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Effect of Preservation Techniques on the Microbiological Safety and Flavor Profile of Tomatoes (*Solanum lycopersicum*)

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ABSTRACT

This study investigates the effects of preservation techniques and storage on the microbiological and sensory properties of five tomato varieties: Marzanino, Xina, NHle 158-3, Picenza 0161, and Roma VF. Preservation methods included freezing and home canning, with additives such as sodium chloride (0-2.5%) and lime juice (0-10%). Using spread plate techniques, microbial loads were enumerated over a storage period of 0-4 months. Fresh tomatoes exhibited total viable fungal counts ranging from 1.60 x 10^3 to 2.68 x 10^4 CFU/g, with the highest counts in the Picenza 0161 variety. Frozen tomatoes stored for 4 months had counts between 1.2 x 10^2 and 4.6 x 10^3 CFU/g, while freshly canned tomato paste and quartered tomatoes showed no bacterial growth. Total viable counts for canned tomatoes ranged from 0 to 6.00 x 10^3 CFU/g. Fungal counts in fresh tomatoes ranged from 2.20 x 10^3 to 5.10 x 10^4 CFU/g, while frozen tomatoes ranged from 1.70 x 10^3 to 6.30 x 10^3 CFU/g. Six bacterial and nine fungal species were isolated, namely *Acetobacter* sp., *Bacillus cereus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Sarcina* sp., and *Staphylococcus aureus*. The fungal isolates included *Aspergillus* sp., *Cladosporium* sp., *Debaryomyces* sp., *Fusarium oxysporum*, *Geotrichum candidum*, *Penicillium expansum*, *Pichia* sp., *Rhizopus stolonifer*, and *Saccharomyces cerevisiae*. *Penicillium expansum* were the most predominant fungal species in fresh, frozen, and canned tomatoes, while *Rhizopus stolonifer* was the least. In the bacterial species *Pseudomonas aeruginosa* was the most predominant in fresh, frozen, and canned tomatoes, while *Sarcina* sp. was the least. Stews made from fresh and canned tomato pastes were rated higher in aroma and taste, with canned quartered tomatoes preserved with 1.25% NaCl showing the best sensory qualities.

Keywords: Sun-drying, Freezing, Storage, Tomato, Sodium Chloride, Sensory Attribute, *Solanum lycopersicum*.

Introduction

The tomato (*Solanum hycopersicum*) is widely consumed throughout the world. Natural genetic variation in tomatoes and their wild relatives has given a genetic treasure trove of genes that produce a variety of antioxidants including lycopene, carotene and anthocyanin. Antioxidants help to detoxify the body system and promote good health (Rao and Balanchandra, 2002).

In Nigeria, tomato is a major ingredient for the preparation of curies. Tomatoes are used extensively in Mediterranean cuisine especially Italian and Middle Eastern cuisines. The tomato is acidic; this makes it especially easy to preserve in home canning as whole, pieces (chopped), a paste or other forms.

Raw red tomatoes contain 92.2g water, 4.0g carbohydrates, 2.6g sugar, 1.0g each of dietary fiber among other nutrients (Peet, 2008).

The high water content is responsible for the produce being highly perishable. It has been reported that as high as 50% of this produce is lost between rural production and term consumption in the tropical areas (Oyemiran, 1988).

It is a good source of magnesium phosphorus, calcium, vitamin A and C (Banet *et al,* 2008).

Like any other fresh fruit or vegetables, tomatoes can be contaminated by bacteria from soil, water and animal source (Smith, 1994)> contamination from human sources many occur before, during or after harvest, right up to the point of consumption.

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Bacteria on the tomato skin can be transferred to its internal flesh during cutting or slicing. Food poisoning out breaks have occurred when poorly washed utensils or cutting boards (especially those used to handle raw meats) have been used to prepare fruits or vegetables. Tomatoes have been linked to food borne illness caused by salmonella typhi (CBS, 2006). The flavor, texture and cooking characteristics of tomatoes depend on the variety, growing method, local environment, handling techniques used during and after harvest.

