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Tomato powder processing involving different pretreatments: its effect on quality of the product packaged in polyethylene terephthalate pouches

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Abstract. The method of drying fresh tomato (*Lycopersicon esculentum* mill) to prevent quick spoilage, could affect the quality of the product, and influence consumer acceptability. This study is focused on determining the effect of different pretreatments on the quality of tomato powders packaged in polyethylene terephthalate pouches, and stored for 16 weeks at room temperature (25±2 °C). A total of six tomato powder samples, which include the blanched ascorbic acid pretreated (BAAP), unblanched ascorbic acid pretreated (UAAP), blanched lime juice pretreated (BLJP), unblanched lime juice pretreated (ULJP), sundried without pretreatment (SDTP), and the control (without pretreatment; dehydrator used for drying), was prepared. The total viable counts (TVC) of the stored tomato powders were within the range of 4.40-7.31 $\log_{10}$CFU/g. Although the TVC of the samples increased within the first few weeks, the values reduced as the storage period increased. The SDTP tomato powder maintained a higher TVC compared with other stored samples. There was a reduction in pH, moisture, ash, titratable acidity, and vitamin C content of the powdered tomatoes. The lycopene content of tomato powders was within the range of 102.13±1.53-132.70±1.46 mg/100g, while the fruit tomato was 18.96±1.27 mg/100g. There were significant differences ($p<0.05$) in the functional properties of the tomato powders, with few exceptions. Different pretreatments increased the water absorption capacity and bulk density of the samples, but reduced their emulsion

stability. The BLJP and BAAP tomato powders had a very high sensory rating, whereas the SDTP sample was the least. Based on the overall results, blanched ascorbic acid pretreatment is recommended for the production of good quality tomato powder.

Keywords: ascorbic acid, blanching, lycopene, postharvest losses, shelf life.

Introduction

Tomatoes typically share the characteristics of fruit and vegetable (Degwale *et al*., 2022; Agada *et al.,* 2023). In some literature, tomato is assigned the scientific name *Solanum lycopersicum* L. (Zambare and Kulkarni, 2023; Obajemihi *et al*., 2024), while others refer to it as *Lycopersicon esculentum* mill (Kumar *et al*., 2016; Adedire *et al*., 2022). Tomato is recognized by the family it belongs to called Solanaceae, while the genus which it is also a member is referred as *Lycopersicon* (Farooq *et al*., 2020). Historical data provided useful evidence that made scientists to believe that tomatoes originated in South America, specifically in the Andean region of the continent. Agriculturists reported that the subtropical and tropical regions are conducive geographical regions for cultivating tomatoes in abundant (Oladipupo *et al.,* 2020).

A ripe fresh tomato can be eaten raw after it has been properly washed with clean water. This is applicable to a lot of fruits and vegetables. Millions of people across the world consume fruit tomatoes in various ways. Further processing of fruit tomatoes has led to the production of a range of products (paste, juice, puree, canned tomatoes, ketchup, dried powders, and pasta sauces) (Kumar *et al.,* 2021; Dūma *et al*., 2022).

It is estimated that tomatoes produced across the world is more than 171 million metric tons, annually. In 2018, 2020, and 2021, the global output of fruit tomato was 182, 186, and 189 million tons, respectively. After taken a lot of factors into consideration, experts projected that 220 million tons of tomatoes will be produced in the year 2030 (Collins *et al*., 2022; Silva *et al*., 2023; Chabi *et al*., 2024). The countries globally recognized as the major producers of tomatoes are China, the USA, Turkey, Egypt, and India (Dube *et al*., 2020; Ogunsola and Ogunsina, 2021). Since the five countries are self-sufficient in tomato production, they usually export the excess to foreign countries in need of the product. In West Africa, Nigeria is a leading country in tomato production. About 6 million tons of tomatoes are produced annually in Nigeria, (Aderibigbe *et al*., 2018; Agada *et al*., 2023). According to Alabi *et al*. (2023), the quantity of tomatoes produced in 2019 and 2020 in Nigeria is 3,798,939 and 3,693,722

tons, respectively. Although Nigeria is not among the top ten tomato producers globally, the country occupies the 13th position. The country accounts for 1.3% and 10.8% of the global and African total tomato output, respectively (Tafida *et al*., 2023).

The skin of tomatoes is reddish in colour when the fruit is ripe. Studies carried out by researchers have linked the reddish colour of ripe tomato to lycopene found in the skin of the fruit (Aguda *et al*., 2021). Fruit tomato is enriched with antioxidant compounds beneficial to human health. They include phenolic compounds, carotenoids, vitamins C, and D (Xu *et al*., 2018). Also found in fresh tomatoes are phenolic compounds which include phenolic acid and flavonoids. It has been well-reported that tomatoes contain carotenoids which include lycopene, α- and, β-carotenes (Hirata *et al*., 2024). Carotene, folate, niacin, vitamin A, B_1, B_2, B_6, B_{12}, C, E, K, and H are the vitamins present in tomato fruit in varying quantities (Yegrem and Dagnaw, 2022; Chabi *et al.,* 2024). Several bioactive compounds which include kaempferol, cholin, lutein, naringenin, and quercetin have been reported in fruit tomatoes (Abdusalam *et al.,* 2023). Minerals such as calcium, sodium, magnesium, phosphorus, zinc, iron, copper, manganese, potassium, boron, and sulfur are also found in tomatoes in varying quantities (Aggarwal *et al*., 2016; Farid *et al*., 2022; Chabi *et al*., 2024). Beta-carotene and lycopene found in tomatoes are linked to health benefits. That is why people who eat tomatoes regularly have reduced risk to suffer from prostate cancer and cardiovascular diseases (Aderibigbe *et al*., 2018; Collins *et al*., 2022). Prevention of certain diseases such as diabetes, atherosclerosis, asthma, and colon cancer are associated with consumption of fruit tomato (Aggarwal *et al*., 2016).

The moisture content of fruit tomato is usually above 90 %. Freshly harvested tomatoes deteriorate very fast as a result of increased activities of spoilage microorganisms favoured by high moisture content. Consequently, the market value of the fruit tomato depreciates as the days go by (Adejo *et al*., 2015; Aderibigbe *et al*., 2018; Farooq *et al*., 2020; Ahmad *et al*., 2022; Degwale *et al*., 2022). Without taking any concrete action after harvesting ripe fruit tomato to preserve it, spoilage of the fruits will take place within two weeks (Anisuzzaman *et al*., 2022).

Massive production of fruit tomato happens during the appropriate season in the year. It largely influences tomato output in many countries (Oboulbiga *et al*., 2022). During the season of plenty, the market is flooded with fresh tomatoes. The prices drop due to market forces of demand and supply. The period fresh tomato is abundant in the market is shorter than the off-season, when tomato scarcity persist and prices skyrocket, until the arrival of another season of harvest. This cycle is usually experienced in many African

countries, including Nigeria. In order to meet high demand for tomato especially during the off-season, importation of tomato concentrate mainly from China, Italy, and Singapore becomes a lucrative business (Oboulbiga *et al.,* 2022; Ossamulu *et al*., 2023). On yearly basis, it is estimated that Nigeria business owners import tomatoes worth US$70 million. This development is pathetic because the country produces enough quantity of tomatoes to feed her population (Amurtiya and Adewuyi, 2020).

With the intention of extending the shelf life of ripe fruit tomato, modern drying methods have been adopted by some researchers different from the traditional practice (Kumar *et al.,* 2016; Ladi *et al*., 2017; Yegrem and Ababele, 2022). The use of solar dryers, microwave drying, sun tunnel drying, and freeze-drying are some of the improved drying methods (Yadav and Ali, 2023; Zambare and Kulkarni, 2023; Gameh *et al*., 2024; Obajemihi *et al*., 2024). Despite the benefits of drying fresh tomatoes, the quality of the product is affected. Some researchers have noted that the application of various physical or chemical pretreatments before drying tomatoes could minimize or resist the reduction in quality of the product attributed to the usual drying process. Other benefits of pretreatments include reduction in the energy requirement, and length of time required for tomato to be properly dried (Yegrem and Dagnaw, 2022). It has been reported that the functional properties of tomato powder is affected during drying. A strategy to cushion the effect of functional property loss of dried tomato powder suggested by some researchers is the use of preservatives and weak acids prior to drying of tomato powder (Chawafambira and Maramba, 2022). The osmotic agents commonly used for pretreatment of tomatoes include NaCl, sucrose, potassium metabisulphate, sodium metabisulphite, sodium benzoate, calcium chloride, weak acids, and sugar. Thermal blanching is another pretreatment fresh tomato could be subjected to before drying. It involves the use of hot water or steam. After drying of tomato is properly done, the product could be stored in polyethylene bags, high density polyethylene (HDPE) bags, aluminum foil pouches, vacuum-packed using a nylon-polyethylene bag, polystyrene cups, polyvinylchloride (PVC) trays, metalized polyester film, low density polyethylene (LDPE), glass jars, and plastic containers (Yegrem and Ababele, 2022). The quality of tomato powder is significantly affected by different pretreatments and drying methods (Aderibigbe *et al*., 2018; Farooq *et al*., 2020; Yegrem and Ababele, 2022). A study was carried out by Sarker *et al*. (2014) to determine the effect of using a cabinet drier to dry sliced tomatoes at 60 ^{o}C. The researchers went further to store the pretreated samples in different wrapping materials for six months at ambient temperature. The various wrapping materials include (i) medium density polyethylene, (ii) HDPE, and (iii) laminated aluminum foil (LAF) pouches. After considering the overall

results from the study, the use of LAF pouches to store tomato powder and pretreatment of dried tomato powder using a salt solution of 1% $CaCl_2$ and 0.2% potassium metabisulphite was recommended.

