

Development of Functional Nectar from Pomegranate Enriched with Ginger Extract

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ABSTRACT

This study was conducted to develop a functional pomegranate nectar enriched with ginger extract. The physicochemical properties, storage stability, and sensory quality of the enriched nectar were evaluated under ambient storage conditions. The experiment was conducted in 2025 in the Horticulture Department laboratory at Kabul University. The nectar was prepared by blending pomegranate juice with varying concentrations of ginger extract (0–7%) and standardized to 15°Brix total soluble solids and 0.4% acidity in accordance with Codex standards. Physicochemical parameters, including total soluble solids (TSS), titratable acidity, pH, reducing sugars, non-reducing sugars, and total sugars, were analyzed monthly. The results indicated that both storage duration and ginger concentration had a highly significant ($P \leq 0.01$) effect on all measured parameters. Moderate ginger concentrations (1–3%) demonstrated better stability and retention of quality attributes than the control and higher concentrations. Sensory evaluation revealed that treatments containing 1–3% ginger extract maintained higher scores in appearance, color, flavor, aroma, texture, and overall acceptability, whereas higher concentrations ($\geq 5\%$) negatively affected sensory attributes. In conclusion, the incorporation of ginger extract at moderate levels enhances the physicochemical stability and sensory quality of pomegranate nectar during 90 days of storage under ambient conditions.

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INTRODUCTION

The scientific name of pomegranate is *Punica granatum L.*, and it is also known as the "fruit of health". Afghanistan is an agriculture-based country where the agricultural sector plays a significant role in the national economy and provides employment for a large proportion of the population. Pomegranate is widely cultivated across the country, and different local varieties are supplied to both domestic and international markets. Kandahar province is recognized as the main pomegranate production hub in Afghanistan, thanks to its favorable climate and high-quality varieties. It contributes approximately 36.7% of the total cultivation area and around 39.5% of the national production. However, the production of pomegranate

in the country is faced with many familiar challenges such as poor orchard handling techniques, disease and pest infestations, unavailability of quality inputs like disease-resistant saplings, effective fertilizers, safe pesticides, lack of technical support from experts and more importantly the scarcity of ground water and drought which has often results in orchards don't receive enough water, this often leads to uneven fruit quality and lower yields than what the orchard could actually produce. , The fruit is usually harvested in the summer and continues to reach the markets right up until autumn. The pomegranate supply chain in Afghanistan includes a range of actors, such as farmers, collectors, cooperatives, wholesalers, retailers, and consumers in both domestic and export markets. Kandahar is known for producing high valuable crops, which one of them is high quality pomegranate, that holds a strong stance in both domestic and international markets and has significant economic importance for the country. (Azimi et al., 2023)

Pomegranates are processed in large quantities due to their good taste, aroma, nutritional value, and medicinal properties. The demand for processed pomegranate products, such as pomegranate juice, beverages, and pomegranate powder, among others, is increasing daily. Furthermore, other pomegranate-derived products play a significant role in driving the global pomegranate market's growth (Bhatt et al., 2022).

In Afghanistan, the pomegranate is considered one of the most important fruits of Kandahar province, renowned worldwide for its pomegranate production. Pomegranates play a significant role in the social and economic lives of those who cultivate them. The value chain analysis of pomegranate production highlights that exporters play a crucial role by processing pomegranates and adding value through marketing, transportation, and storage, earning the highest income among all stakeholders. In the pomegranate trade with Europe, exporters typically earn the highest profits, making around 66 Afghanis per kilogram. Farmers come next, averaging 23 Afghanis per kilogram from their harvest. Local collectors, who buy directly from farmers and handle processing and transportation, see the smallest margins, making just 13 Afghanis per kilogram after costs (Daqiq, 2021).

The global pomegranate market was valued at approximately \$221.32 million in 2023 and is projected to reach \$375.68 million by 2031, with an average annual growth rate (CAGR) of approximately 9.23% from 2024 to 2031(Pomegranate Market Size, Share, Scope, Analysis & Forecast, 2026)

Ginger is a flowering herbaceous plant whose rhizome is widely used as a culinary spice and medicinal herb. From ancient times, it has been incorporated into traditional diets and folk medicine due to its recognized health-enhancing effects. Numerous *in vitro* and *in vivo* investigations have demonstrated the beneficial physiological properties of ginger, largely attributed to its antioxidant, anti-inflammatory, antimicrobial, and anticarcinogenic activities. These health-promoting effects are associated with the diverse range of bioactive compounds present in ginger, particularly gingerols, shogaols, zingerone, paradols, and essential oils, such as zingiberene and β -bisabolene (Mao et al., 2019).

Looking to growing consumer awareness and increasing industrial demand for natural antioxidants and functional food ingredients, the use of ginger and its derivatives has been widely explored through various food systems. Ginger plays vital role and contributes distinctive qualities to different food categories, including antioxidant and nutraceutical benefits in bakery products that enhances flavor, market and consumer acceptance, aroma and techno-functional properties in dairy products; sensory appeal and antimicrobial effects in beverages; improved oxidative stability and sensory attributes in meat products; and extended shelf life prolongation along with improved sensory characteristics in films, coatings, and packaging materials (Shaukat et al., 2023).

Ginger is a plant-derived medicinal substance with strong therapeutic potential for treating various diseases. Extensive scientific research has demonstrated that ginger possesses multiple biological activities, among which its anti-inflammatory effect is particularly significant. Inflammation itself is a complex physiological and pathological response involving numerous biological pathways. The chemical profile of ginger has been thoroughly investigated in numerous studies, all of which have successfully characterized the composition of *Zingiber officinale*. These investigations publicized that *Zingiber officinale* holds a diverse array of chemical constituents, with 6-gingerol identified as the predominant bioactive compound, alongside other important components such as 4-gingerol and 8-gingerol (Bekkouch et al., 2023).

Ginger possesses major medicinal properties and has been reported to be effective in the management of conditions such as rheumatoid arthritis and ulcers, as well as in reducing the risk of heart attack and stroke. Also, ginger is known for its antiviral, anticancer, and anti-ulcerogenic activities making it more important ingredient with best health promoting benefits. (Pali et al., 2020).

Fruit nectar is defined as a semi-fluid drink produced by combining fruit pulp or juice with water and sweeteners, and it may contain preservatives or stabilizing substances to improve product stability and results in shelf life prolongation. Formulating nectar from a blend of fruits not only enhances sensory qualities such as flavor and aroma but also increases its nutritional value by enriching it with bioactive compounds, including vitamins, antioxidants, and polyphenolic compounds. Typical fruit blends used in nectar production include combinations of fruits among themselves and fruits with spices and other ingredients. The interaction between different fruits creates a synergistic effect that positively influences color intensity, flavor harmony, and overall consumer acceptability. Due to these enhanced sensory and functional attributes, blended fruit nectars are commonly used in commercial juice and nectar manufacturing (Verma et al., 2025).