The production of tomato in relation to demand is generally law in Nigeria. This could be partially attributed to the prevailing high temperature in most of the country. Even where cool temperature is obtained such temperature prevails only during the harmattan season, November to February. Outside the short cool period, fresh tomato is very scarce and expensive in the whole country.

There is the need to increase the availability of tomato to meet up with the high demand for this commodity. In terms of production in Nigeria, figures like 6 million tons of tomato have been given as annual production level (Oyeniran, 1988).

Nigeria is second largest producer in Africa (after Egypt) and 13th in the world. In sufficient attention has been given to the preservation aspect of this important agricultural produce in Nigeria. An increase in production is only part of the situation as this would result in gluts at harvest time and very low price, while few months after scarcity sets in resulting in high prices. Harvested vegetables are not eaten because they are made unavailable through some forms of spoilage.

A variety of methods have been used for the preservation of tomatoes such as refrigeration, freezing, dehydration and canning.

The aim of this study was to evaluate the effects of sun-drying technique on the microbiological safety and flavor profile of sun-dried tomatoes (*Solanum lycopersicum*). The objectives were to evaluate the effect of preservation techniques by freezing, canning and storage on the microbial quality of tomato during strange for 0-4 months, and to determine the sensory properties of the processed and stored tomatoes.

Materials and Methods

Source of Tomato

Tomato fruits (Marzanino, Xina, Nhle 158-3, Picenza 0164 and Roma VF varieties) were purchased at Fruit Garden market in Port Harcourt, Rivers State. The tomatoes were identified at Natural Horticultural and Research Institute (NIHORT) Okigwe. They were collected in polyethylene bags and transported to the laboratory for analysis. The tomatoes were sorted, washed and disinfected with chlorinated water.

The following are descriptions of the five (5) varieties of tomato sold in Port Harcourt, Rivers State, Nigeria. These varieties along with their local names are; The Marzanino, known locally as the Gboko variety, is a determinate plant type characterized by its banana-shaped, plum red fruit with pointed tips. The Xina, referred to as Jos UTC, produces round-shaped tomatoes that are deep red when ripe and have a firm texture. The NNHLe158-3, commonly called Kano UTC, features round, flat, and lobed fruits that tend to crack. The Picenza0164, known in the region as Pankshin, yields determinate plum-shaped red fruits, while the RomaVF, referred to as Zaria, produces pear-shaped tomatoes that are red upon ripening. The tomatoes were identified at National Horticultural and Research Institute (NIHORT) Okigwe based on their local names and description.

Preservation of Tomatoes by Freezing and Canning

Firm and ripe tomatoes were selected, washed in clean water and blotted dry with a clean paper napkin. The tomato (150. 1 – 154.9g) were packed in a low density (LDPF) polyethylene bag and frozen in a freezer (model BD-126, Haier Thermocool, Nigeria) at – 4^0C to 0^0C for 4 months.

Tomato for canning was processed in 2 ways: Firstly, the firm, ripe tomatoes (195-200 grammes) were dipped in 2 litres of boiling water for 30 to 60 seconds to split the skins. They were then dipped in cold water to slip off the skins, discolored parts were removed and the tomatoes were cut into quarters. The cut tomatoes were placed in sterile glass jars which had been submerged in boiling water for 10 minutes and allowed to drain. Lime juice was extracted from lime fruits and strained prior to use.

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Adjustments were made in the weight of tomatoes for the addition of lime juice (5% and 10%) and sodium chloride (1.25% and 2.5%). The jars were filled with the cut tomatoes to ¼ inch of the top. Thereafter 100ml of boiling water (100^0C) was added to each jar to ½ inch head space of the top. Air bubbles were removed by gently sliding a spoon down the sides of the jars. The jars were covered with the lids and heated in boiling water for 40 minutes. The jars were then placed on a rack to cool before storage in a cool, dark cabinet.