The traditional method used by rural dwellers in developing countries to reduce drastically the moisture content of sliced fruit tomato is to expose the raw foodstuff under the sun. This drying method is affordable. The product becomes dehydrated after several days of sun-drying. Hot air is another cheap drying method adopted by rural dwellers to dehydrate fresh tomatoes (Farid *et al*., 2022). In addition to obvious benefit of drying fresh tomatoes which usually extend the shelf life of the product, the process also reduces its bulky size which has cost implications of transporting fresh tomato to the final consumer. One of the ingredients used in preparing ketchup, canned products, soup premixes, and sauces is dried tomatoes (Farooq *et al*., 2020; Zambare and Kulkarni, 2023).

Instead of discarding tomatoes that have started spoiling, it can be used to produce a highly soluble powder which has a useful application as a functional food ingredient. In the last few years, food industries are increasingly using tomato powder as a natural food colorant and nutritional additive (Hirata *et al*., 2024; Lyu *et al*., 2024).

Microorganisms are present in intact fruit tomatoes harvested from the farm. Several factors could influence the microbial population and diversity in fruit tomatoes. *Bacillus subtilis*, *Pseudomonas aeruginosa, Klebsiella* sp., and *Proteus mirabilis* are bacterial isolates, while fungal isolates which include *Penicillium* sp., *Rhizopus* sp., *Mucor* sp., *Aspergillus niger*, and *Rhizopus stolonifer* have been isolated from the so called "healthy tomatoes". Some of these bacterial and fungal species are involved in the spoilage of tomatoes (Aguda *et al*., 2021). Currently, there is limited information with regards to the bacterial and fungal species present in stored tomato powder, subjected to different pretreatments before drying, and packaged in different types of materials. Published works on tomato powder reported the population of microorganisms in the samples, but the researchers did not go further to identify the isolates (Sarker *et al*., 2014; Adejo *et al*., 2015, Ladi *et al*., 2017; Obadina *et al*., 2018; Aderibigbe *et al*., 2018; Leke and Bembur, 2023). Identification of microorganisms isolated from stored tomato powder is important because, the presence of pathogens in the product is a potential risk to consumers' health. It is wrong to assume that dried tomato powder is free from microbial contaminants that are pathogenic. Bawa *et al*. (2023) reported the presence of *Escherichia coli* which is a coliform bacteria and *Salmonella* sp. (ubiquitous in the environment) in the tomato powder meant for human consumption, but the researchers did not identify the yeasts and mold isolated from the samples. In this study, bacterial and fungal species isolated from tomato powder subjected to different pretreatments

was identified. The effect of different pretreatments and drying methods on the quality (physicochemical, nutritional, functional, and sensory properties) of tomato powder packaged inside polyethylene terephthalate pouches, and stored for 16 weeks at room temperature was determined.

Materials and methods

Source of tomatoes

About 200 kg of fruit tomatoes were purchased from Fruit Garden Market in Port Harcourt, Rivers state. The selection of tomato samples was based on ripeness and hardness. Soft and damaged tomatoes were separated and discarded from good ones. Each fruit tomato was cleaned three to four times with tap water and rinsed with distilled water.

Preparation of pretreatment solutions

The method describing how pretreatment solutions are prepared as earlier stated by Abano and Sam-Amoah (2011) was slightly modified and adopted in the present study. Preparation of fresh lime juice solution involved mixing 500 mL of lime juice and 500 mL of distilled water. 10% ascorbic acid solution was obtained by dissolving 100 g of food grade ascorbic acid powder (Heilongjiang NHU Biotechnologies, Europe) in 10 L of distilled water.

Sample preparation

Pretreatment of the tomato fruits

The tomato purchased from the Fruit garden were divided into six (6) equal parts. Each of the portions weigh 20 kg. The tomatoes were sliced into small irregular slices using a clean kitchen knife sterilized with 90% alcohol. The sliced tomato fruits were pretreated as follows:

(i) Control (CTRL): The sample was not pretreated. It was dried in a food dehydrator (model LY-FG2).

(ii) Sundried tomato powder (SDTP): The sample was not pretreated. It was dried under the sun.

(iii) Blanched lime juice pretreated (BLJP) sample: Tomato fruits was blanched with hot water for 1 minute, pretreated with lime juice (soaked for 10 minutes), and dried in a food dehydrator.

(iv) Unblanched lime juice pretreated (ULJP) sample: The tomato fruits were not blanched. It was pretreated by soaking it in a lime juice for 10 minutes, and dried in a dehydrator.

(v) Blanched ascorbic acid pretreated (BAAP) sample: The tomato fruits were blanched with hot water for 1 minute, pretreated by soaking it in a 10% ascorbic acid solution for 10 minutes, and dried in a dehydrator.

(vi) Unblanched ascorbic acid pretreated (UAAP) sample: The tomato fruits were not blanched. It was pretreated by soaking it in a 10% ascorbic acid solution for 10 minutes, and dried in a dehydrator.

Drying of samples

The portion of sliced fruit tomato which was sundried involved exposing the sample to direct sunlight for 8 hours. Other portions of sliced fruit tomato (i, iii-vi) were dried using a dehydrator sterilized with 90% alcohol. The temperature of the dehydrator was adjusted to 55 ^{o}C to dry the sliced tomatoes. The dried samples of tomato were milled to powder using a sterilized hammer mill machine. After milling each portion of the sliced and dried tomatoes, they were allowed to cool to room temperature. Without delay, each of the samples were packaged in polyethylene terephthalate pouches for storage, and further analysis. Each of the samples was properly labeled.

Serial dilution

Dilution of each sample of dried tomato powder was carried out (ten-fold serial dilution) by weighing 5 g of the sample in 45 mL of 0.1% sterile peptone water to yield a stock solution. The dilution was performed under aseptic conditions. Stepwise dilution of each sample of dried tomato powder was performed from the 10^{-1} dilution until 10^{-5} dilution was reached. Each stepwise transfer was performed using a sterile pipette.

Microbiological analysis

Isolation of bacteria and fungi

Under aseptic conditions, 0.1 mL of dilution 10^{-2} to 10^{-5} of the tomato powder samples was inoculated into freshly prepared plate count agar (PCA) and MacConkey agar (MCA) plates in accordance with manufacturer's instruction. To inoculate the samples on the agar plates, the spread plate method was used. Similarly, the diluted samples was aseptically inoculated onto Sabouraud dextrose agar (SDA) plates for the isolation of fungal species. The plates intended to isolate bacteria from the tomato powder samples were incubated at 37 ^{o}C in

a Memmert incubator (West Germany) for 48 hours. A longer incubation period of another set of plates (SDA) intended to isolate fungi from the samples lasted for 5 days at ambient temperature (28±2 °C). The colonies that appeared in each culture plate was totaled after counting was done manually and recorded. The total viable count (TVC) of each tomato powder sample was calculated and expressed in $\log_{10}$CFU/g. Monitoring of bacterial population of the tomato powder samples stored at room temperature (25±2 °C) was performed biweekly for 16 weeks.

Determination of pure cultures

Based on unique morphological characteristics of bacteria and fungi that appeared in the culture plates (MCA, SDA, PCA) after the incubation period, a wire loop sterilized by flaming it in a Bunsen burner was used to pick the isolates and subcultured using appropriate agar plates and incubation conditions maintained. Nutrient agar (NA) was used to subculture bacterial isolates. Pure isolates were identified using standard microbiological methods and molecular characterization. Sabouraud dextrose agar (SDA) plates were incorporated with antibiotics to prevent the growth of bacterial species which are contaminants. Repeated subculturing of each isolate was carried out using freshly prepared media until discrete colonies were obtained and transferred into slants. The slants were maintained until proper identification, and characterization of the isolates were concluded.

Identification of bacterial and fungal isolates

Distinct bacterial and fungal colonies that appeared on NA and SDA culture plates were picked based on the uniqueness of colonial characteristics, respectively. Each bacterial colony was characterized based on the colonial morphology, pigmentation, Gram reaction, motility, and biochemical tests performed using standard methods. The fungal isolates were identified based on lactophenol cotton blue stain, and morphological characteristics (Cruickshank *et al*., 1975; Harrigan and McCance, 1976; Samson and Hocstra, 1988; Ire *et al*., 2020).

Molecular identification

DNA extraction

In order to extract the deoxyribonucleic acid (DNA) present in the isolates, a ZR fungal/bacterial DNA mini prep extraction kit was used. The kit was imported from Inqaba, South Africa. A pure culture of each isolate that grew very well was aseptically transferred into e a ZR bashing bead lysis tube that contain

200 µL of isotonic buffer. 750 µL lysis solution was accurately measured and poured inside the lysis tube. Afterwards, the lysis tube was placed in a bead beater (it has a 2 mL tube holder). To achieve the purpose of releasing the lysed DNA inside the cell, machine carrying the lysis tube was operated at full speed for 5 minutes. Afterwards, the ZR bashing bead lysis tube was transferred to a centrifuge and spun for 1 minute at 10,000 x g. After centrifuging the sample, the supernatant measuring 400 µL was poured in a collection tube with an orange-top Zymo-Spin IV spin filter and spun at 8000 x g for 1 minute. The filtrate in the collection tubes was mixed with 1200 µL of fungal/bacterial DNA binding buffer. The total volume of the solution is 1600 µL. Eight hundred microliter (800 µL) of the solution was moved to a Zymo-Spin IIC column which has a collection tube and spun at 10,000 x g for 60 seconds. Coming from the collection tube is a flow that was discarded. What was left in the collection tube was placed on Zymo-spin. Thereafter, it was turned. Two hundred microliter (200 µL) of the DNA prewash buffer was added to the Zymo-spin IIC using a collection tube that is new. The content of the tube was spun at 10,000 x g for 1 minute. Afterwards, 500 µL of the fungal/bacterial DNA Wash Buffer was added, and the tube was spun at 10,000 x g for 1 minute. The Zymo-spin IIC column was moved to a clean 1.5 µL centrifuge tube. Exactly 100 µL of DNA elution buffer was added to the column matrix, and the column was spun at 10,000 x g for 30 seconds to bring out the DNA. The ultra-pure DNA extracted from the isolates was put in a freezer that maintained a temperature as low as -20 ^{o}C. The DNA sample was used in subsequent steps that involves quantification and sequencing.

