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Physicochemical Properties and Antioxidant Activity of Tomato (*Solanum lycopersicum* L.) Products: A Comparative Study of Powder, Juice, and Ketchup

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a popular fruit having high antioxidant content mainly lycopene and vitamin C. As tomatoes spoil immediately as perishable and postharvest losses from 25% to 50%. In this study, we compared three tomato products: dehydrated powder, fresh juice, and ketchup. We dried tomato slices in a cabinet dryer at 60–62°C for 15–16 hours and then ground them. Different parameters were done moisture, protein, ash, vitamin C, pH, and sugar content (TSS) store at refrigerated temperature (5±6°C). For antioxidant activity, total phenolics, DPPH, and ABTS tests were done. The results revealed that fresh juice exhibited the highest antioxidant activity, total phenolic content (22.50 mg/100 g), and ABTS values (42.30 µg/mL). The dehydrated powder showed the highest values (15.20 mg phenolics/100 g; 34.60 ABTS), while ketchup had the lowest values (10.80 mg phenolics/100 g; 25.60 ABTS). In contrast, the powder showed ash (4.22%) and protein (9.25%) content. The vitamin C content was much lower (7.54–8.96 mg/100 g) than that in the fresh juice (33.54 mg/100 g). Over the 60 days, TSS levels in juice showed 5.19°Brix. In conclusion, fresh tomato juice is superior in terms of antioxidant activity, whereas dehydrated tomato powder offers the advantages of an extended shelf life and higher concentrations of protein and minerals. Tomato ketchup exhibited the lowest nutritional quality among the three products tested. These findings provide practical guidance for small-scale food processors in selecting appropriate tomato processing methods based on specific nutritional and commercial objectives.

Keywords: Tomato products, physicochemical properties, antioxidant activity, total phenolics, storage stability.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), which belongs to the Solanaceae family, is globally regarded as one of the most popular vegetable crops and makes a significant nutritional contribution to human dietary intake (Amit *et al.*, 2017; Ali *et al.*, 2021). The rapid growth in global tomato production has been driven by advances in agricultural technologies, such as improved varieties, fertilization, pest management, irrigation systems, protected cultivation, and hydroponics (Sora, 2018; Ahmad *et al.*, 2021). Due to their perishable nature, tomatoes must be consumed fresh or processed form (Latapi and Barrett, 2006). Consequently, tomatoes are the most processed vegetable crop globally (Kozlova *et al.*, 2020).

The high water content of tomatoes renders them highly susceptible to spoilage if not preserved properly (Deng *et al.*, 2019). Due to their perishable nature, postharvest losses reach 25%–50%. Fresh consumption and processing into various products, such as paste, sauce, juice, and dried slices or powder, are common ways to utilize tomatoes (Abdullahi *et al.*, 2016). Lycopene possesses antioxidant properties that help eliminate free radicals in the body, decreasing oxidative stress and inflammation, both of which play significant roles in the development (Rao & Agarwal,

2021; Sesso *et al.*, 2020). In addition to their antioxidant and anticancer properties, tomatoes have anti-inflammatory and skin protective effects. During tomato drying, certain physicochemical changes occur (Taylor *et al.*, 2008; Zhang *et al.*, 2017). Researchers have developed several drying methods, including hot-air, microwave, solar-tunnel, and freeze-drying (Baboua *et al.*, 2018; Zhang *et al.*, 2017).

Tomato acceptance is determined by postharvest quality attributes (Rahman *et al.*, 2018). It is very important to control post-harvest changes through proper handling. Many studies have been conducted on storage conditions to extend the shelf life using different treatments and storage conditions (Tomala *et al.*, 2020).

Tomato juice is a beverage that can be consumed immediately without further preparation. The quality characteristics of tomato juice, including flavor, color, consistency, and nutritional value, are affected by factors such as tomato variety, growing climate, cultivation practices, harvesting procedure, degree of ripeness, length of storage before processing, washing, sorting, and steps of the processing procedure.

Dehydration has been used for years as one of the most common methods to preserve tomatoes and other perishable foods. These techniques remove moisture

from the commodity, inhibiting the growth of microorganisms and enzyme activity, and prolonging shelf life (Sharma *et al.*, 2020). During storage, additional changes can affect the appearance, composition, nutrition, and sensory qualities, such as color, texture, and flavor. Therefore, it is necessary to prepare different types of products and evaluate the effects of storage to assess their physicochemical and antioxidant activities.

