International Journal of Scientific Research and Modern Technology (IJSRMT) ijsrmt.com
Volume 4, Issue 8, 2025
DOI: https://doi.org/10.38124/ijsrmt.v4i8.744

Comparative Evaluation of Effect of Conventional Processing Techniques on the Nutritional Quality of Tomatoes (*Lycopersicon esculentum*)

Faseeha Muqadus[1]; Rabia Batool[2]; Iqra Muneer[3]; Ahmad Raza[4]; Fraz Ahmad[5]; Dr. Ali Hassan[6]

[1]National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan
[2,3,5]Faculty of Food Science and Nutrition, Bahaudin Zakaria University, Multan, Pakistan
[4]Australian Institute of Higher Education (AIH), Melbourne, Australia
[6]National Institute of Food Science and Technology, University of Agriculture, Faisalabad

Publication Date: 2025/08/25

Abstract

Tomato is a highly nutritious fruit. Different processing methods are used to keep its quality attributes. In this study, the effect of four processing methods was assessed on the quality aspects of cherry tomatoes. 5 batches were prepared. First batch was control while the second, third, fourth, and fifth batches were subjected to the processes of drying, blanching, frying and freezing, respectively. After processing the tomatoes, proximate analyses were carried out through standard analytical methods. The results showed that moisture contents were highest in blanched samples and lowest in the dried samples. Ash contents were almost same in all the samples.There was not a prominent difference between crude fiber contents of all processed samples. The crude protein percentage was 12.77% in blanched samples while frozen samples had the lowest percentage, i.e., 1.95%. Crude fat contents were highest in fried samples and lowest in frozen sample. The dried tomato samples had highest carbohydrate content and frozen sample had lowest. The results of the study represented that blanching is comparatively better method to preserve the moisture, ash, fiber and protein contents while to preserve fat and carbohydrate contents, drying and frying are the comparatively better methods, respectively.

Keywords: *Tomatoes, Conventional Processing Techniques, Processing Methods, Blanching Quality Attributes.*

I. INTRODUCTION

Tomatoes (*Lycopersicum esculentum*) are highly perishable fruits with a relatively shorter shelf life. Various processing methods significantly affect their shelf life and quality aspects (Bolano et al., 2024). Their desirable flavour and nutritious components make them one of the most important and popular commercial vegetables in the world (Niu et al., 2024). To increase their versatility and culinary uses, tomatoes are extensively processed into a variety of products, including paste, juice, sauce, puree, and ketchup (Szabo et al., 2025).

Tomatoes contain a wide range of nutrients and bioactive components, such as vitamins, soluble solids, acids, phenolic compounds, and the notable component lycopene (Yin et al., 2024). They contain a high moisture content i.e. 88.16%. The lipid content is relatively low at 0.39%, while the protein and ash contents are 2.18% and 0.75%, respectively. Tomatoes also provide 4.37% dietary fibre and 4.15% carbohydrates. Additionally, they are a good source of bioactive compounds like lycopene present at 1.03% and vitamin C at anotable concentration of 38.32% (Makinde et al., 2025). The Food and Agriculture Organization (FAO) reported in 2023 that tomato production has risen significantly in recent years, from 182 million metric tonnes in 2018 to 189 million metric tonnes in 2021. China, United States, India, and Turkey are among the largest contributors to this growth (Ambreen et al., 2025; Firdous et al., 2021).

It is unfortunate that one-third of the food produced worldwide is lost before it reaches consumers. Tomatoes are climacteric and perishable fruits with a limited shelf

Muqadus, F., Batool, R., Muneer, I., Raza, A., Ahmad, F., & Hassan, D. A. (2025). Comparative Evaluation of Effect of Conventional Processing Techniques on the Nutritional Quality of Tomatoes *(Lycopersicon esculentum)*. *International Journal of Scientific Research and Modern Technology*, *4*(8), 124–135. https://doi.org/10.38124/ijsrmt.v4i8.744

life of 2 to 3 weeks. It makes them vulnerable to post-harvest losses across the food supply chain (Wakene & Sharew, 2024). Compared to fewer than 15% in developed nations, post-harvest nutritional losses in underdeveloped nations range from 30 to 50% (Firdous et al., 2021).

Nutrients and bio-active substances of fruits and vegetables are affected by common food processing techniques such as freezing, canning, and drying. Despite the widespread belief that processed foods are inferior to unprocessed foods, "processing" is not always a bad thing, and processed foods are not always unhealthy or low in nutrients. Food processing can improve food safety and may have positive impacts like increased nutritional digestion and bio-availability (Bolano et al., 2024).

The physicochemical properties of tomatoes are altered by various cooking methods. The heating process raises the temperature, which has thermal impacts and alters the tomatoes' texture, flavour, appearance, and bioactive chemicals. Thus, a variety of cooking techniques were used in this study to assess and ascertain the physicochemical properties and antioxidant content preservation of tomatoes (Teh et al., 2024). The studies conducted in the past included the use of only one or two processing methods on the tomatoes, whereas we chose to analyze the impact of various conventional processing techniques (blanching, drying, freezing, and frying) on the tomatoes' quality. The aim of this study was to evaluate the effect of various processing methods on the quality aspects of tomatoes to minimize the nutritional losses of this highly perishable fruit.

II. MATERIALS AND METHODS

➢ *Raw Materials*

To get the optimum results, organically grown cherry tomatoes were obtained from the region Faisalabad, Punjab Pakistan. Tomatoes were harveste at peak maturity level and transported to Food Processing Laboratory of National Institute of Food Science and Technology, UAF, Pakistan, in cardboard containers.

