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Research Article

Formulation, acceptability, and shelf life evaluation of dried tomato and mixed dried tomato products

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Abstract

In Tanzania, tomatoes (*Solanum lycopersicum*) are widely cultivated and consumed, yet substantial postharvest losses occur due to their high perishability. Drying is a promising method to extend shelf life and add value to tomato products. This study evaluated the physicochemical, nutritional, microbiological, and sensory qualities of tomato soup powders produced using solar tunnel and electric dryers, stored in paper and plastic packaging at room temperature for five months. Two soup formulations were prepared using blends of dried tomato, garlic, onion, ginger, turmeric, cinnamon, monosodium glutamate, and cornstarch, differing in ingredient ratios. The pH, titratable acidity, total soluble solids, lycopene, β-carotene, vitamin C, and yeast and mold counts were measured to assess the effects of drying techniques, packaging materials, and storage duration. Results showed that drying method and packaging significantly influenced nutrient retention and microbial stability ($p < 0.05$). Soups dried with an electric dryer and packed in polyethylene retained higher nutrients, with lycopene decreasing from 17.35 to 13.12 mg/100 g, β-carotene from 5.20 to 3.85 mg/100 g, and vitamin C from 42.30 to 28.10 mg/100 g over five months. Microbial counts in polyethylene-packed samples remained below 10^3 CFU/g after four months but exceeded limits in paper-packed samples. Sensory evaluation indicated both products were acceptable, with a slight preference for electric-dried soups. Overall, combining electric drying with polyethylene packaging effectively preserved the nutritional quality, microbial safety, and sensory acceptability of tomato soup powders for up to four months, offering a practical approach to reducing tomato postharvest losses.

Keywords: Electric dryer, Postharvest loss, Shelf life, Solar dryer, Tomato.

Introduction

Tomato (*Solanum lycopersicum*) is among the most cultivated and consumed horticultural crops worldwide, with an estimated annual production of about 186 million metric tons by 2022. China, India, Turkey, and the United States are the leading producers, significantly influencing the global supply network (FAO 2023). Among the tomato varieties, nutritional composition is highly valued due to the abundance of bioactive compounds (lycopene, β-carotene, vitamin C, and phenolic compounds). These compounds contribute to the antioxidant properties of tomatoes, which offer various health benefits (Li et al., 2024; Motlhalamme et al., 2025). Worldwide, especially in developing countries, the crop succumbs to postharvest losses, which are mainly caused by inadequate infrastructure, poor management, and insufficient preservation technologies, despite high

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production levels (Bisht & Singh, 2024). Tomato cultivation is significant to improving food security as well as an income-generating in Sub-Saharan Africa. The region is, however, plagued by postharvest losses ranging between 30 and 60 %, depending on the season and country. As an example, in Rwanda, it is reported that losses are almost 56%, whereas in Togo, the losses are between 42% and 90% in the reduction of the main season and the minor season, respectively (Goka et al., 2021). These losses have arguably been resulting from poor harvesting methods, improper packaging material, and even the lack of cold stores. Low-cost postharvest innovations, including the use of zero energy cool chambers (ZECCs) and lined crates are relevant, but their adoption is insufficiently high in the face of a lack of awareness and financial limitations (Rutta, 2022).

In Tanzania, tomato is a vital part of the diet and serves as an important economic crop for smallholder farmers. However, postharvest losses are high, with research showing that 30 to 50% of tomatoes harvested are lost before reaching consumers (Akpapunam et al., 2025; FAO, 2022). A study conducted in the Morogoro region has found that losses occur at various points in the value chain, with about 29.7% at the farm level and 18.4% at the small-scale retailer stage (Mwankemwa et al., 2023). Inferior packaging materials, such as wooden crates, combined with long distances and limited access to storage technology, exacerbate these. The implementation of measures such as hessian-lined crates and ZECCs has been proven to reduce physical damage and spoilage, thereby enhancing shelf life and marketability (Okori et al., 2022). It is essential to keep addressing postharvest challenges by promoting affordable, effective technologies and strengthening farmers' capacity to improve the tomato value chain in Tanzania.

Among the traditional and most common methods of preserving tomatoes, drying is the primary technique that has been used over the years due to its effectiveness in extending shelf life by lowering the moisture content of tomatoes to levels that inhibit the growth of microorganisms and enzymatic reactions (Bisht & Singh, 2024). Advanced drying techniques such as solar tunnel dryers and energy-efficient convection dryers have been developed to address the limitations of the traditional open sun drying, which can degrade nutrients, cause contamination, and produce lower-quality products (Paolo et al., 2019). Research has shown that solar tunnel dryers can reduce tomato moisture content to below 15%, while preserving over 80% of key nutrients like lycopene and vitamin C compared to traditional methods (Dufera et al., 2021). These techniques also maintain sensory qualities like color, flavor, and texture, which are crucial for consumer acceptance (Petikirige et al., 2022). As a result, tomato powders produced from solar and electric oven dried products are used in soups, sauces, and seasoning mixes to help reduce postharvest losses and improve food security in Sub-Saharan Africa (Rutta, 2022).

Consumers will accept dried tomato-based products based on sensory characteristics such as appearance, color, flavor, aroma, and texture, along with overall acceptability. Sensory evaluation is therefore vital for determining consumer preferences and guiding product development (Porretta, 2019). Among these attributes, taste and aroma tend to have the strongest influence on consumer liking. Previous research has shown that, depending on the drying method, the flavor profiles of tomato products can be modified by changing volatile compounds and the sugar-acid balance (Paolo et al., 2019). Additionally, although taste plays a significant role in sensory perception, it does not necessarily enhance overall acceptability when other attributes, such as appearance and texture, are compromised.

To enhance the sensory attributes, the analysis of physicochemical, nutritional, and microbial properties is conducted, which is essential in determining the overall quality and shelf life of dried tomato products. Key physicochemical factors that influence shelf life and consumer acceptance by retailers include total soluble solids (TSS), pH, and color (Dufera et al., 2023). Among the nutritional parameters susceptible to changes during drying and storage, lycopene, β-carotene, and vitamin C are particularly important because they significantly affect the health-promoting potential of tomato products (Ali et al., 2020). It is vital to preserve these nutrients after drying, as maintaining their levels is critical to the functional value of dried tomato powders and related products. Microbial quality-particularly the concentration of yeast and molds- is a major factor in defining shelf stability and safety, with poor packaging or high moisture levels being able to give rise to spoilage and mycotoxin formation. Studies have also demonstrated that low-water vapor and low-oxygen permeable packaging materials are effective in substantially limiting microbial growth under ambient conditions (Long et al., 2023). Therefore, a combination of microbial tests with physicochemical and nutritional tests provides a suitable strategy for comparing quality changes over time.

While various studies have explored tomato drying techniques and product development independently, limited research in East Africa has integrated both drying methods and storage to assess their combined effects on the physicochemical, nutritional, and microbial quality of soup products made from dried tomato powders. This study addresses that gap by evaluating the quality and shelf life of soups formulated from two types of dried tomato powders. The findings contribute to evidence-based value addition strategies, reduction of postharvest losses, and improved food security in Tanzania.

Materials and Methods

Study area

The study was carried out in Tanzania's Morogoro Region. Using solar tunnel dryers and energy-efficient electric dryers, tomatoes were dried at the Sokoine University Graduate Entrepreneurs Cooperative (SUGECO), which is situated on the main campus of Sokoine University of Agriculture (SUA) in Morogoro Municipality. Additionally, at the Samia Suluhu Hassan Innovation Laboratory, the sensory evaluation was conducted. Meanwhile, the SUA food quality and nutrition laboratory, located at SUA, Department of Food Technology, Nutrition, and Consumer Sciences, carried out a shelf life examination of the dried tomato products.

Study design

This study employed a factorial completely randomized design (CRD) to evaluate the effects of tomato variety, drying method, packaging material, and storage duration on the quality and shelf life of dried tomato and mixed dried tomato products. Fresh tomatoes of two varieties (Emerald and Dhahabu) were obtained from Mlali Ward, Morogoro Region, Tanzania. Tomatoes were dried using two drying techniques: a solar tunnel dryer and an energy-efficient electric dryer. The dried products were then packaged in two packaging materials, polyethylene bags and paper bags, and stored under ambient conditions (25 ± 2 °C and approximately 60% relative humidity). Storage trials were conducted for up to five months (approximately 18 weeks).

The experiment consisted of 2 tomato varieties × 2 drying methods × 2 packaging materials, with three replicates per treatment combination, resulting in a total of 240 samples. Samples were collected weekly during the first month of storage and twice monthly from the second to the fifth month. All processing, including drying and packaging, was conducted at the SUGECO postharvest processing facility in Morogoro, Tanzania. After drying, samples were cooled to room temperature, packaged, and stored in designated ambient storage units. Each replicate was reduced by 15 g per sampling interval for analysis. Shelf life and quality were assessed through sensory acceptability, physicochemical properties (TSS, titratable acidity, and pH), nutrient retention (vitamin C, β-carotene, and lycopene), color characteristics, and microbial quality (yeast and mold counts). The study was conducted during the tomato harvest season, with analytical evaluations spanning the entire storage period.

Formulation of dried tomato products

Savory dried tomato seasoning product formulation

A combination of dried tomato powder, corn starch, iodized salt, and monosodium glutamate (MSG) was used to create a delicious dried tomato seasoning that would improve the finished product's umami profile. The main flavor foundation (60%) was dried tomato powder, with the addition of maize starch (15%) to prevent caking and to function as a bulking agent. While MSG (10%) was used to increase the savory or umami taste, iodized salt (15%) helped to preserve and enhance flavor (Susi et al., 2023). The first step in the preparation procedure was choosing fresh, ripe, and disease-free tomatoes. These were then carefully cleaned, cut into uniform slices, and dried at a regulated temperature. Once dried to a moisture content below 15%, the tomato slices were milled using a mechanical grinder and sieved through a 630 µm mesh to obtain a uniform fine powder (Shah &

Singh,2025). This powder formed the main ingredient in the seasoning blend.