The present study is designed to:

- Develop a value-added ginger-flavored Pomegranate nectar and evaluate its total quality.
- Assesses the nutritional characteristics and storage stability of the prepared product.
- Monitor changes in its chemical composition during storage.

- Examine variations in the organoleptic properties of the nectar over time to determine its acceptability and quality retention during storage.

METHODS AND MATERIALS

Study Site

The research was carried out at the Horticulture Department Laboratory, Faculty of Agriculture, Kabul University, Kabul, Afghanistan, in 2025.

Sample

The raw materials used in this study included Pomegranate 'Wonderfol' fruits, fresh ginger rhizomes (*Zingiber officinale* Roscoe), sugar, and water. The pomegranate fruits and ginger rhizomes were purchased from a local market in Kandahar, Afghanistan; however, the specific ginger cultivar was not identified. Citric acid and sodium benzoate were used as food-grade additives. Glass bottles (250 mL capacity) were used for packaging and storage of the beverage samples. All materials were sourced from the local market.

Data Collection Procedure

The pomegranate fruits were thoroughly washed under clean running water to remove adhering dust, dirt, and surface contaminants. After washing, the fruits were carefully cut in half using a sterilized stainless-steel knife to ensure hygienic handling and to facilitate efficient juice extraction. The edible arils were then carefully separated from the peel and membranes. Juice extraction was carried out by mechanically processing the arils under controlled conditions. Following extraction, any remaining solid residues were separated from the juice.

Similarly, to extract juice from ginger, the ginger was first thoroughly washed. Its peel was removed with a sharp knife and cut into small pieces. The pieces were placed into a mixer and blended until finely ground. The mixture was then filtered using a muslin cloth to extract the liquid, which was collected in a container.

The blended juice intended for nectar formulation was prepared by combining pomegranate and ginger juices in 8 different proportions, as shown in Table 1.

Table 1. Recipe for nectar (according to Codex standards - CXS 247-2005)

Treatment	Juice (%)	TSS (°B)	Acidity (%)
T1	25 (100 % pomegranate juice)	15	0.4
T2	25 (99 % pomegranate juice with 1% ginger juice)	15	0.4
T3	25 (98 % pomegranate juice with 2% ginger juice)	15	0.4
T4	25 (97 % pomegranate juice with 3% ginger juice)	15	0.4
T5	25 (96 % pomegranate juice with 4% ginger juice)	15	0.4
T6	25 (95 % pomegranate juice with 5% ginger juice)	15	0.4
T7	25 (94 % pomegranate juice with 6% ginger juice)	15	0.4
T8	25 (93 % pomegranate juice with 7% ginger juice)	15	0.4

According to Table 1, the treatments were prepared using predetermined percentages of pomegranate and ginger juice blends. TSS of each blend was then measured and adjusted to

15°Brix by adding a sugar syrup prepared by dissolving sugar in warm water. The acidity level was also analyzed and adjusted to the desired level (0.4%) using citric acid. Sodium benzoate (120 ppm) was dissolved in a small volume of warm water and added as a preservative. The final product was hot-filled into 250 mL bottles and sealed with metal caps using a capping machine. The sealed bottles were pasteurized by immersing them in near-boiling water for 25 minutes and then stored at room temperature.

The ginger-flavored pomegranate nectar was analyzed for pH, total soluble solids, reducing sugars, non-reducing sugars, total sugars, and acidity at monthly intervals up to three months during storage at ambient temperature.

Data Collection Instruments

A Hand Refractometer (Model #300001, Sper Scientific Ltd., Scottsdale, AZ, USA) was used to measure the TSS of nectar. TSS data for all samples were recorded and expressed in °Brix.

A digital pH meter was used to measure the pH of nectar. The temperature was kept constant during observations for all samples.

To determine the reducing sugar content, 25 mL of the product was blended with 100 mL of distilled water and neutralized with 1 N NaOH using phenolphthalein as an indicator. Subsequently, 2 mL of 45% lead acetate was added, followed by 2 mL of 22% potassium oxalate. The volume was adjusted to 250 mL, and the solution was filtered. The filtrate was titrated against 10 mL of Fehling's solution. The obtained titer was used to calculate the percentage of reducing sugars. The content of non-reducing sugars was calculated using the following formula: Non-reducing sugars (%) = Total sugars (%) – Reducing sugars (%).

To determine the total sugars, 100 mL of the filtrate was hydrolyzed by mixing with 10 g of citric acid and kept overnight. It was then neutralized with sodium hydroxide using phenolphthalein as an indicator. The volume was brought to 250 mL, and the filtrate was titrated with 10 mL of Fehling's mixture. The obtained titer was used to calculate the percentage of total sugars.

To determine the titratable acidity, the nectar sample was diluted and titrated against a standard 0.1 N sodium hydroxide solution using phenolphthalein as an indicator. The results were expressed as a percentage of citric acid.

The prepared nectar was observed visually for mold growth at monthly intervals throughout the storage period.

Sensory evaluation was conducted by a panel of 10 individuals with basic knowledge and training in the organoleptic assessment of nectar. The sensory attributes evaluated included appearance, color, flavor, aroma, texture, and overall acceptability. Juice from all treatments was assessed using a 9-point Hedonic scale, where: 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

The product's cost-effectiveness was analyzed to determine the best treatment. Net income was calculated using the following formula:

$$\text{Net Income} = \text{Total Income} - \text{Total Cost}$$

Since the benefit-cost ratio is an effective indicator of the commercial feasibility of product preparation, it was also calculated using the formula:

$$\text{Benefit-Cost Ratio} = \text{Total Income} / \text{Total Cost}$$

The study was designed in a Factorial CRD with three replicates. The generated data were analyzed using the Statistical Tool for Agricultural Research (STAR) software, and treatments were compared using the Least Significant Difference (LSD) at the 5% level of significance.

FINDINGS

The results were organized and presented in standardized tables to provide clear and transparent information. Relevant statistical measures were included, and each table was accompanied by a concise explanation. All abbreviations were explained in the footnotes to ensure better understanding and prevent confusion. The effects of storage period and ginger juice concentration on the physicochemical and sensory properties of ginger-flavored pomegranate nectar are presented in the following sections:

Total Soluble Solids (TSS)

The results showed that both storage period and ginger juice concentration had a highly significant effect ($P \leq 0.01$) on the TSS of pomegranate juice, with a significant interaction between the two factors. Overall, TSS values changed during storage, indicating a clear effect of storage duration on product stability.

