Research Article

Assessing the Hybrid and Local Tomato Varieties Based on Physicochemical and Functional Properties

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Abstract | Tomatoes (*Solanum lycopersicum* L.) are valued for their antioxidant properties, which are attributed to bioactive compounds such as lycopene, ascorbic acid, and phenolics. Six tomato varieties (three local: Riogrand, Naqeeb, Roma; and three hybrids: Anna, Sundar, Sahel) were assessed for physicochemical and functional properties. Standard AOAC and spectrophotometric methods were used to analyze ascorbic acid, lycopene, oxalic acid, total phenolic content (TPC), antioxidant activity, and mineral composition. Results indicated that Naqeeb had the highest ascorbic acid content (18.95 mg/100g), while among the hybrid varieties, Anna exhibited the highest level (18.52 mg/100g). However, lycopene contents were highest in Naqeeb and Sahel varieties i.e. 84.3 µg/g and 81.60 µg/g, respectively. Significant differences were observed between the varieties. The highest TPC was found in Naqeeb (26.41±0.1 mg GAE/100g). Antioxidant activity also varied significantly among the varieties, with Naqeeb showing the highest activity (9.25±0.10%) and Roma the lowest (7.50±0.10%). Regarding oxalic acid contents in local tomato varieties, Roma contained maximum (mg/100g) oxalic acid contents (27.00±1.35) in comparison to Naqeeb and Riogrand and Sundar (31.00±1.55) was at the top among hybrid tomato varieties. These findings highlight the potential of targeted breeding to enhance tomato quality and health benefits. It is further recommended that tomato breeders should focus on breeding of Naqeeb and Sahel varieties in the future to provide better tomato varieties with improved nutrition and public health perspectives.

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Introduction

The tomato (*Solanum lycopersicum* L.) is one of the most important vegetables in the world due to its nutritional, economic, and social values. Tomatoes are not only consumed as a raw flavourful food due to their desirable nutritional and organoleptic properties, but they are also used in the form of a variety of processed products. Tomatoes can be consumed in multiple forms. In processed forms, they are used as tomato pulp, paste, puree, dried tomato powder, soup, ketchup, and sauce. It is also used in many dishes like pasta and with many other vegetables (Kradetskaya *et al*., 2024).

It is particularly important in human nutrition due to its antioxidant properties. Globally, more than 5 million hectares of tomatoes have been cultivated with an average yield of 35.9 tons per hectare, and an annual production of more than 180 million tons, according to FAOSTAT. Tomatoes are widely grown and frequently consumed across the globe. It is majorly consumed owing to its better nutritional profile and essential nutrients present in it (Salehi *et al*., 2019; Odeh *et al*., 2024; Motamedzadegan and Tabarestani, 2018). Quality of fresh tomatoes during consumption depends on several factors such as external (appearance, texture, and freshness) and internal factors (flavour and nutritional profile). Besides, several polygenic characteristics are also influenced by climatic conditions, agronomic practices, genotype, and fruit maturity (Omari *et al*., 2025; Baldwin *et al*., 2015; Zhao *et al*., 2019). Consumer's choice during purchase is primarily on external quality characteristics, however, several studies on fresh market sales of tomatoes have reported texture and flavour are the key factors in consumer choice (Piombino *et al*., 2013; Sinesio *et al*., 2021).

Current conceptions surrounding rational nutrition make the consumption of tomatoes a priority, primarily because they provide the human body with a wide range of nutritious and healthy substances such as vitamins, minerals, and water, which are necessary for the normal physiological activity of the human body. Among the many valuable substances in tomatoes, carotenoids are well-known natural substances that help prevent diseases such as diabetes, gastrointestinal, and cardiovascular diseases, by, among other effects, lowering the number of low-density oxidized lipoproteins in the blood (Felföldi *et al*., 2022).

Tomato is listed among fruits and vegetables that are highly utilized around the globe. It ranks second amongst quinine related vegetables after potatoes and the third most cultivated vegetable after potatoes and sweet potatoes (Dembele *et al*., 2019; Al-Hattali *et al*., 2024). According to the Food and Agricultural Organization (FAO), production of tomatoes increased extensively from 1961 to 2020 with 1.68 to 5.05 million hectares boost in cultivation area. Furthermore, the average per hectare tomato production also increased to 37tons from 16.4tons. Tomato cultivation occupies 4.7million hectares with an annual production of 180million tons (Szabo *et al*., 2019). To fulfil the demand of the domestic market and export potential there is a need for further growth of tomato production by implementing natural conditions and intensive development in agriculture (Pozharskiy *et al*., 2022; Amzeri *et al*., 2024). At first, it was known as toxic fruit being domesticated in Mexico, later it was familiarised in Europe in the 16th century. The tomato has its origin along the Pacific coast mostly in the Galapagos Islands, which are located between the Equator and the north of Chile which shows its cuisine related importance and consumption.

Nevertheless, it contains a higher number of nutritional compounds almost twice as compared to apples with superior food values. Its nutritional value mostly depends on its physicochemical composition including total sugar, total solids ascorbic acid, and titratable acidity. Tomatoes are a rich source of essential amino acids, minerals, and bioactive compounds. Lycopene is one of the prime bioactive that attained researcher's attention due to its antioxidant potential and action against cancer and other degenerative diseases. Tomatoes are also a big source of minerals like calcium, magnesium, zinc and iron and sodium (Bouabid *et al*., 2024; Hadi, 2024; Wang *et al*., 2016; El-Khlifi *et al*., 2024). The ripening process of fruits and vegetables results in various biochemical alterations that improve the quality of fresh fruits like flavour development and accumulation of carotenoids. Nevertheless, the ripening process also induces some degenerative mechanisms such as softening of fruits and vegetables. The texture of ripened fruits also significantly influences the end quality and consumer selection, storage stability, microbial resistance, and transportability of the fruits. The rich nutritional profile of tomatoes is very beneficial for human beings owing to its health-promoting bioactive compounds including essential amino acids, carotenoids, and fibre. These nutritional compounds have their role in the remedy of some cancers and cardiovascular diseases. The number of bioactive compounds in plants varies from variety to variety and on the basis of their local and hybrid breeds as well (Al-Assil *et* al., 2024; Talukder *et al*., 2015; Sumalan *et al*., 2020; Kassim *et al*., 2024).

Among antioxidants, lycopene constitutes the predominant carotenoid in tomato fruits, accounting for over 85% of total carotenoids. Post-harvest storage practices significantly influence lycopene retention; refrigeration at temperatures below 12°C can degrade lycopene, thereby reducing its health-promoting value and compromising visual quality (Felföldi *et al*., 2022; Naveed *et al*., 2023; Rafee *et al*., 2024). Given the rising demand for tomatoes in diverse culinary applications, strategies to enhance nutritional efficacy, yield, and postharvest stability have gained momentum. Prior studies have documented varietal differences in bioactive compounds, underscoring the need for targeted screening. In this context, the current study evaluates nutritional, physicochemical, and functional indices of hybrid and local tomato varieties in Pakistan to identify cultivars with optimal traits for breeding and consumption.

Materials and Methods

Procurement of tomato cultivars

All local and hybrid tomato varieties including Anna, Riogrand, Sundar, Naqeeb, Sahel, and Roma were procured from the Vegetable Research Centre of the Ayub Agricultural Research Institute (AARI), Faisalabad. Tomatoes were harvested early in the morning and transferred to the research station in a temperature-controlled vehicle. This experiment was conducted in year 2017 at Food Safety Research Laboratory of National Institute of Food Science and Technology, University of Agriculture, Faisalabad. In this experiment, hybrid and local varieties of tomato were screened based on the quality attributes especially lycopene, vitamin C and oxalic acid contents.