MATERIALS AND METHODS

Procurement of sample: Fresh tomato fruits (*Solanum lycopersicum* L.) were purchased from a local fruit and vegetable market and brought to the laboratory of the Institute of Food Sciences and Technology (IFST). The tomatoes were selected based on uniformity of size, color, shape, and absence of physical defects or visual signs of spoilage.

Procurement of chemicals and reagents: All chemicals and reagents used in this study were procured from the IFST and the chemicals and reagents utilized for proximate analysis of tomato samples were of analytical grade. These included sulfuric acid (H₂SO₄), potassium sulfate (K₂SO₄), copper sulfate (CuSO₄), sodium hydroxide (NaOH), boric acid, hydrochloric acid (HCl), oxalic acid, dichlorophenol indophenol solution, and phenolphthalein indicator.

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Preparation of tomato products

Preparation of Tomato powder: Tomato powder was prepared according to Rao *et al.* (2011). First, we washed, graded, sorted, and sliced the fresh tomatoes. The tomato slices were kept in a cabinet dryer at 60–62°C for 24 h until a constant weight was achieved. After drying, the tomatoes were ground into a fine powder using a lab grinder to obtain fine powder and packed into airtight polyethylene bags.

Preparation of Tomato Juice: Tomato juice was prepared following the method described by Anthon *et al.* (2011). First, we washed, dried, and cut the tomatoes into pieces. The blended mixture was then passed through a fine mesh sieve to separate the juice from the seeds and skin. The juice obtained was concentrated by gentle heating, packed into glass bottles, and stored in sterilized glass jars under refrigerated conditions.

Preparation of tomato ketchup: Tomato ketchup was prepared using the method described by Anthon *et al.* (2011). Tomatoes and all the required materials, such as garlic, onions, cinnamon, red chilies, cloves, salt, sugar, and vinegar, were used. The mixture was cooked with constant stirring until the required consistency was obtained. The prepared ketchup was poured into sterilized glass bottles, sealed and labeled, and stored under refrigerated conditions for further analysis.

Storage Period: All tomato powder, tomato juice, and tomato ketchup were stored at refrigerated temperature (5–6°C) for 60 days. Physicochemical and antioxidant analyses of all the products were conducted at 0, 30, and 60 days of storage.

Physicochemical analysis

Moisture content (%): Moisture content was measured using the AOAC (2000) method. A 5 g sample was weighed into an empty pre-weighed dish. The samples were kept in an oven at 70°C for 7–8 h. The samples were then cooled in a desiccator, and the values were calculated using the following formula:

$$\text{Moisture (\%)} = (\text{Weight of fresh sample} - \text{Weight of dry sample}) / \text{Weight of fresh sample} \times 100$$

Ash content (%): Ash content, was determined followed by the AOAC (2000) method. Crucibles, dried and recorded their empty weight as W₁. 5 g sample was placed into each crucible and recorded as

W₂. The crucibles kept into a muffle furnace at 550°C for 8 hours. After ashing sample kept into desiccator and weighed them to obtain W₃. The ash content was calculated using the following formula:

$$\text{Ash (\%)} = (W_3 - W_1) / W_2 \times 100$$

Where W₁ = empty crucible (g), W₂ = sample (g), W₃ = crucible + ash (g).

The total soluble solids were determined according to Mazumdar and Majumder (2003). The refractometer was calibrated and adjusted to zero, and the sample was placed onto the prism, and the reading was noted as Brix (°Bx).

pH: The pH of the samples was determined according to the method of AOAC (2000) using a digital pH meter. 10 g of sample mixed with 30 mL of distilled, the pH meter was calibrated using standard buffer

solutions prior to direct insertion of the electrode into the sample. Following the initial pH reading, the electrode was rinsed thoroughly with distilled water and cleaned with tissue paper.

Titrateable acidity (%) and vitamin C (mg/100g): Titrateable acidity was determined by the method of AOAC (2000).