All ingredients were accurately weighed using a precision digital scale under the formulation proportions (per 100 g blend: 60 g tomato powder, 15 g corn starch, 15 g iodized salt, 10 g MSG). The dry ingredients were combined in a clean stainless-steel mixing bowl and manually stirred for 3–5 min until a homogenous mixture with consistent color and texture was achieved. The final product was immediately packaged in airtight, food-grade sachets to prevent moisture absorption and microbial contamination, ensuring shelf stability (Jia et al., 2024).

Dried tomato seasoning blend product

Dried tomato seasoning mixture was created to offer a seasoning that was enhanced by spices and was multifunctional, and may be applied in cooking. The recipe was to mix our dried tomato with commercially dried spices-ginger, garlic, onion, cinnamon, and turmeric-and salt to offset the taste and enhance palatability. The mission of the blend was to provide an intense aromatic flavor with savory and warming-spice tastes to add to the attractiveness of the soups, sauces, stews, and snacks. The mixture recipe (per 100 g) was as follows: 50% tomato powder, 10% onion powder, 10% garlic powder, 8% ground ginger, 7% turmeric, 5% ground cinnamon, and 10% iodized salt. The products were measured for weight with the help of a digital scale. The powders were added to a sterilized, dry mixing bowl, and the contents were manually stirred until achieving a homogeneous mixture, not only based on the texture but also the color (Shah and Singh (2025). To maintain aroma, flavor, and microbiological quality of the final product during storage, the final product was packed into an airtight and moisture-resistant sachet.

Sensory evaluation

Sensory evaluation involved both hedonic testing and Quantitative Descriptive Analysis (QDA). The hedonic test**,** conducted with untrained panelists, compared consumer acceptability of soups prepared from tomato powders produced by the two drying methods, serving as a preliminary assessment for QDA planning. The QDA, following ISO 2023 (8586), was performed with a trained panel to describe and quantify key sensory attributes, including color, aroma, viscosity, flavor, and mouthfeel.

Hedonic

To ascertain the acceptability of soup items manufactured from various dried tomato powders, a sensory evaluation was conducted. The institution used convenience (availability) sampling to select thirty untrained panelists (workers and students, ages 20 to 40) based on their presence on campus and known tomato-based product sensitivities. To lower the likelihood of sensory tiredness, participants were instructed to avoid eating or drinking anything other than water for at least half an hour before the test. Before taking part, all volunteers received written consent and information about the study's goals and methods; they were also told that participation was completely voluntary, that their answers would be kept private and anonymous, and that they could leave at any time without incurring any fees (Owureku-Asare et al., 2022). It was established that panelists were not supposed to consume or drink (except water) 30 minutes before testing to reduce possible sensory tiredness (Owureku-Asare et al., 2022). All participants signed an informed consent, and the tests were conducted in spacious sensory booths operated at a stable level of lighting (~500 lux) and ambient temperature (20 to 22 °C). Coding was done on a 3-digit blind code on each sample type in a randomized complete block design. The expected findings using a 9-point hedonic (1 = dislike extremely, 9 = like extremely) scale, panelists rated five attributes, i.e., color, aroma, flavor, mouthfeel, and overall liking (Addo-Preko et al., 2023). Inhibited by carry-over effects between the samples, the participants neutralized their palate using water at room temperature.

Samples were prepared in hygienic conditions and were served in approximately the same amount, approximately 30 mL of soup at room temperature. The assessment was done within one session that took about 45 min, while notes were taken during the observation of the panelists' behavior and any comments that were given. Such protocol resembles best practice on hedonic sensory testing of dried vegetable products (Owureku Asare et al., 2022), as well as new horizons of solar drying technologies (Ortiz-Rodríguez et al., 2022).

Quantitative Descriptive Analysis

The QDA was used to analyze soups made from tomatoes that had undergone various drying procedures. The sensory panel was made up of fifteen trained assessors, twelve of whom were female and three of whom were male, and they were all between the ages of twenty and forty-five. Participants were selected based on their commitment to the training sessions, availability, curiosity, and a lack of sensitivity to tomato products. The panel received training in compliance with ISO 2023 (8586), which offered recommendations for assessor selection and training. Using existing tomato-based standards as reference benchmarks, the training concentrated on creating a consistent descriptive language for the main sensory aspects of color, fragrance, viscosity, flavor, and mouthfeel (Owureku-Asare et al., 2022). Each of the panelists was given four different tomato soup products, each with a three-digit code for blinding. The results of product coding were: 347 fresh tomato soup, 568 plain dried tomato soup, 619 savory product soup (added spices), and 823 blake product soup (different mixtures). Panelists assessed the intensity of each sensory attribute using a 7-point structured line scale, where a score of 1 indicated very low intensity and a score of 7 indicated extremely high intensity (Addo-Preko et al., 2023). All samples were served in equal portions (30 mL), at normal temperature, and presented in random order to prevent order effects. The testing was conducted in personal sensory booths with controlled lighting and environmental conditions. Between samples, water was provided to cleanse the palate. The testing setup aimed to minimize distractions, and all ethical research standards were strictly followed.

Shelf life evaluation

Determination of nutritional quality

Lycopene content

The amount of lycopene was determined using UV–Vis spectrophotometry as explained by Kakubari et al. (2020). To 0.5 g of tomato powder, 10 mL of hexane (Sigma-Aldrich, St. Louis, MO, USA), 5 mL of ethanol (Merck, Darmstadt, Germany), and 5 mL of acetone (Fisher Scientific, Loughborough, UK) were added. The mixture was vortexed after the addition of 3 mL of distilled water and then centrifuged for 10 min at 3000 × g using a laboratory centrifuge (Eppendorf 5810 R, Hamburg, Germany). Phase separation was allowed by stripping after vortexing, and the top hexane layer was collected. Its absorbance was measured at 503 nm. The lycopene concentration in the sample was determined using the Beer–Lambert law, with an extinction coefficient (ε) of 1.72×10^5 $L \cdot mol^{-1} \cdot cm^{-1}$. The technique enabled observation of the degradation of the lycopene over time, which was affected by both the packaging material and shelf life. Previous study indicated that lycopene is particularly vulnerable to the effects of oxygen and light exposure (Shah & Singh, 2025), thus, it was supposed that the packaging type and drying method would have a powerful effect on retention.

Beta-carotene content

Beta-carotene was measured using spectrophotometry according to Hasan *et al*. (2022) and applied in tomato drying studies by (Shah & Singh,2025). Extracts were made of 10 mL of acetone with 1g of dried tomato powder. The extract was filtered, and 10 mL of hexane was added to a separating funnel. Distilled water (20 mL) was added after mixing using a shaking action to enable phase separation. The upper layer of hexane was removed, and its absorbance was measured at 450 nm. The concentration of beta-carotene was determined either using the extinction coefficient (ε = 2592 in hexane) or with the help of a standard curve obtained from pure beta-carotene. The effects of a drying procedure and a packaging type on beta-carotene retention were considered for both types of tomatoes, focusing on beta-carotene's sensitivity to oxidation during storage.

Vitamin C (ascorbic acid) contents

The vitamin C content of dried tomatoes was determined using a titrimetric method according to AOAC Official Method 967.21, which is widely applied in recent fruit and vegetable preservation studies (Dufera et al., 2023). Briefly, 5 g of dried tomato powder was homogenized in 50 mL of 1% (w/v) oxalic acid solution (Merck Darmstadt, Germany) to ensure adequate extraction of ascorbic acid (Sigma-Aldrich, St. Louis, MO, USA).

The homogenate was filtered to obtain a clear solution, and 10 mL aliquots were withdrawn for analysis. The aliquots were titrated with a standardized solution of 2,6-dichlorophenol-indophenol (DCPIP) (Sigma-Aldrich, St. Louis, MO, USA) until a stable pink endpoint was observed, indicating completion of the reaction. To ensure accurate quantification, the DCPIP reagent was standardized using a known concentration of ascorbic acid prior to analysis.

The findings were at mg of ascorbic acid per 100 g of sample (mg/100 g). This method of analysis enabled comparison of the vitamin C retention among the drying as well as packaging materials, and these could give an insight into the degradation trend during storage. Of special interest was to gain insight into the effect that initial compositional variation between tomato varieties and the permeability of material on the packaging has on the stability of vitamin C after a certain period (Dufera et al., 2023).

Physicochemical quality

Total soluble solids (TSS)

The digital handheld refractometer (Atago Co., Ltd., Tokyo, Japan) was used to measure TSS according to AOAC Method 932.12 (AOAC, 2019). Distilled water was also used to calibrate the instrument before each measurement to ensure accuracy. The prism of the refractometer was then heated, and a small amount of tomato extract, approximately two drops, was added. The Brix value was then recorded. All readings were performed three times to minimize error and ensure reproducibility. The digital refractometer is commonly used to measure Brix degrees for evaluating the quality of fruits and vegetables because it provides a fast, non-destructive way to determine soluble solid content (Jaywant et al., 2022).

TSS values indicate the amount of soluble sugars, acids, and other solutes present, making it an effective attribute for assessing the sensory quality and stability of dried tomato products. In this study, TSS was measured periodically to evaluate variations across different packaging types and storage durations. Previous studies have shown that TSS is susceptible to changes during storage due to moisture absorption, sugar oxidation, and biochemical processes (Bahanla Oboulbiga et al., 2022). Monitoring these changes provides a means to assess the effectiveness of packaging materials in maintaining quality over time, as reflected in recent research on the stability and shelf life of dried tomato products.

pH measurement

The pH was measured with a digital pH meter (Hanna Instruments, Woonsocket, RI, USA) that was properly calibrated following AOAC Method 981.12 (AOAC, 2019). For sample preparation, 5 g of dried tomato powder were homogenized in 50 mL of distilled water, and the mixture was filtered to obtain a clear extract. Immediately after calibrating the meter with standard solutions of pH 4.0 and 7.0, the pH of the filtrate was measured. Before each set of measurements, the calibration process was repeated to ensure the accuracy and reliability of the instrument. This method complies with standardized protocols for measuring the acidity of fruit and vegetable powders (Farooq et al., 2020) it has been widely used in analyzing the physicochemical properties of dried tomato products (Degwale et al., 2022). The pH of the sample was recorded weekly to monitor changes in acidity during the 20-week storage period. This parameter remains essential for assessing the product's stability because it directly affects microbial growth, enzyme activity, and acceptability (Lima et al., 2023). The influence of tomato types, drying methods, and packaging types on pH stability was analyzed to correlate with the long-term quality of dried tomatoes. Recent research confirms that drying and storage environments can significantly alter the pH of tomato products, which in turn impacts shelf life and consumer perception (Bahanla Oboulbiga et al., 2022). Monitoring pH trends at different intervals can provide valuable insights into the biochemical processes occurring in low-moisture foods during extended storage.