Physicochemical and nutritional evaluation of local and hybrid tomato cultivars

Total soluble solids (TSS) contents: TSS of tomato cultivars were determined by applying method of handheld Refractometer (Model; RA-600, Kyoto Electronics, Country of Origin; Japan) by following the official method (No. 920.151) of AOAC (2016).

pH: The pH of samples was reported by a digital pH meter (Ino-Lab, pH-720, Germany) by applying protocol (Method No. 981.12) as outlined in (AOAC, 2016). Purposely, in a 100mL beaker 50mL tomato juice was taken and pH was recorded.

Colour index: Colour, which is derived from natural pigments, is the most commonly used criteria that determine the fruit's appearance and affects consumers' preference. In the present study, harvesting at the commercial pink stage was preferred based on its relevance on functional substances mainly to balance the contents of antioxidant properties. The color parameters (L*, a*, and b*) of tomato varieties were measured using a Minolta Chroma Meter (CR-200, Japan). The data obtained were analysed according to the method explained by Ashebir *et al*. (2009).

Ascorbic acid content: Tomatoes are rich in ascorbic acid (vitamin C), which is easily absorbed by the body. It provides numerous health benefits, such as preventing low-density lipoprotein oxidation, combating scurvy, maintaining collagen, and alleviating neurodegenerative diseases. As observed from this study, the content of vitamin C in tomato fruit is dependent on cultivars (Tilahun *et al*., 2021).

The ascorbic acid was determined from tomato varieties by following the method (Method No. 967.21) described by Famurewa *et al*. (2013). Purposely, ascorbic acid standard, dye, and metaphosphoric acid solutions were prepared. The standard solution of ascorbic acid was titrated against dye (2, 6-dichlorophenol indophenol) and the value was recorded. Afterward, the sample was titrated along with metaphosphoric acid solution with dye and used volume was recorded.

$$\text{Ascorbic acid} = (Vs - Bs) \times (W/\,Vjuice) \times (Vin/Yaliquot)$$

Where; V_s= Volume of sample titration, B_s= Titration volume of blank sample, W= mg of analyte (ascorbic acid) equivalent to 1.0 m L of indophenol dye standard solution, V_{juice}= Volume of Juice Sample, V_{in}= Initial volume of assay solution, V_{ali}= Aliquot volume for titration.

Oxalic acid contents

Oxalic acid contents of local and hybrid tomato varieties were measured by adopting the method outlined by Abdel-Moemin (2014). Purposely, 1g fresh tomato pulp without water addition was taken a sample and mixed with 30mL of 1 Molar hydrochloric acid. The sample mixture was shaken well at 100°C for 30 min. Then 0.5mL of 5% $CaCl_2$ was added and mixed well to precipitate calcium oxalate. The centrifugation of suspension was done at 800rpm for 15 minutes and filtered. The pellets were washed twice with 2mL of NH_4OH (0.35M) and later dissolved in 0.5M H_2SO_4. The solution was then titrated against 0.1 Molar potassium per manganate at 60°C till faint violet colour persisted for at least 15 seconds.

Lycopene contents

The distinctive red colour in tomato fruit is due to the accumulation of lycopene, which constitutes 98% of its carotenoid. The lycopene content of tomato varieties was extracted using the procedure outlined by Santos-SÃ¡nchez *et al.* (2012). For this purpose, 5g sample was dissolved in 10mL distilled water. Test tube having aluminium cover was filled with 1 mL of sample along with 0.5g/L of BHT (butylated hydroxytoluene). Later to this mix 5mL of 95% ethanol and 10mL of hexane were added and mixture was shaken vigorously for 10 minutes for lycopene extraction. Lastly, absorbance of 3.5mL sample was measured at 503nm.

$$\text{Lycopene } (\mu g/g) = \frac{\text{A503} \times 31.2}{\text{wt of sample}}$$

Antioxidant activity

Antioxidant activity was evaluated by measuring the radical scavenging effect of tomato sample methanolic extracts against the 2,2-diphenyl-1-picrylhydracyl (DPPH) as reported by Arslan and Özcan (2011). 2g sample was dissolved in 10mL of methanol for 2h. 4mg DPPH reagent was dissolved in 100mL methanol. Later, 2mL DPPH solution was taken in a flask and 50µL extract was added. The mixture was vigorously shaken and kept at room temperature in the dark for 30 minutes. Absorbance was measured at 515nm.

Total phenolic contents

Total phenolic contents were measured by using the Folin-Ciocalteu reagent with colourimetric method described by Marsic *et al.* (2011). Purposely, 5g sample was dissolved in methanol in 1:5 ratios for 3h at room temperature. Phenolics are a large group of molecules that function as natural antioxidants in plants. They can prevent chronic diseases related to excess free radicals by reducing oxidative stress. In this study, the tested cultivars have shown significantly different contents of total phenolics (Tilahun *et al.*, 2021).

After that, the sample was filtered and concentrated in the rotary evaporator. 125µL sample was taken in a test tube containing 500µL distilled water. Then 125µL Folin-Ciocalteu reagent was added and kept for 6 minutes stay time. Later, 1.25mL of 7%Na_2CO_3 solution was also added. In the end, 3mL total volume was made by adding distilled water and 90 minutes of stay time was given for the completion of the reaction. The absorbance of the gallic acid standard and samples was taken at 760nm.

Mineral contents

Tomato pulp samples were subjected to mineral estimation according to the protocol of (AOAC, 2016). 5g sample was heat digested along with HNO_3 and perchloric acid (7:3) on hot plate until 1-2 mL colourless solution remained. Digested sample was diluted up to 100mL and subjected to mineral analysis. Potassium was estimated through flame photometer-410 (Sherwood Scientific Ltd., Cambridge) whereas Atomic Absorption Spectrophotometer (Varian AA240, Australia) was used to determine minerals.

Statistical analysis

All data were obtained in triplicate manner and Statistic (software ver.8.1) was applied for analysis. One-way ANOVA was applied to check significance of treatments and Tukey's honestly test was applied to find comparison of samples. Significance level of analysis was $p<0.05$ and all analyses of data were done by acting upon the guidelines and procedures given by (Montgomery, 2017).

Results and Discussion

Total soluble solids

As depicted in Figure 1 all tomato varieties had lower TSS values at the turning stage than at the red stage; Sahel had the highest TSS (4.51±0.7 ˚B), followed by Naqeeb (4.05±0.3 ˚B). Umeohia and Olapade (2024) found similar results, with TSS readings being lower at the turning stage than when tomatoes were completely ripe. While sweetness is still developing, the turning stage is distinguished by early colour development and flavour precursors.

TSS increased significantly at the red stage, with Riogrand (7.48Â±0.34 Â˚B) and Sahel (7.89Â±0.54 Â˚B) having the highest values. This peak in sugar accumulation aligns with the findings of Zushi *et al.*

(2020), who reported that red tomatoes exhibited the highest TSS. Sundar had the lowest TSS (4.47±0.34 °B), while Riogrand had the highest at 5.22±0.52 °B during the pink stage. These results highlight varietal differences in sugar synthesis and ripening speeds, indicating that sugar buildup persists into the pink stage while the fruit is still moving toward full ripeness.