Secondly, the tomato (200 grammes) was blended in a Moulinex blender for 5 minutes and then boiled for 5 minutes to obtain a paste. This served as the control while adjustments were made in the weight of tomato for treated samples containing 5% or 10% lime juice and 1.25% or 1.5% sodium chloride (NaCl). The paste was placed in a sterile glass jar. The jar was covered with a lid, heated in a pot for 10 minutes and left to cool. The cooled jars were checked to confirm that they were sealed properly by testing for seal (USDA, 2009). The jars were then stored in a cool, dark cabinet.

Microbiological Analyses of Tomato Samples

Isolation of Microbes from the Samples

The microbial load of the tomato samples was determined by spread plating and the bacteria and fungi were isolated and identified. Triplicate sample sources were processed for the study through which a mean reading is taken after all. Serial dilution of each sample was carbide out by Pipetting line of the sample into give of sterile distilled water in McCartney bottles to give 10^{-1} dilution. Further dilution was made to give higher dilutions as required. For each samples after series of dilution, 0.1ml and 1ml was taken from 10^2, 10^3, 10^5 dilution unto a sterile media.

The sterilized media of Plate Count Agar (PCA) and Potato Dextrose Agar (PDA) used during the study were poured into sterile Petri dishes. Using spread plate technique, the diluted sample was evenly spread across the media with a sterile stirring rod. The inoculated plates were properly labeled for easy identification, and then incubated at 37°C for 24-48 hours for bacterial culture, and at 20-28°C for 2-5 days for fungal growth.

Sub-Culturing by Streak Method

Nutrient agar and potato dextrose agar were prepared, poured into plates aseptically and allowed to solidify respectively. Distinct colonies of the bacteria and fungi obtained samples were sub-cultured using an inoculating loop by streaking onto the sterile plates.

The Nutrient agar cultures were incubated at 37^0C for 24 days, and the potato dextrose agar cultures were incubated at 28^0C for 5days for bacteria and fungi respectively. Subsequent sub-culturing was performed until pure cultures of different isolates were obtained.

These pure isolates were transferred into agar slants in McCartney bottles and kept in the refrigerator at 4^0C to serve as stock cultures for subsequent test during identification of organism.

Biochemical Test and Identification of Bacteria Isolates

Standard microbiological methods were used to identify the microorganisms obtained. The bacteria isolates were identified making use of 24 hours old cultures that were Grain stained for cell morphological differentiation. The test carried out for biochemical tests were catalase test oxidase test, urea utilization, sugar fermentation test, which involved glucose, fructose, lactose, galactose, maltose and sucrose according to the methods described by Cheesebrough (2000). 1 % of each carbohydrate was prepared into test tubes in triplicates containing Durhan tubes in an inverted in an inverted position. Two (2) drops of phenol red indicator was added in a peptone medium and then autoclaved at 112^0C for 10 minutes.

Sugar test tubes were inoculated with appropriate isolate while control tubes were prepared without inoculation. The tubes were incubated and observed daily for two to ten days for ability to utilize a particular sugar as carbon source of energy leading to acid production signified by change in colour of the medium from red to yellow. This may be accompanied with gas production on the top of the inverted Durham tubes provided. The bacterial isolates were also examined for endospore staining, motility test and starch hydrolysis.

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Identification of Fungi

To prepare the sample, a small portion of the fungus was collected using a sterile inoculating loop or scalpel, and then placed on a clean grease-free glass slide. A drop of lacto-phenol cotton blue was added to stain the sample, which enhances the visibility of fungal structures by staining the chitin in the cell walls. The sample was then covered with a cover slip, ensuring that no air bubbles were trapped.

Once prepared, the slide was placed under a microscope, and the focus adjusted to view the fungal mycelia structures, spores, and associated structures which appeared blue against a clear background, according to the descriptions in Samson and Reenen-Hockstrastra (1988). After observation, the slide and coverslip were disposed according to safety guidelines.

Ingredients Used for the Preparation of Tomato Sauces: The ingredients used for the preparation of tomato sauces are as presented in Table 1.