Color measurement

The assessment of color was done with a calibrated colorimeter (Konica Minolta, Osaka, Japan) using the CIE Lab color space range, which is popular in determining the color quality of food items (PA Silva et al., 2019). It was recalibrated, at least in part, by using a calibrated white product to ensure high-quality reading. The sample was measured three times, and the mean values of the L^* (lightness), a^*

(red-green axis), and *b** (yellow-blue axis) components were recorded. The system can give accurate measurements of visual properties, particularly of foods that are color sensitive, like dried tomatoes (Farooq et al 2020). Determination of color values was also extended beyond the 20th week to monitor the degradation of visual pigments, specifically lycopene and beta carotene. These carotenoids give tomatoes their bright red and orange colors and are susceptible to oxidative destruction during dehydration and storage (Farid et al., 2022). Evaluating changes in *L**, *a**, and *b** values provided an indirect yet reliable estimate of color stability and nutrient retention. The question of quality is addressed through the definition of various packaging signs that relate to maintaining the appearance of powders (Ueda et al., 2023).

Determination of titratable acidity (TA)

The TA was used to evaluate the stability of organic acids in tomato powder during storage and was measured according to AOAC 942.15 with modifications in recent research works (Susi et al., 2023; Farooq et al., 2020). A beaker containing 50 mL of distilled water was properly weighed, and approximately 5.0 g of tomato powder was added. The mixture was kept on stirring for 10 min to dissolve the soluble acids that were in it, followed by filtration using Whatman No. 1 filter paper (Cytiva, Maidstone, UK) to obtain a clear extract.

The filtrate was titrated with standardized 0.1N sodium hydroxide, to which 0.1 mL of phenolphthalein was added as an indicator. The endpoint was identified by the appearance of a faint pink color that lasted for at least 30 sec. The titratable acidity was expressed as a percentage of citric acid equivalent using the following formula:

$$\text{TA\%(citric acid)} = \frac{(\text{Volume of NaOH (ml)} \times \text{Normality of NaOH} \times 0.064 \times 100)}{\text{Sample weight (g)}}$$

Each treatment and storage interval (18 weeks) were analyzed thrice, and the mean results were given as the mean value and standard deviation. To determine whether there were stability of the products and their possible fermentation during storage, the TA values were determined as a function of various packaging materials and methods of drying.

Microbial quality

Yeast and mold count

A pour plate method was applied to determine yeast and mold cell numbers as per ISO 2008 (21527-1). To test every sample, 10 g of tomato powder was aseptically collected into sterile stomacher bags and was homogenized using 90 mL sterile 0.1 per cent peptone water with the use of a laboratory homogenizer (Ultra-Turrax® T25, IKA, Staufen, Germany). Serial dilutions in decimals were then made, and 1 mL of the suitable dilutions was poured in duplicate on potato dextrose agar (PDA), (Oxoid, Basingstoke, UK) whereby 10 percent tartaric acid was added to kill the bacteria. The plates were incubated at 25 ± 2 °C in the dark for 5-7 days, and colonies with the usual yeast and mold appearance were counted. Results were recorded as colony-forming units per gram (CFU/g) and subsequently log transformed to even out the data as far as statistical analysis is concerned (ISO, 2008). This analysis was performed weekly over five months to assess microbial stability during storage. The study focused on the influence of various drying techniques, solar tunnel drying and electric drying, and two types of packaging, polyethylene and kraft paper, on fungal growth. The differences in moisture absorption due to packaging permeability were strongly correlated with yeast and mold growth.

Statistical analysis

Version 27 of IBM SPSS Statistics was used to analyze the data. Three-way ANOVA was performed on the physicochemical, nutritional, microbiological, and color characteristics, and Tukey's honestly significant difference test was used to determine the mean separation ($p < 0.05$). Before analysis, microbial counts were $\log_{10}$ transformed. One-way or two-way ANOVA and Duncan's multiple range test (DMRT) were used to assess shelf-life data. Principal component analysis (PCA) biplots and line plots were used to analyze temporal trends. Sensory data were examined independently, ANOVA was used to assess quantitative descriptive analysis (QDA) results, and independent samples t-tests were used to compare hedonic ratings.

Results and Discussion

Sensory evaluation

Hedonic sensory evaluation for comparison of products from the two drying methods

The appearance of the two soup samples, as shown in **Table 1** and **Figure 1**, did not show a statistically significant difference (P = 0.275) based on an independent samples t-test, indicating that panelists perceived both soups as visually similar. This suggests that the drying methods and formulations used did not influence the visual appeal of the final soup products in a notable way. Similar findings have been reported in studies where processing methods did not significantly alter the visual properties of tomato-based products (Jeyaprakash et al., 2020). In terms of color, no significant difference was observed between the two samples (P = 0.296), supporting the finding that both products maintained comparable color quality post-processing. Previous research has highlighted that color retention in tomato products depends more on pigment stability during drying than on the type of formulation (Obadina et al., 2022).

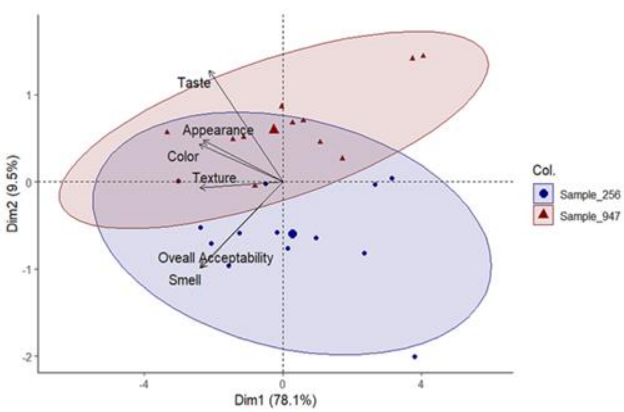

Figure 1. PCA – Biplot for hedonic sensory evaluation of dried tomato soup powders.

For the smell attribute, the results showed no statistically significant difference (P = 0.420), suggesting that the aroma compounds were preserved equally in both samples. This aligns with recent study indicating that moderate drying temperatures can help maintain volatile compounds responsible for tomato aroma (Paolo et al., 2019). Regarding texture, panelists did not report a significant difference between the samples (P = 0.227). Both soups had similar mouthfeel and consistency, indicating that the drying techniques used did not negatively affect the rehydration or solubility properties of the powder. Similar results were observed by Kilicli et al. (2023), who found that drying had a limited effect on the textural qualities of reconstituted tomato products.

Interestingly, taste was the only sensory attribute that showed a statistically significant difference (P = 0.005), with Sample 2 receiving a higher mean score. This suggests that panelists preferred the flavor profile of the soup prepared with the second tomato powder product. Despite the difference in taste, the overall acceptability of the two samples did not differ significantly (P = 0.254). This indicates that while panelists found Sample 2 more palatable in terms of taste, it did not substantially influence their holistic judgment of the product. This trend has also been observed in previous sensory, where isolated preference in one attribute did not always correspond to higher overall acceptability (Sánchez-Rodríguez et al., 2019).

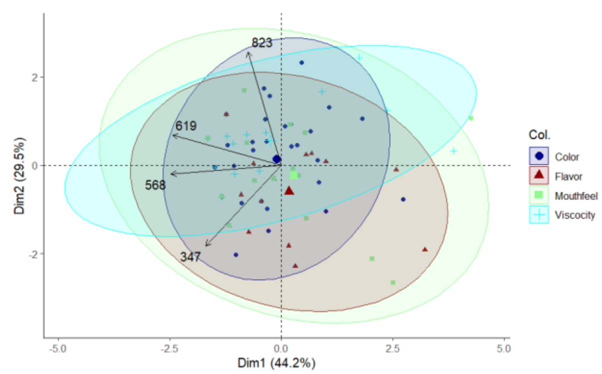

Figure 2. PCA – Biplot for QDA sensory scores of dried tomato soup powder prepared using different treatments.

QDA of tomato products

Key variations in color, flavor, aroma, viscosity, and mouthfeel, dependent on formulation and ingredient sources, were found in a sensory investigation of four tomato-based products (**Table 2** and **Fig. 2**). Sample 347, made from fresh tomatoes with iodized salt, scored significantly higher in color (6.67±0.62) compared to Sample 823 (5.00 ± 1.13), likely due to the preservation of lycopene and vibrant red pigmentation (Li et al., 2023). However, Sample 823, which had cinnamon and turmeric, had a duller, yellow-brown color, suggesting that spices may have a negative effect on tomato products' aesthetic attractiveness (Farid et al., 2022. The moderate color scores of samples 568 and 619, which were manufactured from dried tomato powder, were consistent with the findings that dehydration changes natural pigmentation and decreases brightness (Wambugu, 2020). Aroma was rated highest in Sample 823 (6.20 ± 0.86), due to the inclusion of aromatic spices like garlic, ginger, and cinnamon, which are known to enhance sensory appeal (Sánchez-Rodríguez et al., 2019). Sample 347, with only iodized salt, received the lowest aroma score (5.27 ± 0.80), supporting the improvement, consistent with literature on flavor enhancement. There were no significant differences in viscosity across samples, although Sample 568 showed the highest mean (6.53 ± 1.73). The consistency seen across products indicates that tomato powder alone provides a uniform thickening effect (Sánchez-Rodríguez, 2019; Christian, 2020). Flavor was the most distinguishing attribute, with Sample 347 scoring highest (6.73 ± 0.59), likely due to preserved natural sugars and volatiles in fresh tomatoes. Sample 619, though containing MSG, and 823, with strong spices, scored lower, possibly due to masking of natural tomato taste or flavor imbalance. Mouthfeel scores showed no significant differences, though Sample 347 led again (6.33 ± 1.18), suggesting fresh tomatoes contributed to a smoother texture (Mouritsen & Atyrbaek, 2017; Cano-Lara & Rostro-Gonzalez, 2024).

