



FOOD TECHNOLOGY

VALORIZING TOMATO PEEL FOR THE DEVELOPMENT OF CARROT SAUCE WITH ENHANCED CAROTENOID RETENTION AND STORAGE STABILITY

Hafiz Usama Noor^{1*}, Muhammad Hamdan Rashid^{2*}, Hammad Naeem³, Bareera Shafiq⁴, Sidra Rashid⁵, Rabiya Zulfiqar⁶, Zarina Yasmin⁷, Zafar Iqbal⁸, Sharoon Masih⁹ and Muhammad Abrar¹⁰

^{1,2,3,4,5,6}Scientific Officer,
^{7,9}Principal Scientist, ⁸Senior Scientist, ¹⁰Chief Scientist
Post Harvest Research Centre,
Ayub Agricultural Research
Institute, Faisalabad, Pakistan

*Corresponding author's email:
usamanoor1600@gmail.com
hamdanrashid2@gmail.com

Article received on:

11/02/2026

Accepted for publication:

15/06/2026



ABSTRACT

Utilizing food processing by-products as functional food ingredients is an emerging perspective for sustainable food production. The present study was conducted to develop carrot sauce with enhanced nutritional profile and improved storage stability by utilizing tomato peel powder. The sauce formulations containing 5%, 10%, 15%, and 20% of tomato peels as a substitution of carrot pulp were developed and evaluated for physicochemical properties (pH, acidity, total soluble solids and color parameters), nutritional content (lycopene and β -carotene), microbial safety and sensory acceptability during 90 days of ambient storage. The carrot sauce supplementation with tomato peel powder significantly improved lycopene content, ranging from 102.41 to 131.54 $\mu\text{g/g}$, with maximum retention of 85.37% in T4 (20% tomato peel powder) at the end of storage. T4 also exhibited improved storage stability in terms of pH (4.61 to 4.52), acidity (1.22 to 1.42%), and microbial count ($<4 \log \text{CFU/g}$). This study reveals that tomato peel, a by-product of food processing can be valorized for developing shelf stable, value-added functional food products.

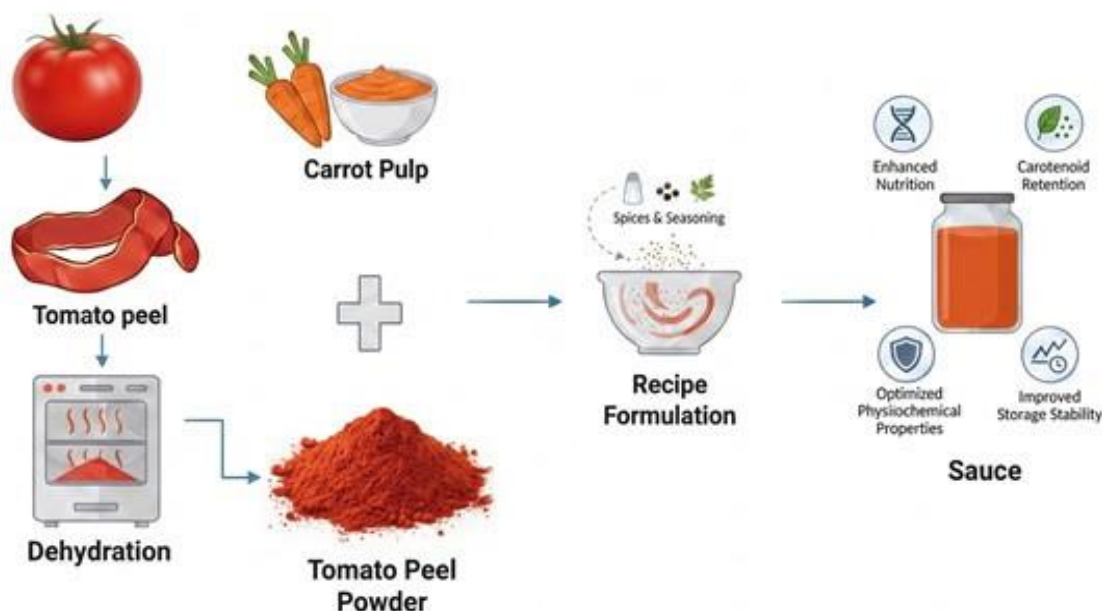
KEYWORDS: Waste valorization; functional foods; carotenoids; value addition; sustainability; Pakistan

INTRODUCTION

Fruits and vegetables sauces have become increasingly popular globally in recent years, due to their compatibility with everyday diets for improved flavor, texture and palatability. These sauces have distinct sensory characteristics which derive from a variety of ingredients, including food pulp, spices and other food additives (Kuliev, 2022). The fortification and enrichment of food products amid rising demand for nutrient-dense and health-promoting foods have grown interest in research based on food value addition and development of functional foods (Tsikritzi *et al.*, 2015). Tomato (*Solanum lycopersicum*) is one of the most popular crops in the world commonly consumed as vegetable and valued for its round the year availability. It is consumed as fresh and in processed forms as pulp, pastes, purees, and sauces (Kiralán *et al.*, 2022). The industrial processing of tomatoes generates by-products like peels and seeds that are high in dietary fiber, polyphenols, lycopene, β -carotene, and vitamin C (Romano *et al.*, 2020; Tchonkouang *et al.*, 2025). These by-products can be used to develop functional food ingredients that can play role in enhancing nutrients availability and reduce malnutrition (Lu *et al.*, 2022).

Carrot (*Daucus carota*) is a rich source of nutrients including phenolic compounds, carotenoids, particularly β -carotene, and dietary fiber (Varshney & Mishra, 2022). These compounds are involved in various health promoting activities such as improving the functions of cardiovascular and immune systems (Sharma, 2018; Haas *et al.*, 2019). Considering their nutritional importance, carrots are widely processed into value-added products like juices, powders, and preserves for meeting the dietary requirements of the population (Motegaonkar *et al.*, 2024).