Table 1: Ingredients for tomato sauce prepared from Xina Variety stored for 0-1 month

S/N	Tomato Sample	Weight (g)	Salt (g)	Onions (g)	Maggi (g)	Red Pepper Ground (g)	Vegetable Oil (ml)
1	Fresh tomato (control 1)	226.2	2.5g	35.9	4.2	5.0	50
2	Frozen canned quartered tomato (control 2)	226.6	2.5g	36.5	4.2	5.0	50
3	Canned quartered tomato (+ 10% lime)	222.4	0	34.4	4.2	5.0	50
4	Canned (+1.25% NaCl)	227.5	0	33.1	4.2	5.0	50
5	Canned (+5 % lime + 1.25% NaCl)	225.9	0	33.4	4.2	5.0	50
6	Canned (+10% lime + 1.25% Nacl)	226.7	0	33.0	4.2	5.0	50
7	Canned (+10% lime + 2.5% Nacl)	226.5	0	35.7	4.2	5.0	50
8	Canned Paste (+5% lime + 1.25% NaCl)	226.1	0	33.1	4.2	5.0	50

Preparation of Tomato Sauces

Fifty milliliters of vegetable cooking oil (Deron Kings, Malaysia) was poured into a clean pre-heated frying pan. For the tomato samples without additives, 2.5g NaCl was added to the hot oil before the addition of the sample. Fresh tomato was diced and poured into the hot oil, this was followed by the addition of 5.0g red ground pepper, a cube of 4.2g of seasoning (Maggi star) and 100ml of water. The mixture was stirred together and allowed to cook for 10 minutes. Different tomato sauces were prepared similarly based on the type of tomato sample used.

Sensory Evaluation

The tomato samples were prepared into souce for sensory test. A panel of ten judges who are regular consumers of tomato sauces and familiar with the attributes, investigated the sensory qualities of the products. Panelists evaluated the samples for color, appearance, texture, aroma, taste, and overall acceptability on a 9-point hedonic scale (Meilgaard *et al.,* 2004).

On this scale, 9 represented extreme liking, while 1 indicated extreme dislike.

Statistical Analysis

The data obtained from this investigation was analyzed using t-test and analysis of variance (ANOVA) for determination of mean difference.

Results

The result of the total viable count (TVC) for bacteria and fungi in fresh, frozen and canned tomato fruit stored for 4 months is presented in Table 2. The Fresh tomato had more bacteria counts than frozen and canned tomato. Canned tomato paste had no bacterial growth at all. Canned quartered tomato had less bacterial counts than frozen due to the canning processes and low pH. Fresh tomato also had more fungal counts than frozen and canned tomato samples.

The characteristics of bacteria isolated from fresh tomato are shown in Table 3 while the characteristics of fungi isolated from fresh tomato fruit are also presented in Table 4.

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Table 2: Total viable count for bacteria and fungi in fresh, frozen and canned tomato fruit stored for 4 months

Tomato Sample	Total Viable Counts (CFU/g)	
	Bacteria	**Fungi**
Fresh		
Xina	5.10×10^3	9.30×10^3
Picenza 0164	2.20×10^3	2.68×10^4
NHle 158-3	6.70×10^3	1.60×10^3
Marzanino	1.56×10^3	1.80×10^4
Roma VF	2.50×10^3	1.22×10^4
Frozen		
Xina	3.00×10^3	4.60×10^3
Picenza 0164	1.70×10^3	3.30×10^3
NHle 158-3	6.30×10^3	1.20×10^2
Marzanino	1.30×10^3	-
Roma VF	1.50×10^3	4.20×10^3
Canned		
Xina (Quartered)	1.40×10^4	6.00×10^3
+ 1.25% NaCl	8.00×10^2	4.00×10^2
+ 10% lime juice	2.10×10^3	2.70×10^3
+ 5% lime juice + 1.25% NaCl	1.60×10^3	1.90×10^3
+ 10% lime juice + 1.25% NaCl	1.00×10^4	4.10×10^3
+ 10% lime juice + 2.5% NaCl	1.10×10^3	1.70×10^3
Canned tomato paste		
+ 10% lime juice + 1.25% NaCl	0	ND
+ 5% lime juice + 1.25% NaCl	0	ND

Table 5 shows the occurrence in percentages (%) of bacterial in canned and stored tomato fruit. *Bacillus cereus*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus were present* in various treatments of canned and stored tomato fruit samples, showing varied bacterial prevalence depending on the treatment and sample type after four (4) months of storage.