Table 1. Hedonic sensory evaluation results of dried tomato soup powders.

Sensory attribute	Sample 1	Sample 2	t-value	p- value
Appearance	5.2 ± 1.52	5.67 ± 0.98	-1	0.275
Taste	4.27±1.03	5.40 ± 0.99	-3.08	0.005
Color	5.60 ± 0.99	5.93 ± 0.70	-1.07	0.296
Smell	5.67 ± 1.05	5.27 ± 1.58	0.82	0.42
Texture	5..00 ± 1.20	5.60 ± 1.45	-1.24	0.227
Overall acceptability	6.07 ± 0.80	5.60 ± 0.80	1.43	0.254

Values are expressed in mean ± SD, and the test used was an independent t-test.

Table 2. Quantitative descriptive analysis (QDA) sensory scores of dried tomato soup powder prepared using different treatments.

Sample code	Color	Aroma	Viscosity	Flavor	Mouth feel
347	6.67 ± 0.62^{a}	5.27 ± 0.80^{a}	6.13 ± 1.25^{a}	6.73 ± 0.59^{a}	6.33 ± 1.18^{a}
568	6.20 ± 0.86^{a}	5.67 ± 1.29^{a}	6.53 ± 1.73^{a}	5.53 ± 1.36^{ab}	5.27 ± 1.83^{a}
619	6.27 ± 0.70^{a}	5.80 ± 1.14^{a}	6.33 ± 1.45^{a}	5.20 ± 1.70^{b}	5.53 ± 1.55^{a}
823	5.00 ± 1.13^{b}	6.20 ± 0.86^{b}	6.26 ± 0.80^{a}	5.27 ± 1.28^{b}	5.40 ± 1.40^{a}
Total	6.03 ± 1.04	5.73 ± 1.07	6.07 ± 1.35	5.68 ± 1.41	5.63 ± 1.53

Values are mean ± standard deviation. Mean values in the same column followed by different superscript letters (a, b, ab) are significantly different ($p < 0.05$). Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test.

Laboratory shelf life determination

Vitamin C

The changes in the vitamin C content of tomato powder during the shelf-life study are shown in **Table 3**. The vitamin C levels in tomato powder samples decreased over time across all treatments during the 18-week storage period. Initial vitamin C values ranged from 3.13 to 4.79 mg/100 g, but by week 18, they had declined to between 1.07 and 1.45 mg/100 g. These results are consistent with those reported by Obadina et al. (2018) and Mishra et al. (2021). This decline can be attributed to factors such as vitamin C being highly labile and sensitive to degradation by agents like heat, oxygen, and light during drying and storage (Obadina et al., 2018; Brar et al., 2020; Mishra et al., 2021). The rapid depletion over the storage period may support vitamin C supplementation in dried products like tomato powder (Obadina et al., 2018). Furthermore, significant ($p < 0.05$) differences in vitamin C depletion were observed among different treatments over the storage weeks. For example, regarding packaging materials, the sample DSPP (Dhahabu variety dried using a solar tunnel and packed in paper) had the highest initial vitamin C content (4.79 ± 0.97 mg/100 g) and maintained relatively high levels at week 3. However, a sharp decline occurred afterward, ending at 1.20 ± 0.01 mg/100g by week 18. Similarly, the DSPE started with an initial vitamin C content of 4.12 ± 0.02 mg/100 g and reached 1.37 ± 0.17 mg/100 g at the end. Overall, the loss of vitamin C was faster in samples packed in paper compared to those in polyethylene, although most cases showed no significant difference in the rate of vitamin C loss. This trend underscores the impact of packaging material on vitamin C stability. Paper packaging, being more permeable to moisture and oxygen, likely promoted oxidative degradation, consistent with findings by Giannakourou & Taoukis, 2021; Nashrin et al., 2021.

Table 3. The changes in the vitamin C content of tomato powder during the shelf-life study period.

Types	Weeks										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	3.13 ± 0.00^{a}	1.91 ± 0.08^{a}	1.88± 0.13^{a}	1.79 ± 0.28^{a}	2.13 ± 0.02^{ab}	2.12 ± 0.01^{ab}	2.10 ± 0.31^{ab}	1.60 ± 0.13^{a}	1.37 ± 0.14^{a}	1.23 ± 0.21^{a}	1.07 ± 0.37^{a}
DSPE	4.12 ± 0.02^{ab}	3.90 ± 0.13^{b}	2.81± 0.16^{b}	2.89 ± 0.04^{bc}	1.81 ± 0.15^{a}	1.83 ± 0.18^{a}	2.01 ± 0.06^{ab}	1.37 ± 0.14^{a}	1.32 ± 0.21^{a}	1.36 ± 0.14^{a}	1.17 ± 0.17^{a}
DEPE	4.12 ± 0.21^{ab}	4.11 ± 0.06^{b}	3.43± 0.19^{bcd}	3.00 ± 0.35^{bcd}	2.16 ± 0.25^{a}	2.20 ± 0.13^{ab}	1.92 ± 0.34^{ab}	1.45 ± 0.20^{a}	1.43 ± 0.21^{a}	1.47 ± 0.31^{a}	1.30 ± 0.38^{a}
ESPE	3.63 ± 0.29^{b}	3.63 ± 0.42^{b}	3.68± 0.40^{cd}	3.34 ± 0.18^{cde}	2.16 ± 0.32^{ab}	2.15 ± 0.30^{ab}	2.01 ± 0.02^{ab}	1.47 ± 0.01^{a}	1.39 ± 0.11^{a}	1.38 ± 0.14^{a}	1.18 ± 0.18^{a}
ESPP	3.84 ± 0.02^{b}	3.74 ± 0.30^{b}	2.92± 0.05^{b}	2.79 ± 0.06^{b}	1.97 ± 0.10^{ab}	2.02 ± 0.11^{ab}	1.43 ± 0.26^{b}	1.56 ± 0.17^{a}	1.59 ± 0.16a	1.55 ± 0.25^{a}	1.45 ± 0.23^{a}
DSPP	4.79 ± 0.97^{c}	3.88 ± 0.45^{b}	4.12± 0.15^{d}	3.41 ± 0.27^{de}	2.13 ± 0.36^{ab}	2.15 ± 0.30^{ab}	1.82 ± 0.22^{ab}	1.60 ± 0.16^{a}	1.44 ± 0.10^{a}	1.47 ± 0.01^{a}	1.30 ± 0.01^{a}
EEPP	3.17 ± 0.01^{a}	3.07 ± 1.33^{ab}	3.18± 0.56^{bcd}	3.07 ± 0.06^{ef}	2.44 ± 0.25^{bc}	2.36 ± 0.01^{b}	1.82 ± 0.25^{ab}	1.35 ± 0.19^{a}	1.36 ± 0.14^{a}	1.36 ± 0.14^{a}	1.17 ± 0.17^{a}
DEPP	4.04 ± 0.20^{ab}	3.92 ± 0.10^{b}	3.66± 0.27^{cd}	3.96 ± 0.20^{f}	2.75 ± 0.08^{c}	2.90 ± 0.14^{c}	2.05 ± 0.27^{ab}	1.59 ± 0.16^{a}	1.59 ± 0.16^{a}	1.57 ± 0.13^{a}	1.43 ± 0.17^{a}
Total	3.59 ± 0.98	3.52 ± 0.80	3.21± 0.70	3.12 ± 0.67	2.19 ± 0.32	2.22 ± 0.33	2.07 ± 0.25	1.50± 0.15	1.44 ± 0.15	1.42± 0.18	1.26 ± 0.22

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Across tomato varieties, the Dhahabu variety samples generally exhibited higher initial vitamin C content and better retention compared to the Emelard variety. For instance, at week 2, DEPP (Dhahabu) maintained 3.66 ± 0.27 mg/100g, while EEPP (Emelard) was at 3.18 ± 0.56 mg/100 g. Although there was no significant difference ($p > 0.05$) in vitamin C content between them, the Dhahabu variety showed higher initial content, which might also explain the difference in retention after 18 weeks. This aligns with varietal effects on nutrient composition, as recently observed by Valšíková-Frey et al. (2017), Evana and Barek (2021), and Trifunschi et al. (2022). Remarkably, the drying method had a pronounced impact on vitamin C retention. Electric drying consistently preserved higher vitamin C levels than solar tunnel drying, likely due to its shorter drying duration and more stable thermal environment, which minimizes nutrient degradation (Verma et al., 2020; Radojčin *et al*., 2021). For example, DEPE (Dhahabu-electric-polyethylene) retained 3.00 ± 0.35 mg/100g at week 4, compared to DSPE (Dhahabu-solar-polyethylene) at 2.89 ± 0.04 mg/100 g. Similar findings were reported by Elghazali et al. (2025), who noted that electric drying was more effective in preserving vitamin C in the studied fruits and vegetables.

Table 4. The changes in the β-carotene content of tomato powder during the shelf-life study period.

