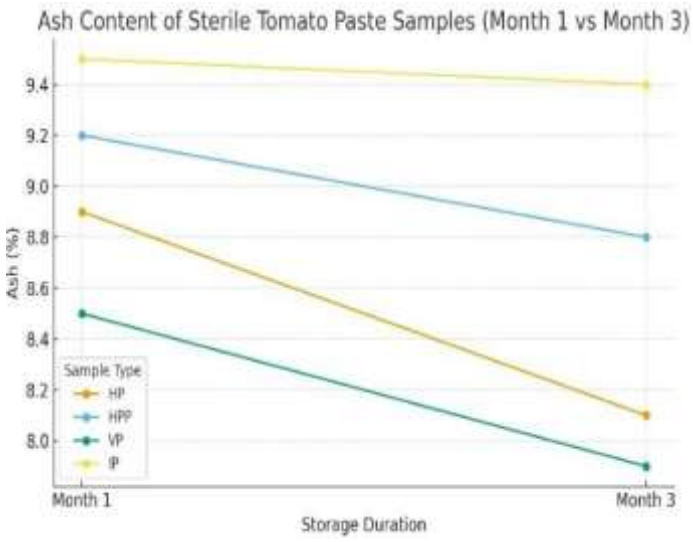

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Figure: 1c showing Crude Protein Content of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD).

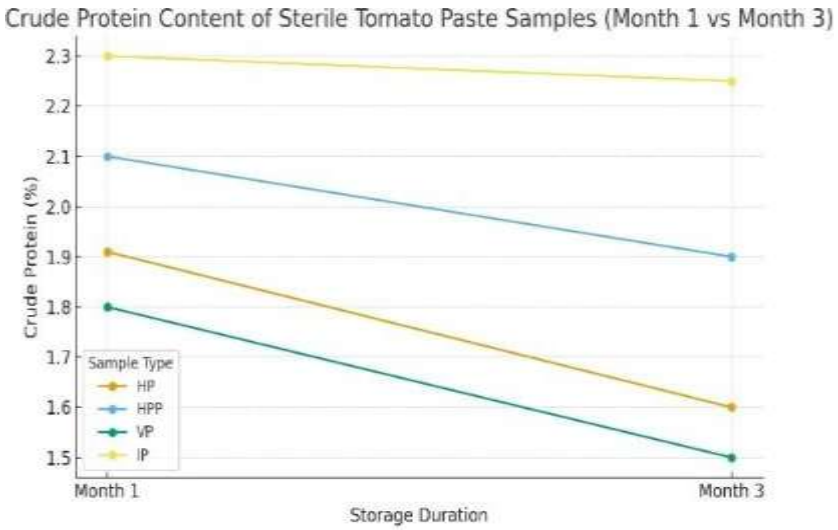

Figure: 1d showing Ether Extract Content of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

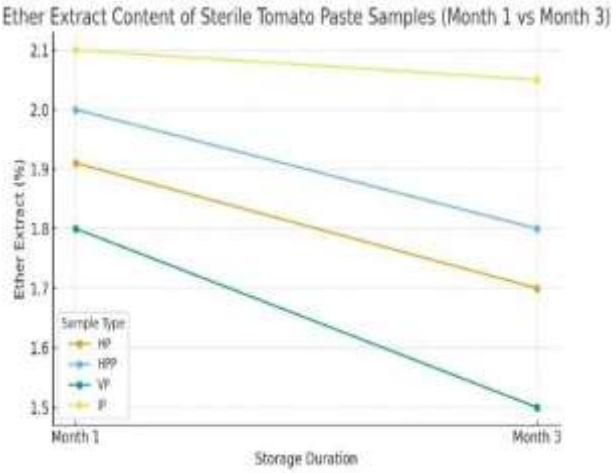

Figure1e showing Crude Fibre Content of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