➢ *Chemicals*

Acetonitrile, ethanol, ultrapure water, Carrez I (potassium hexacyanoferrate II), Carrez II (zinc acetate), Petroleum ether, hexane, concentrated sulfuric acid (H_2SO_4), copper sulfate ($CuSO_4$), sodium hydroxide (NaOH), hydrochloric acid (HCl), acetone, nitric acid (HNO_3), metaphosphoric acid, oxalic acid, 2,6-dichlorophenolindophenol (DCPIP), Folin–Ciocalteu reagent, sodium carbonate (Na_2CO_3), gallic acid, methanol, ethanol, butylated hydroxytoluene (BHT), anhydrous sodium sulfate (Na_2SO_4), 2,2-diphenyl-1-picrylhydrazyl (DPPH), phenolphthalein, methyl red, and boric acid.

➢ *Preparation of Samples*

Tomatoes were washed, trimmed and sorted in the lab to eliminate inedible portion. The washed tomatoes were then uniformly sliced into pieces of approximately 8 mm thickness to ensure consistency for experimental analysis.

Five treatment groups, each containing two kilogrammes of tomatoes, were prepared. Four groups underwent different processing techniques: blanching (T_1), drying (T_2), freezing (T_3), and frying (T_4) as described in table. 1. The first group was kept untreated control (T_0). Tomato samples were blanched (T_1) by immersing them in boiling water(100°C) for 60 seconds followed by immediate chilling in ice water for another 60 seconds. Then, samples were stored in sealed containers after draining water (Chiang and Chiang, 2024). To prepare dried sample (T_2), Tomato slices were put on trays coated with aluminium foil and dried in a hot air oven DHG-9030A, set to 70°C for seven hours (Abioye et al., 2024). In order to prepare fourth batch, frozen sample (T_4), tomatoes were sorted, cleaned, and uniformly sliced. The samples were frozen in plastic containers at -4°C for 24 hours. Sliced tomatoes were pan-fried for 8 minutes at 160–165°C in 100ml olive oil to prepare the fried batch (T_4). After processing, all samples were kept at -18°C until they could be experimented further. Table 1 shows the treatments applied to the samples.

Table 1 Treatments and Processing Conditions applied to the samples

Sr. No.	Treatments	Process
1	T_0	Control
2	T_1	Blanching (95°C, 5 sec.)
3	T_2	Drying (70°C, 7 hrs.)
4	T_3	Freezing (-4°C or -32°F, 8 hrs.)
5	T_4	Frying (190°C or 375°F, 2 min)

(Treatments and processing parameters applied to the experimental samples, along with their respective temperature and time conditions).

➢ *Storage Study*

The processed tomato samples were stored at -4°C, and proximate analyses were carried out at 0, 5th, 10th and 15th day.

➢ *Proximate Analysis*

Proximate analysis of control and treated samples was performed to determine moisture content, crude protein, crude fat, ash, and crude fiber by following methods described by AOAC, 2019. Moisture content was estimated by oven drying at 105 °C until constant weight. The Kjeldahl technique was used to quantify crude protein, while the Soxhlet extraction method was used to analyse crude fat (Fiorilla et al., 2025). Crude fibre was determined using acid and alkali digestion and the sample's total ash content was ascertained by burning it in a muffle furnace

at 550°C (Moningkey et al., 2023). To guarantee accuracy and repeatability of results, all analyses were carried out in triplicate.

- *Determination of Moisture Content*

Moisture content of the tomatoes' samples was measured according to the method of Baparay et al., (2024). The samples placed in glass dishes were placed in oven at a temperature of 70ºC for 24 hours. Then the samples were weighed again. The moisture content of the processed tomato samples were determined by the help of the following formula:

$$\text{Moisture content \%} = (A-B)/A \times 100 \quad (1)$$

Where, A= initial weight before drying, B =weight after drying

$$\text{Weight loss (\%)} = DM1/DM \quad (2)$$

Where, DM1 is dry matter weight before drying the sample, DM is the weight of the dry matter.

- *Determination of Ash Content*

Ash content was measured based on the method used by Teh *et al.*, (2024). 3g of each tomatoes' sample (blanched, dried, frozen and fried) were placed in the porcelain crucible. The samples were burnt in ash furnace at 550°C overnight. The samples were taken out of the muffle furnace and weighed after cooling in a desiccator. The following equation was used to calculate the sample's ash content in percentage:

$$\text{Ash (\%)} = \frac{\text{Weight of ash residue}}{\text{Weight of sample}} \times 100 \quad (3)$$

- *Determination of Crude Fibre*

The cellulose material obtained as a residual in the chemical examination of vegetable components is known as crude fibre. Crude fibre is expressed in percentage. Crude fiber contents in the tomatoes' samples were measured according to the method used by Baparay et al., (2024). The beaker was filled with 5g fat-free sample. Then, to the marked point, concentrated H_2SO_4 was added to the vessel. Then, the mixture of samples was heated for half an hour in a glass on the Bunsen burner. The sample was then rinsed with distilled water to remove any remaining acid. The sample was then heated for 1 hour in NaOH solution before being rinsed with distilled water to remove alkali. It was then placed in a crucible, which was put in a hot air oven for 3-4 hours at 100°C to dry. The crucible was taken out of the oven and placed in a muffle furnace at 550°C -6500°C for 5- 6 hours, when the sample had completely dried. To cool the crucible, it was placed in a desiccator. The following formula was used to calculate crude fibre:

$$\text{Crude fibre (\%)} = \frac{\text{Weight loss after digestion (g)}}{\text{Weight of the sample (g)}} \times 100 \quad (4)$$