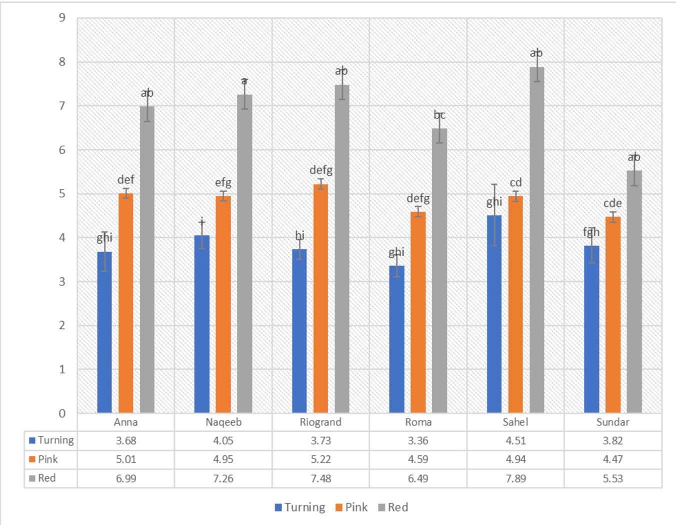

Figure 1: *Total soluble solids at three different stages of tomatoes.*

Statistical analysis (ANOVA, $p<0.05$) confirmed that the differences in TSS among ripening stages and tomato varieties were significant. These results reinforce the influence of genetic and environmental factors on sugar accumulation in tomatoes. Future breeding programs should consider cultivars like Riogrand and Sahel for their superior TSS profiles, which contribute to both sensory attributes and processing efficiency.

pH

The pH values during the turning stage showed a slight increase in acidity compared to the red stage, ranging from 4.01 in Sahel, Anna, and Roma to 4.18 in Riogrand. The relatively lower pH at the turning stage suggests that the tomatoes are still in the early ripening phase, where acidity is more pronounced. This observation aligns with previous research, such as that by Umeohia and Olapade (2024), which reported lower pH values at the color breaker stage. The pH values observed in this study correspond with the ideal pH range for tomato processing (4.2–4.1) recommended by Irina *et al*. (2017), which is essential for controlling microbial growth during processing.

As illustrated in Figure 2, the pH values significantly increased at the red stage, with Riogrand (4.8) and Sundar (4.87) showing the highest pH levels. Typically, as organic acids are broken down during ripening, the pH tends to rise. The pH range noted at this stage, from 4.41 (Naqeeb) to 4.87 (Sundar), aligns with findings by Zushi *et al*. (2020), which indicated that the pH of tomatoes increases as they mature, reaching up to 4.77 in fully ripe tomatoes. Rapa *et al*. (2021) noted that a pH below 4.5 is beneficial for preventing microbial growth, and the pH values at the red stage fall within the optimal range for processing. Based on the study's results, the tomatoes can be further processed since they maintain a balanced acidity that aids in preserving the product.

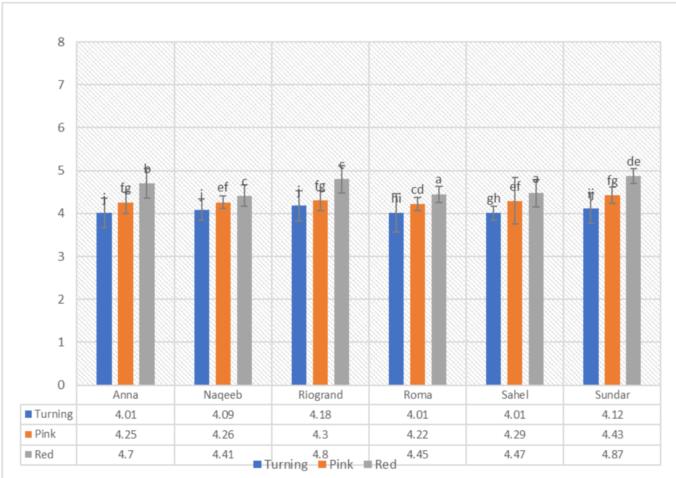

Figure 2: *pH at three different stages of tomatoes.*

The pH values for the pink stage varied from 4.22 in Roma to 4.43 in Sundar, indicating that the pH stayed comparatively constant but was marginally higher than during the turning stage. With continuous metabolic changes that continue to improve their flavour and storage capability, this indicates that the pink-stage tomatoes are moving from the acidic turning phase to the less acidic red stage. In line with the findings of Umeohia and Olapade (2024), the variance in pH at this stage seen among varieties highlights the influence of both maturity and variety on the final acidity of tomatoes.

Colour

Colour is a crucial quality attribute in tomatoes, influencing consumer preference and marketability. It is primarily determined by the accumulation of carotenoids, particularly lycopene and β-carotene, which contribute to the red and orange hues. In this study, significant differences ($p< 0.05$) in colour parameters (L*, a*, b*) were observed among local and hybrid tomato cultivars (Table 1). The notable value of L was observed in Sahel (51.98) in following by the Anna, Sundar, Riogrand, Naqeeb and Roma were 48.07, 45.76, 42.49, 44.90 and 43.10, respectively. Likewise, a* and b* values was found higher in Anna (25.47 and 29.77) followed by Sundar (22.33 and 25.09), Sahel (20.87 and 27.41); Riogrand (21.84 and 23.61), Naqeeb, (25.32 and 23.60) and Roma (21.48 and 21.97), respectively. Wan *et al*. (2018) conducted L a* b* analysis on different tomato cultivars and exhibited results that were in correspondence with present study. Results for L value of tomato were in line with the finding of Ashebir *et al*. (2009) who studied fresh tomato fruit for L, a* and b* parameters.

Table 1: *Colour values (L*, a* and b*) of tomato varieties.*

	Varieties	Colour		
		L*	a*	b*
Hybrid	Anna	48.07±0.37[b]	25.47±0.46[a]	29.77±0.21[a]
	Sundar	45.76±0.41[c]	22.33±0.21[b]	25.09±0.20[c]
	Sahel	51.98±0.65[a]	20.87±0.31[e]	27.41±0.36[b]
Local	Riogrand	42.49±0.23[e]	21.84±0.08[c]	23.61±0.27[d]
	Naqeeb	44.90±0.31[d]	25.32±0.38[a]	23.60±0.14[d]
	Roma	43.10±0.18[e]	21.48±0.04[d]	21.97±0.21[e]

Means having similar letters in column are not significantly different ($p<0.05$) from each other.

Ascorbic acid contents

The results presented in Figure 3 indicate significant variation in ascorbic acid (vitamin C) content across the six tomato varieties (Anna, Naqeeb, Riogrand, Roma, Sahel, and Sundar) at different ripening stages (turning, pink, and red). The lowest vitamin C levels were observed at the turning stage, suggesting that biosynthesis is either inhibited or remains at a minimal level during this early ripening phase. Naqeeb exhibited the lowest mean vitamin C concentration (6.5 mg/100g), which aligns with previous studies such as Mellidou *et al*. (2012), who attributed the reduced levels at the early stage to limited enzymatic activity initiating ascorbic acid biosynthesis.

A significant rise in vitamin C levels was noted during the pink stage, which aligns with the metabolic changes that occur during ripening. This increase in ascorbic acid is linked to enhanced biosynthesis, coinciding with the activation of ascorbate peroxidase, a crucial enzyme for ascorbic acid accumulation (Mellidou *et al*., 2012). Among the varieties tested, Naqeeb consistently showed the lowest vitamin C level at 12.96 mg/100g, while Sahel had the highest concentration at 18.95 mg/100g. This difference underscores the impact of both genetic and environmental factors on ascorbic acid accumulation in tomatoes.