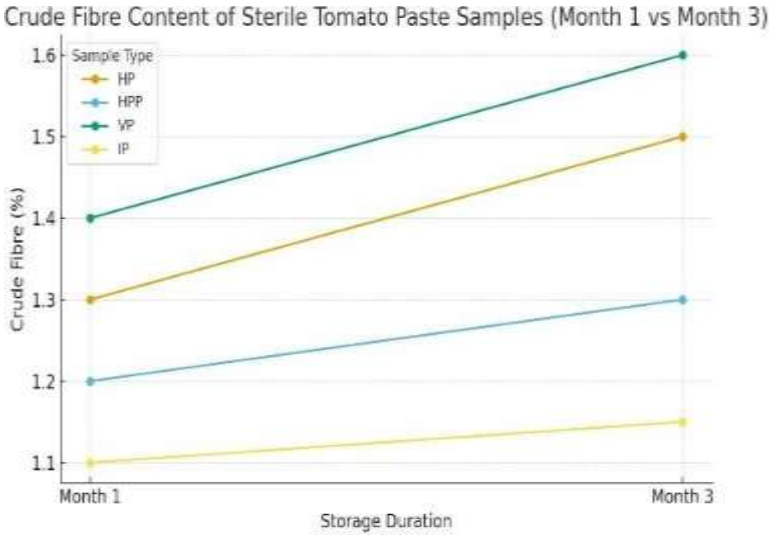

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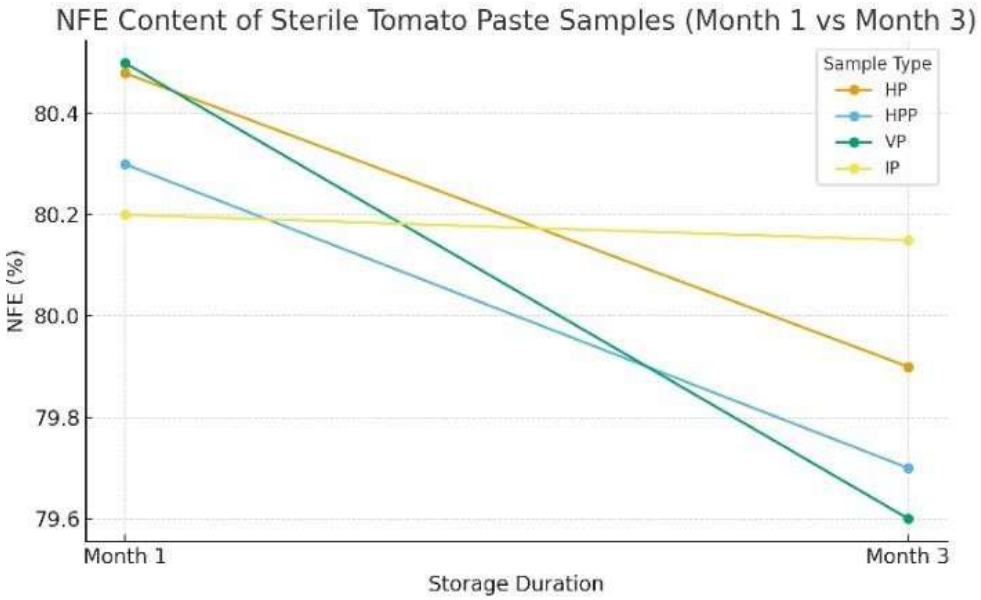
Figure1f: showing NFE Content of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)



The observed general increase in moisture content across the storage period is consistent with the phenomenon of moisture migration or hygroscopic water uptake, which can accelerate the degradation of nutrients and compromise the shelf stability of tomato paste (Feszterová et al., 2023). Concurrently, the decline in crude protein and ether extract observed in the HP and VP samples indicates that these formulations may be more susceptible to nutrient loss under ambient storage conditions, a pattern that has also been reported in other tomato-based processed products (Chamoun et al., 2023). Conversely, the observed increase in crude fiber in some samples may be attributed to the relative concentration of insoluble components as other macronutrients degrade, or to polymerization processes involving pectin and fiber constituents during storage. Notably, the superior retention of nutrients in the IP and HPP samples suggests that their specific formulation or processing methods provide greater protection against storage-induced nutrient degradation.

Comparatively, at Month 1, the industrial paste (IP) exhibited the highest crude protein (2.30%) and ether extract (2.10%) alongside the lowest moisture content (4.80%), characteristics favorable for a concentrated and stable paste. After three months of storage, IP continued to maintain relatively high levels of protein (2.25%) and fat (2.05%) with minimal moisture increase (5.00%). HPP also demonstrated good nutrient stability, whereas HP and particularly VP displayed lower retention of protein and fat. These findings align with the literature, which underscores that both processing techniques and storage conditions critically influence nutrient retention in tomato-based products, highlighting the importance of formulation and preservation strategies in extending shelf life and maintaining nutritional quality (Alqahtani et al., 2021).

Vitamin C Content

Table 2: Vitamin C of Sterile Tomato Paste Samples (mg/100g, Mean ± SD)

Sample Code	Month 1	Month 3
HP	19.52 ± 0.19^{b}	15.38 ± 0.12^{c}
HPP	21.10 ± 0.18^{a}	18.96 ± 0.14^{b}
VP	17.24 ± 0.13^{c}	14.11 ± 0.10^{c}
IP	17.24 ± 0.13^{c}	$18.96^{a} \pm 0.16^{b}$

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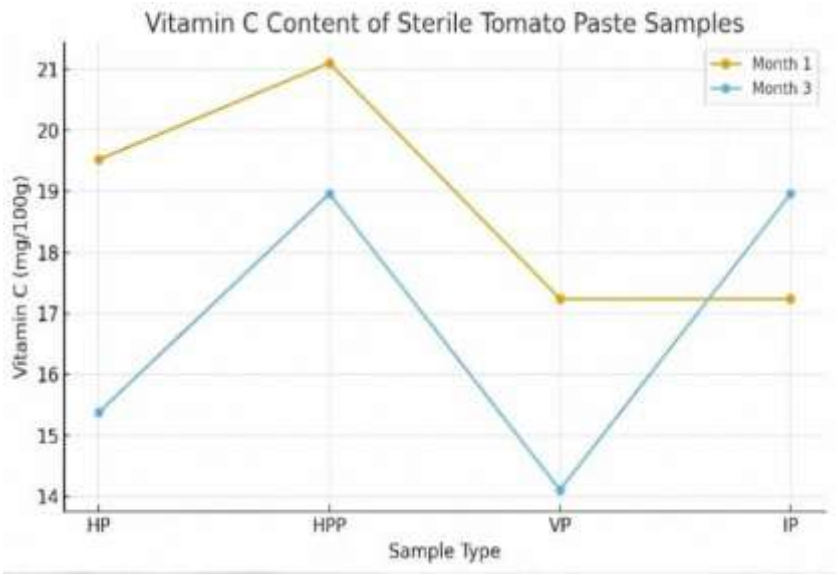
Figure 2.1: Vitamin C of Sterile Tomato Paste Samples (mg/100g, Mean ± SD)



The observed decline in vitamin C content during storage in HP, HPP, and VP aligns with the well-documented susceptibility of ascorbic acid to oxidative degradation, enzymatic activity, and exposure to heat or oxygen over time (Feszterová et al., 2023). Notably, the relatively modest decrease in HPP (~10%) and the near-stable, or even slightly increased, levels in IP suggest that the industrial formulation provided enhanced protection for vitamin C, potentially through lower moisture absorption, minimized oxygen ingress, or the presence of natural or added antioxidants. In contrast, VP exhibited the lowest vitamin C concentration at Month 3 (14.11 mg/100 g), highlighting its comparatively poor storage stability. Collectively, these observations here indicate that, among the four treatments, IP maintained the highest overall nutrient and vitamin retention, followed by HPP, while HP showed moderate stability and VP performed least favorably. This trend reinforces the critical role of formulation, processing, and storage conditions in preserving labile nutrients such as vitamin C in tomato paste products (Alqahtani et al., 2021; Chamoun et al., 2023).