- *Determination of Protein Content*

The term "crude protein" refers to the measurement of all nitrogen sources, including non-protein nitrogen. The protein content was determined using the Kjeldahl method, as stated by Baparay et al., (2024). 2g of anhydrous tomato slices were added to the digestion bottle, followed by 1 digestion tablet and 30 ml of concentrated H_2SO_4. This sample was cooked and digested for 3-4 hours until it turned light green in colour. After that, a 250ml flask was taken, and this mixture was added in it. The mixture was made to 100 ml by adding distilled water. The Kjeldahl device was filled with 10 ml dilution and 10 ml NaOH. 1-2 drops of red methyl indicator were added to 10ml of Boric acid in another beaker. Steam was used to carry the ammonia gas into the Boric acid, and the process lasted for 2 minutes. The bright gold colour was obtained by titrating the distillation against a standard 0.1N H_2SO_4 solution. Crude protein percentage was determined using following formula:

$$\text{Nitrogen (\%)} = \frac{\text{Volume of } 0.1N\ H_2SO_4 \text{ used} \times 0.0014 \times \text{Equivalent weight of nitrogen}}{\text{Sample weight}} \times 100 \quad (5)$$

$$\text{Crude protein \%} = \text{Nitrogen \%} \times 6.25 \quad (6)$$

- *Determination of Fat Content*

"Crude fat" refers to the unprocessed mixture of fat-soluble materials found in a sample. The standard measure of fat in food is crude fat, also known as ether extract or free lipid content. The proximate composition of the tree tomato puree was determined according to the method used by Baparay et al., (2024) using Soxhlet extraction. According to this method, fat was extracted from the sample using petroleum ether. Then, the galvanometric quantification of the sample was carried out. The crude fat percentage was calculated as:

$$\text{Crude Fat (\%)} = \frac{\text{Weight of extracted fat}}{\text{Weight of sample}} \times 100 \quad (7)$$

- *Determination of Carbohydrates content*

Carbohydates content was calculated by the method of Mendelova et al., (2021) using HPLC with a refractive index detector. 2 g of homogenized tomato was extracted in ethanol:water (4:1) for 1 hour to prepare the samples. The samples were then clarified with Carrez I and II reagents followed by centrifugation and filtration. The sugars were separated on a Zorbax aminopropyl column using acetonitrile:water (80:20) as the mobile phase at a flow rate of 1.6 mL/min. Calibration curves of known sugar standards were used to figure out the amount.

- *Determination of Total Phenolic Content*

Polyphenol content was determined using the Folin-Ciocalteau colorimetric technique as followed by Joung et al. (2025). A solution containing 10-50 uL of sample, 50 uL of Folin-Ciocalteau phenol reagent, and 19 to 800 uL of deionised water was prepared. After 1 minute, 100 uL

of 20% sodium carbonate solution was added with vigorously stirring. Afterwarde 1 mL deionised water was added. The mixture allowed to incubation at room temperature fo 2 hours, the total phenol concentration was measured using a Beckman Coulter DU spectrophotometer at 765 nm. The standard curve developed with quercetin was used for quantification. All determinations were made in triplicate.

- *Determination of Lycopene Content*

Lycopene was isolated using a process developed by Kakubari et al. (2020). A tomato slurry was prepared with 0.5 g of tomato in 1 mL of distilled water. Following that, 5 mL of butylated hydroxytoluene solution in acetone (0.5 g/L) was added to the tomato slurry in a photo protected tube. In addition, 10 mL of hexane was combined with 5 mL of aqueous ethanol (95% v/v) and vortexed for 10 minutes. The supernatant was pipetted into a quartz spectrophotometer, at 503 nm, the absorbance was measured. The amount of lycopene in tomato paste was calculated as below:

$$\text{Lycopene (mg/ Kg)} = \frac{A_{sample} \times F}{W_{\text{sample}}} \quad (7)$$

where, A_{sample} is the absorbance at 472nm, F is the calibration factor derived from the standard curve (in $\text{mg}\cdot\text{L}^{-1}$), W_{sample} is the weight of the sample (in kg).

- *Determination of Ascorbic Acid*

Based on the oxidation of L-ascorbic acid by 2,6-dichlorophenol indophenol in an acidic medium, AOAC Method 967.21 (AOAC, 2007) followed by Abdelmonaem *et al*. (2024) was used to measure the ascorbic acid concentration of tomato samples. The dye solution was made with 52mg dye, 42mg sodium bicarbonate, and 200ml of distilled water. After dissolving 200mg of Ascorbic acid in 200ml of 0.4% oxalic acid, 10 mL of this solution was diluted to 100 ml to create a standard solution. To titrate, 1.5 mL of 0.4% oxalic acid and 1 mL of standard were added to the sample, agitated, then titrated with the dye until a pink endpoint emerged.

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Amount of ascorbic acid (mg)}}{\text{Sample weight (g)}} \times 100 \quad (8)$$

- *Determination of Vitamin A:*

HPLC was used to quantify the vitamin A contents, with minor adjustments, in accordance with AOAC Official Method, 2023 (Baparay et al., 2024). Hexane was used to extract the samples after they had been saponified with 60% w/v ethanolic potassium hydroxide (KOH) and Butylated Hydroxytoluene (BHT) for 30 minutes at 70°C. The organic layer was then dried over anhydrous sodium sulphate and evaporated under nitrogen. The residue was reconstituted in 95:5 v/v methanol:water, filtered (0.45 µm), and subjected to isocratic elution at 1.0 mL/min using a C18 column (250 mm × 4.6 mm, 5 µm). At 325 nm, a UV-Vis detector was used for detection. The results were reported as µg retinol equivalents per gramme of material, and the quantification was based on external calibration using all-trans-retinol standards (Van Aard et al., 2025).

- *Determination of Antioxidants:*

DPPH and total phenolic contents were determined using their respective procedures described by Xiao et al. (2020). Specifically, the antioxidant activity was evaluated based on the method by Hossain et al. (2024), which involves assessing the ability of tomato extracts to neutralize the stable free radical DPPH (2,2-diphenyl-1-picrylhydrazyl). In the method, 5 mL of a 0.1 mL methanolic extract of tomato (at different concentrations) was prepared. These mixtures were then kept at a constant temperature of 27°C for 20 minutes to allow the reaction to occur. After the incubation period, the decrease in absorbance at 517 nm was measured using a spectrophotometer. Radical scavenging activity was calculated as a percentage of inhibition using the following formula:

$$\text{Radical Scavenging Activity (\%)} = \frac{A_c - A_s}{A_c} \times 100 \quad (9)$$

Where, A_c is Absorbance of the control (DPPH solution without sample) and A_s is Absorbance of the sample (DPPH solution with extract).