Different studies highlight the importance of blended sauce formulations. Carrot-based sauce containing 60% carrot pulp in replacement of tomato pulp exhibited superior nutritional, sensory and textural characteristics compared to sauce developed with tomato pulp only (Javed *et al.*, 2022). Similarly, whole-tomato sauce (containing peels and seeds) and tomato sauce enriched with other vegetables exhibited superior physicochemical properties and nutritional profile compared to traditional tomato sauce (Milito *et al.*, 2025). However, the previous literature lacks studies on the use of tomato peels in carrot sauce, with particular emphasis on carotenoid retention and storage stability. Therefore, the present study was



Graphical Presentation

designed to develop and evaluate nutrient-rich carrot sauce supplemented with varying levels of tomato peel powder.

MATERIALS AND METHODS

The raw materials required in this study were procured from local market of Faisalabad and brought to the processing area of Food Technology Section, Ayub Agricultural Research Institute, Faisalabad, Pakistan. The carrots were cored, blanched, and blended to a fine pulp. The tomato peels were dried in a dehydrator (PT-100, Pamico Technologies, Pakistan) at 55 °C to a constant moisture content and converted into a fine powder. The tomato peel powder was analysed for lycopene and beta carotene content.

Table 1. Treatment plan for developing sauce

Treatments	Tomato peel powder %	Carrot Pulp %
T ₀	0	100
T ₁	5	95
T ₂	10	90
T ₃	15	85
T ₄	20	80

The sauce was developed following the treatment plan given in the table 1, aseptically filled in glass jars

and stored at room temperature (25±2 °C) for further analysis. The quality characteristics of the sauce were assessed every month for up to 90 days.

Physicochemical characterization

pH: The pH of the sauce samples was determined using digital pH meter (IQ 150 Digital pH meter Spectrum Technologies, Inc., USA).

Acidity (%): The percentage acidity was determined as acetic acid equivalent using standard titration method 942.15 (AOAC, 2016). Briefly 5 ml of sample was diluted up to 100 ml and 10 ml of diluted sample was titrated against 0.1N NaOH using phenolphthalein. The percentage acidity was calculated using the formula:

$$\text{Acidity (\%)} = \left(\frac{T \times N \times V_1 \times E}{V_2 \times W \times 1000} \right) \times 100$$

T=titer; N= Normality; V₁= 100 ml (diluted volume); V₂= 10 ml (Volume taken for titration); W= initial weight of sample taken

Total soluble solids: The total soluble solid content was determined at 20 °C using digital refractometer calibrated for measurement of total soluble solid as °Brix (HI 96801 Refractometer, HANNA Instruments Inc., USA).

β-Carotene determination: β-Carotene content was determined spectrophotometrically following solvent extraction. Sample (1 g) was weighed and homogenized