Types	**Weeks**										
	0	**1**	**2**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**18**
EEPE	8.99 ± 0.43^{ab}	8.03± 0.04^{a}	8.00 ± 0.03^{bcd}	7.02 ± 0.11^{c}	7.21 ± 0.09^{a}	7.08 ± 0.09^{a}	7.05 ± 0.25^{a}	6.99 ± 0.01^{a}	7.11 ± 0.01^{a}	7.42 ± 0.15^{ab}	7.42 ± 0.15^{b}
DSPE	7.79 ± 0.39^{ab}	7.68 ± 0.10^{a}	7.12 ± 0.29^{a}	7.55 ± 0.12^{a}	7.45 ± 0.12^{abc}	7.25 ± 0.21^{ab}	7.12 ± 0.04^{a}	7.28 ± 0.03^{ab}	7.22 ± 0.06^{ab}	7.25 ± 0.35^{a}	7.25 ± 0.35^{ab}
DEPE	7.67 ± 0.41^{a}	7.79 ± 0.15^{a}	7.26 ± 0.28^{a}	7.31 ± 0.15^{b}	7.21 ± 0.11^{a}	7.48 ± 0.28^{abc}	7.15 ± 0.25^{a}	7.43 ± 0.20^{b}	7.22 ± 0.09^{ab}	7.09 ± 0.22^{a}	7.09 ± 0.22^{ab}
ESPE	9.95 ± 0.29^{c}	9.32 ± 0.28^{b}	7.65 ± 0.15^{abcd}	7.17 ± 0.18^{b}	7.18 ± 0.07^{a}	7.18 ± 0.12^{ab}	7.19 ± 0.12^{a}	7.32 ± 0.28^{ab}	7.11 ± 0.01^{a}	7.01 ± 0.05^{a}	6.80 ± 0.02^{a}
ESPP	7.74 ± 0.09^{ab}	8.11 ± 0.32^{a}	7.34 ± 0.04^{ab}	6.94 ± 0.27^{e}	7.47 ± 0.25^{abc}	7.74 ± 0.06^{c}	7.13 ± 0.03^{a}	7.25 ± 0.08^{ab}	7.25 ± 0.08^{ab}	7.18 ± 0.33^{a}	6.98 ± 0.23^{ab}
DSPP	8.57 ± 1.20^{abc}	7.78 ± 0.61^{a}	8.07 ± 0.22c^{cd}	7.91 ± 0.10^{e}	7.87 ± 0.50^{c}	7.30 ± 0.27^{abc}	7.43 ± 0.02^{a}	7.26 ± 0.02^{ab}	7.33 ± 0.07^{b}	7.06 ± 0.11^{b}	7.32 ± 0.10^{b}
EEPP	9.26 ± 0.31^{c}	9.23 ± 0.10^{b}	8.29 ± 0.53^{d}	7.81 ± 0.16^{de}	7.30 ± 0.03^{ab}	7.43 ± 0.16^{abc}	7.20 ± 0.26^{a}	7.14 ± 0.21^{ab}	7.14 ± 0.02^{a}	7.14 ± 0.02^{a}	7.34 ± 0.27^{b}
DEPP	7.70 ± 0.05^{a}	7.83 ± 0.01^{a}	7.39 ± 0.38^{abc}	7.51 ± 0.01^{d}	7.79 ± 0.00^{bc}	7.58 ± 0.10^{bc}	7.06 ± 0.07^{a}	7.04 ± 0.14^{a}	7.31 ± 0.05^{b}	7.16 ± 0.13^{a}	7.03 ± 0.06^{ab}
Total	19.7± 31.33	8.22± 0.67	7.64 ± 0.47	6.93 ± 0.78	7.43 ± 0.30	7.38 ± 0.25	7.17± 0.17	7.21 ± 0.18	7.21 ± 0.09	7.25 ± 0.27	7.15 ± 0.25

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Generally, electric drying and polyethylene packaging were more effective in preserving vitamin C and ensuring product quality over time, although in most cases, there was no significant difference in the rate of vitamin C degradation from different treatments. Dhahabu variety had higher initial vitamin C content than the Emerald variety. The results suggest that although vitamin C degradation occurs, it can remain in some amount in the dried tomatoes up to the 18th week of storage. Shelf life of dried tomato powder, when evaluated based on vitamin C retention, can be considered acceptable for up to 18 weeks under optimal conditions.

Beta-carotene

Beta-carotene content generally decreases during storage due to degradation reactions. Factors such as temperature, light, oxygen exposure, and packaging type significantly influence the rate of this degradation (Syamila et al., 2019; Lavelli & Sereikaitė, 2022). In this study, the changes in the β-carotene content of tomato powder during the shelf-life period are shown in **Table 4**. The results indicate that beta-carotene content generally declined slightly over time across all treatments but remained relatively stable after week 5. The rate of beta-carotene decline in this study was likely affected by initial contents and storage conditions. Significant differences ($p < 0.05$) were observed among treatments, especially during early storage weeks, as indicated by superscripts in the table. For example, at week 1, ESPE (Emelard variety dried using a solar tunnel and packed in polyethylene) recorded the highest beta-carotene level, significantly surpassing DEPE and DSPE. This reflects initial retention efficiency, likely due to varietal differences and minimal oxidative degradation immediately after drying. After 18 weeks, nearly all samples retained relatively higher beta-carotene content (6.80 ± 0.02-7.34 ± 0.27 µg/g), demonstrating good storage stability.

Table 5. The changes in the lycopene content of tomato powder during the shelf-life study period.

Types	Weeks										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	3.45 ± 0.01^{ab}	3.65 ± 0.04^{ab}	3.33 ± 0.06^{a}	3.13 ± 0.10^{ab}	2.78 ± 0.13^{ab}	2.73 ± 0.12^{a}	2.83 ± 0.02^{ab}	2.73 ± 0.07^{abc}	2.61 ± 0.04^{ab}	2.91 ± 0.02^{ab}	2.91 ± 0.02^{b}
DSPE	3.56 ± 0.04^{ab}	3.99 ± 0.03^{c}	3.22 ± 0.36^{a}	2.83 ± 0.32^{ab}	2.99 ± 0.06^{b}	2.91 ± 0.02^{a}	2.86 ± 0.02^{ab}	2.87 ± 0.00^{c}	2.68 ± 0.09^{ab}	2.74 ± 0.11^{ab}	2.74 ± 0.11^{a}
DEPE	3.31 ± 0.00^{a}	3.52 ± 0.01^{a}	2.86 ± 0.07^{a}	3.10 ± 0.10^{ab}	2.74 ± 0.05^{ab}	2.85 ± 0.10^{a}	2.74 ± 0.02^{a}	2.64 ± 0.07^{ab}	2.62 ± 0.07^{ab}	2.62 ± 0.03^{ab}	2.62 ± 0.03^{a}
ESPE	3.45 ± 0.04^{a}	3.64 ± 0.05^{ab}	3.43 ± 0.40^{a}	2.77 ± 0.08^{a}	2.70 ± 0.13^{a}	2.69 ± 0.06^{a}	2.69 ± 0.06^{ab}	2.69 ± 0.02^{abc}	2.67 ± 0.03^{ab}	2.63 ± 0.19^{ab}	2.73 ± 0.10^{a}
ESPP	3.42 ± 0.04^{ab}	3.80 ± 0.15^{bc}	3.07 ± 0.30^{a}	3.22 ± 0.24^{b}	2.89 ± 0.02^{ab}	2.99 ± 0.09^{a}	2.88 ± 0.09^{ab}	2.69 ± 0.00^{abc}	2.66 ± 0.03^{ab}	2.63 ± 0.10^{ab}	2.70 ± 0.07^{a}
DSPP	3.65 ± 0.02^{b}	3.96 ± 0.08^{c}	3.18 ± 0.57^{a}	3.01 ± 0.16^{ab}	2.97 ± 0.16^{ab}	2.76 ± 0.22a	2.83 ± 0.26^{ab}	2.57 ± 0.07^{a}	2.55 ± 0.04^{ab}	2.61 ± 0.26b	2.61 ± 0.04^{a}
EEPP	3.42 ± 0.06^{ab}	3.66 ± 0.17^{ab}	3.36 ± 0.05^{a}	3.21 ± 0.17^{ab}	2.81 ± 0.17^{ab}	2.87 ± 0.25^{a}	2.97 ± 0.10^{b}	2.77 ± 0.18^{bc}	2.76 ± 0.18^{b}	2.56 ± 0.07^{ab}	2.64 ± 0.04^{a}
DEPP	3.47 ± 0.33^{ab}	3.70 ± 0.10^{ab}	3.37 ± 0.12^{a}	2.98 ± 0.00^{ab}	3.01 ± 0.06^{b}	2.92 ± 0.02^{a}	2.95 ± 0.06^{ab}	2.82 ± 0.06^{bc}	2.80 ± 0.05^{b}	2.71 ± 0.02^{a}	2.66 ± 0.09^{a}
Total	3.46 ± 0.13	3.74 ± 0.17	3.23 ± 0.29	3.03 ± 0.20	2.86 ± 0.14	2.84 ± 0.14	2.85 ± 0.12	2.72 ± 0.11	2.67 ± 0.10	2.68 ± 0.14	2.70 ± 0.11

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Regarding the effect of variety, Emelard generally retained more beta-carotene than Dhahabu throughout the storage period. This aligns with previous studies that have found genetic factors to significantly influence carotenoid content and stability (Saini & Keum, 2018; Vela-Hinojosa et al., 2019; Gonzali & Perata, 2021). On the other hand, regarding the effect of Drying Method, electric drying appeared slightly superior to solar tunnel drying in terms of beta-carotene retention during storage. This can be attributed to faster drying rates and lower exposure to light and oxygen in electric drying systems (Mbondo, 2020). Moreover, samples stored in polyethylene packaging generally exhibited better beta-carotene stability than those stored in paper. This is consistent with findings by Chilungo et al. (2019), who reported that polyethylene provides better protection against moisture and oxygen permeability, which are key factors in carotenoid degradation. Generally, at the end of 18 weeks, most treatments retained beta-carotene levels above 7.0 µg/g, which is within acceptable and nutritionally beneficial ranges. Although there is no universal Codex or FAO legal requirement for beta-carotene content in dried food products, beta-carotene levels of 5–7 µg/g are considered sufficient (Waruguru, 2020; Soytong et al., 2021). These findings indicate that beta-carotene is relatively stable during 18 weeks of storage under the different treatments used in this study.

Lycopene

The lycopene content of dried tomato powders from different varieties, drying methods, and packaging materials was monitored over an 18-week storage period, and the results are shown in **Table 5**. Initial lycopene concentrations ranged from 3.31 ± 0.00 to 3.65 ± 0.02 mg/100 g across treatments, with the highest initial retention observed in DSPP (3.65 ± 0.02 mg/100 g) and the lowest in DEPE (3.31 ± 0.00 mg/100 g). Over the storage period, lycopene content showed a gradual decline, reaching final values between 2.61 ± 0.04 and 2.91 ± 0.02 mg/100 g after 18 weeks. The sharp decline was observed in the initial weeks, but remained relatively constant when approaching week 18. The results indicate that there were statistically significant differences ($p < 0.05$) between some treatments at certain time points, but many values shared the same superscript, showing non-significant differences. This pattern of significance versus non-significance was consistent across the weeks, reflecting variability but overall comparable lycopene retention among treatments. The overall lycopene content decreased by approximately 15-25% over the storage period, indicating moderate stability during the 18 weeks under the tested conditions.