Summary of panel mean scores for the sensory characteristics of freshly prepared tomato sauce samples are presented in Table 6.

Panelist rated the fresh tomato sauce significantly ($P \leq 0.05$) higher for their appearance, aroma, colour, taste, texture and overall acceptability. Results indicate that samples A, B, and F received the highest ratings across most parameters, while sample G consistently showed the lowest scores, with significant differences noted among the groups ($p<0.05$).

Table 7 shows the mean scores for sensory characteristics of stew prepared from tomato samples stored for 1 day.

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Table 3: Cultural, morphological and physiological characteristics of bacteria isolated from the different types of fresh tomato fruits stored for 1 day

Isolate Code	Tomato Sample	Cultural Characteristics	Gram Reaction	Shape	Spore	Motility	Catalase	Oxidase	Urease	Citrate	Methyl red	Voges Proskaeur	Indole	Gelatin Liquefaction	Oxidation/Fermentation	H_2S	Flagella polar	Lactose	Sucrose	Glucose	Fructose	Maltose	mannose	Identified Isolate
ZF	Roma VF	Golden-yellow convex with narrow white entire margin and surrounded by clear zones	+	C	-	-	+	-	-	-	-	-	-		+	-	-	-	-	+		-	-	*Staphylococcus*
JP	Xina	Cream convex	-	R	+	+	+	-		+	-	-	-	-	-	-	-	-	-	-	-	-	-	*Acetobacter* sp.
GF1	Marzanino 1	Green pigment with smooth edge convex elevation 2mm	-	R	-	+	+	+	_	+	-	-	-	+	O	-	+	-	-	V(+)	-	-	-	*Pseudomonas*
GF2	Marzanino 2	Cream colour convex mucoid colonies 2mm	+	C	-	+	+	-	-	-	+	-	+	+	O/F	-		+	-	+	+	+	+	*Escherichia coli*
GF3	Marzanino 3	Golden-yellow convex with a narrow white entire margin and clear zones	+	C	-	-	+	-	-	-	-	-	-	+	O/F	-		-	-	+	-	-	-	*Staphylococcus aureus*
PF1	Picenza 01641	Yellow colonies with convex elevation 2mm	-	C	-	-	+	-	+	-	+	-	-	-	O	-		+	-	+	-	-	-	*Sarcina* sp.
PF2	Picenza 01642	Cream colored, circular, rough edges 5mm in 24 hrs	+	R	+	-	+	-	-	+	-	+	-	+	O/F	-		-	-	+	-	-	-	*Bacillus subtilis*
KT	Kano NHle 158-3	Cream coloured, circular, rough edges 5mm in 24 hrs	-	R	-	+	+	+	+	+	-	-	-	+	O	-	+	-	-	V	-	-	-	*Bacillus cereus*

Key: + = positive;- = negative; C= cocci; R = rod; O = oxidation; O/F = oxidation/fermentation; v = variable; V(+) = variable, most negative.

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Table 4: Cultural and Morphological Characteristics of Fungi Isolated from fresh tomato fruit stored for 1 day