DNA quantification

After the genomic DNA from the isolates were successful extracted, each of them was quantified using a Nanodrop 1000 spectrophotometer. Double-clicking of the Nanodrop icon automatically launched the software installed in the equipment. A sterile distilled water measuring 2 µL was used to set up the equipment, while normal saline was used to clear it. Two microliters (2 µL) of the genomic DNA extracted was put on the lower pedestal in the equipment. Thereafter, the upper pedestal was adjusted downwards in order to touch the extracted DNA in the lower pedestal.

16S rRNA amplification

The 16S rRNA region of the rRNA gene of the isolates was amplified. It involved the use of two primers namely 27F: 5'-AGAGTTTGATCMTGGCTCAG-3' and 1492R: 5'-CGGTTACCTTGTTACGACTT-3'. ABI 9700 Applied Biosystems thermal cycler is the equipment used for the amplification. A final volume of 40

µL was analysed by the thermal cycler for 35 cycles. A combination of Taq polymerase, dNTPs, and $MgCl_2$ referred as X2 Dream Taq Master mix was used as the PCR mix. The PCR mix was supplied by Inqaba Biotech., South Africa. The concentration of the primers is 0.5 µM, while the template used is the extracted DNA. The following PCR conditions were maintained during amplification of 16S rRNA: temperature of 95 °C was maintained for a period of 5 minutes for initial denaturation; the same temperature (95 °C) was maintained for 40 seconds for denaturation to occur; a lower temperature (52 °C) was maintained for 40 seconds for annealing to occur; extension occurred when a temperature of 72 °C was maintained for 40 seconds for 35 cycles; and final extension occurred within 5 minutes when the temperature was maintained for 72 °C. Separation of the product was carried out using a 1% agarose gel operated at 130 V for 30 minutes. Visualization of the product is made possible and could be seen on a blue light transilluminator.

Internal Transcribed Spacer (ITS) amplification

The ITS region of the isolate was amplified using the ITS1F: 5'-CTTGGTCATTTAGAGGAAGTAA-3' and ITS4: 5'-TCCTCCGCTTATTGATATGC-3' primers on an ABI 9700 Applied Biosystems thermal cycler at a final volume of 30 µL for 35 cycles. A combination of Taq polymerase, dNTPs, and $MgCl_2$ referred as the X2 Dream Taq Master mix was obtained from Inqaba Biotech., South Africa. The concentration of the primers used was 0.5 µM, while the extracted DNA is the template. The PCR conditions were as follows: temperature of 95 °C was maintained for a period of 5 minutes for initial denaturation; the same temperature (95 °C) was maintained for 40 seconds for denaturation to occur; a lower temperature (53 °C) was maintained for 40 seconds for annealing to occur; extension occurred when a temperature of 68 °C was maintained for 40 seconds for 35 cycles; and final extension occurred in 5 minutes when the temperature was maintained for 68 °C. For a 600bp product, the amplicon product was resolved on a 1% agarose gel. The operational condition is 200 V for exactly 15 minutes. Viewing of the amplicon was done using a blue light transilluminator.

Sequencing of 16S rRNA and ITS

A BigDye Terminator kit on a 3510 ABI sequencer manufactured by Inqaba Biotechnological of Pretoria, South Africa was used for sequencing of 16S rRNA and ITS. The final volume used for the sequencing was 10 µL. The components were as follows: 0.25 µL BigDye® terminator v1.1/v3.1, 2.25 µL of

5 x BigDye sequencing buffer, 10 µL of 10 µM Primer PCR primer, 2-10 ng PCR template per 100 bp. The following describes the sequencing conditions: 32 cycles of 96 °C for 10 seconds, 55 °C for 5 seconds, and 60 °C for 4 minutes.

Physicochemical analysis

Determination of pH

The pH values of tomato powder and fruit tomato samples was ascertained with the aid of a calibrated pH meter (Hanna model). It is a portable device which is carried around with a palm. Before using the pH meter to determine the pH of the fruit tomato, the sample was pulverized without adding water to it. A blender was used to pulverize the sample and poured into a 100 mL beaker. The six tomato powder samples were separately weighed into 100 mL beakers. Fifty millilitre (50 mL) of distilled water was added to each of the tomato powders inside a beaker to form solutions. The pH of all the samples was determined after the digital device was inserted into the solution as instructed by the manufacturer. The pH measurements were performed for all the samples. The analysis was carried out immediately after the tomato powder samples were produced and fresh tomato sampled. Ten replicate samples for each tomato preparation were analyzed. The analysis was repeated after the samples were stored for 16 weeks, at room temperature (25±2 ºC).

Determination of the vitamin C content

The vitamin C content of tomato powder and fruit tomato samples was determined using the AOAC (2000) titrimetric method. The solution used for the analysis was 0.01 g of 2, 6, dichlorophenol-indo-phenol in 100 mL of distilled water. Accurately measured 2 mL and 10 mL of glacial acetic acid were added to 5 mL of standard ascorbic acid and 25 mL of the sample solutions, respectively. While titrating both the standard ascorbic acid and the sample's solutions, indo-phenol was added. Titration continued until a pink colouration of the solution was noticed. Immediately it happened, the titre value was noted. The analysis was performed immediately after the tomato powder samples were produced and fresh tomato sampled. Ten replicate samples for each tomato preparation were analyzed. A repeat analysis was carried out for all the samples stored for 16 weeks, at room temperature (25±2 ºC).

Determination of the moisture content

The air oven drying method described by AOAC (2000) was used as a guide to perform the analysis. The samples involved were tomato powder and fruit tomatoes. Accurate weighing of the samples and empty crucibles used for

the analysis was performed using a calibrated analytical balance. The samples was heated at 100 °C for 10 hours. Afterwards, the samples were allowed to cool in a desiccator. The moisture analysis was performed immediately after the tomato powder was produced and fresh tomato sampled. After storing the tomato powder samples for 16 weeks at room temperature (25±2 °C), the moisture content of the samples was determined. The percentage moisture content of each sample was calculated using the formula overleaf:

$$\% \text{ Moisture content} = \frac{Crucible + Sample\ weight - Final\ weight\ of\ dried\ sample + crucible}{Crucible + Sample\ weight - Empty\ crucible\ weight} \times 100$$

Determination of the ash content

The furnace method described by AOAC (2000) was used as a guide to perform the test. The samples analyzed were tomato powder and fruit tomatoes. Each sample was weighed into an empty crucible which has been polished by flame. The sample inside the crucible was heated to ash in a muffle furnace at 630 °C for 3 hours. The crucible containing the ash was brought out from the muffle furnace and transferred into a desiccator to cool. Afterwards, the crucible containing ash was reweighed. The ash content of the sample was calculated. The analysis was performed immediately after the tomato powder was produced and fresh tomato sampled. Ten replicate samples for each tomato preparation were analyzed. After the samples were stored for 16 weeks at room temperature (25±2 °C), their ash content were also determined. The calculation of percentage ash content of each sample involves the formula:

$$\% \text{ Ash content} = \frac{Weight\ of\ crucible + sample - Weight\ of\ crucible + Sample\ after\ ashing}{Crucible + Weight\ of\ sample - Weight\ of\ empty\ crucible} \times 100$$

Determination of the titratable acidity

The titratable acidity as ascorbic acid of tomato powder samples and fruit tomato, were determined using the AOAC (2000) titrimetric method. Accurately weighed 0.1 g of each sample was transferred into a 250 mL conical flask. Afterwards, 100 mL of distilled water was added to the sample inside the conical flask. Twenty five milliliters (25 mL) of the solution was dispensed into beakers. The solution inside the beaker was used for titration. One drop of phenolphthalein that function as an indicator was added to the sample's solution. The solution was

titrated with 0.1 M sodium hydroxide. The titre value was noted immediately a pink color change appeared in the solution. The titratable acidity of each sample was performed immediately after the production of the tomato powder samples and fresh tomato. Ten replicate samples for each tomato preparation were analyzed. The analysis was repeated after the samples were stored for 16 weeks at room temperature (25±2 ^{o}C).

Determination of the functional properties

Water absorption capacity

The capacity of tomato powder to absorb water is reported as water absorption capacity. The test was performed using the stepwise procedure described by Sosulski *et al.* (1976). One gram (1 g) of the tomato powder was mixed with 10 mL of distilled water. The mixture was kept at room temperature (25±2 ^{o}C) for 30 minutes. The mixture was poured in tubes and centrifuged at 3,000 revolutions per minute. The percentage of water bound per gram of tomato powder was determined and the value(s) was used to calculate the water absorption rate. Ten replicate samples for each dehydrated tomato preparation were analyzed.

Oil absorption capacity

The procedure for determination of oil absorption capacity as described by Sosulski *et al.* (1976) was adopted. Tomato powder were the samples analyzed. One gram (1 g) of the sample was accurately weighed using a calibrated analytical balance. The weighed sample was mixed with 10 mL of soybean oil (Sp. Gravity: 0.9092). The mixture was left undisturbed for 30 minutes at room temperature (25±2 ^{o}C). Afterwards, the mixture was transferred in a test tube and spun in a centrifuge operated for 30 minutes at 300 rpm (2000 x g). Ten replicate samples for each dehydrated tomato preparation were analyzed.