Titrateable acidity was calculated as follows:

Titrateable acidity (%) = (Volume of NaOH × Normality of NaOH × Equivalent weight of acid) / (Volume of sample) × 100

Vitamin C content was determined by the titration method as followed by James (1995) and Mazumdar and Majumder (2003). Ten grams of sample were taken and dissolved in 30 mL of distilled water, then filtered using Whatman filter paper No. 4. Ten milliliters of

filtrate were mixed with 15 mL of oxalic acid and titrated against dichlorophenol indophenol solution until a pink end point was reached. Vitamin C content was calculated as:

Vitamin C (mg/100g) = Titre × Dye equivalent × Dilution factor

Protein content (%)

Protein content (%): The protein content was determined using the Kjeldahl method (AOAC, 2016). A 2 g sample in a Kjeldahl flask was mixed with 30 mL concentrated H₂SO₄, 2 g K₂SO₄, and 0.2 g CuSO₄ and heated gently for 5–8 h. The colorless digest was filtered through Whatman No. 4 paper, transferred to a 250 mL flask, and diluted with distilled water.

Nitrogen (%) = $[1.4 \times (V_1 - V_2) \times \text{Normality of HCl} \times 250] / (\text{Sample weight})$. Protein content was estimated by converting nitrogen percentage to protein using the conversion factor 6.25 (James, 1995):

Antioxidant activity of tomato powder: DPPH radical scavenging assay. The radical scavenging ability of each extract was measured by the method of Costa *et al.* (2014).

Total phenolic content of tomato powder: The total phenolic content (TPC) will be measured using the

Folin–Ciocalteu assay, according to Costa *et al.* (2014).

Organoleptic analysis (sensory evaluation): Sensory evaluation of the tomato-based products was conducted by a panel of 9 judges from the Institute of Food Sciences and Technology. The samples were evaluated for sensory attributes including color, texture, taste, aroma, and overall acceptability using a 9-point hedonic scale as mentioned by Ranganna (2009)

Statistical analysis: The data obtained from all experiments were tabulated in MS Excel (MS Office 2013) and subjected to statistical analysis using standard procedures for analysis of variance (ANOVA). Mean comparison was performed using the Least Significant Difference (LSD) test at a significance level of $P < 0.05$. All statistical analyses were conducted using Statistics 8.1 computer software (Statatix, 2006).

1.60% was recorded for tomato powder after 60 days of storage. The highest titrateable acidity (1.89%) was recorded in tomato juice after one month of refrigerated storage, whereas the lowest titrateable acidity was recorded in tomato ketchup (1.18%) and tomato powder (1.20%) at 0 days. During refrigerated storage, the acidity of all samples decreased with increasing storage periods. The data indicated that the average titrateable acidity remained considerably higher ($P < 0.05$) on the 30th day of storage. This decrease in acidity over time may be attributed to the utilization of organic acids as substrates for microbial growth and chemical reactions during storage.

pH content: Results regarding pH are presented in (Figure 3). The findings for pH varied among products and across storage durations. The data indicated that pH remained considerably higher at the 60th day of storage, with values of 4.42, 4.28, and 4.20 for tomato juice, tomato powder, and tomato ketchup, respectively. The highest pH (4.42) was recorded in tomato juice after 60 days of storage. The lowest pH was recorded in tomato juice (3.70) and tomato ketchup (3.90) at 0 days. The data indicated that the average pH remained considerably higher ($P < 0.05$) in tomato powder during storage. The increase in pH during storage may be due to the degradation of organic acids or the production of alkaline compounds during storage.

RESULTS AND DISCUSSION

Total soluble solids (Brix): Results regarding total soluble solids (°Brix) are presented in (Figure 1). The findings for total soluble solids varied among products and across storage durations. The data indicated that total soluble solids remained considerably higher ($P < 0.05$) at the 60th day of storage, with values of 5.19, 5.02, and 4.96 °Brix for tomato juice, tomato powder, and tomato ketchup, respectively. The highest total soluble solids (5.19 °Brix) were recorded in tomato juice after two months of refrigerated storage, while the lowest total soluble solids were recorded in tomato ketchup (3.44 °Brix) and tomato powder (3.60 °Brix) at 0 days. The rise in total soluble solids of tomato products during storage might be attributed to excessive moisture loss, which increases concentration, as well as carbohydrate hydrolysis into soluble sugars. These findings are consistent with previous studies reporting increased TSS during storage due to moisture loss and enzymatic breakdown of polysaccharides (Rahman *et al.*, 2018; Tomala *et al.*, 2020).