Table 6. The changes in the yeast contamination of tomato powder during the shelf-life study period

Types	Weeks										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	2.69 ± 0.01^{a}	2.98 ± 0.04^{a}	4.22 ± 0.04^{a}	4.85 ± 0.04^{bc}	4.95 ± 0.02^{a}	4.76 ± 0.05^{a}	5.00 ± 0.01^{ab}	4.95 ± 0.09^{a}	4.71 ± 0.05^{a}	4.85 ± 0.03^{a}	4.92 ± 0.04^{a}
DSPE	3.32 ± 0.03^{b}	3.92 ± 0.04^{c}	4.58 ± 0.06^{c}	4.89 ± 0.04^{abc}	4.95 ± 0.00^{a}	4.96 ± 0.05^{a}	5.12± 0.03^{b}	4.84 ± 0.01^{b}	4.95 ± 0.00^{a}	4.87 ± 0.05^{a}	4.98 ± 0.04^{a}
DEPE	3.69 ± 0.10^{c}	3.92 ± 0.03^{d}	4.74 ± 0.03^{c}	5.05 ± 0.08^{cd}	5.21 ± 0.06^{b}	5.30 ± 0.02^{b}	5.24 ± 0.02^{c}	5.11 ± 0.05^{c}	5.31 ± 0.04^{bc}	4.95 ± 0.07^{a}	4.96 ± 0.03^{a}
ESPE	4.15 ± 0.01^{e}	4.12 ± 0.02^{e}	4.74 ± 0.04^{b}	5.85 ± 0.09^{abc}	5.21 ± 0.03^{bc}	5.24 ± 0.01^{b}	5.24 ± 0.05^{cd}	5.41 ± 0.07^{e}	5.32 ± 0.00^{c}	5.24 ± 0.07^{b}	5.37 ± 0.02^{b}
ESPP	3.80 ± 0.04^{de}	3.89 ± 0.04^{cd}	4.82 ± 0.10^{c}	5.20 ± 0.03^{c}	5.21 ± 0.05^{c}	5.30 ± 0.04^{b}	5.36 ± 0.05^{de}	5.25 ± 0.01^{e}	5.16 ± 0.03^{c}	5.28 ± 0.06^{b}	5.37 ± 0.00^{b}
DSPP	3.32 ± 0.03^{b}	3.89 ± 0.07^{cd}	4.58 ± 0.09^{b}	4.85 ± 0.07^{ab}	5.13 ± 0.04^{a}	5.17 ± 0.12^{b}	5.24 ± 0.02^{c}	5.26 ± 0.05^{de}	5.26 ± 0.05^{c}	5.28 ± 0.11^{b}	5.37 ± 0.03^{b}
EEPP	2.79 ± 0.07^{a}	3.13 ± 0.04^{b}	4.31 ± 0.10^{a}	4.75 ± 0.10^{a}	4.95 ± 0.02^{a}	4.96 ± 0.01^{a}	5.00 ± 0.06^{a}	5.11 ± 0.04^{cd}	5.16 ± 0.02^{b}	5.29 ± 0.02^{b}	5.29 ± 0.02^{b}
DEPP	3,69 ± 0.08^{cd}	4.12 ± 0.05^{e}	4.74 ± 0.12^{b}	5.15 ± 0.10^{d}	5.21 ± 0.02^{bc}	5.30 ± 0.01^{b}	5.36 ± 0.03^{e}	5.41 ± 0.05^{e}	5.31 ± 0.10^{d}	5.29 ± 0.04^{b}	5.37 ± 0.02^{c}
Total	3.43 ± 0.43	3.75 ± 0.43	4.59 ± 0.22	4.95 ± 0.16	5.10 ± 0.12	5.15 ± 0.15	5.19 ± 0.13	5.17 ± 0.19	5.17 ± 0.21	5.13 ± 0.20	5.20 ± 0.18

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

The trend generally reveals that electric drying combined with polyethylene packaging generally retained lycopene better than solar tunnel drying with paper packaging (e.g., DSPP, ESPP). This aligns with findings by Moon et al. (2020) and Dufera et al. (2023), who reported that controlled drying temperatures and oxygen-impermeable packaging help reduce lycopene degradation. The polymeric polyethylene packaging provided an effective barrier against oxygen and moisture, which are known to catalyze lycopene oxidation (Shi & Xue, 2019; Dufera et al., 2023). Moreover, the two tomato varieties showed comparable lycopene retention, with some variation likely due to inherent differences in initial carotenoid composition and antioxidant enzyme activities as reported by Vela-Hinojosa et al. (2019) and Gonzali & Perata (2021). These varietal influences are important for cultivar selection in processing for maximum nutrient preservation.

The drivers of lycopene degradation in products like tomato powder during storage are oxygen availability, and it is reported that low moisture content, low oxygen content, low storage temperature, and low water activity have a limiting effect on the lycopene oxidation (Dufera et al., 2023). Different packaging materials have different water vapor and oxygen permeability, and thus, due to its hygroscopic nature, tomato powder should be stored in moisture-proof packaging material (Forsido *et al.*, 2021; Dufera *et al.*, 2023). Generally, this study found a slow rate of lycopene degradation, indicating good storage stability. The minimal differences in lycopene content over time, especially in polyethylene-packaged powders as opposed to paper-packed powders, emphasize the importance of packaging in preserving lycopene during storage, where the polyethylene bags are less permeable to oxygen and water vapor when compared to paper packaging materials.

Table 7. Changes in pH values of dried tomato products during the storage period

Types	Week										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	5.81 ± 0.00^{e}	5.74 ± 0.04^{ab}	5.80 ± 0.01^{ab}	5.72 ± 0.07^{ab}	5.95 ± 0.01^{bcd}	5.92 ± 0.01^{bc}	5.87 ± 0.04^{a}	5.79 ± 0.07^{a}	5.86 ± 0.03^{b}	5.86 ± 0.03^{c}	5.80 ± 0.02^{ab}
DSPE	5.77 ± 0.01^{c}	5.82 ± 0.03^{b}	5.79 ± 0.00^{ab}	5.85 ± 0.01^{cd}	5.85 ± 0.01^{b}	5.87 ± 0.01^{b}	5.90 ± 0.08^{a}	5.86 ± 0.04^{a}	5.81 ± 0.06^{ab}	5.86 ± 0.01^{c}	5.81 ± 0.08^{ab}
DEPE	5.81 ± 0.00^{e}	5.75 ± 0.02^{ab}	5.78 ± 0.11^{a}	5.75 ± 0.09^{a}	5.86 ± 0.01^{b}	5.86 ± 0.01^{b}	5.92 ± 0.09^{a}	5.87 ± 0.01^{a}	5.82 ± 0.09^{ab}	5.87 ± 0.02^{c}	5.87 ± 0.02^{b}
ESPE	5.65 ± 0.00^{a}	5.81 ± 0.05^{b}	5.86 ± 0.04^{ab}	5.77 ± 0.00^{bc}	5.88 ± 0.00^{ab}	5.88 ± 0.00^{b}	5.87 ± 0.01^{a}	5.85 ± 0.04^{a}	5.77 ± 0.01^{ab}	5.87 ± 0.01^{c}	5.87 ± 0.01^{b}
ESPP	5.69 ± 0.01^{b}	5.72 ± 0.03^{ab}	5.79 ± 0.07^{ab}	5.72 ± 0.06^{ab}	5.82 ± 0.06^{a}	5.82 ± 0.06^{a}	5.82 ± 0.08^{a}	5.85 ± 0.05^{a}	5.77 ± 0.01^{ab}	5.81 ± 0.01b	5.81 ± 0.01^{ab}
DSPP	5.79 ± 0.01^{d}	5.68 ± 0.10^{a}	6.00 ± 0.11^{b}	5.71 ± 0.01^{ab}	5.93 ± 0.06^{abc}	5.93 ± 0.06^{bc}	5.78 ± 0.01^{a}	5.86 ± 0.04^{a}	5.72 ± 0.05^{a}	5.80 ± 0.00^{b}	5.80 ± 0.01^{ab}
EEPP	5.80 ± 0.01^{de}	5.76 ± 0.02^{ab}	5.78 ± 0.00^{a}	5.99 ± 0.01^{e}	5.99 ± 0.01^{cd}	5.99 ± 0.01^{c}	5.88 ± 0.01^{a}	5.88 ± 0.01^{a}	5.83 ± 0.06^{ab}	5.88 ± 0.01^{c}	5.88 ± 0.01^{b}
DEPP	5.79 ± 0.01^{de}	5.77 ± 0.02^{ab}	5.90 ± 0.16^{ab}	5.93 ± 0.05d^{de}	6.01 ± 0.00^{d}	5.91 ± 0.01^{b}	5.85 ± 0.02^{a}	5.90 ± 0.05^{a}	5.86 ± 0.01^{b}	5.76 ± 0.01^{a}	5.76 ± 0.01^{a}
Total	5.76 ± 0.06	5.75 ± 0.05	5.84 ± 0.10	5.78 ± 0.13	5.90 ± 0.09	5.88 ± 0.08	5.86 ± 0.06	5.85 ± 0.04	5.80 ± 0.06	5.84 ± 0.04	5.82 ± 0.05

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Fortunately, lycopene content above 2.0 mg/100 g in dried tomato powders is considered sufficient to offer health benefits related to antioxidant activity and reduced disease risk (Przybylska & Tokarczyk, 2022; Shafe et al., 2024). In this study, all treatments kept lycopene levels well above this threshold throughout the 18-week storage period, indicating acceptable nutritional quality and a shelf life of at least 4–5 months under ambient conditions. This demonstrates that dried tomato powders, when properly processed and packaged, can retain significant lycopene content for at least 4-5 months, supporting a shelf life of roughly 18 weeks without major nutritional loss. Maintaining lycopene levels during storage is essential due to its role as a powerful antioxidant associated with a decreased risk of chronic diseases such as cardiovascular diseases and some cancers (Khan et al., 2021; Przybylska & Tokarczyk, 2022).