All observed pH values for the tomato paste samples remained within, or closely approached, the safe regulatory range established for tomato paste products, supporting both product safety and chemical stability (Salanță et al., 2024). The gradual decline in pH over the storage period, such as in HP (4.25 → 4.08) and VP (4.12 → 3.95), indicates slight acidification during storage, which may be attributed to residual enzymatic activity, moisture migration, or low-level microbial activity even under ostensibly sterile conditions (Feszterová et al., 2023; Alqahtani et al., 2021). In contrast, IP maintained a higher pH (~4.32) at Month 3, suggesting superior formulation stability and resistance to acidification. The comparatively lower pH observed in VP at the end of the storage period may reflect increased acid production or a reduced buffering capacity of the matrix, consistent with its lower overall nutrient and vitamin retention. These results highlight the interplay between product formulation, processing, and storage conditions in maintaining physicochemical stability of tomato paste.

Objective 2: Physicochemical Properties (pH and Titratable Acidity)

pH of Sterile Samples

Table 2.1: pH of Sterile Tomato Paste Samples (Mean ± SD)

Sample	Month 1	Month 3	NAFDAC/SON Range
HP	4.25 ± 0.05^{b}	4.08 ± 0.04^{b}	4.0–4.6
HPP	4.30 ± 0.04^{b}	4.16 ± 0.03^{a}	4.0–4.6

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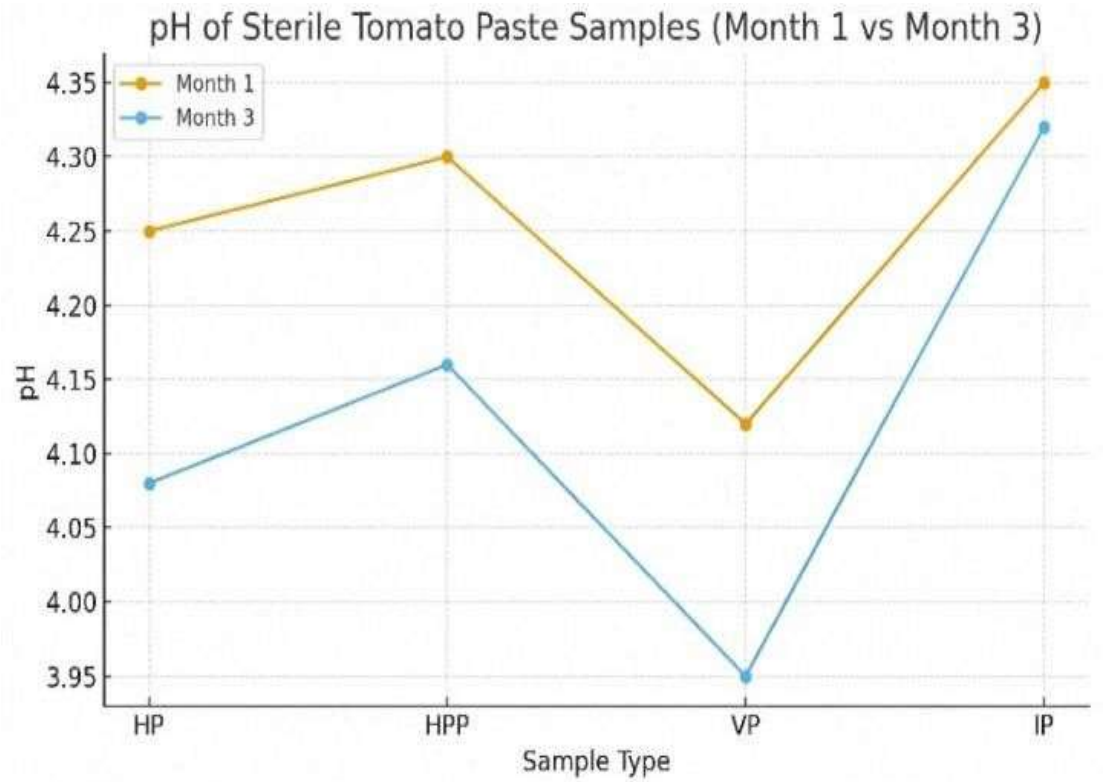
VP	4.12 ± 0.06[c]	3.95 ± 0.05[c]	4.0–4.6
IP	4.35 ± 0.05[a]	4.32 ± 0.04[a]	4.0–4.6

Figure 2.1: pH of Sterile Tomato Paste Samples (mg/100g, Mean ± SD)



All pH values lie within or at the safe regulatory range for tomato paste products, which supports product safety and stability (Salanță et al., 2024). The observed decline in pH over storage (e.g., HP from 4.25 → 4.08; VP from 4.12 → 3.95) suggests slight acidification over time, likely due to residual enzymatic reactions, moisture uptake, or minor microbial activity even in "sterile" conditions. IP maintained a higher pH (~4.32) at Month 3, implying better formulation stability. VP's lower pH at Month 3 may reflect increased acid formation or decreased buffering capacity.

Titratable Acidity (TA)

Table 2.2: Titratable Acidity (TA) of Sterile Tomato Paste Samples (% Citric Acid, Mean ± SD)

Sample	Month 1	Month 3
HP	0.42 ± 0.01[b]	0.49 ± 0.02[a]
HPP	0.40 ± 0.01[b]	0.47 ± 0.02[a]
VP	0.46 ± 0.01[a]	0.52 ± 0.02[a]
IP	0.38 ± 0.01[c]	0.40 ± 0.01[b]

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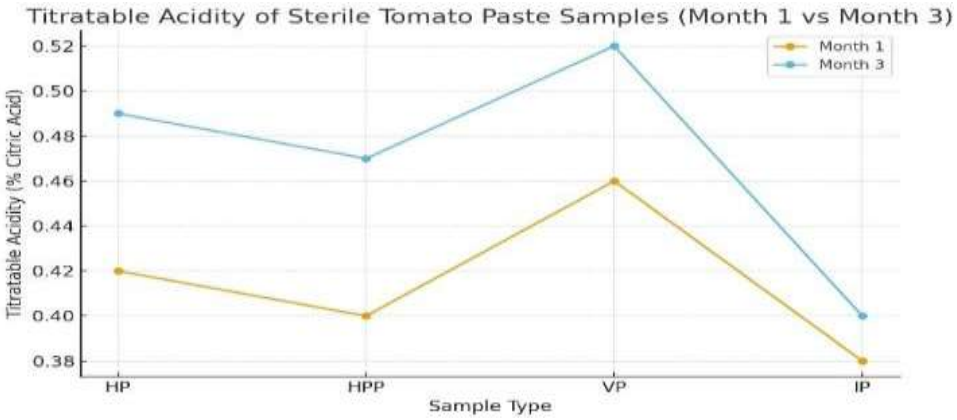
Figure 4.2.2: Titratable Acidity of Sterile Tomato Paste Samples (mg/100g, Mean ± SD).