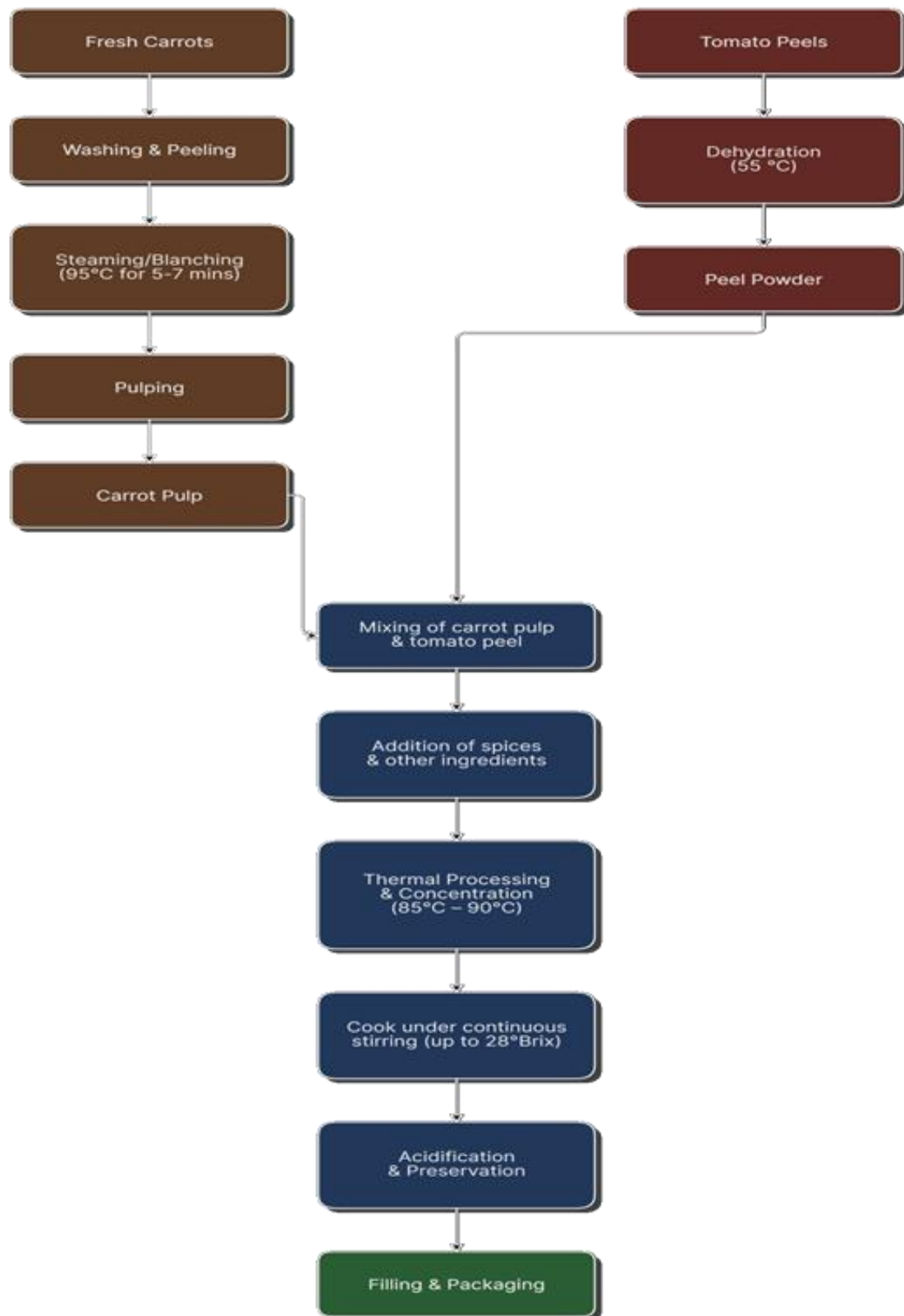


Fig. 1. Process flow diagram of carrot sauce development

in 10 mL of 1:1, v/v solution of acetone and n-hexane. The homogenate was filtered (Whatman filter paper no. 1) and 10 mL of 50% ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$ solution was added to the filtrate. The mixture was shaken vigorously and allowed to stand until phase separation occurred. The upper hexane layer containing β -carotene was carefully collected using separating funnel, and absorbance was measured at 450 nm using a single-beam spectrophotometer (Scitek UV 759, Scitek Global Co., Ltd., Jinan, China), with hexane used as the blank (Ishiwu Charles *et al.*, 2014).

Lycopene determination: Lycopene content was quantified using a solvent extraction method used by Ali *et al.* (2013), with minor modifications. In short, 5 mL of 0.05% butylated hydroxytoluene (BHT) solution in acetone, 5 mL of 95% ethanol, and 10 mL of hexane were combined with 0.6 g of the sample. The mixture was shaken in an ice bath for 15 minutes at 180 rpm to prevent oxidative deterioration of carotenoids. Then 3 mL of ice-cold distilled water added and the mixture was shaken for an additional five minutes to aid in phase separation. A UV-Vis spectrophotometer was used to record the absorbance of hexane layer at 503 nm (Scitek UV 759, Scitek Global Co., Ltd., Jinan, China).

$$\text{Lycopene } (\mu\text{g/g}) = \frac{X \times A \times 3.12}{Y}$$

Where X is the volume of hexane (mL), A is the absorbance reading at 503 nm, 3.12 is the extinction coefficient of lycopene and Y is the weight of sample (g).

Total plate count: The total plate count of the sauce samples was determined at the end of 90 days of storage following the standard method 990.12 (AOAC, 2016). Briefly, 10 g of each sauce sample was aseptically transferred into a sterile stomacher bag containing 90 mL of sterile peptone water (0.1%) and homogenized thoroughly to obtain a 10^{-1} dilution. Subsequent serial dilutions were prepared using the same diluent. The dilutions were pour-plated in duplicate onto nutrient agar and incubated at 35 ± 1 °C for 48 h. After incubation, plates containing 30–300 colonies were selected for enumeration. The total plate count of each sample was reported as $(\log \text{CFU g}^{-1})$ logarithm of colony forming units per gram.

Total color change (ΔE): The variations in lightness (L^*), redness (a^*), and yellowness (b^*) were used to assess color changes at the end of storage period. These coloring parameters were determined using a handheld colorimeter (Chroma Meter CR-400, Konica Minolta Inc., Japan). The overall color difference (ΔE) was calculated using the following equation (Umeohia

& Olapade, 2025).

$$\Delta E = \sqrt{(L^* - L)^2 + (b^* - b)^2 + (a^* - a)^2}$$

where L^* , a^* , and b^* represent the initial lightness, redness-blueness, and yellowness-greenness values, respectively, and L , a , and b correspond to the respective values measured at the end of storage interval.

Sensory evaluation: Sensory evaluation was performed to assess the consumer acceptability of the developed sauce. The samples were assessed by a panel of ten scientists on a 9-point hedonic scale, where 1 indicated extremely disliked and 9 indicated extremely liked. The samples were assessed for flavor, texture, and mouthfeel, then overall acceptability score was calculated as the mean of these sensory attributes (Meilgaard *et al.*, 2007).

Statistical analysis: The analytical measurements were performed in triplicate and analyzed by two-way analysis of variance (ANOVA). Tukey's HSD test was performed for post hoc comparison of means. The results were presented as mean $\pm$ standard deviation (S.D) and graphs were developed using grammar of graphics package (ggplot2). All statistical analysis were performed in RStudio (Montgomery, 2017).

RESULTS AND DISCUSSION

pH: A gradual decrease was observed in the pH of carrot sauce supplemented with varying levels of tomato peel powder during storage, as presented in figure 2 (A). The sample (T_0) containing 100% carrot pulp showed relatively greater reduction in pH, decreasing from 4.52 ± 0.03 to 4.16 ± 0.01 after 90 days of storage. In contrast, the treatment (T_4) containing 20% tomato peel powder as a replacement for carrot pulp showed a minor decline in pH from 4.61 ± 0.02 to 4.52 ± 0.01 during storage. The pH stability in samples containing tomato peel powder may be attributed to the presence of more fiber, which is known to contribute to the chemical stability in food matrices (Navarro-González *et al.*, 2011). The decrease in pH may be attributed to the breakdown and de-esterification of organic acid functional groups occurring during storage (Javed *et al.*, 2022).