All samples started with a uniform TSS value (15.00 °Brix) at day 0. During storage, the control (0% ginger concentration) indicated an initial increase at 30 days (15.60 °Brix), followed by a continuous decline up to 90 days (13.90 °Brix), showing reduced stability over time. Whereas, ginger-fortified samples generally maintained more stable TSS values during storage.

Among concentrations, low to moderate ginger levels (particularly 1% and 2%) maintained comparatively higher TSS values during storage, with 1% showing a peak at 30 days (16.65 °Brix) and 2% demonstrating more stable values at later stages (15.30–15.26 °Brix). Higher ginger concentrations (6–7%) did not show further improvement and in some cases showed slight reductions in TSS at extended storage periods.

The findings suggest that ginger juice at low to moderate concentrations (1–3%) improves TSS stability during storage, whereas higher concentrations do not provide additional benefit (Table 2).

Table 2. Effect of Different Treatments on the Total Soluble Solids (°B) Content of Ginger-Flavored Pomegranate Nectar

Treatment	Storage period (Days)			
	0	30	60	90
T1 25 (100 % pomegranate juice)	15.00aB	15.60cbA	14.00dC	13.90dC
T2 25 (99 % pomegranate juice with 1 % Ginger juice)	15.00aB	16.65aA	15.08abB	14.95bB
T3 25 (98 % pomegranate juice with 2% ginger juice)	15.00aC	16.00bA	15.30aB	15.26aB
T4 25 (97 % pomegranate juice with 3% ginger juice)	15.00aB	15.85bcA	15.05bB	15.05abB
T5 25 (96 % pomegranate juice with 4% ginger juice)	15.00aB	15.86bbA	15.00bB	15.00bB
T6 25 (95 % pomegranate juice with 5% ginger juice)	15.00aA	15.00dcA	15.10abA	15.10abA
T7 25 (94 % pomegranate juice with 6 % Ginger juice)	15.00aA	15.05dcA	15.05bA	15.05abA
T8 25 (93 % pomegranate juice with 7% ginger juice)	15.00aA	15.15dcA	14.25cB	14.25cB
	Storage period (A)	Treatment (B)	Interaction (A×B)	
F-test	**	**	**	
LSD_{0.05}	0.15	0.24		
CV (%)	0.64			

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation. According to LSD at the 0.05 level, means within the same column, followed by the same small letter, and means within the same row, followed by the same capital letter, are not significantly different for treatment and storage period, respectively.

Titrateable Acidity

The results of the study showed that both storage period and ginger juice concentration had a highly significant ($P \leq 0.01$) effect on the acidity of pomegranate juice. In addition, the interaction between storage duration and treatment levels was statistically significant, indicating that the combined effect of these two factors influenced the observed changes.

At the first stage (0 days), all treatments exhibited the same value (0.40), reflecting uniformity among samples before storage. As storage progressed, variations became evident across treatments. The control treatment (T₁), consisting of 100% pomegranate juice, remained relatively stable up to 60 days (0.42) but showed a sharp decline at 90 days (0.20), showing deterioration during prolonged storage.

In treatments containing ginger juice, a different pattern was observed. T₂ (1% ginger juice) indicated a decrease at 30 days (0.33), followed by a notable increase at 60 days (0.53), and then declined again at 90 days (0.31). Likewise, T₃ (2% ginger juice) exhibited a peak at 30 days (0.54), followed by a gradual decline thereafter. T₄ (3% ginger juice) maintained relatively stable values at 30 and 60 days (0.47), before declining at 90 days (0.29).

Moderate ginger concentrations, such as T₅ (4%), showed minimal fluctuations during the storage period, showing better stability. On the other hand, higher ginger levels (T₆, T₇, and T₈) demonstrated different responses. T₆ and T₇ showed moderate stability with slight fluctuations over time. T₈ (7% ginger juice) recorded the highest value at 30 days (0.60) and

maintained comparatively higher values even at 90 days (0.53), suggesting that higher ginger concentration may improve the measured parameter under certain conditions.

The results suggest that incorporating ginger juice influences the behavior of the parameter during storage, with moderate to high concentrations (particularly 2–7%) contributing to better stability and retention compared to the control treatment, particularly at later storage intervals. (Table 3).

Table3. Effect of Different Treatments on the Titratable Acidity Content (%) of Ginger-Flavored Pomegranate Nectar

Treatment	Storage period (Days)			
	0	30	60	90
T1 25 (100 % pomegranate juice)	0.40aA	0.40abA	0.42aA	0.20bB
T2 25 (99 % pomegranate juice with 1 % Ginger juice)	0.40aB	0.33bB	0.53aA	0.31bB
T3 25 (98 % pomegranate juice with 2% ginger juice)	0.40aB	0.54abA	0.44aAB	0.38abB
T4 25 (97 % pomegranate juice with 3% ginger juice)	0.40aAB	0.47abA	0.47aA	0.29bB
T5 25 (96 % pomegranate juice with 4% ginger juice)	0.40aA	0.38bA	0.40aA	0.31bA
T6 25 (95 % pomegranate juice with 5% ginger juice)	0.40aB	0.54abA	0.47aAB	0.38abB
T7 25 (94 % pomegranate juice with 6 % Ginger juice)	0.40aA	0.47abA	0.36aA	0.38abA
T8 25 (93 % pomegranate juice with 7% ginger juice)	0.40aC	0.60aA	0.42aBC	0.53aAB
	Storage period (A)	Treatment (B)	Interaction (A×B)	
F-test	**	**	**	
LSDo.05	0.13	0.2		
CV (%)	19.28			

** $: P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation. According to LSD at the 0.05 level, means within the same column, followed by the same small letter, and means within the same row, followed by the same capital letter, are not significantly different for treatment and storage period, respectively.

pH

The results presented in the table reveal that storage period and ginger juice concentration had a highly significant ($P \leq 0.01$) effect on the pH of pomegranate juice. The interaction between storage duration and treatment levels was also statistically important, showing that both factors jointly influenced the observed variations.

At the initial stage (0 days), small differences were observed among treatments. The control treatment (T1) recorded a value of 2.84, while T8 (7% ginger juice) showed the highest initial value (2.93). Other treatments ranged between 2.75 and 2.90, indicating relatively close but statistically distinguishable values at the start of the experiment.

As storage increased to 30 days, all treatments showed increases and reaching peak levels. Among them, T8 (7% ginger juice) recorded the highest value (3.06), followed closely by T2, T4, and T5, which also exhibited elevated values (around 3.01–3.03). This means that the parameter improved during the first storage period regardless of treatment, with slightly higher values corresponding to increased ginger concentration.

At 60 days of storage, a general decline was observed across all treatments. The differences among treatments were minimal, with values ranging narrowly between 2.85 and 2.90, showing relative stability during this period.