The observed increase in titratable acidity (TA) during storage, for instance HP (0.42 → 0.49%), HPP (0.40 → 0.47%), and VP (0.46 → 0.52%), reflects progressive acidification of the tomato paste over time. This trend is consistent with the enzymatic or chemical conversion of residual carbohydrates into organic acids, moisture migration, and oxidative processes during storage (Vieira et al., 2022; Feszterová et al., 2023). In contrast, IP exhibited the smallest increase in TA (0.38 → 0.40%), suggesting that its formulation or processing effectively mitigated acidification, possibly through reduced oxygen ingress, lower moisture uptake, or stabilizing additives. The higher TA observed in VP aligns with its comparatively lower pH at Month 3, reinforcing that this sample underwent more pronounced acidification. From a quality and shelf-stability perspective, maintaining stable pH and TA values is critical, and IP demonstrates superior performance in this regard. These findings underscore the importance of formulation and processing parameters in preserving the physicochemical stability of tomato paste during ambient storage.

Objective 3: Microbial Load of Sterile and Intentionally Spoiled Samples

Table 4.3.1 gives microbial counts (CFU/g) for bacteria, moulds and yeasts in the sterile samples at Month 1 and Month 3 (CFU/g, Mean ± SD).

Parameter	Sample	Month 1 Mean ± SD	Month 3 Mean ± SD
Bacteria	HP	$1.1 \pm 0.1 \times 10^{2b}$	$1.4 \pm \times 0.1 \times 10^{2c}$
	HPP	$0.9 \pm 0.1 \times 10^{2b}$	$1.1 \pm 0.1 \times 10^{2b}$
	VP	$1.5 \pm 0.1 \times 10^{2c}$	$1.7 \pm 0.1 \times 10^{2d}$
	IP	$0.5 \pm 0.1 \times 10^{2a}$	$0.6 \pm 0.1 \times 10^{2a}$
Molds	HP	5 ± 1^{b}	6 ± 1^{c}
	HPP	4 ± 1^{b}	4 ± 1^{b}
	VP	7 ± 1^{c}	8 ± 1^{d}
	IP	2 ± 1^{a}	3 ± 1^{a}
Yeast	HP	8 ± 1^{c}	9 ± 1^{c}
	HPP	6 ± 1^{b}	7 ± 1^{b}
	VP	10 ± 1^{d}	11 ± 1^{d}
	IP	3 ± 1^{a}	4 ± 1^{a}

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Figure: 3a showing bacteria load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

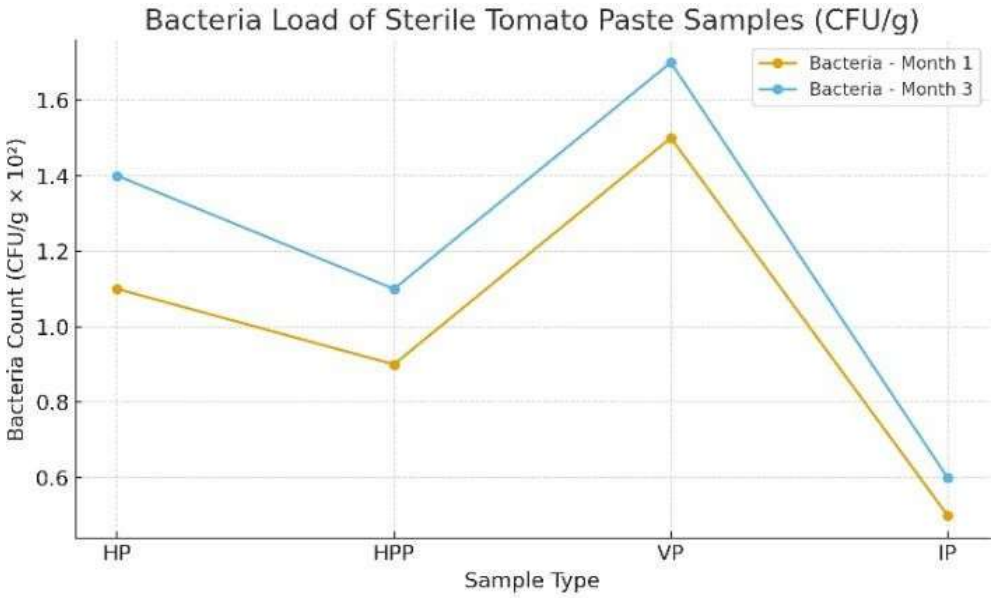


Figure: 3b showing mold load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