Acidity (%): The titratable acidity measured as percentage acetic acid content of the developed sauce is illustrated in figure 2 (B). All treatments presented a statistically significant increase ($p < 0.05$) in acidity throughout the storage period. The treatment (T_0) containing 100% carrot pulp presented the highest increase in acidity from 1.21 ± 0.03 to 1.93 ± 0.02 . In contrast, the lowest increase in titratable acidity was recorded in treatment T_4 , in which 20% tomato peel

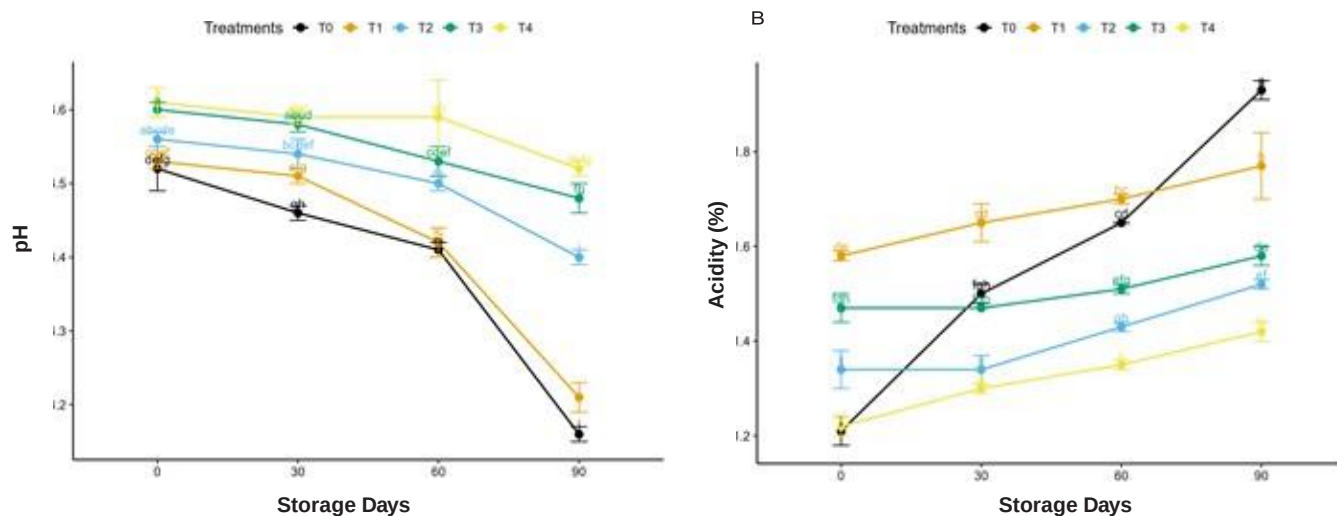


Fig. 2. A) pH of sauce during storage; B) % Acidity of sauce during storage. Data points with different lettering having significant differences from each other. T₀=Contains 100% carrot pulp; T₁=95% Carrot pulp and 5% Tomato peel powder; T₂=90% Carrot pulp and 10% Tomato peel powder; T₃=85% Carrot pulp and 15% Tomato peel powder; T₄= 80% Carrot pulp and 20% Tomato peel powder.

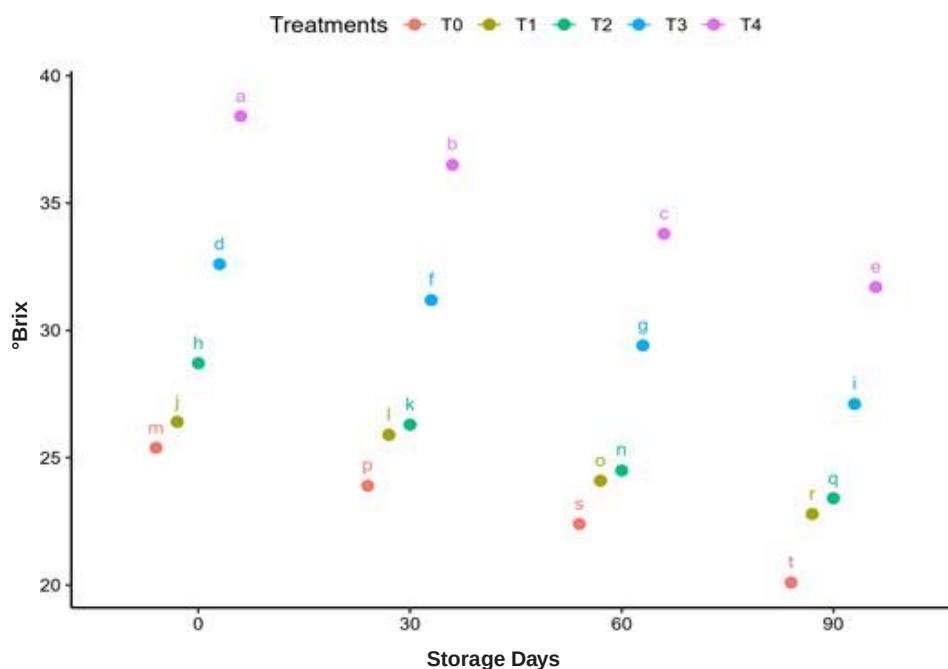


Fig. 3. Total soluble solids of sauce during storage. Data points with different lettering having significant differences from each other. T₀=Contains 100% carrot pulp; T₁=95% Carrot pulp and 5% Tomato peel powder; T₂=90% Carrot pulp and 10% Tomato peel powder; T₃=85% Carrot pulp and 15% Tomato peel powder; T₄= 80% Carrot pulp and 20% Tomato peel powder.

powder was used as a replacement for carrot pulp, acidity increased marginally from 1.22 ± 0.02 to 1.42 ± 0.02 . Samples containing 5%, 10%, and 15% tomato peel powder showed intermediate increases in acidity, with final values ranging from 1.58 ± 0.01 to 1.77 ± 0.07 , 1.34 ± 0.04 to 1.52 ± 0.01 , and 1.47 ± 0.03 to 1.58 ± 0.02 , respectively. The comparatively lower

increase in acidity of samples containing tomato peel powder may be attributed to the buffering capacity of dietary fiber and antioxidant activity of phenolic compounds present in tomato peel (Valdez-Morales *et al.*, 2014). The overall increase in titratable acidity during storage can be associated with the degradation of polysaccharides, sugars, and pectic substances into

organic acids, as well as possible enzymatic and non-enzymatic reactions occurring in the product matrix. Similar trends have also been reported in vegetable-based sauces and purees fortified with plant by-products, where compositional changes, including degradation of organic acid and breakdown of complex carbohydrates, influence acidity over time (Kebede et al., 2015; Donega et al., 2015).