Titrateable acidity: The results regarding titrateable acidity are presented in (Figure. 2). The titrateable acidity findings varied among products and across storage durations. The data indicated that the titrateable acidity remained considerably higher on the 30th day of storage, with values of 1.89% and 1.59% for tomato juice and tomato ketchup, respectively. A value of

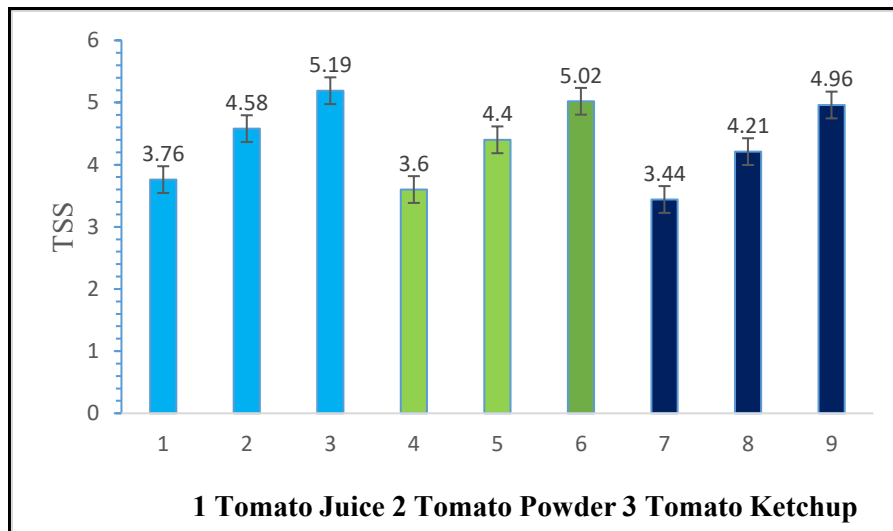


Figure. 1. Total soluble solids (°Brix) of tomato products during storage

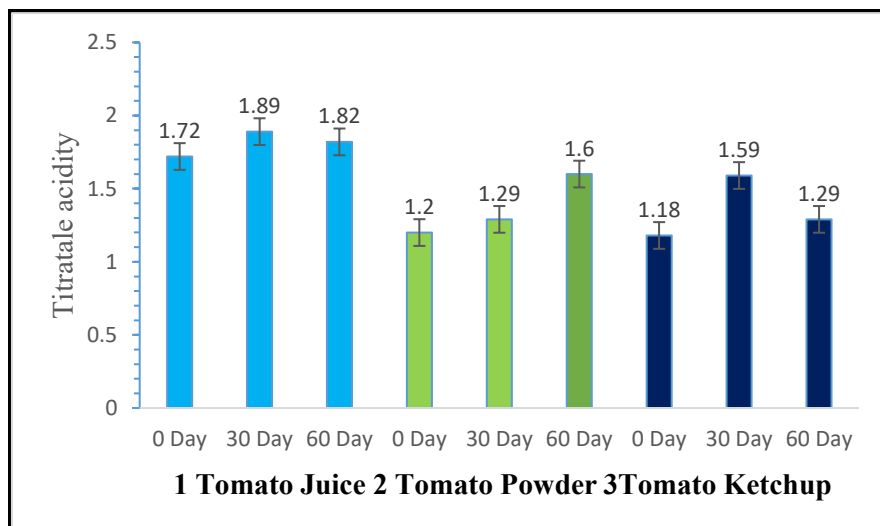


Figure. 2. Titratable acidity of tomato products during storage.

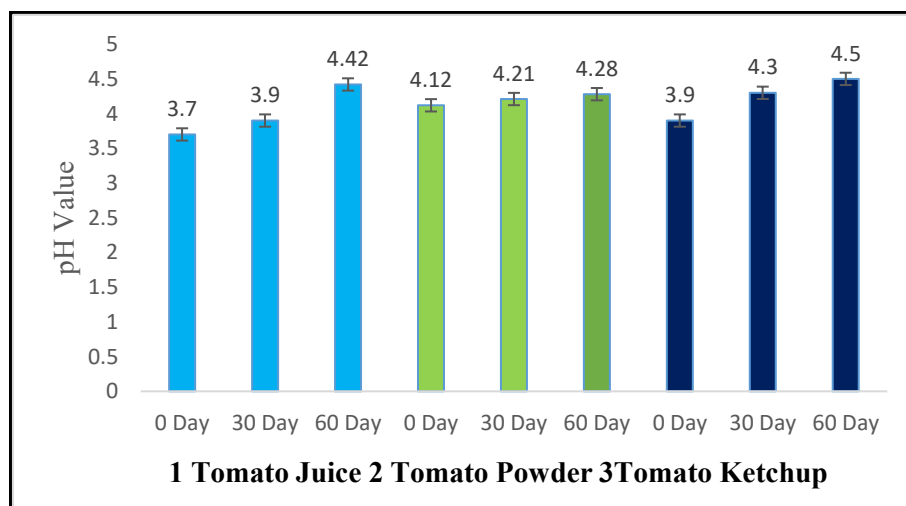


Figure. 3. pH value of tomato products during storage.