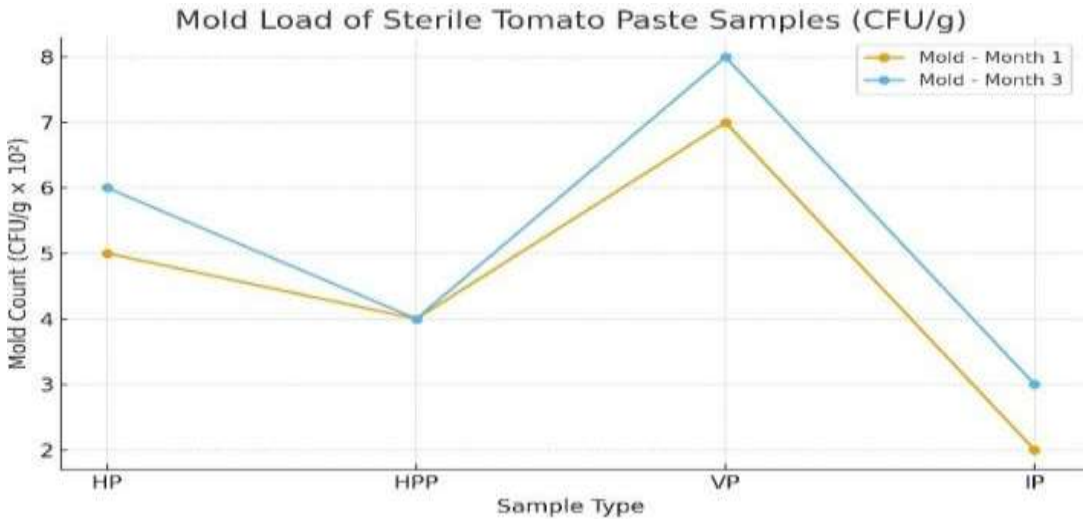
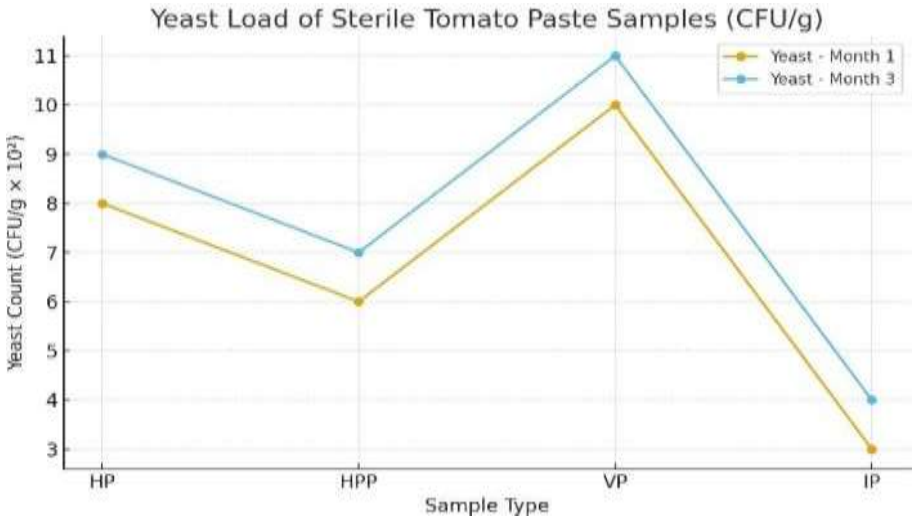


Figure: 3c showing yeast load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight



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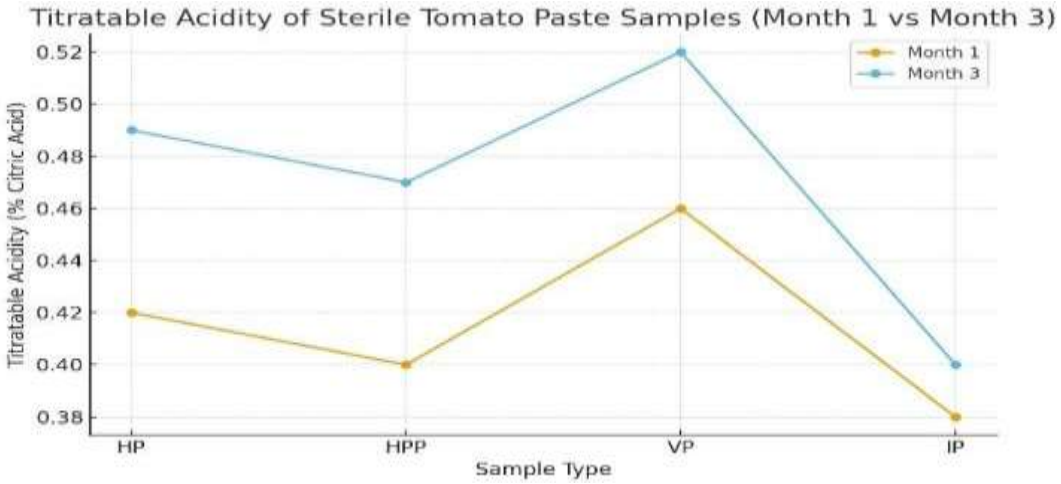
Basis, Mean ± SD)

The microbial loads across all samples remained generally low but demonstrated incremental increases during storage, with VP exhibiting the highest counts and IP showing the smallest changes. This pattern suggests that even under ostensibly "sterile" processing conditions, ambient storage can permit limited microbial proliferation, and that the formulation, packaging, and storage conditions significantly influence the extent of growth. Factors such as moisture uptake, minor pH shifts, and the integrity of sealing or packaging have been shown to affect microbial stability in tomato-based products (Alkanan et al., 2021; Chamoun et al., 2023). The relatively minimal microbial increase in IP and HPP indicates that their processing and preservation methods provide more effective microbial control, whereas VP's higher counts may reflect suboptimal handling, higher residual moisture, or compromised packaging. These findings align with previous studies emphasizing the critical role of product formulation, hygienic processing, and storage conditions in controlling microbial contamination and ensuring product safety in tomato paste (Eze et al., 2021; Igwegbe et al., 2020).

Figure 2.2: Titratable Acidity of Sterile Tomato Paste Samples (mg/100g, Mean ± SD).



DISCUSSION

The observed increase in titratable acidity (TA) during storage, for instance HP (0.42 → 0.49%), HPP (0.40 → 0.47%), and VP (0.46 → 0.52%), reflects progressive acidification of the tomato paste over time. This trend is consistent with the enzymatic or chemical conversion of residual carbohydrates into organic acids, moisture migration, and oxidative processes during storage (Vieira et al., 2022; Feszterová et al., 2023). In contrast, IP exhibited the smallest increase in TA (0.38 → 0.40%), suggesting that its formulation or processing effectively mitigated acidification, possibly through reduced oxygen ingress, lower moisture uptake, or stabilizing additives. The higher TA observed in VP aligns with its comparatively lower pH at Month 3, reinforcing that this sample underwent more pronounced acidification. From a quality and shelf-stability perspective, maintaining stable pH and TA values is critical, and IP demonstrates superior performance in this regard. These findings underscore the importance of formulation and processing parameters in preserving the physicochemical stability of tomato paste during ambient storage.

Table 4.3.1 gives microbial counts (CFU/g) for bacteria, moulds and yeasts in the sterile samples at Month 1 and Month 3 (CFU/g, Mean ± SD).