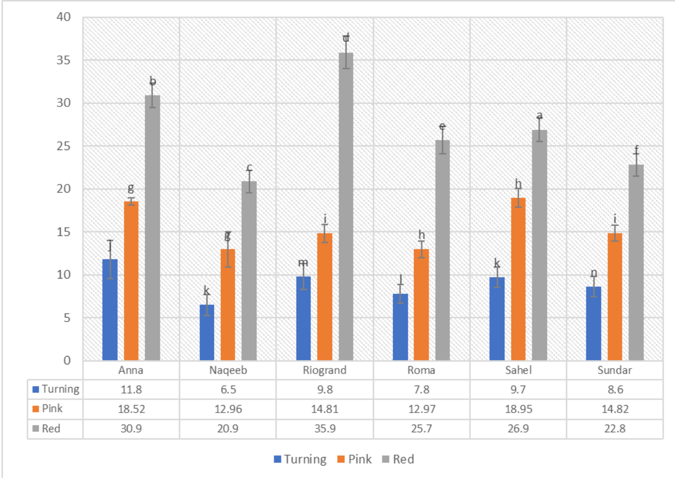

Figure 3: *Ascorbic acid at three different stages of tomatoes.*

By the red stage, vitamin C levels had risen significantly across all varieties, reaching peak values that indicate full metabolic maturation. Riogrand had the highest ascorbic acid concentration at 35.9 mg/100g, followed by Anna at 30.9 mg/100g and Sahel at 26.9 mg/100g, suggesting that these cultivars have a greater genetic potential for synthesizing and retaining vitamin C. Despite the overall increase, Naqeeb still had the lowest vitamin C content at 20.9 mg/100g, further highlighting its genetic limitations in accumulating high levels of ascorbic acid. These findings are consistent with Mellidou *et al*. (2012), who noted that vitamin C accumulation peaks during ripening, followed by a slight oxidative degradation phase due to heightened enzymatic activity and exposure to environmental factors like oxygen and light.

The variations in ascorbic acid concentration among different tomato cultivars highlight the genetic diversity in the biosynthesis and retention of vitamin C. Varieties such as Riogrand and Sahel, which showed higher levels of ascorbic acid, are promising candidates for breeding programs aimed at enhancing nutritional quality. The high heritability of vitamin C content, as shown by Dar and Sharma (2011) and Nour *et al*. (2014), further indicates that genetic improvements for increased vitamin C yield in tomatoes are feasible.

Moreover, postharvest practices are crucial for maintaining vitamin C levels. Mellidou *et al*. (2012) noted that optimized storage and handling techniques like controlled atmospheric conditions, temperature management, and minimizing oxidative stress can help reduce vitamin C degradation and improve retention throughout the ripening process. By implementing these strategies, high-ascorbic-acid tomato cultivars can maintain their nutritional value from harvest to consumption.

Oxalic acid contents

The results presented in Figure 4 indicate that the oxalic acid levels in six tomato varieties Anna, Naqeeb, Riogrand, Roma, Sahel, and Sundar vary significantly across three ripening stages: turning, pink, and red. As the tomatoes ripen, their nutritional content improves, reflected in a gradual decrease in oxalic acid levels. Sahel and Roma exhibited the lowest oxalic acid levels (33 mg/100g and 33.17 mg/100g, respectively), while Naqeeb had the highest (43 mg/100g) at the turning stage. This early accumulation of oxalic acid is often associated with the metabolic activity in young fruits. All types showed a moderate drop in oxalic acid levels during the pink stage. Roma had the lowest amount (22.25 mg/100g), while Naqeeb maintained the greatest concentration (31.17 mg/100g), followed by Sundar (27 mg/100g). The observed decrease points to the beginning of oxalate breakdown as ripening proceeds, which is in line with previous research such as that conducted by Abdel-Moemin (2014). Oxalic acid level had drastically decreased by the red stage, which signified the end of ripening. Once more, Roma had the lowest level (13.17 mg/100g), whereas Naqeeb had the highest (18.07 mg/100g). Oxalates are broken down by metabolic changes that coincide with the fruit's gradual drop throughout ripening, increasing its nutritional value. Similar patterns were seen by Truffault *et al.* (2017), who found that fresh and raw tomato extracts had higher levels of oxalic acid than ripe tomatoes.

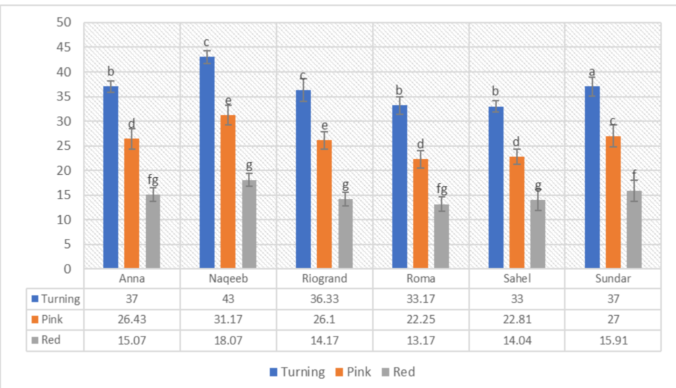

Figure 4: *Oxalic acid at three different stages of tomatoes.*

The results underline the negative health effects of oxalic acid, including kidney stone development and hyperoxaluria, which have been noted in research by Marina *et al.* (2019) and Sofia *et al.* (2016). To create tomato varieties that are safer and more nutritious, breeding programs should focus on cultivating cultivars like Roma and Sahel, which have continuously shown lower amounts of oxalic acid.

Lycopene contents

In this study, six tomato varieties (Anna, Naqeeb, Riogrand, Roma, Sahel, and Sundar) were evaluated for lycopene content at three ripening stages turning, pink, and red. As depicted in Figure 5, lycopene levels increased significantly as the fruit matured, underscoring the impact of ripening on carotenoid biosynthesis.

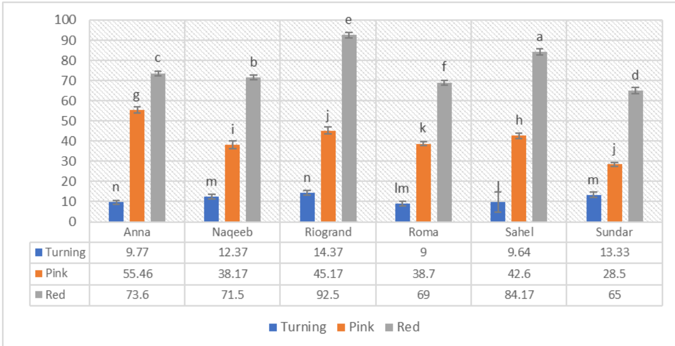

Figure 5: *Oxalic acid at three different stages of tomatoes.*

At the turning stage, all varieties exhibited very low lycopene concentrations. This is expected during the early ripening phase when chlorophyll is still predominant and the enzymatic pathways for carotenoid synthesis have not been fully activated. Such low levels align with the findings of Tilahun *et al.* (2021), who noted that the initiation of lycopene production occurs only as ripening advances.

A pronounced rise in lycopene content was observed during the pink stage. At this stage, carotenoid biosynthesis begins, and lycopene starts replacing chlorophyll. Although the increase at this stage is significant, the levels remain below those found at full ripeness, confirming that the pink phase acts as a transition period. Similarly Mellidou *et al.* (2012) reported that lycopene accumulation intensifies only as the fruit nears complete maturation.