Emulsion stability

The method described by Yasumatsu *et al*. (1972) for measuring the emulsion activity of food samples was adopted. In this experiment, an emulsion was created by adding 1 g of each tomato powder sample to 10 mL of distilled water and 10 mL of soybean oil in a calibrated centrifuge tube. The mixture was centrifuged at 2, 000 g for 5 minutes. The emulsion activity in the sample was calculated by dividing the emulsion layer height by the entire mixture height and expressed in percentage. The emulsion inside a calibrated centrifuge tube was heated at 80 °C in a water bath for 30 minutes. Afterwards, it was chilled

for 15 minutes under running tap water. The centrifuge tube containing the emulsion was transferred to a centrifuge and operated at 2, 000 g for 15 minutes. Thereafter, the emulsion stability was measured. A ratio of the emulsified layer's height to the whole mixture's height was used to estimate the stability of the emulsion. The result was expressed in percentage. Ten replicate samples for each dehydrated tomato preparation were analyzed.

$$\text{Emulsion stability} = \frac{Height\ of\ emulsion\ layer}{Total\ height} \text{ x } 100$$

Foaming capacity

The foaming capacity (FC) of tomato powder samples was determined by using the procedure described by Narayana and Narsinga (1982). Analytical balance was used to weigh 1 g of the sample. It was poured in a graduated measuring cylinder containing 50 mL of distilled water. The mixture was mixed at 30.2 °C. In order to create foam inside the measuring cylinder, the suspension was shaken vigorously for 5 minutes. The foam capacity of the sample was calculated by measuring the volume of foam, 30 seconds after whipping. Ten replicate samples for each dehydrated tomato preparation were analyzed.

$$\text{Foam capacity (FC)} = \frac{Volume\ of\ foam\ (AW) - Volume\ of\ foam\ (BW)}{Volume\ of\ foam\ (Bw)} \text{ x } 100$$

Where: AW = after whipping
BW = before whipping

After whipping the sample for 1 hour, the volume of foam formed was recorded. The result was used to calculate the stability of the foam, which is the percentage of the original volume of foam.

Bulk density

The procedure described by Jones *et al*. (2000) was used as a guide to perform the test. A calibrated analytical balance was used to weigh 20 g of tomato powder sample. It was poured in a 250 mL cylinder. The cylinder containing the sample was placed on a wooden board, and tapped several times. It continued until visible loss in volume was not observed any longer. The apparent (bulk) density was then determined using the weight and volume. Ten replicate samples for each dehydrated tomato preparation were analyzed.

Determination of the lycopene content

The quantity of lycopene present in the tomato powder samples was extracted using the procedure earlier described by Fish *et al.* (2002). One gram (1 g) of tomato powder was accurately weighed using a calibrated analytical balance. The sample was mixed with 5 mL of butylated hydroxytoluene (BHT) dissolved in acetone, 5 mL of ethanol, and 10 mL of hexane (Darmstard, Germany). The same procedure was repeated using fruit tomatoes. The ingredients were added to a bowl of ice. A magnetic stirring plate was used to swirl the content of the bowl for 15 minutes. Exactly 3 mL of deionized water was measured. Immediately after adding the deionized water to each sample vial, the solution was shaken on ice for 5 minutes at room temperature. Thereafter, it was noticed that the samples had been successfully separated into their respective phases. The absorbance of the hexane layer (upper layer) was measured at 503 nm in a spectrophotometer (UV-visible 754, Siemens, China). Estimated concentration of lycopene in the samples was obtained using the Beer-Lambert law that involves making the appropriate substitution for the molar extinction coefficient of lycopene in hexane. The equation is thus:

$$\text{Lycopene content (mg/100g)} = A_{503} \times 31.2/\text{g tissue}$$

Sensory evaluation

Sensory evaluation of the tomato powder without pretreatment, pretreated samples, and the control wrapped in polyethylene terephthalate pouches, was carried out before storage (week 0). Twenty (20) untrained panelists selected among the students of the University of Port Harcourt, evaluated the sensory properties of the coded samples (BAAP, UAAP, BLJP, ULJP, SDTP, and CTRL) of tomato powder for colour, smell, and handfeel, on a 9-point Hedonic scale. On this scale, the numbers 1-9 represent the following: 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

Statistical analysis

Analysis of Variance (ANOVA) was deployed in statistical analysis of the data emanating from the study. In addition, a Duncan's Multiple Range Test (DMRT) was carried out to test for a significant difference at $P<0.05$, between the treatment combinations. In order to carry out the statistical analysis of the data with ease, the Statistical Package for the Social Sciences (SPSS) version 23 software was used. Box plot and regression analysis were carried out using R Programming Software for Statistical Analysis.

Results

Bacterial population

The range of total viable count (TVC) of the stored samples include tomato blanched lime juice pretreated tomato powder (4.41-6.64 log_{10}CFU/g), unblanched lime juice pretreated tomato powder (4.45-4.95 log_{10}CFU/g), sundried tomato powder (5.99-7.31 log_{10}CFU/g), blanched ascorbic acid pretreated tomato powder (4.41-4.95 log_{10}CFU/g), unblanched ascorbic acid pretreated tomato powder (4.43-5.13 log_{10}CFU/g), and the control (4.57-5.17 log_{10}CFU/g). The TVC of the fruit tomato was 4.02 log_{10}CFU/g. The regression analysis shows that all the samples experienced a decrease in the total viable count, as indicated by the negative slope values (Fig. 1). The rate at which the TVC declined vary among the stored tomato powder subjected to different pretreatments, samples without pretreatment, including the control, with each sample showing a different slope. The SDTP and BLJP tomato powder showed stronger relationships, with R^2 values of 0.602 and 0.329, respectively. This suggests that the effect of sun-drying and pretreatment on the TVC of the SDTP and ULJP tomato powder, respectively, were more predictable and stable throughout the storage period (Fig. 2). On the other hand, the Control (R^2=0.054), ULJP (R^2=0.198), BAAP (R^2=0.231), and UAAP (R^2=0.264) tomato powder showed a weaker relationships, as evidenced by their low R^2 values.

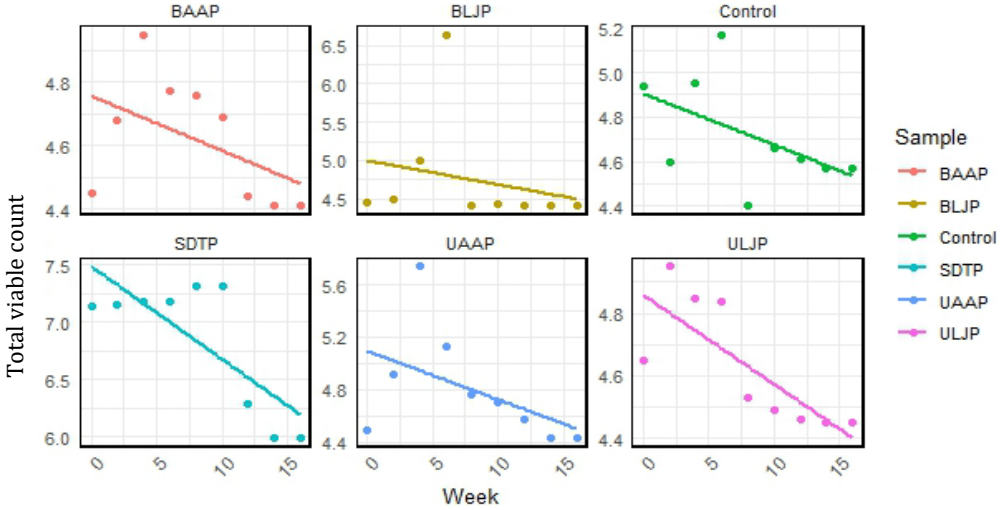

Figure 1. Linear regression of total viable count of tomato powder stored for 16 weeks at room temperature. Keys: BAAP - Blanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; UAAP - Unblanched ascorbic acid pretreatment; CTRL - Control sample, without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment.

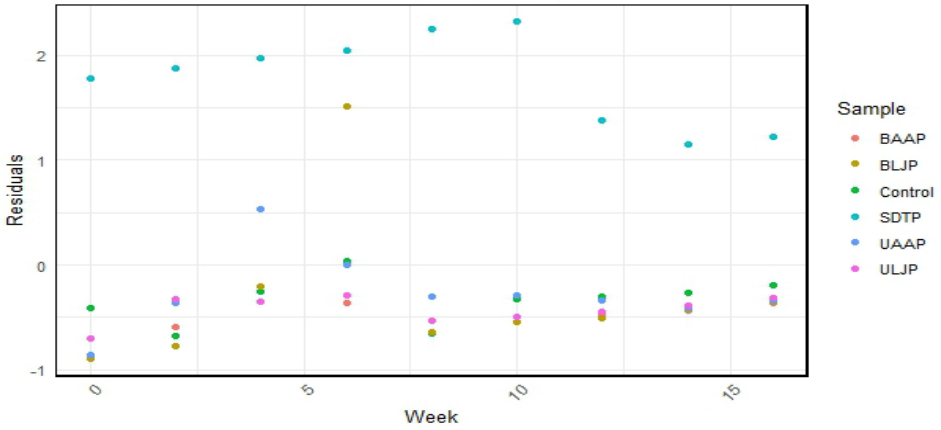

Figure 2. Residuals of linear regression for each sample of stored tomato powder for 16 weeks. Keys: BAAP - Blanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; UAAP - Unblanched ascorbic acid pretreatment; CTRL - Control sample, without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment.

Microbial species

The bacterial species isolated from the tomato samples were *Bacillus cereus, B. anthracis, Proteus mirabilis, Acinetobacter calcoaceticus,* and *Klebsiella pneumonia* (Tab. 1), while the fungal isolates were *Pichia kudriavzevii, Trametes polyzona, Aspergillus foetidus,* and *Aspergillus novoparasiticus* (Tab. 2). The agarose gel electrophoresis and accession numbers of the bacterial isolates are presented in Fig. 3 and Tab. 2, while the results for the fungal isolates are depicted in Fig. 4 and Tab. 3, respectively. Fig. 5 depicts the tomato powder without pretreatment, pretreated samples, and the control, stored inside polyethylene terephthalate pouches for 16 weeks, at room temperature (25±2 ºC).

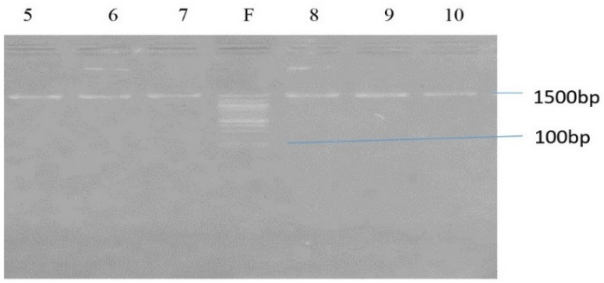

Figure 3. Agarose gel electrophoresis of the 16 S rRNA gene of the bacterial isolates. Lanes 5, 6, 7, 8, 9, and 10 represent the 16*S* rRNA gene band (1500 bp). Lane F represents the 100 bp molecular ladder of 1500 bp.