Tomato Sample	Isolate Code	Cultural characteristics	Morphological Characteristics	Identified Isolates
Marzanino	GF1	Whitish, cottony, raised	Septate hyphae with branched conidiophores having matulae, Brush like appearance	*Penicillium expansum*
	GF2	Whitish, mucoid, convex	Budding unicellular-oval cells, no pseudohyphae	*Saccharomyces cerevisiae*
	GF3	Whitish, granular wrinkled, flat	Cylindrical budding cells oblong. Pseudo mycelium formed	*Pichia* sp.
	GF4	Whitist colonies becoming grayish brown due to brown sporangia often about 20m high	Solitary sporangiophore globose	*Rhizopus stolonifer*
	GF5	Milkfish, mucoid, convex	Budding cells, unicellular oval cells	*Debaryomyces* sp
	GF6	Milkish, mucoid, convex	Budding cells, unicellular over cells	*Saccharomyces cerevisiae*
Marzanino	RF1	Milkish, mucoid, flat	Budding cells, multilateral budding, pseudomycelium form pseudomycelium form	*Debaryomyces* sp
	RF2	Whitish, cottony, raised	Branched conidiophores, conidia smooth or rough walled in chains or pairs	*Fusarium oxysporium*
Picenza 0164	PF1	Whitish, cottony, raised	Septate hyphae, conidiophores absent, conidia cylindrical chains and erect, dichotomously branched	*Geotrichum candidum*
	PF2	Milkfish, mucoid, flat	Single ovoid budding cells	*Saccharomyces cerevisiae*
Xina	JF1	Whitish, cottony, raised	Septate hyphae, multicellular and sickle cell (canoe) shape	*Fusarium oxysporium*
	JF2	Milikish, mucoid, raised	Unicellular budding cells, oval	*Saccharomyces cerevisiae*
Roma VF	ZF1	Whitish, fluffy, raised	Septate hyphae, multcellular and sickle cell (canoe) shape conidia	*Fusarium oxysporium*
	ZF2	Whitish, cottony, raised	Conidiophores absent, septate hyphae conidia cylindrical chains and erect	*Geotrichum candidum*
	ZF3	Cream, mucoid, convex	Budding unicellular-oval cells, no pseudohyphae	*Saccharomyces cerevisiae*
	KT1	Milkfish, mucoid, convex	Budding unicellular oval cells, no pseudohyphae	*Saccharomyces cerevisiae*
NHLe 158-3	KT2	Whitish, cottony, raised	Septate hyphae with branched conidiophores having metulae. Branch-like appearance	*Penicilluim expansum*

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Table 5: Table: Occurrence (%) of bacteria in canned and stored tomato fruit after four (4) months storage

Sample	Treatment	*Bacillus cereus*	*Pseudomonas aeroginosa*	*Staphylococcus aureus*
Marzanino	10% + 1.25% salt	50	25	25
NHLe 158-3	10% 1.25% salt	33.3	66.7	-
Roma VF	10% + 1.25% salt	-	100	-
Xina	Control	-	50	50
Xina	Lime only	-	100	-
Xina	Salt only	-	-	100
Xina	5% + 1.25% salt	33.4	33.3	33.3
Xina	10% + 1.25% salt	-	50	50
Xina	10% + 2.5% salt	50	-	50

Table 6: Sensory properties of freshly prepared tomato sauce sample

Parameters	Tomato Sauce Sample						
	A	B	C	D	E	F	G
Appearance	8.9 ± 0.06^{a}	6.7 ± 0.06^{c}	6.6 ± 0.07^{c}	8.3 ± 0.07^{a}	7.7 ± 0.07^{b}	8.3 ± 0.05^{a}	8.9 ± 0.05^{a}
Aroma	8.7 ± 0.06^{a}	6.5 ± 0.06^{c}	5.6 ± 0.07^{d}	7.9 ± 0.07^{b}	6.3 ± 0.07^{c}	5.6 ± 0.05^{b}	5.7 ± 0.09^{d}
Colour	8.4 ± 0.04^{a}	6.2 ± 0.04^{c}	6.5 ± 0.07^{c}	7.9 ± 0.07^{b}	7.6 ± 0.07^{b}	7.6 ± 0.06^{b}	9.0 ± 0.06^{a}
Taste	8.6 ± 0.06^{a}	5.4 ± 0.03^{D}	4.7 ± 0.06^{e}	7.9 ± 0.07^{b}	3.9 ± 0.07^{f}	3.9 ± 0.0^{f}	4.7 ± 0.09^{e}
Texture	8.4 ± 0.03^{a}	6.3 ± 0.03^{c}	5.6 ± 0.07^{d}	7.7 ± 0.07^{b}	7.2 ± 0.07^{b}	7.7 ± 0.06^{b}	8.3 ± 0.09^{a}
General Acceptability	8.6 ± 0.06^{a}	6.2 ± 0.03^{c}	5.8 ± 0.06^{d}	7.9 ± 0.07^{b}	6.5 ± 0.07^{c}	6.6 ± 0.05^{c}	7.3 ± 0.09^{b}