By the red stage, lycopene content surged dramatically, thereby enhancing the tomato's nutritional and functional properties. Notably, the Riogrand variety achieved the highest lycopene concentration (92.5 mg/100g), followed closely by Sahel. This suggests that these cultivars have a robust genetic propensity for carotenoid biosynthesis. The elevated lycopene levels not only contribute to the vibrant red color but also improve the antioxidant capacity of the fruit a correlation supported by the work of Ilahy *et al.* (2011).

The marked variation in lycopene levels among the varieties highlights their potential for targeted breeding. Cultivars like Riogrand and Sahel, with their superior lycopene content, could be prioritized in breeding programs aimed at enhancing the antioxidant profile of tomatoes. Furthermore, the role of postharvest storage in preserving lycopene cannot be overlooked. Research by Mellidou *et al.* (2012) and Al-Dairi *et al.* (2021) emphasizes that careful control of storage conditions such as temperature and light exposure can minimize degradation of lycopene, thereby maintaining the fruit's nutritional quality.

Total phenolic contents

The total phenolic content (TPC) of six tomato varieties Anna, Naqeeb, Riogrand, Roma, Sahel, and Sundar was assessed in this study at three different stages of ripening: turning, pink, and red. There were notable variations in TPC between the ripening stages, with the turning stage showing the lowest values and the red stage the greatest. TPC varied from 16.34 ± 1.72 mg GAE/100g in Sahel to 21.1 ± 0.99 mg GAE/100g in Roma at the turning point. Higher phenolic content was found in Roma and Riogrand, suggesting that these varietal variations were caused by either genetic or environmental reasons. This early ripening period is characterized by variability in phenolic synthesis, as indicated by the modest standard deviations (0.99–1.88). From 22.9 ± 1.09 mg GAE/100g in Naqeeb to 26.4 ± 1.09 mg GAE/100g in Sahel, TPC rose during the pink stage. The active development of bioactive substances is seen in the change from the turning to the pink stage. While indicating consistent phenolic accumulation at this stage, the moderate standard deviations (0.86–1.14) emphasize variation among cultivars.

In Figure 6 the highest TPC concentration was found in Sahel (29.33 ± 1.17 mg GAE/100g), followed by Roma (28.5 ± 0.79 mg GAE/100g) and Riogrand (28.33 ± 1.29 mg GAE/100g) at the red stage. These results are consistent with earlier research that found higher antioxidant activity at full ripeness leads to higher phenolic content. Throughout the last stage of ripening, the standard deviations (0.79–1.32) show steady rises among cultivars.

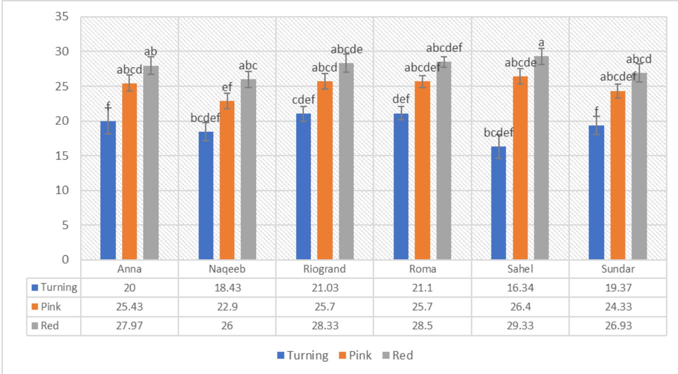

Figure 6: *Total phenolic content at three different stages of tomatoes.*

The impact of variety and ripening stage on phenolic content and its possible health benefits was highlighted by the increased TPC values in this study, especially at the red stage, when compared to earlier research by Mellidou *et al.* (2012).

Antioxidant activity (DPPH %)

The evaluation of antioxidant activity in six tomato varieties (Anna, Naqeeb, Riogrand, Roma, Sahel, and Sundar) across three ripening stages (turning, pink, and red) reveals significant impacts of both developmental and genetic factors. As shown in Figure 7, Roma consistently exhibited the lowest antioxidant activity, with values ranging from 7.3% ± 0.38 at the turning stage to 7.4% ± 0.67 at the red stage. In contrast, Naqeeb displayed the highest antioxidant activity at all ripening stages, peaking at 9.35% ± 0.67 during the turning stage and slightly declining to 9.2% ± 0.98 at the red stage.

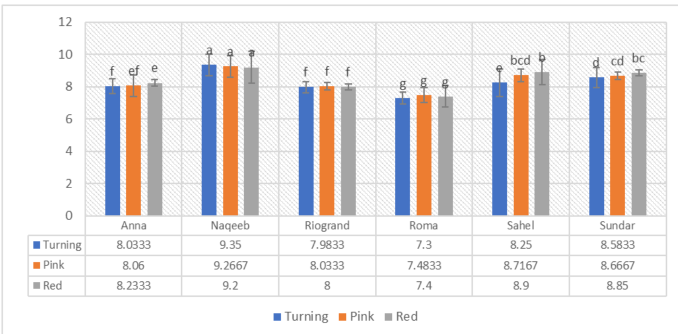

Figure 7: *DPPH % at three different stages of tomatoes.*

Naqeeb's higher antioxidant activity suggests a rich profile of bioactive compounds such as lycopene. This observation aligns with research by Borguini *et al.* (2009) and Stajčić *et al.* (2015), which showed that the accumulation of bioactive compounds during ripening correlates with enhanced antioxidant potential. The recorded standard deviations (0.18–0.98) further emphasize how both genetic traits and environmental factors play a role in the variability of antioxidant activity across different tomato varieties. The higher antioxidant activity in Naqeeb highlights its potential for breeding programs focused on improving the nutritional and functional quality of tomatoes, while also stressing the need for careful variety selection to optimize health benefits.

Mineral contents

Significant difference was seen in minerals content in different varieties of local and hybrid tomato in (Figure 8a, b). The highest value for Na was recorded in Roma (5.55±0.31 mg/100g) followed by Sundar (5.55±0.31 mg/100g) and both were statistically different from each other, and lowest Na was found in Anna (2.71±0.21 mg/100g). Regarding K contents, the cultivar Anna, Naqeeb and Sundar were non-significant among each other, whereas Anna have the highest K contents and cultivar Roma was characterised having the lowest K contents. The highest Ca contents were recorded in variety Roma (14.89±2.24 mg/100g) and highest Fe contents were observed in Sundar (7.54 ±0.15 mg/100g) followed by Sahel (6.23±0.22 mg/100g).

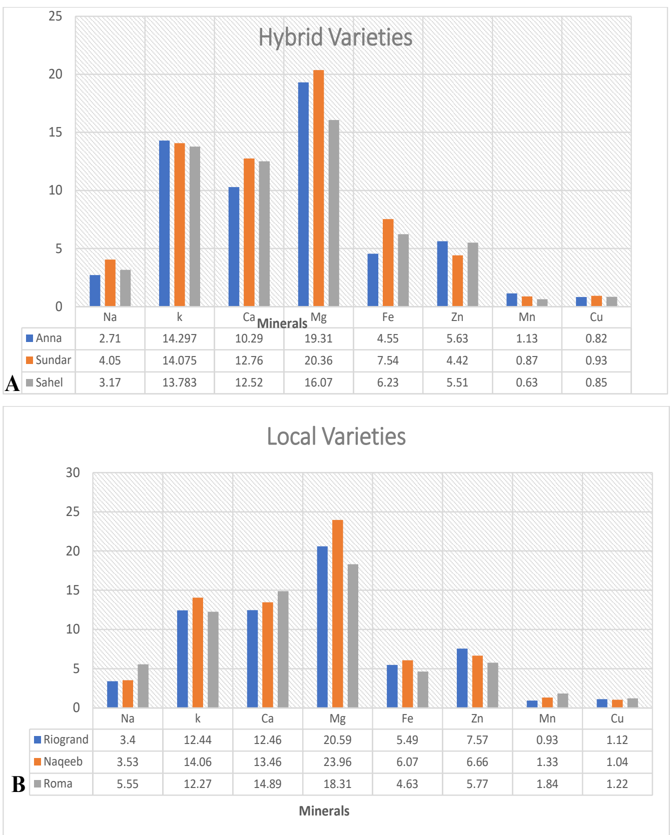

Figure 8: *Mineral contents in the hybrid variety (A) and local variety (B) of tomatoes.*