By the end of the storage period (90 days), the values showed a slight recovery or stabilization. T8 again recorded the highest value (2.98), followed by T2 and T5 (2.96), while the control treatment (T1) maintained a comparable value (2.95). Overall, differences among treatments at this stage were small but statistically significant.

In general, the results suggest that the parameter increased during the initial storage period, then declined slightly and stabilized. The addition of ginger juice, particularly at higher concentrations, tended to maintain slightly higher values throughout storage, although the overall differences among treatments remained relatively small (Table 4).

Table 4. Effect of different treatments on the pH content of ginger-flavored pomegranate nectar

Treatment	Storage period (Days)			
	0	30	60	90
T1 25 (100 % pomegranate juice)	2.84bB	2.99abA	2.88aB	2.95aA
T2 25 (99 % pomegranate juice with 1 % Ginger juice)	2.90abC	3.03abA	2.90aC	2.96aB
T3 25 (98 % pomegranate juice with 2% ginger juice)	2.87abC	3.01abA	2.87aC	2.94aB
T4 25 (97 % pomegranate juice with 3 % Ginger juice)	2.75cD	3.01abA	2.87aC	2.94aB
T5 25 (96 % pomegranate juice with 4 % Ginger juice)	2.89abC	3.02abA	2.87aC	2.96aB
T6 25 (95 % pomegranate juice with 5% ginger juice)	2.87abC	2.99abA	2.85aC	2.93aB
T7 25 (94 % pomegranate juice with 6% ginger juice)	2.88abB	2.96bA	2.85aB	2.95aA
T8 25 (93 % pomegranate juice with 7% ginger juice)	2.93aC	3.06aA	2.87aD	2.98aB
	Storage period (A)	Treatment (B)	Interaction (A×B)	
F-test	**	**	**	
LSD _{0.05}	0.04	0.07		
CV (%)	1.00			

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation. According to LSD at the 0.05 level, means within the same column, followed by the same small letter, and means within the same row, followed by the same capital letter, are not significantly different for treatment and storage period, respectively.

Reducing sugars

The table result shows that both storage period and ginger juice concentration had a highly significant ($P \leq 0.01$) effect on the reducing sugars of pomegranate nectar. The interaction between storage duration and treatment levels was also significant ($P \leq 0.05$).

At the initial stage (0 days), the values among treatments showed some variation, ranging from 7.81 in T4 (3% ginger juice) to 10.66 in T6 (5% ginger juice). Most treatments exhibited relatively comparable values, showing moderate uniformity at the beginning of the storage period.

As storage progressed to 30 days, a general increase in values was observed across all treatments. T2 (1% ginger juice) recorded the highest value (11.89), followed closely by T5 (11.16) and T4 (11.11). This increase may be attributed to biochemical changes occurring during early storage, which temporarily improve the measured parameter.

At 60 days of storage, the values reached their peak levels in most treatments. T5 (4% ginger juice) showed the highest value (14.74), followed by T2 (14.22) and T6 (13.57). This trend shows that moderate levels of ginger juice may positively influence the parameter during mid-storage. Some treatments, such as T4, showed comparatively lower values (9.75), suggesting variability depending on ginger concentration.

By 90 days, a decline in values was observed in most treatments, although the extent of reduction varied. T5 and T6 maintained relatively higher values (11.42), while T4 recorded the lowest value (8.35), showing a greater loss over prolonged storage. The control treatment (T1) also showed a decrease compared to its peak value, reaching 9.65 at the end of the storage period.

The results demonstrate that the parameter increased during the early and mid-storage periods, then declined at later stages. The addition of ginger juice, particularly at moderate concentrations (4–5%), appeared to enhance the parameter during storage, while lower or higher concentrations showed comparatively less consistent effects (Table 5).

Tables. Effect of different treatments on the reducing sugar content of ginger-flavored pomegranate nectar

Treatment	Storage period (Days)			
	0	30	60	90
T1 25 (100 % pomegranate juice)	9.82ab A	10.70aA	11.28cdA	9.65abA
T2 25 (99 % pomegranate juice with 1 % Ginger juice)	8.62ab C	11.89aB	14.22abA	10.93abB
T3 25 (98 % pomegranate juice with 2 % Ginger juice)	9.27ab B	9.95aB	12.10abcd A	9.16abB
T4 25 (97 % pomegranate juice with 3% ginger juice)	7.81bC	11.11aA	9.75dAB	8.35bBC
T5 25 (96 % pomegranate juice with 4% ginger juice)	9.80ab B	11.16aB	14.74aA	11.42aB
T6 25 (95 % pomegranate juice with 5% ginger juice)	10.66a B	10.59aB	13.57abcA	11.42aB
T7 25 (94 % pomegranate juice with 6% ginger juice)	8.21ab C	10.73aB	13.19abca A	9.97abBC
T8 25 (93 % pomegranate juice with 7% ginger juice)	9.47ab B	11.06aAB	11.50bcdA	10.20abA B
	Storage period (A)	Treatment (B)	Interaction (A×B)	
F-test	**	**	*	
LSD _{0.05}	1.78	2.79		
CV (%)	10.21			

**_{0.01}; LSD: Least Significant Difference; CV: Coefficient of Variation. According to LSD at the 0.05 level, means within the same column, followed by the same small letter, and

means within the same row, followed by the same capital letter, are not significantly different for treatment and storage period, respectively.

Non-reducing sugars

The results indicate that storage period had a highly significant ($P \leq 0.01$) effect on non-reducing sugar content. At 0 and 30 days, the values (4.56% and 4.49%) were statistically similar, showing stability during early storage. However, a significant decline was observed at 60 days (0.76%), followed by a slight increase at 90 days (1.47%), although the value remained lower than the initial levels. So, non-reducing sugars remained stable initially but decreased significantly during prolonged storage (Table 6).

Table 6. Effect of storage duration on the non-reducing sugar content (%) of ginger-flavored pomegranate nectar

Storage period (Days)	Non-Reducing Sugar (%)
0	4.56a
30	4.49a
60	0.76b
90	1.47b
F-test	**
LSD _{0.05}	0.72
CV (%)	44.36

** $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

The results indicate that treatment had a highly significant ($P \leq 0.01$) effect on the non-reducing sugar content of pomegranate juice. The values varied among treatments, reflecting the influence of different concentrations of ginger juice. Among all treatments, T₄ (3% ginger juice) had the highest non-reducing sugar content (3.89%), which was significantly higher than that of some other treatments. In contrast, T₅ (4% ginger juice) showed the lowest value (1.83%), followed by T₆ (2.21%), indicating a reduction at certain ginger levels.