Ash content: The ash content results are shown in Figure. 4. The results varied across products and storage periods. Tomato powder had the highest ash

content, 4.22% at day 60 compared to 3.41% after one month of storage. However, tomato juice had the lowest values (0.20% at 0 days and 0.42% at 30 days).

Overall, tomato powder had a significantly higher ash content ($P < 0.05$) throughout the storage. The higher ash content was recorded in the tomato powder, as water removal increased the relative proportion of

mineral matter. These findings are consistent with those of Mishra *et al.* (2018), who reported that minerals are commonly stable during dehydration and become concentrated as the water content decreases

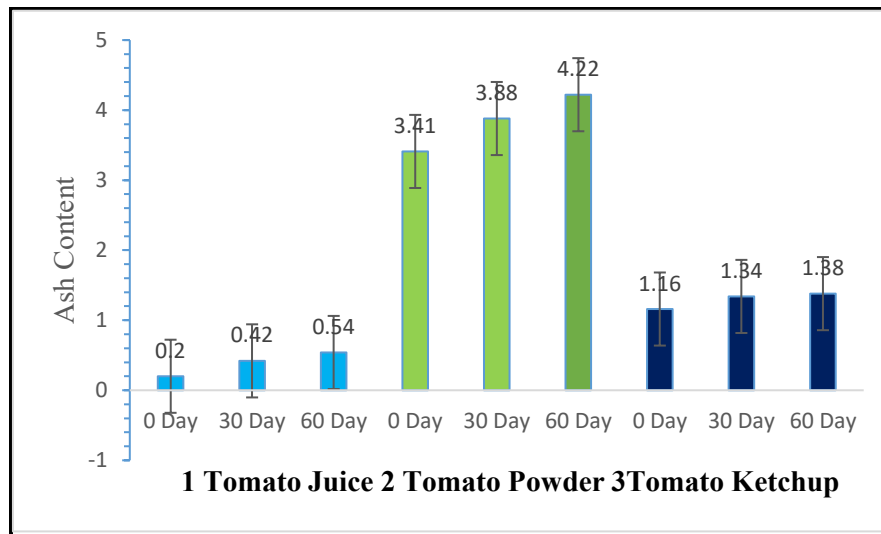


Figure. 4. Ash content of tomato products during storage.

Vitamin C (mg/100g): Results regarding vitamin C are presented in (Figure. 5). The findings for vitamin C varied among treatments and storage durations. The data indicated that the average vitamin C remained considerably higher ($P < 0.05$) at the 0th day of storage (36.44 mg/100g). The highest vitamin C (33.54 mg/100g) was recorded after one month of refrigerated storage, while the lowest vitamin C was recorded in tomato powder (8.96 mg/100g) during storage after 60 days. The vitamin C content of tomato powder ranged from 7.54 to 8.96 mg/100g, which was significantly different from other products. The degradation of

vitamin C during storage is attributed to oxidation reactions, temperature exposure, and the presence of oxygen in the product and headspace of the package. These findings are consistent with Hussain *et al.* (2011), who found that ascorbic acid decreased from 5.67% to 3.64% in apple and apricot blend juice during storage. Similarly, Zeb *et al.* (2009) and Ayub and Khan (2001) reported losses in vitamin C content of pomegranate syrup preserved under different light conditions and packaging materials during four months of storage at room temperature.