Yeast

Numerous studies confirm that yeast contamination in stored dried fruit products generally increases over time. The growth rate is higher if the products' moisture content and storage conditions are poorly managed (Gientka et al., 2020; Alp & Bulantekin, 2021; Naeem et al., 2022). Therefore, proper drying and storage practices, such as keeping moisture low and using suitable packaging, can help reduce yeast growth and preserve product quality over time. Similarly, this study found that the yeast count (log_{10} CFU/g) in dried tomato powder gradually increased during the 18-week storage period across all treatments, as shown in **Table 6**. Initial yeast levels ranged from 1.19 ± 0.01 to 1.64 ± 0.01 log_{10}CFU/g (week 1), indicating a low microbial load immediately after drying. However, by week 18, levels had grown to between 4.92 ± 0.04 and 5.37 ± 0.02 log_{10} CFU/g. Throughout storage, significant differences ($p \leq 0.05$) in yeast counts were observed among treatments at several time points, as indicated by different superscripts. By week 18, DEPP showed the highest yeast load (5.37 ± 0.02 log_{10} CFU/g), while EEPE had the lowest (4.92 ± 0.04 log_{10} CFU/g).

Generally, samples stored in polyethylene packaging showed slower yeast growth rates compared to their paper-packed counterparts, consistent with observations by Korese et al. (2022), and Sarkar and Aparna (2020), who found that polyethylene acts as an effective moisture and oxygen barrier during dry storage. The tomato variety also influenced microbial behavior. For instance, Emelard (EEPE, ESPE) showed better resistance to yeast proliferation in polyethylene packs than Dhahabu (DSPE, DEPE), particularly in the early and mid-storage stages. This might be attributed to inherent varietal differences in acidity or bioactive compounds like lycopene and β-carotene, which may possess antifungal properties (Rusu et al., 2023; Li et al., 2024; Umeohia & Olapade, 2024). According to East African Standards (EAS), (2011), acceptable yeast levels in many dried food products should not exceed 4 log_{10} CFU/g during their shelf life. None of the samples in this study remained within acceptable limits throughout the 18-week storage period, although most remained within recommended limits up to week 7, suggesting microbiological stability under storage conditions, with a suggestion of some improvement in storage conditions. Generally, the yeast growth trend highlights that electric drying combined with polyethylene packaging provides the most effective control of yeast proliferation. The choice of drying method and packaging material is therefore critical in prolonging the shelf life of dried tomatoes and ensuring product safety for consumers. It is important to note that, during the study, the mold growth was also monitored, but was not detected in any sample throughout the study period.

Table 8. Total soluble solids changes of the dried tomato product during the storage period

Types	Week										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	1.90 ± 0.00^{a}	2.20 ± 0.14^{a}	1.85 ± 0.07^{a}	0.90 ± 0.00^{ab}	0.95 ± 0.07^{a}	0.90 ± 0.00^{ab}	0.90 ± 0.00^{a}	0.90 ± 0.14^{a}	0.80 ± 0.00^{a}	0.85 ± 0.07^{a}	0.80 ± 0.00^{a}
DSPE	2.15 ± 0.07^{cd}	2.10 ± 0.42^{a}	1.95 ± 0.07^{a}	1.05 ± 0.07^{c}	0.80 ± 0.00^{a}	0.85 ± 0.07^{a}	0.80 ± 0.14^{a}	0.80 ± 0.14^{a}	0.80 ± 0.14^{a}	0.75 ± 0.07^{a}	0.75 ± 0.07^{a}
DEPE	2.20 ± 0.00^{d}	1.95 ± 0.35^{a}	1.95 ± 0.07^{a}	1.00 ± 0.00^{bc}	0.90 ± 0.00^{a}	0.95 ± 0.07^{ab}	0.85 ± 0.07^{a}	0.80 ± 0.14^{a}	0.90 ± 0.14^{a}	0.80 ± 0.00^{a}	0.80 ± 0.00^{a}
ESPE	2.00 ± 0.00^{ab}	2.25 ± 0.21^{a}	1.85 ± 0.21^{a}	0.90 ± 0.00^{ab}	0.90 ± 0.00^{a}	0.90 ± 0.00^{ab}	0.75 ± 0.07^{a}	0.90 ± 0.00^{a}	0.75 ± 0.07^{a}	0.75 ± 0.07^{a}	0.74 ± 0.09^{a}
ESPP	2.15 ± 0.07^{cd}	1.95 ± 0.21^{a}	2.00 ± 0.14^{a}	0.85 ± 0.07^{a}	0.90 ± 0.14^{a}	0.85 ± 0.07^{a}	0.90 ± 0.00^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}
DSPP	2.05 ± 0.07^{bc}	2.15 ± 0.07^{a}	1.95 ± 0.07^{a}	1.00 ± 0.00^{bc}	0.90 ± 0.00^{a}	0.95 ± 0.07^{ab}	0.80 ± 0.00^{a}	0.90 ± 0.14^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}
EEPP	1.95 ± 0.07^{ab}	2.00 ± 0.14^{a}	1.95 ± 0.21^{a}	0.90 ± 0.00^{ab}	0.95 ± 0.07^{a}	0.90 ± 0.00^{ab}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}	0.90 ± 0.14^{a}	0.85 ± 0.07^{a}	0.85 ± 0.07^{a}
DEPP	2.15 ± 0.07^{cd}	2.05 ± 0.07^{a}	2.05 ± 0.07^{a}	0.95 ± 0.07^{abc}	0.90 ± 0.00^{a}	1.00 ± 0.00^{b}	0.85 ± 0.07^{a}	0.90 ± 0.14^{a}	0.75 ± 0.07^{a}	0.80 ± 0.00^{a}	0.80 ± 0.00^{a}
Total	2.07 ± 0.11	2.06 ± 0.23	1.94 ± 0.12	0.94 ± 0.07	0.90 ± 0.06	0.91 ± 0.06	0.84 ± 0.07	0.86 ± 0.10	0.83 ± 0.09	0.81 ± 0.06	0.80 ± 0.06

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Changes in pH during storage

The pH of dried tomato products ranged from 5.75 to 5.90 across the 18-week storage period (**Table 7**). At week 0, the average pH was 5.76 ± 0.06, gradually increasing to a peak of 5.90 at week 5, before stabilizing around 5.80–5.88 in the later weeks. This trend suggests that the drying and packaging methods employed were effective in preserving the acidity levels of the tomato products, with only slight fluctuations observed. Such minor variations in pH are typical in dried products during storage, often influenced by enzymatic activity, microbial dynamics, or moisture exchange, depending on packaging permeability. Specifically, the electrically dried polyethylene-packed samples (EEPE and DEPE) maintained relatively stable pH values over time, indicating better preservation due to their limited oxygen permeability and reduced microbial intrusion. In contrast, solar-dried paper-packed samples showed slightly more variability, potentially due to the higher permeability of paper packaging to moisture and gases, which could promote minor microbial or oxidative changes over time (Dladla, 2020).

The general maintenance of pH within a narrow range above 5.7 indicates that the dried tomato products remained within safe and acceptable limits for storage and consumption. According to Codex Alimentarius standards, dried fruits and vegetables with pH levels above 4.5 are generally considered microbiologically safe when properly dehydrated and packaged (FAO/WHO, 2020). Moreover, higher pH stability contributes positively to sensory quality and biochemical stability. These findings align with recent reports that electric drying combined with impermeable packaging (e.g., polyethylene) effectively minimizes post-drying biochemical changes in tomatoes (Dufera et al., 2023). Furthermore, low water activity resulting from proper drying further reduces microbial activity, limiting acid degradation and thus supporting pH retention.

Table 9. Titratable acidity in dried tomato powder during the storage period

Types	Week										
	0	1	2	3	5	7	9	11	13	15	18
EEPE	0.42 ± 0.04^{bcd}	0.35 ± 0.03^{a}	0.33 ± 0.09^{ab}	0.25 ± 0.00^{a}	0.21 ± 0.00^{a}	0.21 ± 0.00^{a}	0.16 ± 0.01^{a}	0.13 ± 0.00^{a}	0.12 ± 0.00^{a}	0.12 ± 0.01^{a}	0.10 ± 0.00^{a}
DSPE	0.37 ± 0.04^{abc}	0.49 ± 0.06^{b}	0.47 ± 0.03^{c}	0.30 ± 0.02^{abc}	0.27 ± 0.03^{a}	0.27 ± 0.03^{a}	0.27 ± 0.06^{bc}	0.19 ± 0.03^{abc}	0.18 ± 0.02^{bc}	0.18 ± 0.03^{bc}	0.20 ± 0.00^{ab}
DEPE	0.51 ± 0.01^{d}	0.39 ± 0.09^{ab}	0.39 ± 0.02^{abc}	0.29 ± 0.01^{ab}	0.22 ± 0.02^{a}	0.23 ± 0.03^{a}	0.27 ± 0.01^{bc}	0.20 ± 0.01^{bc}	0.20 ± 0.01^{c}	0.21 ± 0.00^{bc}	0.23 ± 0.03^{bc}
ESPE	0.38 ± 0.03^{abcd}	0.36 ± 0.01^{a}	0.31 ± 0.02^{a}	0.31 ± 0.00^{abcd}	0.21 ± 0.00^{a}	0.21 ± 0.00^{a}	0.31 ± 0.04^{c}	0.23 ± 0.03^{c}	0.23 ± 0.02^{c}	0.23 ± 0.03^{c}	0.26 ± 0.07^{c}
ESPP	0.41 ± 0.03^{bcd}	0.33 ± 0.01^{a}	0.39 ± 0.02^{abc}	0.39 ± 0.05^{d}	0.22 ± 0.02^{a}	0.23 ± 0.03^{a}	0.25 ± 0.05^{c}	0.22 ± 0.03^{c}	0.23 ± 0.03^{c}	0.22 ± 0.04^{c}	0.26 ± 0.01^{c}
DSPP	0.27 ± 0.10^{a}	0.44 ± 0.04^{ab}	0.33 ± 0.00^{a}	0.36 ± 0.03^{bcd}	0.27 ± 0.02^{a}	0.27 ± 0.03^{a}	0.29 ± 0.00^{c}	0.21 ± 0.00^{c}	0.20 ± 0.01^{c}	0.21 ± 0.00^{bc}	0.20 ± 0.00^{bc}
EEPP	0.49 ± 0.06^{cd}	0.42 ± 0.07^{ab}	0.37 ± 0.01^{ab}	0.39 ± 0.07^{cd}	0.25 ± 0.05^{a}	0.25 ± 0.06^{a}	0.30 ± 0.05^{c}	0.22 ± 0.04^{c}	0.23 ± 0.03^{c}	0.23 ± 0.03^{c}	0.18 ± 0.04^{b}
DEPP	0.32 ± 0.02^{ab}	0.45 ±0.01^{ab}	0.42 ± 0.00^{bc}	0.40 ± 0.05^{d}	0.27 ± 0.02^{a}	0.23 ± 0.03^{a}	0.19 ± 0.03^{ab}	0.14 ± 0.03^{ab}	0.14 ± 0.03^{ab}	0.14 ± 0.03^{ab}	0.20 ± 0.00^{bc}
Total	0.40 ± 0.08	0.40 ± 0.06	0.38 ± 0.06	0.34 ± 0.06	0.24 ± 0.03	0.24 ± 0.03	0.27 ± 0.07	0.19 ± 0.04	0.19 ± 0.04	0.19 ± 0.04	0.20 ± 0.05