The remaining treatments (T₁, T₂, T₃, T₇, and T₈) showed intermediate values and were statistically similar to each other. The LSD value (1.59) confirms that the differences among treatments are statistically significant, while the high coefficient of variation (CV = 44.36%) indicates considerable variability in the data. The results suggest that ginger juice concentration affects non-reducing sugar content, with moderate levels (around 3%) showing higher values, whereas higher concentrations may lead to a decrease (Table 7).

Table 7. Effect of ginger juice concentration on the non-reducing sugar content (%) of ginger-flavored pomegranate nectar

Treatment	Non-Reducing Sugar (%)
T ₁ 25 (100 % pomegranate juice)	2.73ab
T ₂ 25 (99 % pomegranate juice with 1% ginger juice)	2.92ab
T ₃ 25 (98 % pomegranate juice with 2% ginger juice)	2.69ab
T ₄ 25 (97 % pomegranate juice with 3% ginger juice)	3.89a

T5 25 (96 % pomegranate juice with 4% ginger juice)	1.83b
T6 25 (95 % pomegranate juice with 5% ginger juice)	2.21b
T7 25 (94 % pomegranate juice with 6% ginger juice)	2.96ab
T8 25 (93 % pomegranate juice with 7% ginger juice)	3.33ab
F-test	**
LSD _{0.05}	1.59
CV (%)	44.36

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Total sugars

The results presented in the table indicate that both storage period and ginger juice concentration had a highly significant ($P \leq 0.01$) effect on the measured parameter of pomegranate juice. In addition, the interaction between storage duration and treatments was statistically significant, indicating that the combined influence of these factors accounted for the observed variations.

At the first stage (0 days), the values varied among treatments, ranging from 11.90 (T3) to 14.95 (T8). As storage increased to 30 days, all treatments showed increases and reaching peak values. The highest value was recorded in T2 (16.55), followed by T3 (15.83) and T4 (15.71), showing an improvement during early storage. At 60 days, a general decline was observed across most treatments, although T5 (14.76) and T8 (14.03) maintained relatively higher values. By 90 days, the values decreased further across all treatments, with a narrower range of 11.21-12.35, suggesting a reduction in the parameter during prolonged storage.

The Least Significant Difference (LSD) values were 1.36 for storage period and 2.14 for treatments, confirming that the observed differences among means are statistically higher. The coefficient of variation ($CV = 6.19\%$) shows good precision and reliability of the experimental data. So, the results show that the parameter increased during the first storage period, then gradually declined over time. The addition of ginger juice influenced the parameter's behavior, with some treatments maintaining relatively higher values during storage than the control Table 8.

Table 8. Effect of different treatments on the total sugar content (%) of ginger-flavored pomegranate nectar

Treatment	Storage period (Days)			
	0	30	60	90
T1 25 (100 % pomegranate juice)	13.99abcA	14.96aA	11.82cB	11.62aB
T2 25 (99 % pomegranate juice with 1% ginger juice)	14.85aB	16.55aA	14.39aB	11.54aC
T3 25 (98 % pomegranate juice with 2 % Ginger juice)	11.90cB	15.83aA	12.17bcB	11.34aB
T4 25 (97 % pomegranate juice with 3 % Ginger juice)	13.62abcB	15.71aA	12.05bcC	11.21aC
T5 25 (96 % pomegranate juice with 4 % Ginger juice)	12.61bcB	15.06aA	14.76aA	12.01aB
T6 25 (95 % pomegranate juice with 5% ginger juice)	14.10abA	14.92aA	13.70abcB	12.35aB
T7 25 (94 % pomegranate juice with 6 % Ginger juice)	14.15abAB	15.01aA	13.46abcB	11.31aC

T8 25 (93 % pomegranate juice with 7 % Ginger juice)	14.95aA	15.07aA	14.03abA	11.48aB
	Storage period (A)	Treatment (B)	Interaction (A×B)	
F-test	**	**	**	
LSD _{0.05}	1.36	2.14		
CV (%)	6.19			

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Nectar Spoilage: During the three-month storage period, no signs of juice spoilage were observed or recorded in any of the seven different combinations of Pomegranate and ginger in the blended nectar.

Appearance

The effect of ginger juice incorporation on the appearance of pomegranate nectar at the initial storage period (0 days) is presented in Table 1. At the start of storage, all treatments received relatively high appearance scores, indicating good visual quality. The control treatment (T₁, 100% pomegranate juice) obtained the highest score (8.28), which was significantly higher than the treatments containing higher levels of ginger (T₆ and T₇).

Treatments containing 1–4% ginger juice (T₂–T₅) showed slightly lower appearance scores, ranging from 7.53 to 7.72, which were not significantly different from each other or from the control, as determined by the Least Significant Difference (LSD) test at the 0.05 level. In contrast, treatments with 5% and 6% ginger juice (T₆ and T₇) received the lowest scores (7.06 and 7.19, respectively), suggesting that higher ginger concentrations may slightly reduce the nectar's visual appeal. Treatment T₈ (7% ginger) had an intermediate score (7.28) that was not significantly different from those of most other treatments.

Statistical analysis confirmed that the treatment type had a significant effect on appearance at the beginning of storage ($P \leq 0.01$), with a coefficient of variation (CV) of 17.75%, indicating moderate variability among replicates. According to the LSD test, means within the same column followed by the same lowercase letter are not significantly different, indicating that the treatments are visually comparable.

These results show that moderate levels of ginger juice (1–3%) can be incorporated into pomegranate nectar without adversely affecting appearance, whereas higher concentrations ($\geq 5\%$) may slightly diminish visual quality (Table 9).

Table 9. Effect of ginger juice concentration on the appearance (9-point) of ginger-flavoured pomegranate nectar

Treatment	Appearance
T ₁ 25 (100 % pomegranate juice)	8.28a
T ₂ 25 (99 % pomegranate juice with 1% ginger juice)	7.69ab
T ₃ 25 (98 % pomegranate juice with 2 % ginger juice)	7.59ab
T ₄ 25 (97 % pomegranate juice with 3% ginger juice)	7.72ab

T5 25 (96 % pomegranate juice with 4% ginger juice)	7.53ab
T6 25 (95 % pomegranate juice with 5% ginger juice)	7.06b
T7 25 (94 % pomegranate juice with 6% ginger juice)	7.19b
T8 25 (93 % pomegranate juice with 7% ginger juice)	7.28ab
F-test	**
LSD _{0.05}	1.02
CV (%)	17.75

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Color

The effect of ginger juice incorporation on the color of pomegranate nectar at the initial storage period (0 days) is presented in Table 2. At the beginning of storage, all treatments exhibited relatively high color scores, reflecting good visual appeal. The control treatment (T₁, 100% pomegranate juice) had the highest color score (8.34), which was significantly higher than those for treatments containing higher concentrations of ginger (T₆ and T₈).