Table 1. Accession number for the bacteria isolated from the tomato powder samples.

Isolate code	Accession number	Similarity index	Bacterial species
F5	0N763797	99	*Bacillus cereus*
F6	CP073248	96	*Proteus mirabilis*
F7	CP101560	70	*Klebsiella pneumoniae*
F8	KT362717	100	*Bacillus anthracis*
F9	OP160033	58	*Acinetobacter calcoaceticus*
F10	OP160033	58	*Acinetobacter calcoaceticus*

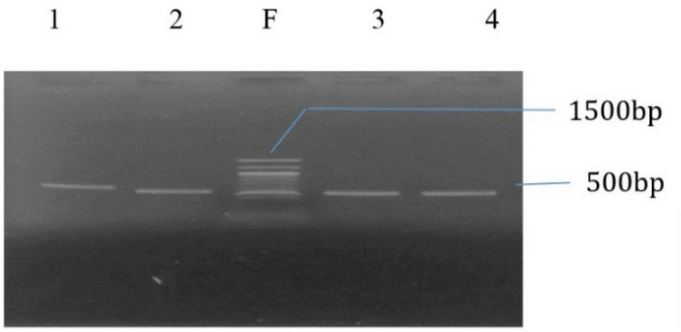

Figure 4. Agarose gel electrophoresis showing ITS gene of the fungal isolates. Lane 1 represents 600 bp; Lane 2 is 550 bp; and Lanes 3 and 4 are 500 bp of the ITS gene. F represents a100 bp DNA ladder of 1500 bp.

Table 2. Accession number for the fungi isolated from the tomato powder samples.

Isolate code	Accession number	Similarity index	Fungal species
F1	MK294305	100	*Pichia kudriavzevii*
F2	OP482406	100	*Aspergillus foetidus*
F3	OL685335	100	*Trametes polyzona*
F4	OL711681	100	*Aspergillus novoparasiticus*

Figure 5. Tomato powder without pretreatment, pretreated samples, and the control, stored inside polyethylene terephthalate pouches for 16 weeks, at room temperature. Keys: BAAP - Blanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; UAAP - Unblanched ascorbic acid pretreatment; CTRL - Control, without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment.

Physicochemical parameters and nutritional content

Fig. 6 shows the box plot for the pH, titratable acidity, moisture, ash, and vitamin C content of the fruit tomato, tomato powder without pretreatment, pretreated tomato powder, and the control, at week 0. Also presented as a box plot (Fig. 7) is the pH, titratable acidity, moisture, ash, and vitamin C content of the tomato powder without pretreatment, pretreated tomato samples, and the control, stored for 16 weeks, at room temperature (25±2 ºC).

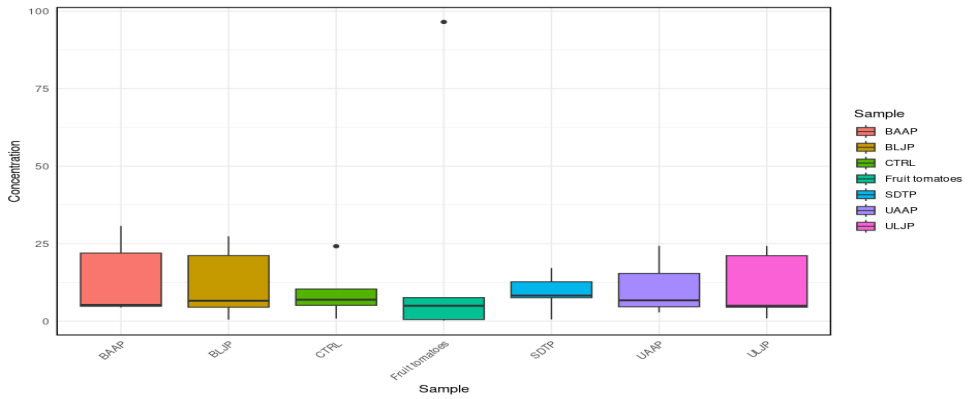

Figure 6. Boxplot of physicochemical, proximate composition, and vitamin C content of fruit tomato, tomato powder without pretreatment, pretreated samples, and the control, at week 0. Keys: BAAP - Blanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; UAAP - Unblanched ascorbic acid pretreatment; CTRL – Control, without pretreatment, dried with a dehydrator; SDTP – Sundried, without pretreatment.

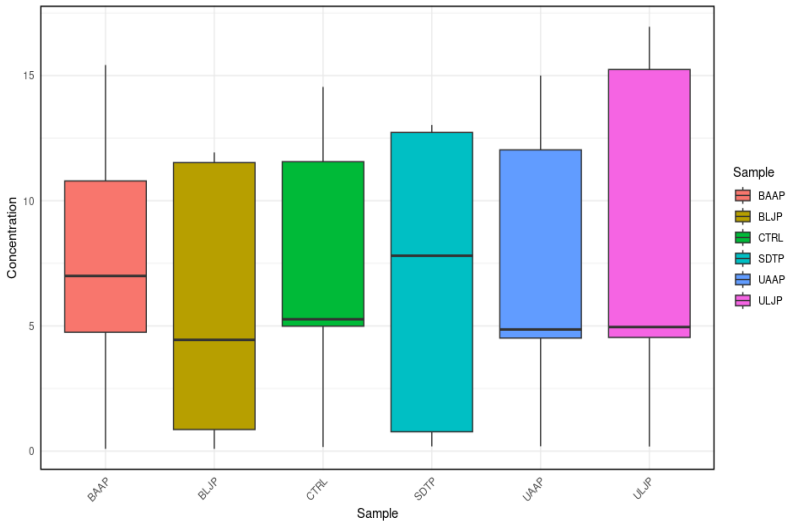

Figure 7. Boxplot of physicochemical, proximate composition, and vitamin C content of tomato powder without pretreatment, pretreated samples, and the control at week 16. Keys: BAAP - Blanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; UAAP - Unblanched ascorbic acid pretreatment; CTRL – Control, without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment.

At week 0, the pH of fruit tomato was 4.96±0.02, while the tomato powder samples was within the range of 4.50±0.02-8.25±0.01. The BLJP and ULJP tomato powder samples had the least pH, whereas the sundried tomato powder (SDTP) had the highest. At week 16, the pH of the stored tomato samples was within the range of 4.42±0.10-7.8±0.06. A slight reduction in pH was reported in the stored tomato powder samples, with the exception of the control (pH 5.10).

The moisture content of the fruit tomato was 96.53±0.38%, while the tomato powder without pretreatment and the pretreated samples was within the range of 12.70±0.30-27.37±0.34%, at week 0. Meanwhile, the moisture content of the control sample was 24.18±0.26%. At week 16, the moisture content of all the samples of tomato powder within the range of 10.79±0.07-15.24±0.09% decreased from their initial values at week 0. The moisture content of the control sample was 14.55±0.10%.

The ash content of the tomato powder without pretreatment and the pretreated samples at week 0, were within the range of 4.95±0.11-17.15±0.12%. Meanwhile, the ash content of fruit tomato and control sample was 0.53±0.06% and 6.92±0.10%, respectively. Among the tomato powder samples, sundried

tomato powder (SDTP) had the highest ash content, whereas the unblanched lime juice pretreated (ULJP) tomato had the least. At week 16, the ash content of stored tomato powder samples were within the range of 0.86±0.06-13.02±0.11%. SDTP sample also had the highest ash content, whereas the BLJP tomato powder had the lowest. The ash content of the control sample was 5.27±0.11%.

At week 0, the vitamin C content of the fruit tomato, sundried tomato powder, and control sample was 0.20±0.03%, 0.56±0.09%, 0.85±0.07%, respectively. The vitamin C content of the pretreated tomato powder samples was within the range of 0.52±0.05-4.41±0.09%. BLJP and BAAP tomato powder had the lowest and highest vitamin C content, respectively. At week 16, the vitamin C content of all the samples of stored tomato powder was below 1%.

The titratable acidity (TA) of fruit tomato was 7.60±0.14%, while the tomato powder without pretreatment and pretreated samples was within the range of 7.57±0.30-30.73±0.10%. The TA of the control sample was 10.37±0.10%. Fruit tomato and SDTP sample had relatively the same titratable acidity (7.60%). After the tomato samples were stored for 16 weeks, the TA of the products decreased from their initial values, with the exception of the control. The TA of the stored tomato powder samples were within the range of 0.77±0.08-16.94±0.09%.

Lycopene content

The lycopene content of the fruit tomatoes, tomato powder without pretreatment, the pretreated samples, and the control are presented in Tab. 3.

Table 3. Lycopene content (mg/100g) of fruit tomatoes, tomato powder without pretreatment, pretreated samples, and the control at week 0.

Sample	BAAP	BLJP	CTRL	UAAP	ULJP	SDTP	Fruit tomato
R1	129.84	123.11	134.11	123.15	113.23	100.45	19.90
R2	130.45	120.45	130.05	121.04	112.45	101.67	16.83
R3	127.85	119.84	131.66	120.67	108.84	103.80	19.84
R4	128.34	121.07	132.49	118.85	109.25	101.29	19.17
R5	131.11	122.21	133.78	121.00	110.43	100.58	19.54
R6	128.14	121.53	130.99	117.59	111.95	99.99	18.94
R7	131.02	123.11	132.35	118.77	108.47	104.13	20.34
R8	129.23	120.89	133.11	119.48	112.80	103.49	19.04
R9	129.99	118.34	134.39	122.22	112.29	103.33	16.55
R10	130.14	120.23	134.08	117.11	108.99	102.54	19.48
Mean	129.61±1.75^{e}	121.08±1.49^{d}	132.70±1.46^{f}	119.11±1.96^{d}	110.87±1.86^{c}	102.13±1.53^{b}	18.96 ±1.27^{a}

Values in the last row represent the mean of ten samples ± standard error. Means with different superscripts along the row are significantly different at $p<0.05$. Keys: BAAP - Blanched ascorbic acid pretreatment; UAAP - Unblanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; CTRL - Control without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment; R-Replicate.