As for as Zn is concerned, Riogrand variety was at top (7.57±0.12 mg/100g) followed by Naqeeb (6.66±0.17 mg/100g), Roma (5.77±0.22 mg/100g) and lowest Zn contents were seen in Sundar variety (4.42±0.15 mg/100g) and all these are statistically significant among each other. Regarding manganese highest level was found in Roma (1.84±0.11 mg/100g) and lowest in Sahel (0.63±0.08 mg/100g). Khan *et al*. (2017) demonstrated that mineral contents in tomatoes are correlated with other nutrients and recent studies showed that sodium was significantly higher in tomato fruits than in leaf and stem. However, calcium, magnesium, potassium and phosphorus are significantly higher in different tomato varieties (Sultana *et al*., 2019). Present findings are in-line with those reported by Nour *et al*. (2014) that several tomato cultivars grown in southwestern Romania varied in mineral content and antioxidant activity.

Conclusions and Recommendations

In the current study, tomatoes (*Solanum lycopersicum* L.) were highlighted for their global importance, owing to their rich nutritional value, including a wealth of minerals and vitamin C contents. It ranks second amongst quinine related vegetables after potatoes and the third most cultivated vegetable after potatoes and sweet potatoes. Tomatoes are consumed in raw form for their excellent nutritional and organoleptic properties and are also widely used in various processed products at the household level across numerous dishes. This study highlights Naqeeb and Sahel as nutritionally superior varieties due to their high ascorbic acid, lycopene, and antioxidant contents. These cultivars hold promise for future breeding programs targeting improved nutritional quality.

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The authors hereby confirm that this manuscript has not been published previously, nor is it currently under consideration by any other journal.

Novelty Statement

This study provides a unique comparative analysis of six tomato varieties grown in Pakistan by evaluating key bioactive components such as lycopene, ascorbic acid, and antioxidant activity across distinct ripening stages. The identification of superior cultivars like

Naqeeb and Riogrand offers novel insights for targeted breeding and industrial processing, ultimately contributing to the development of nutritionally enhanced, functional tomato products.

Author's Contribution

Muhammad Atif Randhawa: Conceptualized the study, designed the experiments, and drafted the manuscript.
Muhammad Nadeem: Carried out the laboratory work.
Ahmad Din and Kashif Nadeem: Made the research materials available particularly the tomato varieties.
Hafiz Muhammad Jawad Saleem and Ali Hassan: Contributed to data analysis, critical revisions, and overall supervision.
All authors reviewed and approved the final manuscript.

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Data availability statement
Data of the current manuscript is available from the corresponding author upon reasonable request.

Ethical guidelines
No human or animal subjects were involved in this study. All experimental protocols strictly adhered to the relevant institutional and national guidelines for research ethics.

Conflict of interest
The authors have declared no conflict of interest.

References

Abdel-Moemin, A.R., 2014. Oxalate content of Egyptian grown fruits and vegetables and daily common herbs. J. Food Sci., 3: 66-77. https://doi.org/10.5539/jfr.v3n3p66

Al-Assil, B.J. and T.A. Wahwah. 2024. The involvement of lactic acid bacteria in modulating the levels of biogenic amino acids within fermented Tarasas products. J. Glob. Innov. Agric. Sci., 12(3): 855-862. https://doi.org/10.22194/JGIAS/24.1305

Al-Dairi, M., P.B. Pathare and R. Al-Yahyai. 2021. Chemical and nutritional quality changes of tomato during postharvest transportation and storage. J. Saudi Soc. Agric. Sci., 20(6): 401-408. https://doi.org/10.1016/j.jssas.2021.05.001

Al-Hattali, Y., A. Al-Maskri, W. Al-Busaidi, M.M. Khan and M.T. Akram. 2024. Impact of cadmium contaminated growing medium on the growth and physiological responses of tomato seedlings (*Solanum lycopersicum* L.). J. Glob. Innov. Agric. Sci., 12(2): 307-313. https://doi.org/10.22194/JGIAS/24.1321

Amzeri, A., F. Adiputra, S. Khoiri and S.B. Santoso. 2024. Selection of maize hybrids resulting from line × Tester crossing tolerant to drought stress. J. Glob. Innov. Agric. Sci., 12(3): 575-584. https://doi.org/10.22194/JGIAS/24.1326

AOAC, 2016. Official methods of analysis. association of official analytical chemists. AOAC press, Arlington, VA, USA.

Arslan, D. and M. Özcan. 2011. Drying of tomato slices: Changes in drying kinetics, mineral contents, antioxidant activity and colour parameters Secado de rodajas de tomate: cambios en cinéticos del secado, contenido en minerales, actividad antioxidante y parámetros de colour. CYTA J. Food, 9(3): 229-236. https://doi.org/10.1080/19476337.2010.522734

Ashebir, D., K. Jezik, H. Weingartemann and R. Gretzmacher. 2009. Change in colour and other fruit quality characteristics of tomato cultivars after hot-air drying at low final-moisture content. Int. J. Food Sci. Nutr., 60(Sup. 7): 308-315. https://doi.org/10.1080/09637480903114128

Awan, Z.A., A. Shoaib and K.A. Khan. 2018. Variations in total phenolics and antioxidant enzymes cause phenotypic variability and differential resistant response in tomato genotypes against early blight disease. Sci. Hortic., 239: 216-223. https://doi.org/10.1016/j.scienta.2018.05.044

Baldwin, E.A., J.W. Scott and J. Bai. 2015. Sensory and chemical flavor analyses of tomato genotypes grown in Florida during three different growing seasons in multiple years. J. Am. Soc. Hortic. Sci., 140(5): 490-503. https://doi.org/10.21273/JASHS.140.5.490

Barbu, V., C. Neagu, and M. Dragan. 2015. Principal component analysis of some parameters used for lycopene extraction from tomatoes. Acta Aliment., 44(4): 473-481. https://doi.org/10.1556/AAlim.2015.0002

Bazani, E.J., M.S. Barreto, A.J. Demuner, M.H. Dos Santos, C.I. Cerceau, D.E. Blank, M.J. Firmino, G.S. Souza, M.O. Franco and W.T. Suarez. 2021. Smartphone application for total phenols content and antioxidant determination in tomato, strawberry, and coffee employing digital imaging. Food Anal. Methods, 14: 631-640. https://doi.org/10.1007/s12161-020-01907-z

Borguini, R.G. and E.A. Ferraz Da Silva Torres. 2009. Tomatoes and tomato products as dietary sources of antioxidants. Food Rev. Int., 25(4): 313-325. https://doi.org/10.1080/87559120903155859

Bouabid, B., O.E. Yahyaoui, M.E. Bakkali, N.A. Ouaaziz, L.A. Lrhorfi, A. Quyou and R. Bengueddour. 2024. Comparative nutritional analysis of zest and pulp in red and yellow grapefruit varieties. J. Glob. Innov. Agric. Sci., 12(3): 653-660. https://doi.org/10.22194/JGIAS/24.1253