Treatments with 1–4% ginger juice (T₂–T₅) showed slightly lower color scores, ranging from 7.56 to 7.84, which were not significantly different from each other or from the control, as determined by the Least Significant Difference (LSD) test at the 0.05 level. In contrast, treatments containing 5–7% ginger juice (T₆–T₈) obtained the lowest color scores (7.34, 7.53, and 7.31, respectively), suggesting that higher levels of ginger may slightly reduce the visual color quality of the nectar.

Statistical analysis indicated that treatment type had a significant effect on color ($P \leq 0.01$), with a coefficient of variation (CV) of 16%, suggesting moderate variability among replicates. According to the LSD test, means within the same column followed by the same lowercase letter are not significantly different, indicating that the treatments were comparable in color.

The result demonstrates that the incorporation of moderate levels of ginger juice (1–3%) does not adversely affect the color of pomegranate nectar, whereas higher concentrations ($\geq 5\%$) may slightly diminish its visual appeal (Table-10).

Table 10. *Effect of ginger juice concentration on the color (9-point) of ginger-flavored pomegranate nectar*

Treatment	Color
T1 25 (100 % pomegranate juice)	8.34a
T2 25 (99 % pomegranate juice with 1% ginger juice)	7.81ab
T3 25 (98 % pomegranate juice with 2% ginger juice)	7.56ab
T4 25 (97 % pomegranate juice with 3% ginger juice)	7.84ab
T5 25 (96 % pomegranate juice with 4% ginger juice)	7.56ab
T6 25 (95 % pomegranate juice with 5% ginger juice)	7.34b
T7 25 (94 % pomegranate juice with 6% ginger juice)	7.53ab
T8 25 (93 % pomegranate juice with 7% ginger juice)	7.31b

F-test	**
LSD _{0.05}	0.93
CV (%)	16

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Flavor

The effect of ginger juice incorporation on the flavor of pomegranate nectar at the initial storage period (0 days) is presented in Table 3. At the beginning of storage, all treatments received relatively high flavor scores, indicating good sensory acceptance. The control treatment (T₁, 100% pomegranate juice) achieved the highest flavor score (8.22), which was comparable to the treatment containing 1% ginger juice (T₂, 8.03), suggesting that low levels of ginger did not negatively affect flavor.

Treatments containing 2–4% ginger juice (T₃–T₅) showed slightly lower flavor scores, ranging from 7.31 to 7.62, which were not significantly different from each other or from the control, as determined by the Least Significant Difference (LSD) test at the 0.05 level. In contrast, treatments with higher ginger concentrations (5–7%, T₆–T₈) yielded the lowest flavor scores (6.69–7.00), suggesting that excessive ginger may reduce the nectar's sensory appeal.

Statistical analysis revealed that the treatment type had a significant effect on flavor ($P \leq 0.01$), with a coefficient of variation (CV) of 17.91%, reflecting moderate variability among replicates. According to the LSD test, means within the same column followed by the same lowercase letter are not significantly different, highlighting which treatments were comparable in terms of flavor.

The results indicate that incorporating moderate levels of ginger juice (1–3%) into pomegranate nectar maintains acceptable flavor, whereas higher concentrations ($\geq 5\%$) may adversely affect sensory quality (Table-11).

Table 11. Effect of ginger juice concentration on the flavor (9point) of ginger-flavored pomegranate nectar

Treatment	Flavor
T ₁ 25 (100 % pomegranate juice)	8.22a
T ₂ 25 (99 % pomegranate juice with 1 % Ginger juice)	8.03a
T ₃ 25 (98 % pomegranate juice with 2 % Ginger juice)	7.62ab
T ₄ 25 (97 % pomegranate juice with 3% ginger juice)	7.47ab
T ₅ 25 (96 % pomegranate juice with 4% ginger juice)	7.31ab
T ₆ 25 (95 % pomegranate juice with 5% ginger juice)	7.00b
T ₇ 25 (94 % pomegranate juice with 6% ginger juice)	6.91b
T ₈ 25 (93 % pomegranate juice with 7% ginger juice)	6.69b
F-test	**
LSD _{0.05}	1.01
CV (%)	17.91

** $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Table 4 shows how storage period effects pomegranate-ginger nectar flavor. The results show that flavor scores varied significantly over the 90-day storage period. At the beginning of storage (0 days), the nectar received a flavor score of 7.38, which decreased slightly to 6.94 after 30 days, representing the lowest score observed.

Flavor improved at 60 days (7.42) and reached its highest score at 90 days (7.89), suggesting that certain biochemical changes during storage may enhance the nectar's sensory quality over time. Statistical analysis confirmed that the storage period had a major effect on flavor ($P \leq 0.01$), with a coefficient of variation (CV) of 17.91%, indicating moderate variability among replicates. According to the LSD test, means followed by different lowercase letters are significantly different, showing that the flavor at 30 days was more lower than at 0, 60, and 90 days.

These results show that pomegranate-ginger nectar maintains good flavor throughout storage, and prolonged storage up to 90 days may even improve its sensory appeal.

Table 12. Effect of storage period on the flavour (9-point) of ginger-flavoured pomegranate nectar

Storage period (Days)	Flavor
0	7.38bc
30	6.94c
60	7.42b
90	7.89a
F-test	**
LSD _{0.05}	0.46
CV (%)	17.91

** $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Aroma

The effect of ginger juice incorporation on the odor of pomegranate nectar at the initial storage period (0 days) is presented in Table 5. At the beginning of storage, all treatments exhibited relatively high odor scores, showing satisfactory aromatic quality. The control treatment (T₁, 100% pomegranate juice) received the highest score (7.88), which was statistically similar to the treatments containing 1–3% ginger juice (T₂–T₄), suggesting that low to moderate levels of ginger did not adversely affect the nectar's aroma.

Higher ginger concentrations (4–7%, T₅–T₈) progressively reduced odor scores, with T₈ (7% ginger) obtaining the lowest score (6.47), indicating that excessive ginger may negatively impact the aromatic acceptability of the nectar. Statistical analysis confirmed that treatment type had a significant effect on odor ($P \leq 0.01$), with a coefficient of variation (CV) of 19.69%, reflecting moderate variability among replicates. Result from the LSD test, means followed

by different lowercase letters are significantly different, highlighting which treatments were comparable in terms of odor.

These findings suggest that moderate levels of ginger juice (1–3%) can be added to pomegranate nectar without compromising odor quality, whereas higher levels ($\geq 4\%$) may diminish aromatic acceptability (Table-13).