- *Storage Study*

To estimate the shelf life, processed tomatoes were stored at a temperature of 4°C for 5, 10 and 15 days. At the end, comparative analysis of the physicochemical properties and shelf life of all batches were carried out to figure out the batch with better quality aspects and longer shelf life.

- *Statistical Analysis:*

The obtained data was subjected to statistical analysis using the analysis of variance technique by two factor factorial design (Basit *et al.*, 2024). Fig 1 summarizes all the steps carried out during this research.

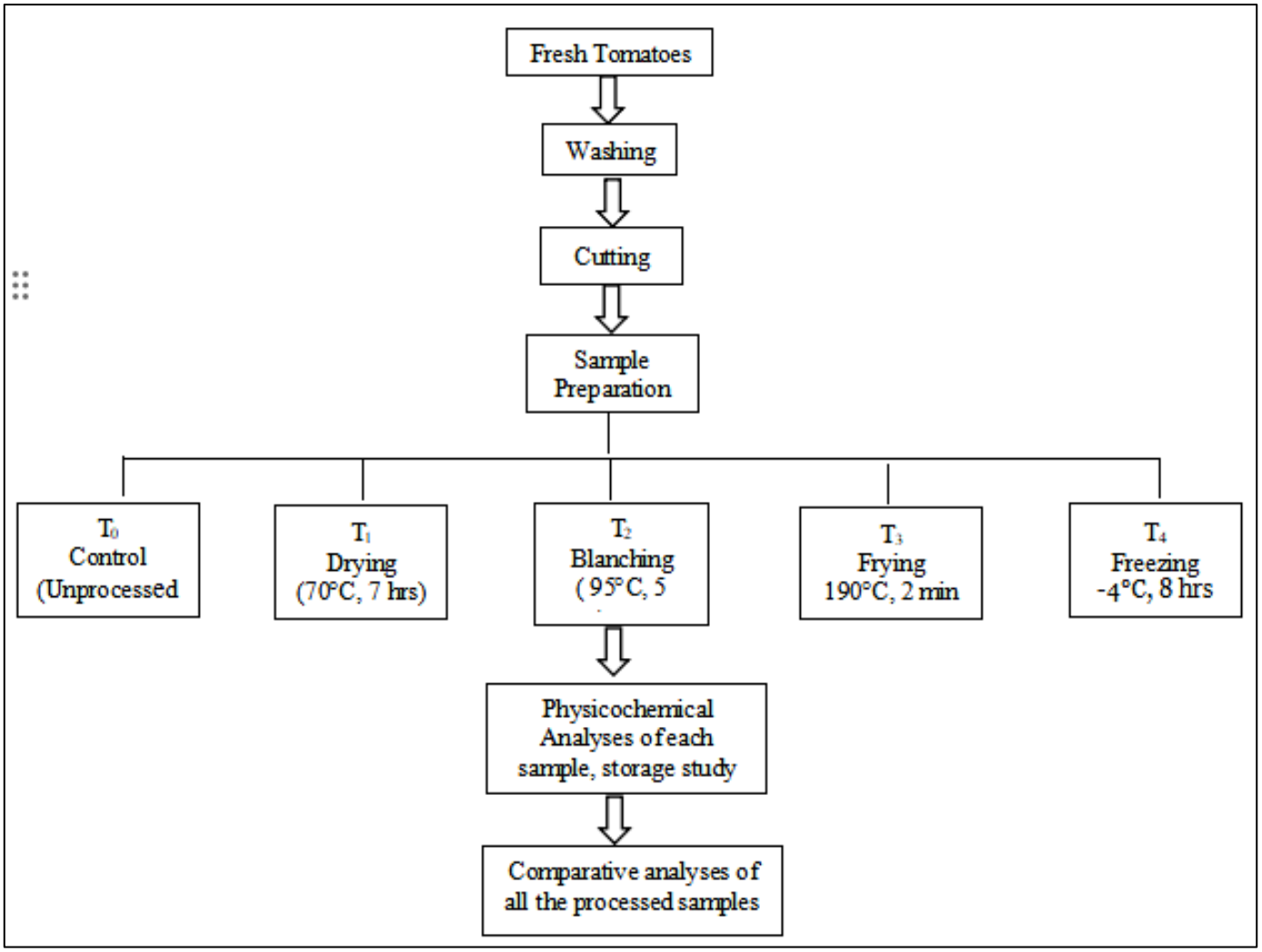

Fig 1 Flow Chart Showing the Processes Involved and the Conditions Applied During the Whole Experimental Procedure

III. RESULTS AND DISCUSSION

In this study, statistical software statistix 8.1 was used for data analysis to observe significance. Liner model method was used to conduct analysis of variance of the results by implementing two factor factorial design. Three replicates and four variables i.e., drying, freezing, blanching, and frying were taken and results were analyzed at 0, 5, 10 and 15 days (4 levels) under CRD at 0.05% confidence interval (Basit *et al.*, 2024).

➢ *Moisture Content*

Investigations on the effects of various treatments and storage techniques on moisture content of tomato samples depicted statistically significant differences between the treatments. Fresh tomatoes (T_0) exhibited 94.21% moisture. Blanched tomatoes (T_1) had the highest moisture i.e. 95.97% because of being subjected to a water treatment. Dried tomatoes (T_2) had the lowest moisture i.e. 62.98% due to moisture loss during drying. Frozen tomatoes (T_3) had 84.68%, and fried tomatoes (T_4) had 85.28%, both lower than fresh samples, due to moisture loss from freezing and heat treatment, respectively. The results align with previous studies as Ahmed et al. (2020) reported moisture contents of about 97.58% for blanched and 62.71% for dried tomatoes. Arkoub-Djermoune et al. (2019) found fried tomatoes to have around 82.12% moisture, while Wang et al. (2015) reported freeze-dried tomatoes with approximately 90.23% moisture.