Ten replicate samples for fruit tomato and dehydrated tomato preparations were analyzed. The mean lycopene content of the fruit tomatoes was 18.96±1.27 mg/100 g, while the tomato powder samples were within the range of 102.13±1.53-132.70±1.46 mg/100g. On average, the control sample had the highest lycopene content. There is a significant difference ($p<0.05$) in the lycopene content of the tomato samples, with the exception of BLJP and UAAP tomato powder.

Functional properties

Tab. 4 shows the functional properties of the tomato powder without pretreatment, the pretreated samples, and the control, at week 0. Among the samples, the blanched ascorbic acid pretreated (BAAP) tomato powder, had the highest water absorption capacity (WAC), bulk density, and foaming capacity reported as 15.53±1.70%, 1.17±0.32 g/cc, and 61.05±1.70%, respectively. The control sample had the lowest WAC (12.05±1.81%) and bulk density (0.64±0.07 g/cc), whereas its emulsion stability (55.62±1.88%) was the highest among the tomato powder samples.

The water absorption capacity (WAC) of the tomato powder samples was within the range of 12.05±1.81- 15.85±1.45%. The unblanched ascorbic acid pretreated tomato powder had the highest WAC, whereas the control sample had the least. There is a significant difference ($p<0.05$) in the WAC of the tomato powder samples.

The oil absorption capacity (OAC) of the tomato powder without pretreatment, the pretreated samples, and the control, was within the range of 12.53±1.57-16.66±1.40%. Among all the samples, the highest and lowest OAC were reported in the unblanched ascorbic acid pretreated (UAAP) and blanched lime juice pretreated (BLJP) tomato powder, respectively. The OAC of the control was 14.25±1.71%. There is no significant difference ($p>0.05$) in the OAC of the control and ULJP tomato samples; BAAP and UAAP tomato powder samples.

The emulsion stability of the tomato powder without pretreatment, the pretreated samples, and the control was within the range of 10.67±1.88-55.62±1.88%. The sample that had the highest and lowest emulsion stability was the control and blanched lime juice pretreated (BLJP) tomato powder, respectively. There is a significant difference ($p<0.05$) in the emulsion stability of the samples, with the exception of BLJP tomato powder and sundried tomato powder (SDTP).

The bulk density of the tomato powder without pretreatment, the pretreated samples, and the control was within the range of 0.64±0.07-1.17±0.32 g/cc. The control and blanched ascorbic acid pretreated (BAAP) tomato powder sample had the lowest and highest bulk densities, respectively. There is a significant difference ($p<0.05$) in the bulk density of the tomato samples.

The foaming capacity of the tomato powder without pretreatment, the pretreated samples, and the control was within the range of 26.02±0.10-61.05±1.70%. Among the tomato powder samples, blanched ascorbic acid pretreatment (BAAP) tomato powder had the highest foaming capacity, whereas the sundried tomato powder (SDTP) had the least. There is a significant difference ($p < 0.05$) in the foaming capacity among the samples, with the exception of the BLJP and the ULJP tomato powder samples.

Table 4. Functional properties of tomato powder without pretreatment, pretreated samples, and the control at week 0.

Functional property	Samples					
	BAAP	BLJP	CTRL	UAAP	ULJP	SDTP
Water absorption capacity (%)	15.53±1.70^{d}	14.27±1.09^{bc}	12.05±1.81^{a}	15.85±1.45^{d}	14.02±1.30^{b}	14.87±1.23^{cd}
Oil absorption capacity (%)	15.73±1.17^{c}	12.53±1.57^{a}	14.25±1.71^{b}	16.66±1.40^{c}	14.12±1.38^{b}	13.58±1.45^{a}
Emulsion stability (%)	14.78±1.62^{b}	10.67±1.88^{a}	55.62±1.88^{e}	49.81±1.78^{d}	25.42±1.80^{c}	11.37±1.43^{a}
Bulk density (g/cc)	1.17±0.32^{d}	0.73±0.11^{a,b}	0.64±0.07^{a}	0.84±0.09^{b,c}	0.88±0.09^{c}	0.75±0.09^{a,b,c}
Foaming capacity (%)	61.05±1.70^{e}	30.14±1.10^{b}	41.06±1.50^{d}	32.24±1.80^{c}	26.61±1.46^{b}	26.02±0.10^{a}

Values represent the mean of ten samples± standard error. The means with different superscripts in the same row are significantly different at $p<0.05$. Keys: BAAP - blanched ascorbic acid pretreatment; UAAP - Unblanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; CTRL - Control without pretreatment, dried with a dehydrator; SDTP - Sundried, without pretreatment.

Sensory evaluation

Tab. 5 shows the results of the sensory evaluation of the tomato powder without pretreatment, the pretreated samples, and the control, at week 0. In terms of colour, the blanched lime juice pretreated (BLJP) tomato powder had the highest average sensory score (8.85±0.00), whereas the sundried tomato powder (SDTP) had the least score (3.40±0.82). There is a significant difference ($p<0.05$) in the colour rating of the tomato powder samples, with the exception of the unblanched lime juice pretreated (ULJP) and unblanched ascorbic acid pretreated (UAAP) tomato powder samples. The sensory rating of handfeel of the blanched lime juice pretreated tomato powder (8.30±0.82) was the highest among all the tomato samples, whereas the control was the least (6.10±1.20). All the tomato powder samples were not significantly different ($p>0.05$) in

terms of handfeel, with the exception of the control. With regards to smell as a sensory attribute of a product, the blanched lime juice pretreated (BLJP) tomato powder was assigned an average sensory score of 8.40±1.07. It is the highest sensory score among all the samples, whereas the sundried tomato powder (SDTP) was the least (2.40±1.00). There is no significant difference ($p>0.05$) between the control, ULJP, and UAAP tomato powder samples.

Table 5. Sensory evaluation of tomato powder without pretreatment, pretreated samples, and the control at week 0.

Parameter	Samples					
	BAAP	CTRL	BLJP	ULJP	SDTP	UAAP
Colour	8.0 ± 0.92^{d}	6.05 ± 0.89^{b}	8.85 ± 0.00^{e}	7.25 ± 0.85^{c}	3.40 ± 0.82^{a}	7.45 ± 1.0^{c}
Handfeel	8.10 ± 0.99^{b}	6.10 ± 1.20^{a}	8.30 ± 0.82^{b}	7.40 ± 0.97^{b}	7.30 ± 1.16^{b}	7.40 ± 1.35^{b}
Smell	$8.10\pm1.00^{b, c}$	7.20 ± 1.72^{b}	8.40 ± 1.07^{c}	7.20 ± 1.60^{b}	2.40 ± 1.00^{a}	7.40 ± 1.38^{b}

Values represent the mean of ten samples$\pm$standard error. The means with different superscripts in the same row are significantly different at $p<0.05$. Keys: BAAP - Blanched ascorbic acid pretreatment; UAAP - Unblanched ascorbic acid pretreatment; BLJP - Blanched lime juice pretreatment; ULJP - Unblanched lime juice pretreatment; CTRL - Control without pretreatment, dried with a dehydrator; SDTP – Sundried, without pretreatment.

Discussion

Bacterial population of the stored tomato powder

The result from this study shows that the blanched ascorbic acid pretreated (BAAP) tomato powder and unblanched lime juice pretreated (ULJP) tomato powder stored for 16 weeks at room temperature (25±2 ºC), met the International Commission on Microbiological Specification for Foods (ICMSF) standard. Stored samples of the blanched lime juice (BLJP) and unblanched ascorbic acid pretreated tomato powders (UAAP) also met the ICMSF standard, except at weeks 4 and 6. The ICMSF standard was met by the control sample, except at week 6. The bacterial population in 3 out of 6 samples of stored tomato powders that exceeded the limit stipulated by the ICMSF at week 4 and 6 could be attributed to the initial level of microbial contamination of the samples, availability of nutrients, and storage condition. In contrast, the stored sample of the sundried tomato powder (SDTP) did not meet the ICMSF standard. The ICMSF stipulates that the total bacterial count (TBC) of acceptable food should be $< 10^5$ (Adejo *et al.,* 2015).

Exposure of tomatoes to the environment during sun-drying could be responsible for high bacterial population in the stored samples. Bacteria surviving in the air and dust particles especially spore formers could settle on the exposed tomato slices during sun-drying. Under a favourable condition, the spores would germinate as vegetative cells and increase the bacterial load of the product during storage. Consequently, the microbial load of the product is most likely to exceed the limit permissible by the ICMSF. The sundried tomato powder (SDTP) did not undergo pretreatment which could have reduced the microbial population in the product (Obadina *et al*., 2018; Owureku-Asare *et al*., 2022). The control sample which did not undergo pretreatment before a dehydrator was used instead of drying it under the sun had a lower bacterial count than the SDTP sample. This result is an indication that the use of dehydrator to dry tomato was more effective in reducing the bacterial population in the samples than the pretreatments. In a related study, Ladi *et al*. (2017) reported that the total bacterial count of the sundried tomato powder stored for 3 and 6 months is 7.7 x 10^5 and 7.3 x 10^5 CFU/g, respectively. Obadina *et al.* (2018) reported that during ambient temperature storage of cherry and plum tomato powder which were not pretreated before drying, the population of microorganisms in the products steadily increased. The total aerobic count in both varieties of dried tomato powder were lower than the results reported in this study. This could be as a result of a higher temperature (60 ^oC, 65 ^oC, and 70 ^oC) used by the researchers to dry the tomato slices compared with 55 ^oC used in this study. Generally, dehydrated food products have a lower microbial load, compare with fresh products. The level of microbial load in the product that is being dried could be influenced by temperature and other factors. Jayathunge *et al.* (2012) reported that the total plate count (TPC) of tomato powder stored inside polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and triple laminated aluminum (PET/Al/PE), for six months is within the range of 1.06 x10^2-4.45 x10^2 CFU/g. The result is lower than the total viable count (TVC) of tomato samples reported in this study. Differences in packaging material, pretreatment prior to drying, and drying method could be responsible for the differences in the TVC of the stored tomato powder.