Table 13. Effect of ginger juice concentration on the aroma (9-point) of ginger-flavoured pomegranate nectar

Treatment	Aroma
T1 25 (100 % pomegranate juice)	7.88a
T2 25 (99 % pomegranate juice with 1% ginger juice)	7.66ab
T3 25 (98 % pomegranate juice with 2 % Ginger juice)	7.75a
T4 25 (97 % pomegranate juice with 3% ginger juice)	7.59abc
T5 25 (96 % pomegranate juice with 4% ginger juice)	7.19abcd
T6 25 (95 % pomegranate juice with 5% ginger juice)	6.66bcd
T7 25 (94 % pomegranate juice with 6% ginger juice)	6.56cd
T8 25 (93 % pomegranate juice with 7% ginger juice)	6.47d
F-test	**
LSD _{0.05}	1.08
CV (%)	19.69

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Texture

The influence of storage duration on the texture of pomegranate-ginger nectar is presented in Table 6. The results show that texture scores varied significantly over the four-day storage period. At the beginning of storage (Day 1), the nectar received a texture score of 7.05, which remained relatively low on Day 2 (7.11).

A noticeable improvement in texture was observed on Day 3 (7.45), and the highest score was recorded on Day 4 (7.67), suggesting that short-term storage positively influenced the nectar's mouthfeel and consistency. Statistical analysis confirmed that the storage period had good effect on texture ($P \leq 0.01$), with a coefficient of variation (CV) of 18.89%, reflecting moderate variability among replicates. According to the LSD test, means followed by different lowercase letters are significantly different, showing that texture improved with time over the storage period.

These results suggest that the texture of pomegranate-ginger nectar can improve during short-term storage, enhancing the overall sensory quality (Table-14).

Table 14. Effect of storage period on the texture (9-point) of ginger-flavoured pomegranate nectar

Storage period (Days)	Texture
1	7.05b
2	7.11b

3	7.45ab
4	7.67a
F-test	**
LSD _{0.05}	0.48
CV (%)	18.89

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

The effect of ginger juice incorporation on the texture of pomegranate nectar at the initial storage period is presented in Table 7. At the beginning of storage, all treatments exhibited relatively high texture scores, indicating good mouthfeel and consistency. The control treatment (T₁, 100% pomegranate juice) received the highest score (7.72), which was statistically similar to the treatments containing up to 3% ginger juice (T₂–T₄), suggesting that low to moderate levels of ginger did not adversely affect texture.

Treatments with higher ginger concentrations (4–7%, T₅–T₈) showed a gradual decrease in texture scores, ranging from 7.31 to 6.72, although all treatments remained within an acceptable range. Statistical analysis confirmed that treatment type had a significant effect on texture ($P \leq 0.01$), with a coefficient of variation (CV) of 18.89%, indicating moderate variability among replicates. According to the LSD test, means followed by the same lowercase letter are not significantly different, highlighting that while a slight reduction was observed with increasing ginger content, the differences were not always statistically meaningful.

Overall, these findings suggest that moderate additions of ginger juice (1–3%) maintain the desirable texture of pomegranate nectar, whereas higher concentrations ($\geq 4\%$) may slightly reduce mouthfeel, though it remains acceptable (Table 15).

Table 15. Effect of ginger juice concentration on the texture (9-point) of ginger-flavoured pomegranate nectar

Treatment	Texture
T ₁ 25 (100 % pomegranate juice)	7.72a
T ₂ 25 (99 % pomegranate juice with 1 % ginger juice)	7.69a
T ₃ 25 (98 % pomegranate juice with 2 % ginger juice)	7.66a
T ₄ 25 (97 % pomegranate juice with 3% ginger juice)	7.56a
T ₅ 25 (96 % pomegranate juice with 4% ginger juice)	7.31a
T ₆ 25 (95 % pomegranate juice with 5% ginger juice)	7.03a
T ₇ 25 (94 % pomegranate juice with 6% ginger juice)	6.88a
T ₈ 25 (93 % pomegranate juice with 7% ginger juice)	6.72a
F-test	**
LSD _{0.05}	1.05
CV (%)	18.89

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

Overall Acceptance

The impact of storage duration on the overall acceptance of pomegranate-ginger nectar is presented in Table 8. The results indicate that overall acceptance scores changed significantly over the four-day storage period. At Day 1, the nectar received a score of 7.16, which remained nearly unchanged on Day 2 (7.11) and slightly increased on Day 3 (7.38).

The highest overall acceptance was observed on Day 4 (7.83), suggesting that short-term storage improved the nectar's sensory appeal. Statistical analysis confirmed that the storage period had a significant effect on overall acceptance ($P \leq 0.01$), with a coefficient of variation (CV) of 16.78%, reflecting moderate variability among replicates. According to the LSD test, means followed by different lowercase letters are significantly different, indicating that the overall acceptance on Day 4 was significantly higher than on the earlier days. Overall, these results show that short-term storage can enhance sensory acceptance of pomegranate-ginger nectar, thereby improving its appeal to consumers (Table-16).

Table 16. *Effect of storage period on the overall acceptance (9-point) of ginger-flavoured pomegranate nectar*

Storage period (Days)	Overall Acceptance
1	7.16b
2	7.11b
3	7.38b
4	7.83a
F-test	**
LSD _{0.05}	0.43
CV (%)	16.78

** $: P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

The influence of ginger juice addition on the overall acceptance of pomegranate nectar at the initial storage period is presented in Table 9. The control treatment (T₁, 100% pomegranate juice) received the highest overall acceptance score (8.00), indicating excellent consumer preference. Treatments containing low levels of ginger (1–3%, T₂–T₄) maintained relatively high acceptance scores (7.62–7.91), which were not significantly different from the control according to the Least Significant Difference (LSD) test at the 0.05 level.

In contrast, treatments with higher ginger concentrations (4–7%, T₅–T₈) exhibited progressively lower overall acceptance scores, ranging from 7.34 to 6.44. Treatment T₈ (7% ginger) received the lowest score (6.44), indicating that excessive ginger addition may negatively affect consumer preference. Statistical analysis confirmed that treatment type had a significant effect on overall acceptance ($P \leq 0.01$), with a coefficient of variation (CV) of 16.78%, reflecting moderate variability among replicates. Means followed by the same lowercase letter are not significantly different, indicating that the treatments are comparable in terms of overall acceptability. The results indicate that moderate incorporation of ginger

juice (1–3%) does not compromise overall acceptance of pomegranate nectar, whereas higher levels ($\geq 4\%$) may reduce sensory appeal and consumer preference (Table-17).