Total soluble solids (TSS): The total soluble solids (TSS), expressed as °Brix (sucrose equivalents), of carrot sauce supplemented with tomato peel powder are presented in figure 3. The sauce containing higher amount of tomato peel powder had a greater degree of brix among the treatments. A significant ($p < 5$) decrease in soluble solids (°Brix) was observed during storage. The highest initial TSS value (38.41 ± 0.01 °Brix) was recorded by treatment T₄ (20% tomato peel powder), which also showed a substantial decrease up to 31.70 ± 0.02 °Brix by the end of the storage period. Similarly, treatment T₃ (15% tomato peel powder) showed a decrease from 32.60 ± 0.02 to 27.11 ± 0.02 °Brix. The decreasing trend in remaining treatments T₀, T₁, and T₂ was comparable i.e., 24.59 ± 0.01 to 20.10 ± 0.03 , 26.41 ± 0.02 to 22.79 ± 0.01 , and 28.71 ± 0.02 to 23.41 ± 0.01 , respectively. This decreasing trend of TSS during storage can be explained by the hydrolysis of complex polysaccharides and subsequent degradation of soluble carbohydrates in the presence of organic acids (Guo et al., 2022). The similar declining trend of TSS during storage (TSS decreased from 34.14 to 19.64 °) has been reported in tomato sauce supplemented with plant roots (Din et al., 2020).

Lycopene and β-carotene: The lycopene and β-carotene content of tomato peel powder was 25.14 ± 0.80 and 7.80 ± 0.31 microgram/g, respectively. The lycopene and β-carotene concentrations of the sauce exhibited a gradual decrease over 90 days

of storage as shown in table 2; however, substantial retention was observed at the end of storage across all treatments. In treatments (T₀ to T₄) the lycopene was increased from 102.41 ± 1.09 to 131.54 ± 0.92 as the percentage of supplementation with tomato peel powder was increased from 0 to 20%. The maximum lycopene content (131.54 ± 0.92) was observed in T₄ containing 20 % tomato peel powder while minimum was in T₀ (102.41 ± 1.09) made with carrot pulp only. The retention percentage of lycopene ranged from 76.75% to 85.37% after 90 days in T₀ to T₄ respectively (figure 3). Treatments containing higher levels of tomato peel powder showed significantly more lycopene retention compared to those with lower level. This can be attributed to the inherently high concentration of lycopene in tomato peel and its association with the fibrous matrix, which may limit oxygen diffusion and reduce oxidative degradation (Martínez-Hernández et al., 2016). Moreover, Lycopene is known to be relatively stable in thermally processed tomato products because of the formation of cis-isomers (Gupta et al., 2010). However, exposure to oxygen and light, and residual enzymatic activity during storage can promote oxidation of the polyene chain, leading to a gradual loss. The stabilization of lycopene during prolonged storage in this study may be attributed to the fibrous composition of the sauce matrix, combined with antioxidant compounds (phenolics and flavonoids) naturally present in tomato peel (Saini et al., 2019; Chabi et al., 2024).

In contrast β-carotene exhibited a comparatively higher degree of degradation, with retention values ranging between 62.74% and 71.97% among treatments (T₀ to T₄) after 90 days of storage (figure 4). This loss is consistent with the known chemical instability of β-carotene, which is more susceptible to oxidation due to the presence of β-ionone rings and its higher

Table 2. Major antioxidant and carotenoid compounds in developed sauce

Treatment	Lycopene (microgram/g)	Lycopene (microgram/g)	β-Carotene (microgram/g)	β-Carotene (microgram/g)
	0 day	90 day	0 day	90 day
T ₀	$102.41 \pm 1.09e$	$78.6 \pm 1.4e$	$23.75 \pm 0.13a$	$14.9 \pm 0.4a$
T ₁	$120.77 \pm 0.56d$	$94.8 \pm 0.2d$	$18.01 \pm 0.43c$	$11.7 \pm 0.3c$
T ₂	$124.91 \pm 0.74c$	$100.9 \pm 1.1c$	$20.98 \pm 0.39b$	$14.6 \pm 0.5b$
T ₃	$128.05 \pm 0.35b$	$105.7 \pm 0.9b$	$17.57 \pm 0.22c$	$10.2 \pm 0.4d$
T ₄	$131.54 \pm 0.92a$	$112.3 \pm 1.3a$	$20.98 \pm 0.64b$	$15.1 \pm 0.6b$

Values are mean±S.D with superscripts representing significant differences. T₀=Contains 100% carrot pulp; T₁=95% Carrot pulp and 5% Tomato peel powder; T₂=90% Carrot pulp and 10% Tomato peel powder; T₃=85% Carrot pulp and 15% Tomato peel powder; T₄= 80% Carrot pulp and 20% Tomato peel powder.