Parameter	Sample	Month 1 Mean ± SD	Month 3 Mean ± SD
Bacteria	HP	$1.1 \pm 0.1 \times 10^{2b}$	$1.4 \pm \times 0.1 \times 10^{2c}$
	HPP	$0.9 \pm 0.1 \times 10^{2b}$	$1.1 \pm 0.1 \times 10^{2b}$
	VP	$1.5 \pm 0.1 \times 10^{2c}$	$1.7 \pm 0.1 \times 10^{2d}$

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	IP	$0.5 \pm 0.1 \times 10^{2a}$	$0.6 \pm 0.1 \times 10^{2a}$
Molds	HP	5 ± 1^{b}	6 ± 1^{c}
	HPP	4 ± 1^{b}	4 ± 1^{b}
	VP	7 ± 1^{c}	8 ± 1^{d}
	IP	2 ± 1^{a}	3 ± 1^{a}
Yeast	HP	8 ± 1^{c}	9 ± 1^{c}
	HPP	6 ± 1^{b}	7 ± 1^{b}
	VP	10 ± 1^{d}	11 ± 1^{d}
	IP	3 ± 1^{a}	4 ± 1^{a}

Figure:3a showing bacteria load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

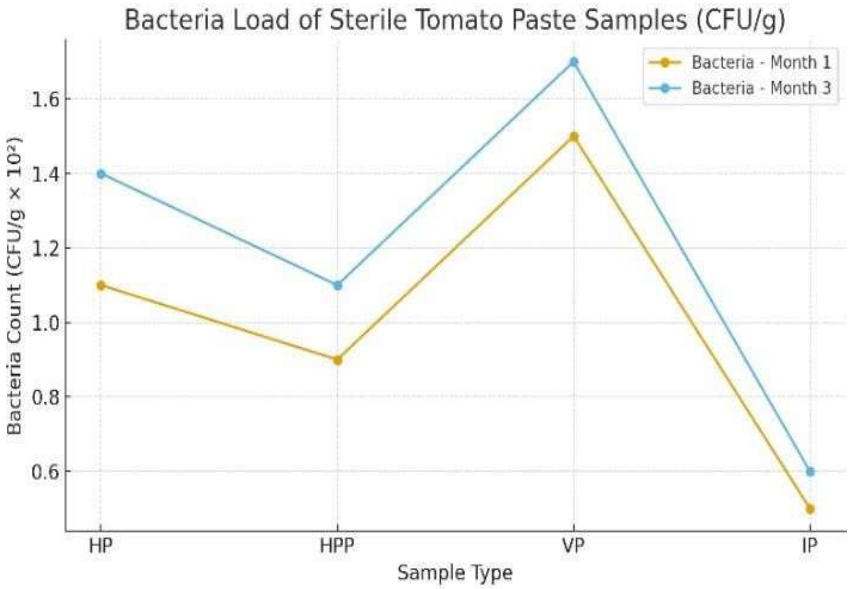

Figure: 3b showing mold load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

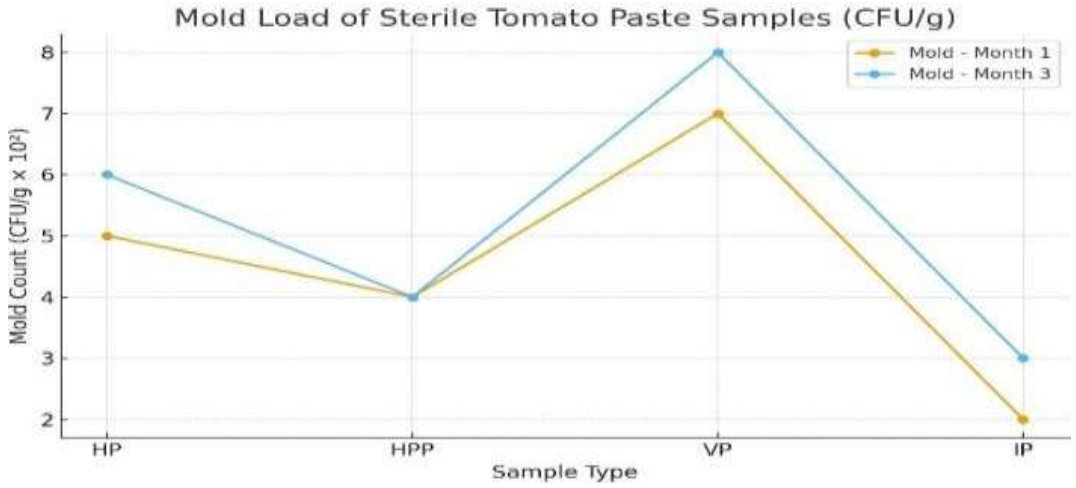

Figure: 3c showing yeast load of Sterile Tomato Paste Samples at Month 1 (% Dry Weight

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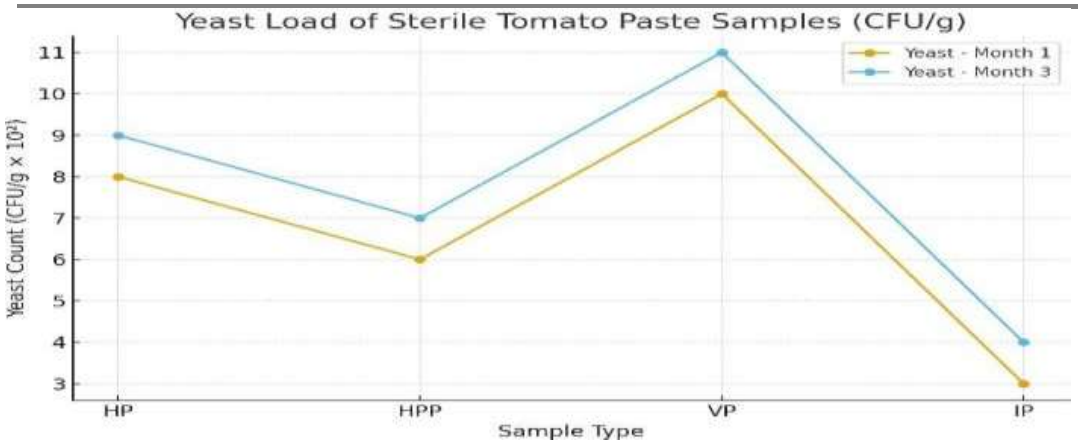