➢ *Ash and Crude Fiber*

Ash content showed minimal variation across samples. Fresh tomatoes (T_0) had 0.14g, while T_1 and T_2 had 0.13g, T_3 had 0.15g, and T_4 had 0.12g. Processing had little effect on ash content, as these methods do not significantly impact inorganic compounds. Ahmed et al. (2020) reported ash contents of about 0.92% in blanched and 0.16% in dried tomatoes. Arkoub-Djermoune et al. (2019) found fried tomatoes to have ~0.59% ash, while Wang et al. (2015) reported ~0.70% ash in frozen tomatoes.

Treatments and storage had a highly significant effect on the fiber content of tomatoes. Fresh tomatoes (T_0) had 1.72g of crude fiber, while treated samples showed reduced levels: T_1(dried) had 1.26g, T_2(blanched) 0.94g, T_3(fried) 1.00g, and T_4(frozen) 1.13g. Blanching increased crude fiber content, likely because minerals, vitamins, and low-molecular-weight carbohydrates leached into the blanching water, concentrating the fiber (Wenberg et al., 2006). These findings are consistent with Severeni et al. (2016), who reported fiber contents of 1–2% in blanched and dried tomatoes, and Fillion et al. (2009), who found similar fiber levels (1–2%) in freeze-dried and fried tomatoes.

➢ *Protein and Fat Content*

The protein content of fresh tomatoes (T0) was 16.67%. Treated samples showed reduced protein levels. The protein content of T_1(dried), T_2(blanched), T_3(fried), and T_4(frozen), was 5.49%, 11.29%, 1.8%, 2.68% respectively. The decrease is attributed to protein denaturation caused by both high (heat treatments) and low (freezing) temperatures. Reis (2016) found that blanching reduced tomato protein content to 10.7–12%. Opega et al. (2017) reported protein levels of 6.71–7.79% in dried tomatoes. Arkoub-Djermoune et al. (2019) observed about 2% protein in fried tomatoes, while Wang et al. (2015) found freeze-dried tomatoes to contain approximately 3.01% protein.

After 15 days of storage, the fat content in fresh tomatoes (T_0) was 2.31g. Treated samples showed the fat contents as T_1(dried) 8.14g, T_2(blanched) 2.26g, T3(fried) 12.23g and T_4 (frozen) 2.20g. Drying apparently increased fat contentis due to water loss. It concentrated existing fat and improved extractability during analysis. This is a common effect seen in drying fruits and vegetables by Minuye et al., (2024). Fat content slightly decreased in T_2 and T_4 due to cell structure damage from heat and freezing, respectively. T_3 had the highest fat content due to oil absorption during frying. These findings align with the study conducted by Hossain et al., (2018).

➢ *Carbohydrates*

Notably, all treatments showed a gradual increase in carbohydrate content as storage progressed, although the magnitude of increase varied across treatments. At day 0, the initial carbohydrate content ranged narrowly between 17.80g to 18.10g/100g. This baseline aligns with earlier findings by Shi et al. (2022) and Jorge et al. (2018)**,** who reported carbohydrate content in fresh tomatoes generally falls between 17g–20g/100g, largely influenced by cultivar, ripeness, and postharvest handling. As storage duration increased, T_0 (control) demonstrated a more noticeable rise in carbohydrate concentration, reaching 18.55g/100g by day 15, compared to T_1 and T_4, which ranged from 18.25g to 18.40g/100g. This pattern can be attributed to moisture loss through transpiration and respiration during storage, which concentrates soluble solids such as carbohydrates. Wakene & Sharew (2024) and Firdous et al., (2021) have emphasized that physiological weight loss in tomatoes due to dehydration can result in an apparent increase in nutrient density. Furthermore, Severini et al. (2016) observed that coatings or treatments like blanching could modulate transpiration rates, possibly explaining the relatively lower increase in carbohydrate content in treated samples (T_1–T_4) compared to the control. Among the treated samples, T3 consistently exhibited slightly higher carbohydrate retention than T_1, T_2, and T_4, suggesting it may offer better moisture retention or slower metabolic degradation. This aligns with findings by Gębczyński et al. (2024)**,** who reported that specific drying and preservation techniques influence the rate of carbohydrate changes during storage.

➢ *Total Phenolic Content*

When compared to fresh tomatoes, the content of phenolic compounds was greater following all processing methods. Total phenolic content was highest in the control batch at day 0 (18.08), gradually decreasing over 15 days to 15.85. Blanched tomatoes started at 19.07 and declined to 16.14 values with in storage. Narra et al., (2024) found that blanching tomatoes significantly reduced TPC by around 30% as compared to untreated tomatoes. Thermal breakdown during the procedure and the leaching of water-soluble phenolic compounds into the blanching water are responsible for this decrease. Another study showed that heating tomatoes at 75–95°C for 2 minutes resulted in a reduction of their nutrient content, with levels decreasing by 19.46 ± 0.86 mg per 100 grams (Shi et al., 2022). Dried tomatoes showed higher initial values (20.72), dropping to 16.65 by day 15 that consisting with the findings of (Tan et al., 2021). Jorge et al. (2018) observed reported that the loss of polyphenols might be attributed to oven drying-induced thermal degradation. Dying method results consisted with the findings of Da Costa et al. (2023) that observed phenolic content was considerably impacted by various drying methods, with the oven drying method retaining a phenolic concentration that was much greater than the control and other methods such as dehydration and freez drying. T_3 (fried) and T_4 (frozen) also declined from 22 to 16 over the storage period. A study showed that phenolic contents variations during frying process also dependent of cultivars, two different cultivars Aranca and Excell of tomatoes showed varies phenolic content levels after frying (Sahlin et al., 2004). Our findings of freezing treatment are lined with Ergün & Baysal (2020), where total phenolic content was observed as 286.49 (mg/Kg) and 274.20 (mg/Kg) in quick and slow freezing effects, respectively. Overall, phenolic content decreased with time across all treatments. It is important to note that many factors can lead to significant changes in a fruit's chemical composition. According to Barros et al. (2012), there might be differences in phenolic contents based on processing and storage conditions.