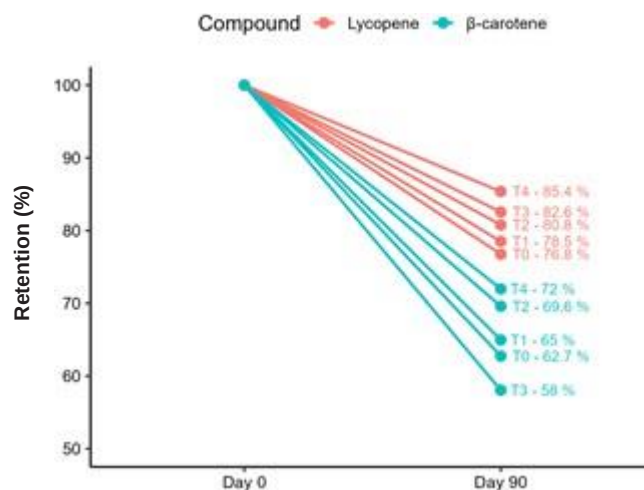


Fig. 4. Lycopene and β -Carotene retention in sauce at the end of storage

Table 3. Sensory acceptability, microbial load, and total color change at the end of storage

Treatment	Overall acceptability	TPC (log CFU/g)	ΔE
T ₀	7.83 $\pm$ 0.06 ^a	2.26 $\pm$ 0.08 ^{ab}	12.67 $\pm$ 0.29 ^a
T ₁	7.93 $\pm$ 0.06 ^a	2.06 $\pm$ 0.14 ^{cd}	12.68 $\pm$ 0.51 ^a
T ₂	7.57 $\pm$ 0.12 ^b	1.90 $\pm$ 0.02 ^d	11.69 $\pm$ 0.29 ^b
T ₃	7.83 $\pm$ 0.06 ^a	2.12 $\pm$ 0.30 ^{bc}	10.97 $\pm$ 0.13 ^b
T ₄	7.07 $\pm$ 0.06 ^c	2.47 $\pm$ 0.03 ^a	13.06 $\pm$ 0.10 ^a

Values are mean $\pm$ S.D with superscripts representing significant differences. T₀=Contains 100% carrot pulp; T₁=95% Carrot pulp and 5% Tomato peel powder; T₂=90% Carrot pulp and 10% Tomato peel powder; T₃=85% Carrot pulp and 15% Tomato peel powder; T₄= 80% Carrot pulp and 20% Tomato peel powder; TPC= Total plate count; ΔE =Total color change

reactivity towards oxygen. The decrease in β -carotene can be attributed to oxidative reactions triggered by the presence of residual oxygen in the packaging material (Pénicaud *et al.*, 2011). The treatments with a higher proportion of tomato peel exhibited improved β -carotene retention as observed in T₄ (71.97% retention) indicating the antioxidant abilities of tomato peel constituents. Previous research studies have found that the product matrix composition and presence of antioxidants play a role in β -carotene preservation, which are in line with the findings of the current study (Atilgan & Bayraktar, 2022; Gutiérrez-del-Río *et al.*, 2021). Furthermore, the structural integration of dietary fiber imparts a thick consistency, which restricts the oxygen mobility in the product matrix due to an increase in internal resistance that enhances carotenoid retention (Trombino *et al.*, 2021; Juchniewicz, 2026).

Total plate count (TPC): Total plate count (TPC)

values, expressed as log CFU/g, ranged from 1.90 to 2.47 log CFU/g across all treatments, indicating acceptable microbiological quality of the developed product at the end of 90-day storage (table 3). The values of total plate count for all treatment were below the normal value (≤ 4 log CFU/g) prescribed under different local and international regulatory standards for microbiological safety of processed fruits and vegetables products specifically sauces and ketchup (Anandsynal *et al.*, 2018). The treatment T₃ exhibited the lowest TPC (1.90 $\pm$ 0.02 log CFU/g), which was statistically significant ($p < 0.05$) compared to other treatments. The treatments T₀ and T₄ were recorded with comparatively higher TPC values of 2.26 $\pm$ 0.08 and 2.47 $\pm$ 0.03 log CFU/g, respectively, but were below the permissible microbiological safety limits. The microbial count in food product depends on the processing and storage temperature, holding time as

well as the intrinsic factors related to the food product, such as water activity, and acidity or pH of the product (Kirse-Ozolins et al., 2019).

Total color change (ΔE): The total color change of the samples recorded at the end of 90 days of storage period as the difference of L (lightness/darkness), a (redness/blueness) and b (yellowness/greenness) values at first and last day of storage and presented in table 3. The ΔE values ranged from 10.97 ± 0.13 to 13.06 ± 0.10 across the five treatments (T_0 to T_4). Treatments T_0 (12.67 ± 0.29), T_1 (12.68 ± 0.51), and T_4 (13.06 ± 0.10) exhibited significantly higher ΔE values and were statistically grouped together, suggesting greater color deviation compared to the other treatments during storage. In contrast, Treatments T_3 (11.69 ± 0.29) and T_4 (10.97 ± 0.13) showed significantly lower ΔE values, indicating relatively improved color retention and stability. The lower ΔE values are generally associated with reduced pigment degradation and consequently better color quality preservation. Food components like carotenoids, phenolics, and dietary fibers have been found to protect pigments from oxidative and thermal degradation. Nonetheless, exposure to environmental factors like oxygen and light influences the color changes in food products (Pathare et al., 2013; Martínez-Hernández et al., 2016).

Overall acceptability: The sensory acceptability of the sauce was expressed as the mean score of mouthfeel, texture, and flavor on a 9-point hedonic scale. The sensory score ranged from 7.07 to 7.93 among all treatments at the end of storage (table 3), indicating very good consumer acceptability of the products. The sensory scores of treatments T_0 , T_1 , and T_3 were statistically similar. While the treatment T_4 achieved the lowest but still very good sensory acceptability score (7.07 ± 0.06). This slight reduction in mean acceptability score may be attributed to changes in mouthfeel due to the addition of tomato peels that provide a thick consistency to the product (Navarro-González et al., 2011). The addition of such food particles is known to influence textural perception and flavor release in food matrices (van Eck & Stieger, 2020). Similar reduction in sensory scores with increased fiber content have been reported in previous studies, where the presence of insoluble fiber negatively affected textural properties and overall palatability of food products (Elleuch et al., 2011; Gómez et al., 2014).