Basis, Mean ± SD)

The microbial loads across all samples remained generally low but demonstrated incremental increases during storage, with VP exhibiting the highest counts and IP showing the smallest changes. This pattern suggests that even under ostensibly "sterile" processing conditions, ambient storage can permit limited microbial proliferation, and that the formulation, packaging, and storage conditions significantly influence the extent of growth. Factors such as moisture uptake, minor pH shifts, and the integrity of sealing or packaging have been shown to affect microbial stability in tomato-based products (Alkanan et al., 2021; Chamoun et al., 2023). The relatively minimal microbial increase in IP and HPP indicates that their processing and preservation methods provide more effective microbial control, whereas VP's higher counts may reflect suboptimal handling, higher residual moisture, or compromised packaging. These findings align with previous studies emphasizing the critical role of product formulation, hygienic processing, and storage conditions in controlling microbial contamination and ensuring product safety in tomato paste (Eze et al., 2021; Igwegbe et al., 2020).

Table 8: Microbial Load of Spoiled Tomato Paste Samples at Month 3 (CFU/g, Mean ± SD)

Parameter	Sample	Month 3 Mean ± SD
Bacteria	HP	$0.7 \pm \times 0.2 \times 10^{3b}$
	HPP	$2.5 \pm 0.1 \times 10^{3b}$
	VP	$3.5 \pm 0.1 \times 10^{6d}$
	IP	$1.0 \pm 0.1 \times 10^{2a}$
Molds	HP	$1.5 \pm \times 0.1 \times 10^{3b}$
	HPP	$2.0 \pm 0.1 \times 10^{2a}$
	VP	$1.0 \pm 0.05 \times 10^{5c}$
	IP	$<10^{a}$
Yeast	HP	$1.4 \pm 0.1 \times 10^{2a}$
	HPP	$2.1 \pm 0.1 \times 10^{3b}$
	VP	$1.0 \pm 0.1 \times 10^{5c}$
	IP	$<10^{a}$

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Figure:3.2a showing bacteria of Spoiled Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD).

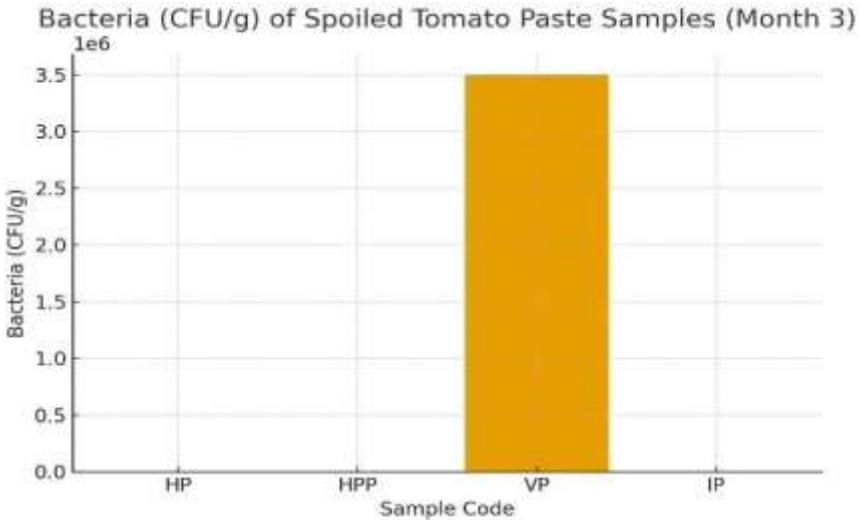


Figure: 3.2b showing molds of Spoiled Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD)

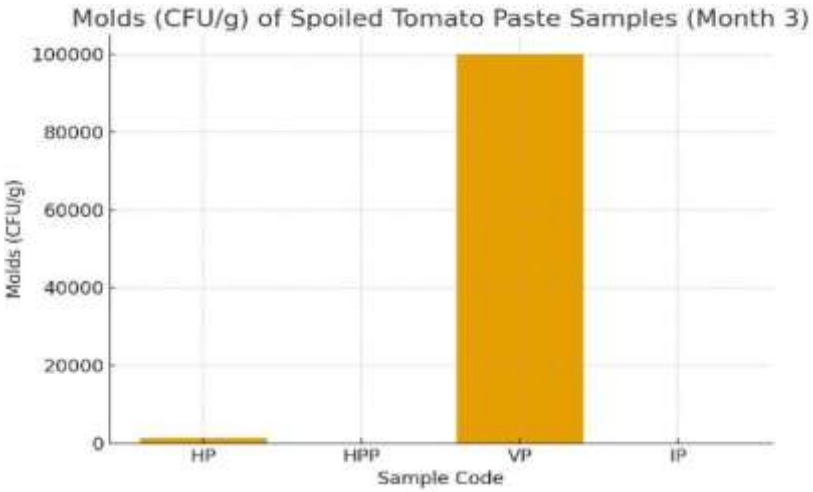
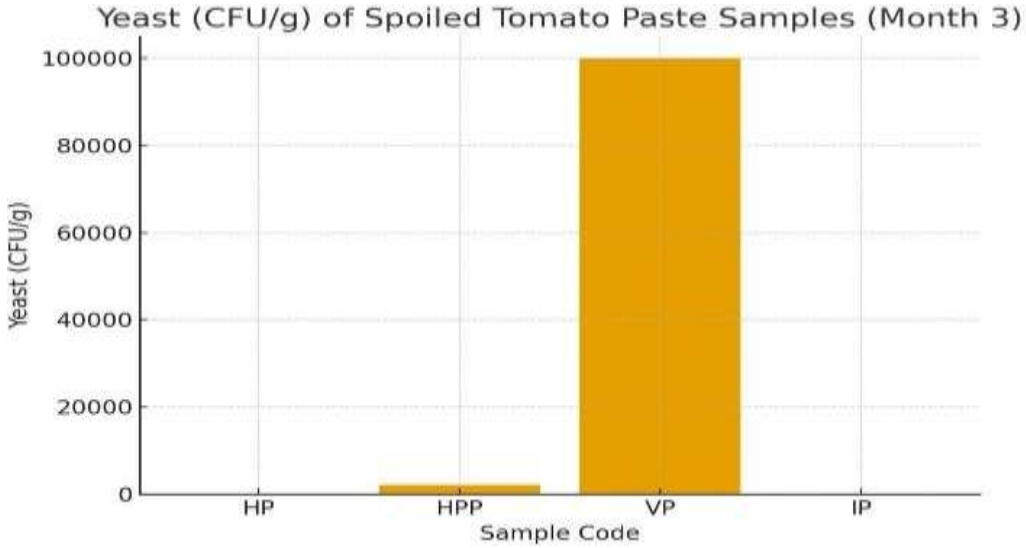


Figure: 3.2c showing yeast of Spoiled Tomato Paste Samples at Month 1 (% Dry Weight Basis, Mean ± SD).