Microbial species isolated from the tomato samples

Two species of *Bacillus,* one species of *Proteus, Acinetobacter,* and *Klebsiella* each were isolated from tomato powder without pretreatment, pretreated samples, and the control. In a related study, Garg *et al*. (2013) reported the presence of *Proteus mirabilis* and *Klebsiella* sp. and other bacterial species in tomato puree sold in India. Among the bacterial species isolated from selected commercial brands of tomato paste sold in Katsina metropolis, Nigeria, it was

reported that *Bacillus* sp. had the highest percentage occurrence (Dabai *et al*., 2020). *Bacillus* sp. is characterized by its ability to form spores. It gives the organism ability to survive in a harsh environmental condition. The bacterium is present everywhere. That is why *Bacillus* species frequently contaminate various food products including stored tomato powder. *Bacillus* sp. is capable of surviving in acidic foods such as tomatoes. Possible sources of contamination of tomato powder with *Bacillus cereus* and *B. anthracis* include, air, soil, water, and food handlers (Ire *et al*., 2020; Akpaetok *et al*., 2023). According to Ahaotu *et al.* (2021a), ingestion of food contaminated with large population of *Bacillus cereus* and *B. anthracis* could manifest severe symptoms of foodborne illness. In humans and animals, *Klebsiella pneumoniae* could be isolated from their respiratory and intestinal tracts. The bacterium is commonly encountered in foods such as powder foods specially prepared for babies. Consumption of food contaminated with *K. pneumoniae* could cause infections in humans. Findings from this study shows that two species of *Aspergillus*, one species of *Pichia* and *Trametes* each were also isolated from the tomato samples. The environment where the tomato samples were prepared could be the source of the fungal species isolated from the samples. In a related study, Aliyu *et al*. (2018) isolated *Aspergillus fumigatus, A. flavus, A. oryzae, A. niger,* and a few other fungal species from the sundried tomato chips sold in Sokoto metropolis, Nigeria. Suleiman *et al.* (2023) tested the capability of fungi isolated from dry tomato chips sold in Keffi, Nigeria, to produce mycotoxins. The study reported that some of the fungal species produced aflatoxin, fumonisins, patulin, ochratoxin, and cyclopiazonic acid toxin. The presence of *Aspergillus* sp. and other fungal species in tomato paste were reported by Dabai *et al.* (2020). Going by the information currently available on dried tomato powder, this report could be considered as the first time microorganisms isolated from dehydrated tomato powder, subjected to different pretreatments, was identified using molecular methods. With this information, the health risk of consuming tomato powder contaminated with potential pathogenic microorganisms have been brought to the knowledge of tomato farmers, consumers, and the relevant regulatory bodies.

Vitamin C content of the tomato samples

A striking result from this study is that the quantity of vitamin C in the fresh tomato was lower than the dried tomato powder without pretreatment and the pretreated samples prior to storage. Low moisture content and pretreatment of the dried tomato powder could be responsible for higher vitamin C content of the product compared with the fresh fruit. The temperature of drying could also influence the quantity of vitamin C in the tomato powder. Ranjan and Shankar (2024) reported that the amount of vitamin C in the tomato

powder dried using a dehydrator set at 60 and 100 ^{o}C is 15 mg/100g and 10 mg/100g, respectively. Meanwhile the vitamin C content of the sample dried under the sun for 2 weeks is 13mg/100g. The use of ascorbic acid in the pretreatment of tomato powder could be responsible for high vitamin C content of the BAPP (4.37±0.0%) and UAAP (2.82±0.1%) tomato powder samples. In a related study, Farooq *et al*. (2020) reported that the pretreatment of tomato powder with 0.5% ascorbic acid and 0.5% citric acid could be responsible for the increase in quantity of ascorbic acid (mg/100g) present in the product. At week 16 of storage, the UAAP tomato powder had the highest vitamin C content (0.19±0.0 %), whereas the blanched ascorbic acid pretreated (0.09±0.0 %) and blanched lime juice pretreated (0.09±0.0 %) tomato powder were the least. This result suggest that blanching of the tomato slices before drying it affected the vitamin C content of the product. Notably, the vitamin C content of all the tomato powder samples decreased during the period of storage. This is in agreement with the findings from a related study by Dufera *et al*. (2023). Vitamin C is highly sensitive to oxidation when it is stored (Caritá *et al.,* 2020). This could be the reason for the reduction in the vitamin C content of the tomato samples during storage at room temperature. The sample with the least capability to retain vitamin C during storage, was the sundried tomato powder (SDTP). In contrast, the blanched lime juice pretreated (BLJP) tomato powder had the greatest ability to retain vitamin C among all the tomato powder samples. According to Dufera *et al.* (2023), the ability of any food to retain vitamin C shows the extent the food can also retain other nutrients. The researchers reported that the vitamin C content of tomato powder stored inside low density polyethylene bags for six months is within the range of 31.84±3.4-50.57±0.025 mg/100 g DM.

pH and titratable acidity of the tomato samples

The pH of all the tomato powder samples including the control were slightly acidic, with the exception of the sundried tomato powder (SDTP) which was non-acidic. It was also observed that the pH of fresh tomato was higher than the dried pretreated samples. This result is in agreement with a similar study by Degwale *et al*. (2022). The researchers reported that the pH of fresh tomato (4.567±0.10408) is higher than the tomato powder (4.55±0.05-4.267±0.05774). The use of lime during pretreatment could have contributed to the slight reduction in the pH of the BLJP and ULJP tomato powder samples. Farooq *et al.* (2020) reported that the pH of hot-air and freeze-dried tomato powder (with or without pretreatment), monitored for 30 days is within the range of 4.39±0.25-5.53±0.25. According to Sarker *et al*. (2014), the pH requirement that makes it most suitable for tomatoes to be processed into different products is 3.77. The researchers used 1% calcium chloride and 0.2%

potassium metabisulphite as a salt solution to pretreat tomato slices before it was dried, and packaged using three different packaging materials (LAF, HDPE, and MDPE). Each of the packaged tomato powder was stored at ambient temperature for six months. The pH of the samples is within the range of 3.58-4.30. This result is lower than the pH of stored tomato samples reported in this study. The variety of tomato, the osmotic agent used for the pretreatment, the activities of microorganisms present in the tomato, and the type of packaging material used for storing the product, could be responsible for the variations in pH. During industrial processing of tomatoes, it is recommended that the final pH of the product should not exceed 4.7. This condition will inhibit the growth of spoilage microorganisms, and extend the shelf life of the product (Sarker *et al*., 2014). The samples that met the requirement (pH > 4.7) were BLJP, UAAP, and ULJP tomato powder. Pretreatment of the tomato powder samples with lime and ascorbic acid could be partly responsible for the reduction in pH.

Most of the dried tomato powder samples had a relatively high values of titratable acidity (TA). This observation could be attributed to the concentration of organic acids in the tomato samples due to drying. A similar result was reported by Aderibigbe *et al.* (2018) and Obadina *et al.* (2018) from related studies. The observation that the TA of fresh tomato was lower than the pretreated tomato powder samples is in agreement with the findings from a related study by Degwale *et al*. (2022). The researchers reported that the TA of fresh tomato is 0.1433±0.00577%, while the dehydrated tomato powder samples were within the range of 0.2867±0.01528-0.4933±0.05508%. The breakdown of organic acids during storage of tomato powder could be the reason why the stored samples had a lower TA compared with the freshly prepared tomato powder samples. According to Aderibigbe *et al.* (2018), TA influences the taste, quality, and flavour of food products.

Ash and moisture content of the tomato samples

The ash content of sundried tomato powder (17.15±0.12%) at week 0 reported as the highest among all the samples could be attributed to mineral concentration due to the drying process. The fact that the fresh tomato (0.53±0.06%) had the least ash content compared to the dried tomato samples could be as a result of not drying the sample. Drying of tomatoes at different temperatures could also affect the ash content of the product. A study carried out by Ranjan and Shankar (2024) reported that the tomato powder dried under the sun; using a dehydrator set at 60 ^{o}C, and 100 ^{o}C is 5.00%, 5.20%, and 4.80%, respectively. Oladipupo *et al.* (2020) reported that the ash content of tomato powder stored for 6 weeks, using a black polyethylene and white polyethylene bag, is within the range of 10.2 to 10.80%. This result is partly in

agreement with our findings. Sarker *et al.* (2014) reported that the ash content of the tomato powder prepared using a salt solution (1% calcium chloride and 0.2% potassium metabisulphite) to pretreat the sample before it was dried, and stored inside a high density polyethylene (HDPE), medium density polyethylene (MDPE), and laminated aluminum foil (LAF) for 6 weeks is within the range of 9.22-9.52, 9.22-9.55 and 9.22-9.45%, respectively.