CONCLUSION

The present study demonstrates that valorizing tomato peel powder as a functional ingredient significantly improved the nutritional value, physicochemical and storage stability of the product. The carrot sauce formulation with 20% tomato peel in replacement

of carrot pulp exhibited elevated lycopene retention (85.37%), reduced oxidative degradation of carotenoids, stabilized pH and acidity, polysaccharides degradation and color variations. Moreover, the microbiological stability across all formulations remained under the acceptable limit ($<4 \log \text{CFU/g}$). Lastly, sensory evaluation of all formulations resulted in acceptable scores in terms of mouthfeel, taste and texture. The results of the study validated that the tomato peel can be valorized as a functional food ingredient for reducing tomato processing waste and enhancing the nutritional profile of processed foods. Future research should focus on optimizing the particle size of powder for improved textural properties and bioavailability assessments of carotenoids enriched food products.

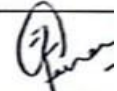
REFERENCES

- Aleman, R.S., Marcia, J.A., Montero-Fernández, I., King, J., Pournaki, S.K., Hoskin, R.T. and Moncada, M. 2023. Novel liquor-based hot sauce: Physicochemical attributes, volatile compounds, sensory evaluation, consumer perception, emotions and purchase intent. *Foods*. 12(2):369.
- Ali, A., M. Maqbool, P.G. Alderson and N. Zahid, 2013. Effect of gum arabic as an edible coating on antioxidant capacity of tomato (*Solanum lycopersicum* L.) fruit during storage. *Postharvest Biology and Technology*. 76:119–124.
- Anand synal, B. Mumtaz, M. Motalab, S. Jahan, M.M. Hoque and B.K. Saha, 2018. Nutritional and microbiological evaluation on sauces and ketchups available in Bangladesh. *International Food Research Journal*. 25(1):357–365.
- AOAC. 2016. Official methods of analysis of the Association of Official Analytical Chemists. 20th Edition. AOAC Inc., Washington DC.
- Atilgan, M.R. and O. Bayraktar, 2022. Enhancing shelf life and functionality of food matrices by utilization of natural compounds. *Journal of Food Processing and Preservation*. 46(5):e15197.
- Chabi, I.B., O. Zannou, E.S. Dedehou, B.P. Ayegnon, O.B.O. Odouaro, S. Maqsood, and A.P.P. Kayodé, 2024. Tomato pomace as a source of valuable functional ingredients for improving physicochemical and sensory properties and extending the shelf life of foods: A review. *Heliyon*. 10(3).
- Din, A., R.M. Amir, K. Ameer, A. Ahmad, M. Nadeem, M.F.J. Chughtai and R. Kausar 2020. Assessment of quality attributes of tomato sauce supplemented with moringa root. *Food Science and Technology*. 40(4):1014–1020.
- Donegà, V., M.G. Marchetti, P. Pedrini, S. Costa,

- and E. Tamburini, 2015. Valorization of tomato dried peels powder as thickening agent in tomato purees. *Food Chemistry*. 179:94–102.
- Elleuch, M., D. Bedigian, O. Roiseux, S. Besbes, C. Blecker, and H. Attia 2011. Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*. 124(2):411–421.
- Gómez, M., F. Ronda, C.A. Blanco, P.A., Caballero and A. Apesteguía 2003. Effect of dietary fibre on dough rheology and bread quality. *European Food Research and Technology*. 216(1):51–56.
- Guo, X., T. Luo, D. Han, D. Zhu, Z. Li and Z. Wu 2022. Multi-omics analysis revealed room temperature storage affected the quality of litchi by altering carbohydrate metabolism. *Scientia Horticulturae*. 293:110663.
- Gupta, R., V.M. Balasubramaniam, S.J. Schwartz and D.M. Francis 2010. Storage stability of lycopene in tomato juice subjected to combined pressure–heat treatments. *Journal of Agricultural and Food Chemistry*. 58(14):8305–8313.
- Gutiérrez-del-Río, I., S. López-Ibáñez, P. Magadán-Corpas, L. Fernández-Calleja, A. Pérez-Valero, M. Tuñón-Granda and F. Lombó 2021. Terpenoids and polyphenols as natural antioxidant agents in food preservation. *Antioxidants*. 10(8):1264.
- Haas, K., P. Robben, A. Kiesslich, M. Volkert and H. Jaeger 2019. Stabilization of crystalline carotenoids in carrot concentrate powders: Effects of drying technology, carrier material and antioxidants. *Foods*. 8(8):285.
- Heumann, C. and M.S. Shalabh, 2016. Introduction to statistics and data analysis. Springer, Switzerland.
- Ishiwu Charles, N., J.O. Iwouno, E. Obiegbuna James and C. Ezike Tochukwu 2014. Effect of thermal processing on lycopene, beta-carotene and vitamin C content of tomato [Var. UC82B]. *Journal of Food and Nutrition Sciences*. 2(3):87–92.
- Javed, M.S., A. Amjad, F.U.H. Shah, Z. Ahmad, A. Hameed, M.J. Anwar and M. Abrar, 2022. Probing the physicochemical characteristics of carrot sauce during storage. *PLoS ONE*. 17(11):e0273857.
- Juchniewicz, S., and J. Harasym 2026. Oxidation Mechanism in Bigels and Emulgels—Challenges and Solutions. *Molecules*, 31(6), 970.
- Kebede, B.T., T. Grauwet, J. Magpusao, S. Palmers, C. Michiels, M. Hendrickx and A. Van Loey. 2015. An integrated fingerprinting and kinetic approach to accelerated shelf-life testing of chemical changes in thermally treated carrot puree. *Food Chemistry*. 179:94–102.
- Kiralan, M. and O. Ketenoglu 2022. Utilization of tomato (*Solanum lycopersicum*) by-products: An overview. In: *Mediterranean Fruits Bio-wastes: Chemistry, Functionality and Technological Applications*. pp. 799–818.
- Kirse-Ozolins, A., E. Raits, E. and I. Ciprovica 2019. Designing of thermal treatment parameters for tomato sauces. In: *Proceedings of the 18th International Scientific Conference “Engineering for Rural Development”*, Jelgava, Latvia, 22–24 May 2019. Latvia University of Life Sciences and Technologies. pp. 1140–1146.
- Kuliev, N. 2022. New fruit and vegetable sauces with functional properties. *IOP Conference Series: Earth and Environmental Science*. 981(2):022080.
- Lu, S., S. Chen, H. Li, S. Paengkoum, N. Taethaisong, W. Meethip and P. Paengkoum 2022. Sustainable valorization of tomato pomace (*Lycopersicon esculentum*) in animal nutrition: A review. *Animals*. 12(23):3294.
- Martínez-Hernández, G.B., M. Boluda-Aguilar, A. Taboada-Rodríguez, S. Soto-Jover, F. Marín-Iniesta and A. López-Gómez 2016. Processing, packaging and storage of tomato products: Influence on the lycopene content. *Food Engineering Reviews*. 8(1):52–75.
- Meilgaard, M.C., G.V. Civille and B.T. Carr 2007. Sensory evaluation techniques. 4th Edition. CRC Press LLC, New York.
- Milito, E.M., L. De Luca, G. Basile, M. Calabrese, A. Santini, S. Ambrosio and R. Romano, 2025. Development of a new tomato sauce enriched with bioactive compounds through the use of processing by-products and vegetables. *Foods*. 14(12):2037.
- Montgomery, D.C. 2017. Design and analysis of experiments. 9th Edition. Wiley, USA.
- Motegaonkar, S., A. Shankar, H. Tazeen, M. Gunjal and S. Payyanad 2024. A comprehensive review on carrot (*Daucus carota* L.): The effect of different drying methods on nutritional properties and its processing as value-added foods. *Sustainable Food Technology*. 2(3):667–688.
- Navarro-González, I., V. García-Valverde, J. García-Alonso and M.J. Periago 2011. Chemical profile, functional and antioxidant properties of tomato peel fiber. *Food Research International*. 44(5):1528–1535.
- Pathare, P.B., U.L. Opara and F.A.J. Al-Said, 2013. Colour measurement and analysis in fresh and processed foods: A review. *Food*