Dar, R. and J. Sharma. 2011. Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicum* L.). Int. J. Plant Breed. Genet., 5: 168-174. https://doi.org/10.3923/ijpbg.2011.168.174

Dembele, S., E.N.D. Koffi, I. Cisse, A.A. Adima, K. Yao and A.A.A. Louise. 2019. Nutritional composition and antioxidant capacity of four tomato varieties (*Lycopersicon esculentum* Mill.) cultivated in Côte d'Ivoire. Curr. Appl. Sci. Technol., 36(5): 1-11. https://doi.org/10.9734/cjast/2019/v36i530255

El-Khlifi, F., K. Kriri, M. El-Bakkali, O. Chetto, A. Talha, R. Benkirane and H. Benyahia. 2024. The serial mediating role of acidity content and total soluble solids in linking peel thickness to vitamin C content in some accessions of *Citrus limon* (L.) Burm. J. Glob. Innov. Agric. Sci., 12(2): 293-305. https://doi.org/10.22194/JGIAS/24.1233

Famurewa, J., P. Ibidapo and Y. Olaifa. 2013. Storage stability of tomato paste packaged in plastic bottle and polythene stored in ambient temperature. Int. J. Appl. Sci. Technol., 3(6): 34-42.

Felföldi, Z., F.R. Ranga, I.A. Roman, A.F. Sestras, D.C. Vodnar, J. Prohens and R.E. Sestras. 2022. Analysis of physico-chemical and organoleptic fruit parameters relevant for tomato quality. Agronomy, 12(5): 1232. https://doi.org/10.3390/agronomy12051232

Frenich, A.G., M.H. Torres, A.B. Vega, J.M. Vidal and P.P. Bolanos. 2005. Determination of ascorbic acid and carotenoids in food commodities by liquid chromatography with mass spectrometry detection. J. Agric. Food Chem., 53(19): 7371-7376. https://doi.org/10.1021/jf050973o

Garcia, E. and D.M. Barrett. 2006. Assessing lycopene content in California processing tomatoes. J. Food Process. Preserv., 30(1): 56-70. https://doi.org/10.1111/j.1745-4549.2005.00047.x

Hadi, T.S., 2024. Effect of irrigation water and spraying with proline acid on growth and yield components of wheat *Triticum aestivum* L. J. Glob. Innov. Agric. Sci., 12(1): 181-185. https://doi.org/10.22194/JGIAS/12.1152

Hasanuzzaman, M., M. Kamruzzaman, M.M. Islam, S.A.A. Khanom, M.M. Rahman, L.A. Lisa and D.K. Paul. 2014. A study on tomato candy prepared by dehydration technique using different sugar solutions. Food Nutr. Sci., 5: 1261-1271. https://doi.org/10.4236/fns.2014.513137

Hussain, M., S. Ali, S. Wali, A. Hussain, F. Faiz and S. Hussain. 2020. Performance and quality attributes of tomato cultivars under agro-climate of Bagrote Valley, Gilgit-Baltistan. Pak. J. Bot., 52(4): 1299-1303. https://doi.org/10.30848/PJB2020-4(20)

Ilahy, R., C. Hdider, M.S. Lenucci, I. Tlili and G. Dalessandro. 2011. Antioxidant activity and bioactive compound changes during fruit ripening of high-lycopene tomato cultivars. J. Food Compos. Anal., 24(4-5): 588-595. https://doi.org/10.1016/j.jfca.2010.11.003

Irina, Z., I. Polikarpova, D. Eliseev, I. Petrova, A. Chernukha, A. Pikhalo and N. Hryhorenko. 2024. Assessment of vitamin- and mineral-content stability of tomato fruits as a potential raw material to produce functional food. Funct. Foods Health Dis., 14(1): 14-32.

Jackman, R.J. and D.W. Stanley. 1995. Creep behavior of tomato pericarp tissue as influenced by ambient temperature ripening and chilled storage. J. Texture Stud., 26(5): 537-552. https://doi.org/10.1111/j.1745-4603.1995.tb00802.x

Kassim, W.Y. and M.F.A. Helou. 2024. The impact of folic acid and B12 administration on growth, wool traits and some hormones concentrations of male Arabi lambs. J. Glob. Innov. Agric. Sci., 12(2): 365-372. https://doi.org/10.22194/

JGIAS/24.1162

Khan, M.Y., M.M. Haque, A.H. Molla, M.M. Rahman and M.Z. Alam. 2017. Antioxidant compounds and minerals in tomatoes by Trichoderma-enriched biofertilizer and their relationship with the soil environments. J. Integr. Agric., 16(3): 691-703. https://doi.org/10.1016/S2095-3119(16)61350-3

Kradetskaya, O., D. Dzhazina, Y. Kairzhanov, S. Dashkevich, I. Chilimova, M. Utebayev and T. Shelayeva. 2024. Amino acid composition of proteins and technological indicators of grain quality of genotypes and varieties of spring soft wheat in northern Kazakhstan. J. Glob. Innov. Agric. Sci., 12(1): 197-206. https://doi.org/10.22194/JGIAS/12.1221

Marina, M., F.M. Romero, N.M. Villarreal, A.J. Medina, A. Gárriz, F.R. Rossi, G.A. Martinez and F.L. Pieckenstain. 2019. Mechanisms of plant protection against two oxalate-producing fungal pathogens by oxalotrophic strains of *Stenotrophomonas* spp. Plant Mol. Biol., 100(2019): 659-674. https://doi.org/10.1007/s11103-019-00888-w

Marsic, N.K., L. Gasperlin, V. Abram, M. Budic and R. Vidrih. 2011. Quality parameters and total phenolic content in tomato fruits regarding cultivar and microclimatic conditions. Turk. J. Agric. For., 35(2): 185-194. https://doi.org/10.3906/tar-0910-499

Mellidou, I., J. Keulemans, A.K. Kanellis and M.W. Davey. 2012. Regulation of fruit ascorbic acid concentrations during ripening in high and low vitamin C tomato cultivars. BMC Pl. Biol., 12: 1-19.

Montgomery, D.C., 2017. Design and analysis of experiments. 9th Ed. John Wiley and Sons Inc., Tempe, Arizona, USA. pp. 1-735.

Motamedzadegan, A. and H.S. Tabarestani. 2018. Tomato production, processing, and nutrition. Handbook of Vegetables and Vegetable Processing. pp. 839-861. https://doi.org/10.1002/9781119098935.ch36

Naveed, M., M.N. Khalid, W. Sabir, M.W. Jamil, M. Nasir, M.I. Khokhar, S. Jamil, S.U. Rahman, H.U. Rafa, A.L.K. Tipu and T.M. Khan. 2023. Estimation of mean performance of parents and their hybrids for yield related traits in *Gossypium hirsutum* L. Phytopathogenomic. Dis. Cont., 2(20): 49-55. https://doi.org/10.22194/Pdc/2.1020

Nour, V., I. Trandafir and M.E. Ionica. 2014. Evolution of antioxidant activity and bioactive compounds in tomato (*Lycopersicon esculentum* Mill.) fruits during growth and ripening. J. Appl. Bot. Food Qual., 87: 97-103.