The moisture content (MC) of the fruit tomato was quite higher than the tomato powder samples (without pretreatment, the pretreated samples, and the control). Generally, freshly harvested fruits and vegetables have a high MC. It is one of the reasons fruits and vegetables have a short shelf life (Obiaocha-Nwaogwugwu *et al.,* 2024). Low MC of the tomato powder samples could be attributed to the effect of drying, which resulted in moisture loss of the fruit tomato. It has been reported that the temperature of drying could influence the MC of tomato power. Ranjan and Shankar (2024) reported that the MC of sundried tomato powder is 10%, while the samples dried at 60 ^{o}C and 100 ^{o}C is 10% and 20%, respectively. According to Nanelo and José (2023), the MC of dried tomatoes that ranges from 50-55% is acceptable. The MC of the tomato powder samples partially met the Commission économique pour l´Europe des Nations unies (CEE-ONU) standard which ranges from 12 to 18%. A very firm texture is one of the physical properties of the dried tomatoes that met the standard (Oboulbiga *et al*., 2022). In a related study that involved subjecting tomatoes to different pretreatments and storage conditions for a period of 60 days, Nanelo and José (2023) reported that the MC of the samples is within the range of 20.30±2.61-94.24±1.29%. The reduction in the MC of the stored samples of tomatoes, could be attributed to the metabolic activities of microorganisms present in the samples during storage. Moisture content within the range of 12.5 to 14.5% was reported by Oladipupo *et al*. (2020), in a study that involved storing the tomato powder pretreated with 1% $CaCl_2$ solution and 1% KMS, before it was dried and stored inside a laminated aluminum foil, black polyethylene, and white polyethylene bags, for 6 weeks. Sarker *et al*. (2014) reported that the MC of the tomato powder prepared using a salt solution (1% calcium chloride and 0.2% potassium metabisulphite) to pretreat the sample for 10 minutes, before it was dried, is 8.12%.

Lycopene content of the tomato samples

The lycopene content of the sundried tomato without pretreatment and tomato powder subjected to different pretreatments using weak acids were higher than the fruit tomato. This result is in agreement with the report by Degwale *et al*. (2022). According to the researchers, the increase in the lycopene content of the dehydrated tomatoes could be attributed to water loss. They also noted that the amount of lycopene in the tomato powder is concentrated after

the moisture content in the product is reduced. The lycopene content of the control sample was higher than other tomato powder samples subjected to different pretreatments. This result could be attributed to the leaching effect of nutrients caused by blanching and soaking the samples in the pretreatment solutions. Nishizono *et al*. (2023) reported that the lycopene content of three varieties of raw tomato fruit is within the range of 6.69±0.885 to 10.03±1.711 mg/100g. The lycopene content of the tomato powder stored in low density polyethylene bags for six months is within the range of 58.487±5.25 to 102.5±0.057 mg/100 g DM (Dufera *et al*., 2023). The lycopene content of the fruit tomato (18.96±1.27 mg/100g) evaluated in this study is lower than 85.33 mg/100g reported by Chen (2005) in the Tau-tai-lan T93 tomato variety. Studies have shown that different varieties of tomatoes have varying quantities of lycopene. The differences in lycopene content could be attributed to environmental factors and farming practices (Abushita *et al.,* 2000).

The lycopene content of tomatoes is influenced by the variety, growing area, varying temperature conditions, and agricultural methods, and equipment. According to Dūma *et al.* (2022), the lycopene content in the cherry tomato is higher than the big sized tomato. Drying of fruit tomato or subjecting the tomato slices to pretreatments before drying, could be responsible for the increase in lycopene content of tomato powder. Low moisture content of tomato powder compared with the fruit tomatoes could be responsible for "concentration effect", which increased the lycopene content of the product. The lycopene content of the sundried tomato powder was lower than other pretreated tomato powder, and the control samples. This result could be attributed to long period of sun-drying of tomato at an uncontrolled temperature, compared with quick drying of samples using a dehydrator at a high temperature (55 ^{o}C). According to Yusuf *et al.* (2013), the increase in temperature and duration of heat treatment of tomatoes could be responsible for lycopene degradation.

Functional properties of the tomato powders

It was observed that the bulk density of tomato powder without pretreatment, pretreated samples, and the control was low. Furthermore, the result indicate that pretreatment of the tomato powder samples dried in a dehydrator increased its bulk density. The way a food product is packaged is influenced by its bulk density. Packaging of any food product influences the final cost of the product. Bulk density is a parameter that determines the extent dried food products or powder will occupy space. Low bulk density is an indicator that a particular food is suitable to use in formulating a complementary food that is rich in nutrients. Therefore, tomato powder that were subjected to different pretreatments is more valuable than the fresh tomato. The size of particle,

protein, and starch content of a food substance influences its bulk density (Hussein *et al.,* 2016; Ahmad *et al*., 2022). Low bulk density of tomato powder reported in this study is an indication that during handling, storage, and distribution of the product, reduction in its volume, will not occur. This is in agreement with the report by Ahmad *et al*. (2022). The researchers reported that the bulk density of the sundried tomato and the tomato powder packaged in a polyethylene bag is 0.61±0.01 mg/100 g each.

The water absorption capacity (WAC) of pretreated tomato powder and the control indicate that pretreatment improved the WAC of the samples. According to Hussein *et al*. (2016), 'juiciness' of a food material could be rated using the parameter referred as water absorption index (WAI). Ahmad *et al.* (2022) reported that the WAC of sundried tomato and tomato powder packaged in polyethylene bags is 2.26±0.23 and 2.30±0.0.35 mg/100 g, respectively. The result is far lower than the WAC of tomato powder without pretreatment, pretreated samples, and the control. According to Ahmad et al. (2022), high WAC translate to low moisture content of a food product. In essence, the product shelf life is prolonged due to very slow activities of spoilage microorganisms. The ingredients that possess high water hydration capacity are recommended for food manufacturers to use as a thickening agent. Such ingredients can also be added to foods that contain too much water in order to reduce syneresis (Bhat *et al*., 2023).

According to Ahaotu *et al*. (2021b), oil absorption capacity (OAC) indicate the level of entrapment of oil by a food material. It is not only the mouth feel of a food product that is improved when the capacity of the food to absorb oil is increased, but also its flavour. Therefore, the unblanched ascorbic acid pretreated (UAAP) tomato powder ought to have the best sensory rating in terms of mouthfeel and flavour because the sample had the highest OAC compared with other tomato powders. A contrary sensory rating should involve the blanched lime juice pretreated (BLJP) tomato powder.

The blanched ascorbic acid pretreated (BAAP) tomato powder had the highest foaming capacity, whereas the least involved sundried tomato powder (SDTP). This result could be attributed to higher nutritional composition of the BAAP tomato powder, which caused the surface tension between water and air to reduce (Kaushal *et al.,* 2012). The unfolded protein that assemble at the boundary that separate the aqueous phase from the air phase is referred to as foams. Some researchers have suggested that the improvement in the foaming capacity (FC) and foaming stability (FS) by the formation of bubbles that are more uniform in size and adsorb faster, could be achieved with higher protein concentrations (1% w/w) (Mateo-Roque *et al*., 2024).

Our result indicate that pretreatment of tomato powder reduced the emulsion stability of the samples compared with the control. The emulsion stability of powders is an important functional property taken into consideration, while making and keeping emulsions stable in many food products (cake, coffee whiteners, and frozen desserts etc.). Owing to different components which they are made up of, the preparation of the above listed food products require different processes; their emulsifying and stabilizing requirements varies (Adebowale *et al.,* 2005).

Sensory report of the tomato powders

Blanched lime juice pretreated (BLJP) tomato powder was assigned the highest sensory score with regards to colour, smell, and handfeel of the samples, followed by the blanched ascorbic acid pretreated (BAAP) tomato powder. It is important to note that the three sensory attributes of BLJP and BAAP tomato powder samples were assigned average sensory scores interpreted as like very much. This sensory rating could be attributed to the combined effects of blanching, the use of ascorbic acid or lime juice during processing of the tomato powder, which contributed in stabilizing the colour and appearance of the product. Our sensory result is in agreement with the report by Latapi and Barrette (2005). According to the researchers, dipping tomatoes in 6% or 8% sodium metabisulphite for 5 minutes before drying, tremendously improved the colour of the product. Masamba *et al*. (2013) also reported that the fruit samples exposed to 1% sodium metabisulphite and lemon juice pretreatment before dying, had a better colour than the control sample. In terms of handfeel, the panelists recruited to carry out sensory evaluation of the samples regarded BLJP tomato powder as the most preferable product. In a related study, Panagiotou (1998) reported that the texture of vitamin C and honey-treated fruit samples were assigned a higher sensory score than the control sample. Overall sensory result from this study indicate that the sundried tomato powder (SDTP) was the least preferred sample. The sensory panelists had a moderate dislike for the colour of the SDTP, while the smell was disliked very much. Lack of pretreatment and exposure of the tomato sample to direct heat from the sun probably affected the sensory attribute of the product. According to Ramya *et al.* (2017), the ability of any dried food product to retain the original colour when it is still fresh, influences the choice of consumers and the market price of the product. Poor sensory rating of the SDTP sample could be attributed to higher fermentative activities of spoilage microorganisms from the environment on the sliced tomato during sun-drying. In addition, sun-drying of tomato powder could degrade the colour of the product by browning (Hameed *et al*., 2018; Degwale *et al*., 2022; Leke and Bembur, 2023). Our result clearly shows that the different pretreatments

applied during the production of tomato powder positively impacted the sensory attributes of the product. To some extent, the method of drying also played a role in the sensory attributes of the dehydrated tomato powder. In a related study, Ladi *et al*. (2017) reported that the oven-dried tomato powder had a better sensory rating in terms of colour, consistency, taste, flavour, and overall acceptability, compared with the sundried tomato powder.

Conclusions

Drying of the sliced tomato under the sun or the use of a dehydrator significantly reduced the moisture content of the fresh fruit tomato. It also influenced the nutrient composition, functional properties, and sensory attributes of the tomato samples. Blanched ascorbic acid pretreatment, unblanched ascorbic acid pretreatment, blanched lime juice pretreatment, and unblanched lime juice pretreatment, influenced the reduction in the microbial load of the dehydrated tomato powder, and reasonably improved the sensory attributes, functional properties, and quantity of lycopene and vitamin C in the product. Notably, different pretreatments of tomatoes affected the quantity of lycopene content in the dehydrated tomato powder, while exposure of sliced tomato to the environment during sun-drying is largely responsible for high bacterial load of the product. Although all the samples of stored tomato powders were packaged in polyethylene terephthalate pouches, there is possibility that the packaging material also influenced the quality of the product during storage. Based on the overall results, blanched ascorbic acid pretreatment is recommended for tomato slices, before drying the food material.

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