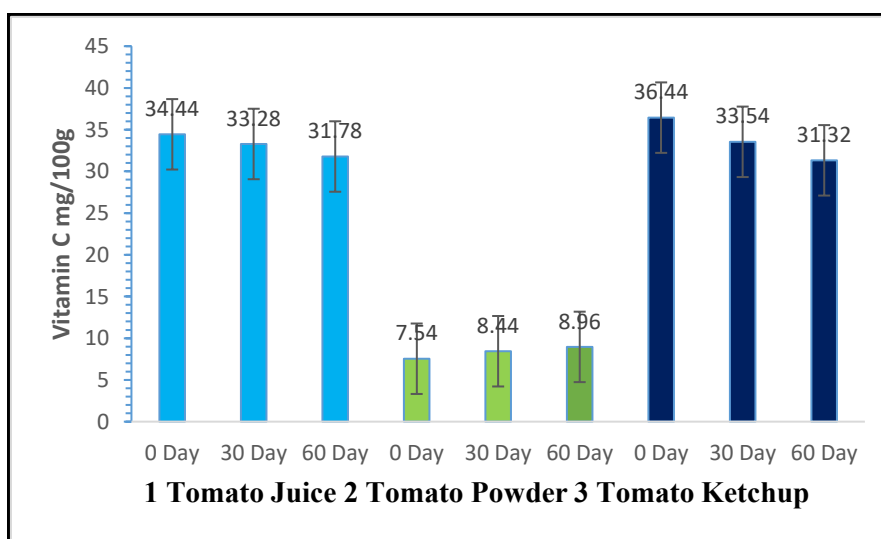


Figure. 5. Vitamin C mg/100g of tomato products during storage

Protein content: Results regarding protein content are presented in (Figure. 6). The data indicated that protein remained considerably higher in tomato powder during storage, ranging from 8.64% to 9.25%. The protein content of tomato juice and tomato ketchup was considerably lower (1.44% and 1.64%, respectively) compared to tomato powder. The highest protein content (9.25%) was recorded in tomato powder at 0

days, and 8.84% was recorded after 60 days of storage. The lowest protein content ranged from 1.34% to 1.40% in tomato juice. The data indicated that the average protein content remained considerably higher ($P < 0.05$) in tomato powder during storage. The higher protein concentration in tomato powder is due to the removal of water during dehydration, which increases the relative proportion of protein in the final product

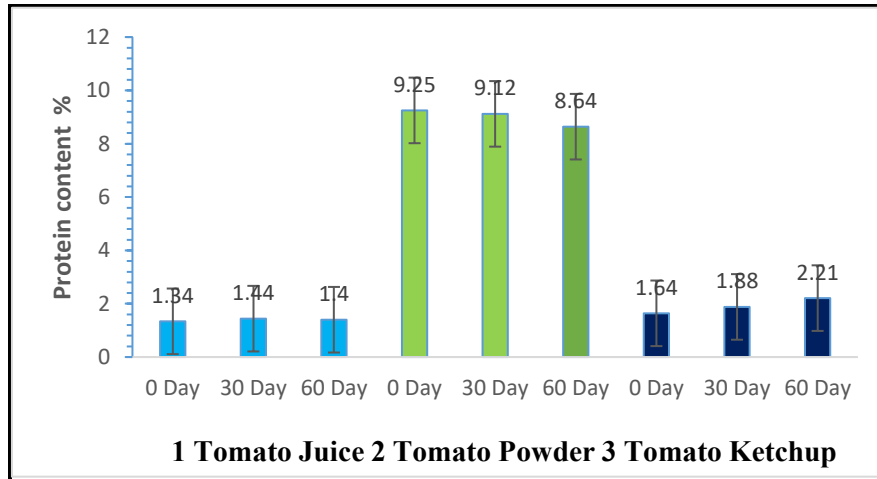


Figure. 6. Protein content of tomato products during storage.

Comparative antioxidant properties of tomato products: Table 1 presents the antioxidant properties of tomato products. Among all tomato products, fresh tomato juice exhibited the highest total phenolic content (22.50 ± 1.4 mg/100g) and the strongest DPPH radical scavenging activity (28.40 ± 1.8 μ g/mL), as well as the highest ABTS radical scavenging activity (42.30 ± 2.0 μ g/mL), indicating that minimal thermal processing best preserves overall antioxidant capacity. While tomato powder can be added to dry mixes, seasonings, baked goods, and sauces utilizing current drying, milling, and blending processes, tomato juice can be readily included into liquid-based food compositions (Wang, F.; Cui, H *et al.*, 2026). Dehydrated tomato powder (65°C) showed moderate antioxidant retention, with total phenolics of 15.20 ± 1.1 mg/100g, DPPH value of 32.50 ± 2.3 μ g/mL, and ABTS value of 34.60 ± 1.8 μ g/mL. Statistically, the DPPH activity of tomato powder (32.50) was not significantly different from tomato juice (28.40). As a shelf-stable and value-added product, tomato ketchup