* Each value represents mean ± standard error; Value having different superscript letters in a row significantly different ($p<0.05$).
Key: A=Fresh (control); B=No salt, no lime (canned quartered); C=Canned quartered (+ 10% lime); D= Canned quartered (+ 5% + 1.25% lime); E=Canned quartered (+10% + 1.25% NaCl); F=Canned quartered (+10% + 2.5% NaCl); G=Canned paste (+5% + 1.25% NaCl).

Table 7: Sensory properties of sauce prepared from tomato samples after 1 month of storage

Parameters	Tomato Sauce Sample						
	A	B	C	D	E	F	G
Appearance	8.3 ± 0.04^{a}	8.0 ± 0.04^{a}	7.7 ± 0.07^{b}	6.5 ± 0.07^{c}	6.6 ± 0.05^{c}	8.0 ± 0.05^{a}	2.2 ± 0.05^{a}
Aroma	8.6 ± 0.06^{a}	8.2 ± 0.05^{a}	7.8 ± 0.07^{b}	5.9 ± 0.06^{d}	6.9 ± 0.06^{c}	8.0 ± 0.06^{a}	7.1 ± 0.07^{b}
Colour	8.3 ± 0.04^{a}	8.3 ± 0.05^{a}	6.8 ± 0.06^{c}	6.9 ± 0.06^{c}	6.9 ± 0.06^{c}	7.9 ± 0.07^{b}	8.0 ± 0.05^{a}
Taste	8.1 ± 0.06^{a}	6.9 ± 0.06^{c}	6.3 ± 0.06^{c}	7.5 ± 0.07^{b}	6.6 ± 0.07^{c}	8.2 ± 0.06^{b}	7.7 ± 0.07^{b}
Texture	8.2 ± 0.06^{a}	7.5 ± 0.07^{b}	6.5 ± 0.07^{c}	6.5 ± 0.07^{c}	7.1 ± 0.07^{b}	7.8 ± 0.07^{b}	8.2 ± 0.09^{a}
General Acceptability	8.3 ± 0.06^{a}	7.8 ± 0.07^{b}	7.0 ± 0.06^{b}	6.7 ± 0.06^{c}	6.8 ± 0.06^{c}	7.9 ± 0.07^{b}	7.8 ± 0.09^{b}

* Each value represents mean ± standard error; Value having different superscript letters in a row significantly different ($p<0.05$).
Key: A=Fresh (control); B=No salt, no lime (canned quartered); C=Canned quartered (+ 10% lime); D= Canned quartered (+ 5% + 1.25% lime); E=Canned quartered (+10% + 1.25% NaCl); F=Canned quartered (+10% + 2.5% NaCl); G=Canned paste (+5% + 1.25% NaCl).

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Discussion

This research provides a comprehensive assessment of the microbial, sensory, and biochemical characteristics of tomatoes under various conditions, offering valuable insights into tomato quality and safety in Port Harcourt, Nigeria. The findings show that various microorganisms may be due to contamination from the soil, mode and period of transportation, market handling, baskets used for storage and hygiene of the market. The bacterial counts for fresh and frozen tomato samples was higher than the canned tomatoes because of the low pH of the canned tomato samples this is shown in table 3. Generally, over 50% of the types of bacteria and fungi isolated from fresh tomatoes were present in frozen and canned quartered tomatoes stored for 4 months. These bacteria were absent in tomato paste stored for 4 months and only 14.3% of the fungal types were in the paste. *Aspergillus niger and Cladosporium* species were persecuted in canned quartered tomatoes but not in the fresh samples. *B. cereus* had the highest occurrence in fresh tomatoes 30% while *E. coli* and *P. aeroginosa* had the least (6.66%).