➢ *Lycopene*

Lycopene content was highest at day 0 in fresh tomatoes (T_0) i.e. 7.52. Initial values for treated samples were: T_1 (3.06), T_2 (7.71), T_3 (2.20), and T_4 (6.62). Lycopene levels declined over 15 days in all samples due to storage and processing effects. By day 15, contents decreased to 6.53 (T_0), 0.93 (T_1). This is consistentconsisited with Shi et al. (2022) that reported heating of tomatoes at 75–95°C for 2 minutes resulted in a reduction of their nutrient content, with levels decreasing by 19.46 ± 0.86 mg per 100 grams. Dried tomatoes showed decline value 5.79 (T_2), 0.92 (T_3), and 3.61 (T_4), with the most significant losses in blanched (T_1) and frozen (T_3) samples. Prior research has shown that drying tomatoes at various temperatures significantly reduces their lycopene concentration (Mendelová et al., 2013; Peng et al., 2024). According to Pathak et al. (2023), drying tomatoes at 55 °C resulted in a substantial decrease in lycopene content compared to fresh samples. The primary causes of lycopene loss during the storage of dried tomatoes are oxidation and isomerisation. While oxidation increases as

storage temperature rises, isomerisation increases as storage duration increases under lightening circumstances. In this study lycopene content is higher followed by dried as compared to other processing. In contrast, similar research conducted onfrying effects of tomato puree that showed frying for 2 min increases the lycopene value by 11.1 % and frying for 30 min extended the amount by 32.9% (Ishiwu Charles et al., 2014) . Analysis of variance showed highly significant effects ($P<0.01$) of treatments and storage time on lycopene content, which decreased over time due to its instability. These findings align with Xu et al. (2018), who reported that lycopene and ascorbic acid breakdown during storage at 4°C reduces antioxidant activity.

- *Ascorbic Acid*

Vitamin C content was highest at day 0 in fresh tomatoes (T_0) at 19.7g. Treated samples had lower initial levels: T_1 (3.31g), T_2 (5.53g), T_3 (6.65g), and T_4 (1.16g). Over 15 days, vitamin C levels significantly declined in all samples due to its sensitivity to processing and storage. By day 15, contents dropped to 17.53g (T_0), 1.5g (T_1), 4.07g (T_2), 4.41g (T_3), and 0.96g (T_4), with the greatest losses observed in heat-treated and fried samples. Vitamin C content decreased over the storage period due to its sensitivity and tendency to degrade with time, similar trend was found by Bapary et al. (2024). In this study vitamin C content of fresh tomatoes were observed higher as compared to processing treatment that are lined with the findings of The & Ting. (2024). Another study showed that the fresh tomato sample (T_0) contained higher vitamin C content 30.23 mg/100g, while significantly lower levels were observed in preserved samples: 19.15 ± 1.67 mg/100g in frozen tomatoes and 6.11 ± 0.76 mg/100g in hot air dried samples indicating that both freezing and hot air drying negatively impact the retention of vitamin C (Fraps et al., 2017). Analysis of variance showed that both treatment and storage had highly significant effects on vitamin C levels, as well as their interaction.

- *Vitamin A*

Vitamin A content was highest on day 0, with T_0 (fresh) 3.82g. Over 15 days, vitamin A levels declined across all samples due to its sensitivity to storage. By day 15, contents dropped to 3.01g (T_0), 1.18g (T_1), 2.45g (T_2), 0.08g (T_3), and 0.03g (T_4). The results of this investigation showed that dried tomatoes had higher levels of vitamin A that the blanched, freezed and fried tomatoes. Similar trend was observed by Ahmed et al. (2020) who observed 4.72ug concentration of Vitamin A in dried tomatoes as compared to blanched i.e 3.41ug. Meanwhile, according to the study's findings, the fresh sample had the highest concentration of vitamin A, while the sun-dried sample had the lowest. These findings, however, indicate that the tomato sample's vitamin A content is impacted by the preservation techniques (Baparay et al., 2025). The decline was most significant in fried (T_3) and frozen (T4) samples. Fraps et al. (2017) also concluded that vitamin A levels decrease with longer storage periods. Our results are consistent with the results of Baker et al. (2020), who also found that the quantity of vitamin A in Opuntia ficus-indica fruit that was sun- and microwave-dried was much lower than that of fresh fruit. Another study on tomatoes with okro found that fresh samples had a much higher level of vitamin A than dried ones (Minuye et al., 2024).

- *Antioxidants*

Fresh tomatoes (T_0) had the highest DPPH antioxidant activity at 68.77%. Treated samples showed reduced activity: T_1 (40.14%), T_2 (40.87%), T_3 (49.92%), and T_4 (47.69%). Processing treatments lowered antioxidant levels compared to the fresh batch. Processed tomato samples showed a decrease in DPPH antioxidant activity compared to the control (Wenberg et al., 2006). In this study, antioxidants content of blanched and dried samples were seen reduced as compared to freezed and fried tomatoes samples, similar trend was seen in frozen legumes investigated by Gębczyński et al. (2024). Arkain and Alibas (2025) also observed that when dried at various temperatures, in a microwave, and naturally using the TEAC (ABTS) technique, medlar fruit's antioxidant content significantly decreased. Blanching also leads to the greatest antioxidant loss, with levels dropping up to 60% during cooking (Fillion et al., 2009). Similarly, Xu et al. (2018) reported significant declines in antioxidant content in processed tomatoes during storage. Freezing is often regarded as the best technique for maintaining the nutritional value of tomatoes among the techniques included in this study since it minimises nutrient loss, preserves antioxidant activity, and protects the tomatoes' sensitive vitamins (Baparay et al., 2024). Meanwhile various researches predicted increasing trend of antioxidant activity with increase in temperature (Kim et al., 2008; Wu et al., 2023). Table 2 to Table 6 present the changes in nutritional and antioxidant content (Mean ± SD) of tomato samples subjected to different treatments (T_0–T_4) over a 15-day storage period.