- and Bioprocess Technology. 6(1):36–60.
- Pénicaud, C., N. Achir, C. Dhuique-Mayer, M. Dornier, and P. Bohuon 2011. Degradation of β -carotene during fruit and vegetable processing or storage: Reaction mechanisms and kinetic aspects: A review. *Fruits*. 66(6):417–440.
- Romano, R., L. De Luca, N. Manzo, F. Pizzolongo and A. Aiello 2020. A new type of tomato puree with high content of bioactive compounds from 100% whole fruit. *Journal of Food Science*. 85(10):3264–3272.
- Saini, R.K., A.E.D. Bekhit, S. Roohinejad, K.R. Rengasamy and Y.S. Keum 2019. Chemical stability of lycopene in processed products: A review of the effects of processing methods and modern preservation strategies. *Journal of Agricultural and Food Chemistry*. 68(3):712–726.
- Sharma, H.K. 2018. Carrots production, processing and nutritional quality. In: *Handbook of Vegetables and Vegetable Processing*. pp. 589–608.
- Tchoukouang, R.D., D.M. Martey, M. Bal, M.H. Oztop, C. Gago, A. Guerreiro and M.M.C. Vieira, 2025. Development of a novel formulation of a functional tomato sauce. *Food Science and Technology*. 13(1):76–96.
- Trombino, S., R. Cassano, D. Procopio, M.L. Di Gioia, M.L. and E. Barone 2021. Valorization of tomato waste as a source of carotenoids. *Molecules*. 26(16):5062.
- Tsikritzi, R., J. Wang, V.J. Collins, V.J. Allen, V.J., Mavrommatis, P.J. Moynihan and L. Methven, 2015. The effect of nutrient fortification of sauces on product stability, sensory properties and subsequent liking by older adults. *Journal of Food Science*. 80(5):S1100–S1110.
- Umeohia, U.E. and A.A. Olapade 2025. Influence of tomato peel fiber and moringa leaf extract bioactive coatings on the quality, shelf life and sensory properties of fresh tomatoes. *Food Chemistry: X*. 27:102396.
- Valdez-Morales, M., L.G. Espinosa-Alonso, L.C. Espinoza-Torres, F. Delgado-Vargas and S. Medina-Godoy 2014. Phenolic content and antioxidant and antimutagenic activities in tomato peel, seeds and by-products. *Journal of Agricultural and Food Chemistry*. 62(23):5281–5289.
- van Eck, A. and M. Stieger, 2020. Oral processing behavior, sensory perception and intake of composite foods. *Trends in Food Science and Technology*. 106:219–231.
- Varshney, K. and K. Mishra 2022. An analysis of health benefits of carrot. *International Journal of Innovative Research in Engineering and Management*. 9(1):211–214.

CONTRIBUTION OF AUTHORS

Sr. No.	Authors' name	Contribution	Signature
1.	Hafiz Usama Noor	Conceptualization, Methodology design, Drafted Original Manuscript, Visualization	
2.	Muhammad Hamdan Rashid	Methodology design, Proof read, Formal Analysis	
3.	Hammad Naeem	Helped in the interpretation of results, Performed analytical work, Investigation	
4.	Bareera Shafiq	Assisted to wrote up the manuscript	
5.	Sidra Rashid	Assisted to wrote up the manuscript	
6.	Rabiya Zulfiqar	Assisted to wrote up the manuscript	
7.	Zarina Yasmin	Supervised the research work	
8.	Zafar Iqbal	Anaysed the data statistically	
9.	Sharoon Masih	Proof read the manuscript	
10.	Muhammad Abrar	Supervised the research work and analysed the data statistically	