can be used as a handy, antioxidant-rich component in a variety of processed goods. Additionally, by minimizing the need for synthetic antioxidants, partially replacing conventional raw materials, and lowering total manufacturing costs, the use of tomato-based products like juice and powder may offer financial benefits (Lopez Bermudez, Y.N *et al.*, 2022). Tomato ketchup demonstrated the lowest antioxidant activity across all parameters, with total phenolics of 10.80 ± 0.9 mg/100g, DPPH of 38.20 ± 2.1 μ g/mL, and ABTS of 25.60 ± 1.5 μ g/mL, indicating significant difference. The lower antioxidant activity in ketchup is attributed to severe heat degradation during processing and dilution by added sugar and salt. These findings suggest that for maximum health benefits, fresh tomato juice or properly dehydrated powder should be recommended over commercial ketchup. In Table 1, superscript letters (A, B, D) indicate statistically significant differences between treatment means at $p < 0.05$

Table. 1. Comparative antioxidant properties of tomato products

Parameter	Tomato Powder (Dehydrated 65°C)	Tomato Juice	Tomato Ketchup
Total Phenolics (mg/100g)	15.20 ± 1.1 B	22.50 ± 1.4 A	10.80 ± 0.9 D
DPPH (μ g/mL)	32.50 ± 2.3 A	28.40 ± 1.8 A	38.20 ± 2.1 B
ABTS (μ g/mL)	34.60 ± 1.8 B	42.30 ± 2.0 A	25.60 ± 1.5 D
LSD Value (5%)	0.05	0.05	0.05
P-Value	< 0.05	< 0.05	< 0.05

Sensory evaluation: The sensory evaluation of tomato-based products was conducted using a 9-point hedonic scale by a panel of 9 judges. The results for color, texture, taste, aroma, and overall acceptability are presented in Table 2. Tomato juice received the highest scores for overall acceptability (8.2), followed by tomato ketchup (7.8) and tomato powder (7.5). The

color of tomato juice was rated highest (8.5), while tomato powder received slightly lower scores for texture due to its powdered form. These results indicate that all three tomato-based products were well-accepted by the panelists, with tomato juice being the most preferred

Table. 2. Sensory evaluation of tomato products

Product	Color	Texture	Taste	Aroma	Overall Acceptability
Tomato Juice	8.5	8.0	8.3	8.0	8.2
Tomato Powder	7.8	7.2	7.6	7.4	7.5
Tomato Ketchup	8.0	7.8	7.9	7.6	7.8

CONCLUSION

From an industrial view, the suggested method is very scalable because the processing sector consistently produces enormous amounts of tomato by-products, which are simple to incorporate into current drying and milling processes. Additionally, by minimizing waste management expenses and partially replacing conventional raw materials, their use as food additives may offer financial benefits by lowering overall manufacturing costs.

The findings indicate that tomato-based products (tomato powder, tomato juice, and tomato ketchup) have good nutritional value and can be stored in refrigeration for up to 60 days. Tomato juice showed the highest antioxidant activity, indicating that total phenolics (22.50 mg/100 g), DPPH (28.40 µg/mL), and ABTS (42.30 µg/mL) showed that minimal processing preserved bioactive compounds. The results further demonstrated that the dehydrated tomato powder had moderate antioxidant levels (15.20 mg phenolics/100 g; 34.60 ABTS), but excelled in ash (4.22%), protein (9.25%), and mineral content, all concentrated by the drying process. Results further showed tomato ketchup had the lowest nutritional quality in all parameters, including the ABTS (25.60 µg/mL) and lowest total phenolics (10.80 mg/100g). after the 60-day refrigerated storage, total soluble solids increased while titratable acidity decreased. Vitamin C content showed a declining in all products, with the highest retention observed in tomato juice (33.54 mg/100g) and the lowest in tomato powder (7.54–8.96 mg/100g). Based on these findings, it is concluded that fresh tomato juice is excellent for antioxidant activity, while dehydrated tomato powder minerals, and extended shelf life. Tomato ketchup is the least recommended product from a nutritional perspective. Further studies are recommended to evaluate longer storage periods (beyond 60 days), by different drying methods and the application of tomato powder in various food formulations.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

S.G.K. supervised the project and wrote the manuscript. A.H.S. provide laboratory facilities and A.R.J and S.G.K. collected and analyzed the data and revised the manuscript.

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