Table 2 Nutritional and Antioxidant Properties of Tomatoes under Treatment T_0 (Control) across Storage Days

Storage (Days)	Moisture Content	Ash Content	Fat Content	Protein Content	Fiber Content	Carbohydrate	Vitamin A	Vitamin C	Lycopene	DPPH Activity	Total Phenol
0	94.21 ± 0.35^{b}	3.50 ± 0.05^{ab}	-	17.02 ± 0.01^{a}	1.78 ± 0.01^{a}	9.94 ± 0.01^{g}	3.83 ± 0.01^{d}	19.70 ± 0.10^{a}	7.52 ± 0.03^{a}	68.77 ± 0.50^{a}	18.08 ± 0.25
5	94.42 ± 0.96^{c}	3.45 ± 0.04^{de}	-	17.02 ± 0.01^{a}	1.68 ± 0.01^{b}	9.93 ± 0.01^{g}	3.73 ± 0.01^{d}	18.69 ± 0.03^{b}	7.42 ± 0.01^{a}	66.20 ± 0.45^{a}	17.20 ± 0.23
10	93.62 ± 0.88^{b}	3.37 ± 0.06^{fg}	-	16.89 ± 0.10^{a}	1.75 ± 0.06^{ab}	9.89 ± 0.02^{g}	3.51 ± 0.34^{e}	17.53 ± 0.21^{c}	6.85 ± 0.07^{b}	63.75 ± 0.43^{b}	16.40 ± 0.22
15	93.12 ± 0.49^{c}	3.32 ± 0.05^{gh}	2.31 ± 0.05	15.79 ± 0.31^{b}	1.69 ± 0.02^{b}	9.87 ± 0.01^{g}	3.02 ± 0.01^{g}	16.94 ± 0.04^{d}	6.54 ± 0.02^{cd}	60.90 ± 0.41^{b}	15.85 ± 0.21

Values are expressed as Mean ± SD with superscript letters indicating statistical significance at $p < 0.05$

Table 3 Nutritional and Antioxidant Properties of Tomatoes under Treatment T_1(Drying) across Storage Days

Storage (Days)	Moisture Content	Ash Content	Fat Content	Protein Content	Fiber Content	Carbohydrate	Vitamin A	Vitamin C	Lycopene	DPPH Activity	Total Phenol
0	97.70 ± 0.62^{a}	3.70 ± 0.03^{b}	-	12.44 ± 0.01^{c}	1.16 ± 0.00^{e}	3.70 ± 0.01^{h}	3.41 ± 0.01^{ef}	3.32 ± 0.01^{l}	3.06 ± 0.01^{d}	40.14 ± 0.35^{d}	19.07 ± 0.28
5	96.61 ± 0.51^{b}	3.65 ± 0.05^{cd}	-	11.96 ± 0.02^{d}	1.14 ± 0.01^{e}	3.69 ± 0.01^{h}	2.99 ± 0.02^{g}	2.27 ± 0.01^{m}	2.97 ± 0.01^{d}	38.50 ± 0.33^{e}	18.10 ± 0.26
10	97.32 ± 0.68^{a}	3.60 ± 0.04^{ef}	-	10.92 ± 0.06^{e}	1.13 ± 0.01^{e}	3.68 ± 0.01^{h}	2.13 ± 0.02^{i}	1.50 ± 0.31^{n}	1.62 ± 0.39^{e}	36.80 ± 0.31^{ef}	17.10 ± 0.25
15	98.08 ± 0.59^{a}	3.58 ± 0.03^{gh}	2.26 ± 0.04	9.84 ± 0.12^{f}	1.11 ± 0.01^{e}	3.60 ± 0.01^{h}	1.18 ± 0.12^{k}	$0.05 \pm 0.04^{\varphi}$	0.94 ± 0.07^{k}	35.20 ± 0.30^{f}	16.14 ± 0.24

Values are expressed as Mean ± SD with superscript letters indicating statistical significance at $p < 0.05$

Table 4 Proximate Composition and Bioactive Components of T_2 (Blanching) across Storage Duration

Storage (Days)	Moisture Content	Ash Content	Fat Content	Protein Content	Fiber Content	Carbo-hydrate	Vitamin A	Vitamin C	Lycopene	DPPH Activity	Total Phenol
0	97.93 ± 0.48^{d}	3.68 ± 0.04^{bc}	8.14 ± 0.12	5.61 ± 0.01^{g}	1.11 ± 0.01^{e}	21.76 ± 0.01^{a}	4.72 ± 0.01^{a}	5.54 ± 0.01^{g}	7.71 ± 0.04^{a}	40.87 ± 0.38^{d}	20.72 ± 0.30
5	97.21 ± 0.56^{e}	3.64 ± 0.03^{de}	8.14 ± 0.12	5.57 ± 0.03^{g}	1.37 ± 0.06^{c}	20.91 ± 0.01^{b}	4.16 ± 0.04^{b}	4.60 ± 0.15^{h}	6.72 ± 0.24^{bc}	39.25 ± 0.36^{e}	19.45 ± 0.28
10	97.40 ± 0.52^{d}	3.59 ± 0.05^{gh}	8.14 ± 0.12	5.41 ± 0.00^{h}	1.33 ± 0.15^{c}	19.34 ± 0.53^{c}	3.97 ± 0.01^{c}	4.07 ± 0.01^{j}	6.32 ± 0.52^{d}	37.95 ± 0.33^{e}	18.05 ± 0.27
15	97.68 ± 0.53^{e}	3.55 ± 0.04^{j}	8.14 ± 0.12	5.38 ± 0.01^{h}	1.23 ± 0.06^{d}	18.88 ± 0.01^{d}	2.45 ± 0.01^{h}	3.30 ± 0.07^{l}	5.79 ± 0.20^{e}	36.40 ± 0.32^{e}	16.65 ± 0.26