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

TSS changes during storage

The TSS of the dried tomato products showed a decreasing trend during the 18-week storage period, ranging from 2.07 ± 0.11 °Brix at week 1 to 0.80 ± 0.06 °Brix at week 18 (**Table 8**). The most significant drop occurred between weeks 1 and 5, where the average TSS decreased by over 50%, followed by a slower decline in the following weeks. Electric-dried polyethylene-packed samples (EEPE and DEPE) consistently maintained higher TSS levels during storage compared to solar-dried and paper-packed samples (e.g., DSPP and DEPP), which showed the lowest TSS levels by week 18. These differences may be due to both the drying method and packaging material, which are important for preserving soluble sugars and organic acids. The observed decline in TSS over time mainly results from biochemical degradation processes such as non-enzymatic browning and potential microbial activity, especially in less protective packaging materials like paper. TSS is an important indicator of sweetness, flavor retention, and nutritional quality in tomato products, and its reduction can harm consumer acceptance (Li et al., 2025). The better retention of TSS in polyethylene-packed products supports earlier findings that moisture-proof packaging minimizes solute loss and microbial growth during storage (Dufera et al., 2023). Solar drying, particularly when combined with paper packaging, likely led to increased exposure to environmental factors (e.g., humidity and oxygen), which speed up chemical breakdown and volatilization of soluble compounds (Farid et al., 2022). Furthermore, high initial TSS levels (above 2.0 °Brix) at week 0 reflect successful concentration of solutes due to drying, but retention over time depends heavily on the packaging environment. Effective moisture barriers are essential to prevent moisture absorption and subsequent dilution or microbial activity, which can hydrolyze or consume soluble sugars and acids.

Titratable acidity in tomato powder during shelf-life evaluation

The TA of the dried tomato products showed a progressive decline throughout the 18-week storage period (**Table 9**). The mean TA decreased from 0.40 ± 0.08% at week 0 to 0.20 ± 0.05% at week 18 (**Table 9**). The most significant reductions occurred during the first seven weeks, dropping from 0.40% to 0.24%, followed by slower reductions in subsequent weeks. Electric-dried samples packed in polyethylene (EEPE and DEPE) generally retained higher TA values than solar-dried and paper-packed samples (e.g., DSPP and DEPP), especially in the later weeks, indicating better acid preservation under those treatments.

Table 10. Changes in color parameters (L*, a*, and b*) of tomato powder during the storage period.

Week	0			4			10			18		
CIE LAB	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**	*L**	*a**	*b**
DHB Solar	45.81 ± 1.44[b]	25.08 ± 0.81[b]	16.67 ± 0.11[a]	42.30 ± 2.50[a]	24.87 ± 0.81[b]	16.45 ± 0.19[a]	41.73 ± 2.45[a]	24.61 ± 0.80[b]	16.19 ± 0.11[a]	30.65 ± 1.08[a]	20.27 ± 0.59[a]	9.68 ± 0.74[a]
DHB Electric	42.06 ± 0.85[a]	23.34 ±0.30[a]	16.42 ± 0.12[a]	41.41 ± 0.11[a]	23.22 ± 0.35[a]	16.28 ± 0.16[a]	40.36 ± 0.05[a]	22.80 ± 0.47[a]	15.95 ± 0.12[a]	32.18 ± 0.62[a]	19.84 ± 0.34[a]	12.08 ± 0.59[b]
EME Solar	44.19 ± 0.50[ab]	23.87 ±0.11[ab]	16.61 ± 0.34[a]	43.58 ± 0.51[a]	23.67 ± 0.11[ab]	16.44 ± 0.40[a]	42.91 ± 0.24[a]	23.24 ± 0.12[ab]	15.84 ± 0.41[a]	32.80 ± 0.65[a]	18.98 ± 0.35[ab]	11.90 ± 0.81[ab]
Total	44.02 ± 1.85	24.09 ± 0.89	16.5± 0.20	42.4± 1.50	23.92 ± 0.86	16.3± 0.23	41.6± 1.59	23.55 ± 0.94	15.9± 0.25	31.8± 1.18	19.70 ± 0.68	11.22 ± 1.32

Values are presented as mean ± standard deviation. Mean values within the same column followed by different superscript letters (a–f) are significantly different ($p < 0.05$). Statistical differences among samples were determined using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test.

Titratable acidity is a critical indicator of the sourness, stability, and microbial safety of tomato-based products. The consistent decline observed across all storage durations suggests that organic acids were lost or degraded over time, a common trend during prolonged storage of dried fruit and vegetable products (Nzimande et al., 2024). The reduction in TA may be attributed to Chemical degradation of organic acids, particularly citric and malic acid, through oxidative reactions, Microbial metabolism, especially in less-protected packaging, and Enzymatic reactions remaining active post-drying in inadequately inactivated tissues (Li et al., 2025). Electric drying likely induced higher temperatures and better enzyme inactivation, while polyethylene packaging reduced oxygen and moisture exposure, both of which contributed to better acid retention. Conversely, solar drying, coupled with paper packaging, may have permitted higher residual moisture and oxygen permeability, accelerating acid degradation. Despite the decline, TA values stabilized from week 11 to week 18 at around 0.19–0.20%, indicating that acid loss slowed significantly after the initial stages of storage. Maintaining acidity is important not only for flavor but also for suppressing microbial growth during ambient storage (Farid et al., 2022).

Color

As indicated in **Table 10**, the CIE Lab system, which measures color based on three parameters: *L** (lightness), *a** (red/green intensity), and *b** (yellow/blue intensity), was used to track the color stability of tomato powder over an 18-week storage period. Consumer attractiveness depends on color retention, which also acts as a proxy for the deterioration of important pigments like lycopene and β-carotene (Schweiggert, 2023). Lightness readings at week 0 varied between 45.81 ± 1.44 in Dhahabu Solar samples and 42.06 ± 0.85 in Dhahabu Electric dried samples. All treatments showed a steady decline over time, with final values at week 18 ranging from 30.65 ± 1.08 to 32.80 ± 0.65. The continuous browning, indicated by the drop in *L** values, is likely caused by oxidative processes such as Maillard reactions and pigment breakdown during storage (Li et al., 2024). Notably, Emelard Solar maintained slightly higher lightness levels compared to Dhahabu samples, suggesting better color preservation under solar drying, which may be attributed to optimized handling.

Redness, indicated by the *a** values, decreased significantly during storage. Initial values ranged from 23.34 ± 0.30 to 25.08 ± 0.81, dropping to 18.98 ± 0.35–20.27 ± 0.59 by week 18. The reduction in redness reflects lycopene degradation, a common occurrence in tomato powders exposed to oxygen, light, and higher temperatures over time (Dufera et al., 2021). Dhahabu Electric showed the largest decrease, while Emelard Solar retained relatively higher values, likely due to gentler drying and improved lycopene stability. The *b** values, indicating yellowness mainly caused by β-carotene, showed a consistent but moderate decrease during storage. In week 0, *b** values ranged from 16.42 ± 0.12 to 16.67 ± 0.11, decreasing to between 9.68 ± 0.74 and 12.08 ± 0.59 by week 18. This decline is attributed to the oxidative degradation of carotenoids, particularly with prolonged storage and inadequate packaging (Meléndez-Martínez et al., 2023). Notably, Emelard Solar maintained better stability than Dhahabu Solar, emphasizing how raw material type and drying technique influence pigment preservation. Overall, color changes occurred across all treatments during storage, but products dried using electric dryers and packaged in polyethylene retained higher color stability compared to other treatments. Despite the decline, the color values of dried tomato products remained within acceptable limits for consumer acceptability after 18 weeks of storage.

Conclusion

This study demonstrated that drying and packaging methods significantly influenced the quality and shelf life of dried tomato and mixed tomato products. Electric oven drying preserved higher levels of vitamin C, β-carotene, and lycopene, improved color stability, and enhanced sensory acceptability compared to solar drying. Polyethylene packaging outperformed paper bags in nutrient retention, microbial stability, and physicochemical integrity (TSS, pH, TA), maintaining yeast and mold counts within acceptable limits. Overall, electric drying combined with polyethylene packaging provided the most effective approach for producing shelf-stable, high-quality dried tomato products suitable for small- and medium-scale processors.

Based on these findings, it is recommended that electric dryers be prioritized for dried tomato production where feasible, while solar tunnel dryers can still be used in resource-limited settings if paired with polyethylene packaging. Further research should explore advanced storage strategies, including modified atmosphere or vacuum packaging, and the incorporation of natural antioxidants (e.g., rosemary extract, citric acid) to enhance nutrient stability and prolong shelf life under different storage conditions, including refrigeration and dark storage. These measures can improve product quality, add value to tomatoes, and reduce postharvest losses in Tanzania and similar agro-ecological regions.

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Conflicts of interest

The authors declare no conflict of interest.

Disclaimer

Authors The authors confirm that no artificial intelligence tools were used in the preparation, analysis, and writing of this manuscript.

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