The spoilage experiment highlights pronounced differences in microbial susceptibility among the four tomato paste samples. VP was highly prone to microbial proliferation, reaching bacterial counts of approximately 3.5 ×

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10^6 CFU/g, whereas IP demonstrated remarkable resistance, with mold/yeast counts below 10 CFU/g and bacterial counts around 1×10^2 CFU/g. This stark contrast underscores the critical role of formulation, processing, and storage conditions in determining microbial safety and spoilage dynamics. Factors such as higher residual moisture, inadequate acidification, and compromised packaging integrity in VP likely facilitated accelerated microbial growth (Vieira et al., 2022; Igwegbe et al., 2020). Conversely, the low microbial proliferation in IP indicates that its formulation and processing effectively inhibited microbial contamination, likely through reduced moisture uptake, optimal acidity, and proper sealing. The extremely high microbial load observed in VP would pose a significant safety risk if the product were produced and distributed commercially, highlighting the necessity for strict quality control, hygienic processing, and appropriate storage practices to prevent spoilage and ensure consumer safety (Eze et al., 2021; Alkanan et al., 2021).

CONCLUSION

This study concludes that glass-bottle preservation of tomato paste can effectively sustain microbial safety, nutritional integrity, and sensory acceptability comparable to industrial paste when adequate sterilization and hygienic procedures are maintained (Ibrahim et al., 2023).

The comparative assessment between sterile and spoilage studies established that the inclusion of natural preservatives and proper sealing significantly enhanced product stability under ambient Nigerian conditions (Umar & Yusuf, 2023).

Home and vendor-preserved samples without stringent processing controls were more susceptible to microbial spoilage and nutrient degradation, underscoring the importance of standardized heat treatment and airtight packaging (Ajayi & Ogunyemi, 2022).

Therefore, local production of glass-bottled tomato paste, if regulated to meet SON/NAFDAC standards, offers a viable pathway to reducing postharvest losses, enhancing nutrition security, and promoting small-scale agro-processing industries in Nigeria (Okonkwo & Eze, 2024).

This study provides new evidence that locally prepared and glass-bottle-preserved tomato paste can maintain nutritional and microbiological quality comparable to industrially processed paste when sterilization and preservation procedures are properly controlled (Mohammed et al., 2023).

Unlike earlier works that focused mainly on industrial formulations, this research demonstrated that home-level preservation especially with mild preservatives can sustain proximate stability and microbial safety for up to three months under Nigerian ambient conditions (Umar & Yusuf, 2023).

The study also introduces a comparative experimental framework that integrates sterile and intentionally spoiled samples, providing a more holistic view of post-processing deterioration mechanisms in tomato paste systems (Nguyen et al., 2022).

By aligning results with NAFDAC and SON microbiological thresholds, the research offers a scientific benchmark for quality assurance applicable to small-scale tomato processors in Nigeria (Adeleke et al., 2023).

Furthermore, the generated baseline data on nutrient retention and microbial dynamics can serve as a reference for future formulation optimization, shelf-life modeling, and regulatory standardization within the agro-processing value chain (Liang et al., 2023).

RECOMMENDATIONS

Based on the results, several practical and policy-level recommendations are advanced.

First, local producers of tomato paste should adopt standardized sterilization techniques—such as wet-heat processing at controlled temperatures and durations—to minimize microbial contamination and extend shelf life (Ogunbanwo et al., 2023).

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Second, the use of transparent glass bottles should be coupled with light-protective storage to limit vitamin C oxidation and pigment fading (Salunkhe & Kadvekar, 2023).

Third, small-scale processors should be trained through agricultural extension services on good manufacturing practices (GMP), safe handling, and hygienic bottling procedures to meet SON/NAFDAC specificat ions (Okonkwo & Eze, 2024).

Fourth, policymakers should encourage investment in community-level tomato preservation clusters equipped with autoclaves and heat-sealers to support rural value-addition and reduce postharvest losses (Abubakar & Oladipo, 2023).

Finally, consumer awareness campaigns are needed to promote acceptance of locally produced, safely preserved tomato paste as a cost-effective and nutritious alternative to imported brands (Duodu et al., 2023).

CONCLUSION

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Furthermore, the generated baseline data on nutrient retention and microbial dynamics can serve as a reference for future formulation optimization, shelf-life modeling, and regulatory standardization within the agro-processing value chain (Liang et al., 2023).

RECOMMENDATIONS

Based on the results, several practical and policy-level recommendations are advanced.

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First, local producers of tomato paste should adopt standardized sterilization techniques—such as wet-heat processing at controlled temperatures and durations—to minimize microbial contamination and extend shelf life (Ogunbanwo et al., 2023).

Second, the use of transparent glass bottles should be coupled with light-protective storage to limit vitamin C oxidation and pigment fading (Salunkhe & Kadvekar, 2023).

Third, small-scale processors should be trained through agricultural extension services on good manufacturing practices (GMP), safe handling, and hygienic bottling procedures to meet SON/NAFDAC specifications (Okonkwo & Eze, 2024).

Fourth, policymakers should encourage investment in community-level tomato preservation clusters equipped with autoclaves and heat-sealers to support rural value-addition and reduce postharvest losses (Abubakar & Oladipo, 2023).

Finally, consumer awareness campaigns are needed to promote acceptance of locally produced, safely preserved tomato paste as a cost-effective and nutritious alternative to imported brands (Duodu et al., 2023).

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