The study revealed that fresh tomatoes had higher fungal and bacterial counts compared to frozen and canned tomatoes (Tables 2 & 3), aligning with previous research indicating that fresh produce is more susceptible to microbial contamination (Obeng *et al*., 2018). The absence of bacterial growth in canned tomato paste suggests the effectiveness of canning processes in inhibiting microbial proliferation, as also noted by other studies (Obeng *et al*., 2018). Specific bacteria such as *Bacillus cereus*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* were identified in canned tomato samples, with their occurrence varying depending on the treatment methods (Table 4). This highlights the importance of appropriate preservation techniques to minimize the presence of spoilage-causing microorganisms (Aneja *et al.,* 2014). The identified fungal isolates, including *Penicillium expansum*, *Saccharomyces cerevisiae*, and *Fusarium oxysporum* (Table 8), are consistent with other studies that have reported these fungi as common tomato spoilage agents (Obeng *et al*., 2018). Moreover, the isolation of bacteria such as *Staphylococcus*, *Pseudomonas*, *Escherichia coli*, and *Bacillus cereus* from fresh tomato fruit (Table 7) corroborates findings from other research, emphasizing the diverse microbial communities associated with tomatoes and their potential for spoilage and fermentation (Obunukwu *et al*., 2018).

From frozen tomato, *B. cereus* and *E. coli* occurred at 37.5% and *P. aeroginosa* and *Sarcina sp.* Occurred at 12.5%. for canned quartered tomato with various additives, *P. aeroginosa* had the highest occurrence (47.2%), while *B. cereus* had the least (18.50%). Amongst the fungal isolates for fresh tomato, *S. cerevisiae* had the highest occurrence (4.13%) while *Rhizopus* and *Pichia* species had the least (2.7%). For *P. expansum* and *G. candidum* had the least (12.5%). Similarly *S. cerevisiae* had the highest occurrence in canned quartered tomato with various additives (37.8%) while *Cladosporium* sp. had the least (4.2%) (Yu *et al.,* 2020).

Sensory analysis indicated that freshly prepared tomato sauce samples were rated higher in appearance, aroma, color, taste, texture, and overall acceptability compared to canned samples (Table 5). This suggests that fresh tomatoes contribute to superior sensory attributes in tomato-based products. However, after one month of storage, samples A, B, and F maintained higher sensory scores, while sample G (canned paste) received the lowest ratings (Table 6), indicating that certain preservation methods may negatively impact sensory qualities over time. These findings align with studies that have explored the sensory characteristics of fresh and processed tomatoes, noting differences in flavor, texture, and aroma9 (Sammi and Masud, 2007). The preference for fresh tomatoes in sensory attributes is consistent with consumer studies that value the organoleptic qualities of fresh produce (Felfoldi *et al*., 2021). Sauce prepared from fresh tomato and canned tomato pastes were rated higher for aroma and tastes than for other processed tomato samples. Stew prepared with canned quartered tomato preserved with only 1.250% NaCl was rated higher in appearance, colour, taste and texture (Wu *et al*., 2021).

Conclusion

This study has shown that fresh, frozen, and canned tomatoes can be contaminated by bacteria and fungi, highlighting the significant impact of storage methods on microbial load and sensory attributes. It revealed that frozen tomatoes can be stored for 1 to 12 weeks in a freezer with a constant power supply while maintaining their texture and quality.

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However, once thawed, tomatoes should be used immediately, as they lose texture, appearance, and nutritional value. Among the canned quartered tomato samples, those with 10% lime juice and 2.5% NaCl exhibited the lowest bacterial counts and pH, making them a recommended option. While canning effectively reduces microbial growth, it may compromise certain sensory qualities compared to fresh tomatoes. The identification of specific spoilage organisms under different storage conditions provides valuable insights for developing targeted preservation strategies to enhance tomato quality and safety. Further research could focus on optimizing canning processes to minimize sensory losses and exploring alternative preservation techniques to extend the shelf life of fresh tomatoes while maintaining their desirable sensory characteristics.

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