Values are presented as Mean ± SD with significance superscripts at $p < 0.05$

Table 5 Proximate Composition and Bioactive Components of T_3(Frying) across Storage Duration

Storage (Days)	Moisture Content	Ash Content	Fat Content	Protein Content	Fiber Content	Carbohydrate	Vitamin A	Vitamin C	Lycopene	DPPH Activity	Total Phenol
0	97.20 ± 0.40^{e}	3.61 ± 0.03^{a}	2.20 ± 0.04	2.75 ± 0.01^{i}	1.13 ± 0.06^{e}	19.51 ± 0.01^{c}	1.21 ± 0.01^{k}	6.65 ± 0.02^{e}	2.21 ± 0.01^{e}	49.92 ± 0.40^{c}	22.00 ± 0.32
5	96.62 ± 0.55^{d}	3.57 ± 0.02^{bc}	2.20 ± 0.04	2.71 ± 0.01^{ij}	0.99 ± 0.01^{f}	18.96 ± 0.03^{d}	1.15 ± 0.04^{kl}	5.94 ± 0.02^{f}	1.79 ± 0.07^{e}	48.10 ± 0.39^{c}	20.35 ± 0.30
10	96.97 ± 0.51^{e}	3.54 ± 0.03^{cd}	2.20 ± 0.04	2.68 ± 0.01^{ij}	0.97 ± 0.02^{f}	17.90 ± 0.53^{e}	1.04 ± 0.06^{l}	4.42 ± 0.76^{i}	1.01 ± 0.37^{k}	46.30 ± 0.37^{c}	18.50 ± 0.28
15	97.08 ± 0.38^{d}	3.50 ± 0.02^{ij}	2.20 ± 0.04	2.59 ± 0.01^{j}	0.94 ± 0.01^{f}	16.42 ± 0.27^{f}	0.08 ± 0.01^{m}	3.70 ± 0.10^{k}	0.93 ± 0.06^{k}	44.55 ± 0.35^{d}	16.00 ± 0.25

Values are expressed as Mean ± SD with superscript letters indicating statistical significance at $p < 0.05$

Table 6 Nutritional and Antioxidant Properties of Tomatoes under Treatment T_4 (Freezing) across Storage Days

Storage (Days)	Moisture Content	Ash Content	Fat Content	Protein Content	Fiber Content	Carbohydrate	Vitamin A	Vitamin C	Lycopene	DPPH Activity	Total Phenol
0	97.17 ± 0.61^{e}	3.65 ± 0.03^{d}	12.23 ± 0.15	1.96 ± 0.01^{k}	0.97 ± 0.01^{f}	2.59 ± 0.02^{t}	3.35 ± 0.01^{f}	1.17 ± 0.01^{o}	6.62 ± 0.01^{b}	47.69 ± 0.36^{c}	22.00 ± 0.31
5	96.71 ± 0.57^{a}	3.60 ± 0.04^{ef}	12.23 ± 0.15	1.85 ± 0.04^{kl}	0.96 ± 0.01^{f}	2.45 ± 0.06^{t}	2.17 ± 0.01^{i}	1.08 ± 0.01^{p}	5.49 ± 0.05^{d}	46.10 ± 0.34^{c}	20.20 ± 0.29
10	97.13 ± 0.49^{c}	3.56 ± 0.03^{hi}	12.23 ± 0.15	1.78 ± 0.01^{l}	0.94 ± 0.00^{f}	1.85 ± 0.12^{j}	1.97 ± 0.01^{j}	0.96 ± 0.01^{p}	4.54 ± 0.19^{f}	44.55 ± 0.32^{cd}	18.15 ± 0.27
15	96.85 ± 0.57^{b}	3.52 ± 0.02^{j}	12.23 ± 0.15	1.74 ± 0.02^{l}	0.92 ± 0.01^{f}	1.62 ± 0.06^{k}	0.03 ± 0.02^{m}	$0.004 \pm 0.002^{\varphi}$	3.61 ± 0.36^{g}	42.85 ± 0.31^{d}	16.00 ± 0.25

Values are expressed as Mean ± SD with superscript letters indicating statistical significance at $p < 0.05$

IV. CONCLUSION AND FUTURE RECOMMENDATIONS

This study concluded that different processing methods affect the nutritional composition of . Among the treatments, blanching was the most effective in preserving moisture, protein, ash, and fiber contents. It proved blanching a preferable method for retaining key nutrients. Drying came out as the best option for enhancing carbohydrate content, while frying resulted in the highest fat content due to oil absorption during processing. Freezing, although helpful for storage, led to the greatest reduction in nutritional quality. These results highlight the importance of selecting appropriate processing methods according to the desired nutritional attributes for tomato preservation. The main goal of future studies should be optimizing blanching and drying techniques to maximize nutrient retention and reducequality degradation. Additionally, the possibility for preserving both nutritional and sensory quality should be investigated through the use of combination or innovative preservation procedures, such as vacuum drying, infrared blanching, or cryogenic freezing. In order to evaluate the shelf-life and bioavailability of nutrients after processing, long-term

storage experiments are also advised.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Dr. Ali Hassan, for his invaluable guidance and continuous support throughout this research project. I am also thankful to the faculty and staff of the Department of Food Technology, University of Agriculture, Faisalabad, for providing the necessary facilities and assistance. Special thanks to my colleagues for their helpful contribution in this work. I also extend my appreciation to my family for their encouragement during this study.

- *Data Availability*

  Data will be available on request.

- *Funding Sources*

  This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

- *Conflicts of Interest*

  The authors have no conflict of interest.

- *Ethical Approval*

  Ethical approval was not required for this research.

- *Author Contributions*

  Conceptualization Faseeha Muqadus, Data Curation Iqra Muneer, Formal analysis Rabia Batool, Investigation Fraz Ahmad, Methodology Dr. Ali Hassan Software Ahmad Raza Visualization Rabia Batool, Writing– review & editing Faseeha Muqadus.

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