Odeh, M.M., A.M. Abd and N.A. Obaid. 2024. Efficiency of antioxidants on physiological traits and growth curve of date palm fruit cultivars Barhi and Zamli. J. Glob. Innov. Agric. Sci., 12(2): 341-347. https://doi.org/10.22194/JGIAS/24.1171

Omari, F.E., L. Beniken, A. Zouahri, H. Benaouda, R. Benkirane and H. Benyahia. 2025. Impact of nitrogen fertilization and rootstock genotype on growth and fruit quality of *Nules clementine*. J. Glob. Innov. Agric. Sci., 13(1): 1-17. https://doi.org/10.22194/JGIAS/25.1228

Piombino, P., F. Sinesio, E. Moneta, M. Cammareri, A. Genovese, M.T. Lisanti, M.R. Mogno, M. Peparaio, P. Termolino and L. Moio. 2013. Investigating physicochemical, volatile, and sensory parameters playing a positive or a negative role in tomato liking. Food Res. Int., 50(1): 409-419. https://doi.org/10.1016/j.foodres.2012.10.033

Pozharskiy, A., V. Kostyukova, A. Taskuzhina, G. Nizamdinova, N. Kisselyova, R. Kalendar, N. Karimov, and D. Gritsenko. 2022. Screening of the collection of local and foreign varieties of *Solanum lycopersicum* L. for genetic markers of resistance against three tomato viruses. https://doi.org/10.2139/ssrn.4080759

Rafee, M., M.S. Jaffar, U. Kalsoom, M.B. Khan, Z.U. Haq and S. Ali. 2024. Effect of manure addition on the growth, yield, and disease (leaf spot) resistance of different varieties of okra. Phytopathogenomic. Dis. Cont., 3(2): 221-232. https://doi.org/10.22194/Pdc/3.1041

Rapa, M., S. Ciano, L. Gobbi, R. Ruggieri and G. Vinci. 2021. Quality and safety evaluation of new tomato cultivars. Ital. J. Food Sci., 33(2): 35-45. https://doi.org/10.15586/ijfs.v33i2.1921

Salehi, B., R. Sharifi-Rad, F. Sharopov, J. Namiesnik, A. Roointan, M. Kamle, P. Kumar, N. Martins and J. Sharifi-Rad. 2019. Beneficial effects and potential risks of tomato consumption for human health: An overview. Nutrition, 62: 201-208. https://doi.org/10.1016/j.nut.2019.01.012

Santos-Sánchez, N.F., R. Valadez-Blanco, M.S. Gómez-Gómez, A. Pérez-Herrera and R. Salas-Coronado. 2012. Effect of rotating tray drying on antioxidant components, colour, and rehydration ratio of tomato saladette slices.

LWT Food Sci. Technol., 46(1): 298-304. https://doi.org/10.1016/j.lwt.2011.09.015

Sinesio, F., M. Cammareri, V. Cottet, L. Fontanet, M. Jost, E. Moneta, S. Palombieri, M. Peparaio, R. Romero Del Castillo and E.S. Civitelli. 2021. Sensory traits and consumers perceived quality of traditional and modern fresh market tomato varieties: A study in three European countries. Foods, 10(11): 2521-2543. https://doi.org/10.3390/foods10112521

Sofia, N.H., T.M. Walter and T. Sanatorium. 2016. Prevalence and risk factors of kidney stone. Glob. J. Res. Anal., 5(3): 183-187.

Stajcic, S., G. Cetkovic, J. Canadanovic-Brunet, S. Djilas, A. Mandic and D. Cetojevic-Simin. 2015. Tomato waste: Carotenoids content, antioxidant and cell growth activities. Food Chem., 172: 225-232. https://doi.org/10.1016/j.foodchem.2014.09.069

Sultana, N., H. Zakir, M. Parvin, S. Sharmin and H. Seal., 2019. Effect of chitosan coating on physiological responses and nutritional qualities of tomato fruits during postharvest storage. Asian J. Adv. Agric. Res., 10(2): 1-11. https://doi.org/10.9734/ajaar/2019/v10i230027

Sumalan, R.M., S.I. Ciulca, M.A. Poiana, D. Moigradean, I. Radulov, M. Negrea, M.E. Crisan, L. Copolovici and R.L. Sumalan. 2020. The antioxidant profile evaluation of some tomato landraces with soil salinity tolerance correlated with high nutraceutical and functional value. Agronomy, 10(4): 500-516. https://doi.org/10.3390/agronomy10040500

Szabo, K., Z. Diaconeasa, A.F. Catoi and D.C. Vodnar. 2019. Screening of ten tomato varieties processing waste for bioactive components and their related antioxidant and antimicrobial activities. Antioxidants, 8(8): 292. https://doi.org/10.3390/antiox8080292

Talukder, M.M.I., P.K. Dash and M.A. Mannan. 2015. Physico-chemical characteristics and antioxidant assay of tomato (*Lycopersicon esculentum* Mill.) germplasm available in the south western region of Bangladesh. Int. J. Biosci., 6: 26-33. https://doi.org/10.12692/ijb/6.9.26-33

Tieman, D., G. Zhu, M.F. Resende Jr, T. Lin, C. Nguyen, D. Bies, J.L. Rambla, K.S.O. Beltran, M. Taylor and B. Zhang. 2017. A chemical genetic roadmap to improved tomato flavor. Science, 355(6323): 391-394. https://doi.org/10.1126/science.aal1556

Tigist, M., T.S. Workneh and K. Woldetsadik. 2013. Effects of variety on the quality of tomato stored under ambient conditions. J. Food Sci. Technol., 50: 477-486. https://doi.org/10.1007/s13197-011-0378-0

Tilahun, S., H.R. Choi, M.W. Baek, L.H. Cheol, K.W. Kwak, D.S. Park and C.S. Jeong. 2021. Antioxidant properties, γ-aminobutyric acid (GABA) content, and physicochemical characteristics of tomato cultivars. Agronomy, 11(6): 1204. https://doi.org/10.3390/agronomy11061204

Truffault, V., S.C. Fry, R.G. Stevens and H. Gautier. 2017. Ascorbate degradation in tomato leads to accumulation of oxalate, threonate and oxalyl threonate. Pl. J., 89(5): 996-1008.

Turhan, A., V. Seniz and H. Kuscu. 2009. Genotypic variation in the response of tomato to salinity. Afr. J. Biotechnol., 8(6): 1062-1068.

Umeohia, U.E., and A.A. Olapade. 2024. Quality attributes, physiology, and postharvest technologies of tomatoes (*Lycopersicum esculentum*)–A review. Am. J. Food Sci.Technol., 12(2): 42-64.

Wan, P., A. Toudeshki, H. Tan and R. Ehsani. 2018. A methodology for fresh tomato maturity detection using computer vision. Comput. Electron. Agric., 146: 43-50. https://doi.org/10.1016/j.compag.2018.01.011

Wang, Y., E.J. Jacobs, C.C. Newton and M.L. Mccullough. 2016. Lycopene, tomato products and prostate cancer- specific mortality among men diagnosed with nonmetastatic prostate cancer in the cancer prevention study II nutrition cohort. Int. J. Cancer, 138(12): 2846-2855. https://doi.org/10.1002/ijc.30027

Zhao, J., C. Sauvage, J. Zhao, F. Bitton, G. Bauchet, D. Liu, S. Huang, D.M. Tieman, H.J. Klee and M. Causse. 2019. Meta-analysis of genome-wide association studies provides insights into genetic control of tomato flavour. Nat. Commun., 10(1): 1534. https://doi.org/10.1038/s41467-019-09462-w

Zushi, K., C. Suehara and M. Shirai. 2020. Effect of light intensity and wavelengths on ascorbic acid content and the antioxidant system in tomato fruit grown in vitro. Sci. Horticult., 274: 109673.