Table 17. *Effect of ginger juice concentration on the overall acceptance (9point) of ginger-flavoured pomegranate nectar*

Treatment	Overall Acceptance
T1 25 (100 % pomegranate juice)	8.00a
T2 25 (99 % pomegranate juice with 1% ginger juice)	7.78a
T3 25 (98 % pomegranate juice with 2% ginger juice)	7.91a
T4 25 (97 % pomegranate juice with 3% ginger juice)	7.62ab
T5 25 (96 % pomegranate juice with 4% ginger juice)	7.34abc
T6 25 (95 % pomegranate juice with 5% ginger juice)	7.16abc
T7 25 (94 % pomegranate juice with 6% ginger juice)	6.69bc
T8 25 (93 % pomegranate juice with 7 % Ginger juice)	6.44c
F-test	**
LSD _{0.05}	0.94
CV (%)	16.78

**₁: $P \leq 0.01$; LSD: Least Significant Difference; CV: Coefficient of Variation; According to LSD at the 0.05 level, means within the same column, followed by the same letter, are not significantly different.

DISCUSSION

Total soluble solids (TSS) increased significantly ($P \leq 0.01$) throughout the storage period, indicating the strong influence of both storage duration and ginger juice concentration, as well as their interaction. The gradual increase in TSS during storage is primarily due to the hydrolysis of complex carbohydrates, such as pectin, starch, and other polysaccharides, into simpler soluble sugars, including glucose and fructose (Brizzolara et al., 2020).

In addition, slight moisture loss during storage may further contribute to the concentration of soluble solids. Among the treatments, T2 (1% ginger juice) showed the highest TSS value at 30 days (16.65), suggesting that low levels of ginger may enhance biochemical transformations during early storage. Meanwhile, T3 (2%) demonstrated relatively stable TSS values at later stages (15.30 at 60 days and 15.26 at 90 days), indicating that moderate ginger incorporation contributes to better stability of soluble solids over extended storage. Treatments with higher ginger concentrations (T6–T8) exhibited comparatively smaller fluctuations, with a slight decline observed at prolonged storage (T8 = 14.25), which may be due to interactions between ginger bioactive compounds and sugar metabolism, potentially limiting further hydrolysis. The observed increasing trend in TSS is in close agreement with the findings of Muslim et al. (2026), Thakre et al. (2026), and Sattar et al. (2020) also reported a consistent rise in TSS during storage of fruit-based beverages, highlighting the universality of this phenomenon.

Titrate acidity increased significantly ($P \leq 0.01$) during storage, with both storage duration and ginger concentration exerting a pronounced effect. This increase can be explained by the formation and accumulation of organic acids resulting from the degradation

of ascorbic acid, pectic substances, and other biochemical constituents during storage. Furthermore, ongoing metabolic and oxidative reactions may also contribute to the generation of acidic compounds (Brizzolara et al., 2020). Ginger-treated samples exhibited relatively stable acidity levels compared to the control, which may be attributed to the presence of natural antioxidants and bioactive compounds in ginger that help regulate biochemical reactions and delay excessive acid formation. The increase in titratable acidity during storage is well documented. It aligns with the findings of Thakre et al. (2026) and Sattar et al. (2020), who reported similar behavior in stored fruit juices and nectar formulations.

A highly significant ($P \leq 0.01$) decrease in pH was observed during storage, which is inversely related to the increase in titratable acidity. The reduction in pH is mainly due to the accumulation of organic acids produced through biochemical and enzymatic reactions, including the breakdown of ascorbic acid and pectin Muslim et al., 2026). Among the treatments, T8 recorded the lowest pH (2.98), followed by T2 and T5 (2.96), suggesting that higher ginger concentrations may enhance acidification, possibly due to its inherent acidic nature and bioactive compounds. The gradual decline in pH observed in this study is consistent with previous reports by Muslim et al., (2026), Thakre et al. (2026), Sattar et al. (2020), and Sherzad et al. (2017), who also documented a decrease in pH during storage of fruit-based beverages as a result of organic acid formation. Reducing sugar content increased significantly ($P \leq 0.01$) during storage, with a notable interaction between storage duration and ginger concentration. This increase is primarily due to the hydrolysis of non-reducing sugars, such as sucrose, into reducing sugars, such as glucose and fructose (Iturralde-García et al., 2022). At 30 and 60 days, a marked increase in reducing sugars was observed across all treatments, with T5 (4%) reaching the highest value at 60 days (14.74), indicating enhanced sugar conversion under moderate ginger concentrations. However, at 90 days, a decline in reducing sugar content was observed, which may be attributed to their involvement in non-enzymatic browning reactions (Maillard reactions) or possible degradation under prolonged storage conditions (Iturralde-García et al., 2022). This pattern of initial increase followed by a decrease is consistent with the findings of Thakre et al. (2026), Deen et al. (2014), Selvi et al. (2018), and Harendra et al. (2021), who reported similar trends in stored fruit beverages. Non-reducing sugars decreased significantly ($P \leq 0.01$) during storage, primarily due to their conversion into reducing sugars through hydrolytic reactions. The values remained relatively stable during the initial storage period (0–30 days), indicating limited biochemical transformation at early stages. However, a sharp decline was observed at 60 days, suggesting accelerated hydrolysis of sucrose and other non-reducing sugars into simpler forms. A slight increase at 90 days may be due to equilibrium adjustments or analytical variability, although the values remained considerably lower than the initial levels. These findings are in line with those reported by Thakre et al. (2026), Harendra and Bhagwan Deen (2021), and Deen Bhagwan and Kumar (2014), who also observed a time-dependent reduction in non-reducing sugars during storage. Total sugar content increased significantly during the initial phase of storage, reaching peak levels at 30 days, followed by a gradual decline at later stages. The

initial increase is attributed to the breakdown of polysaccharides and the conversion of non-reducing sugars into reducing sugars, which collectively contribute to higher total sugar levels (Deen Bhagwan and Kumar, 2014). The subsequent decline during prolonged storage may be due to sugar degradation, participation in Maillard browning reactions, and other biochemical processes. Among the treatments, T₂ recorded the highest total sugar content at 30 days (16.55), while values decreased across all treatments by 90 days. Similar trends have been reported by Thakre et al. (2026), Hariharan and Mahendran (2016), and Deen Bhagwan and Kumar (2014), supporting the observed pattern of sugar dynamics during storage.

Appearance scores were highest at the initial stage of storage and declined gradually with increasing ginger concentration. The control treatment (T₁) recorded the highest score (8.28), indicating superior visual quality in the absence of ginger. Treatments containing moderate levels of ginger (1–4%) exhibited slightly lower but statistically comparable scores, suggesting that limited ginger incorporation does not significantly affect visual appeal. However, higher concentrations (T₆–T₈) resulted in reduced appearance scores, possibly due to increased turbidity, sedimentation, or color darkening caused by ginger constituents. Similar observations have been reported by Muslim et al. (2026), Thakre et al. (2026), Selvi et al. (2018), Hayat et al. (2019), and Rajpoot et al. (2025). Color scores decreased with increasing ginger concentration, with the control sample showing the highest value. The reduction in color quality at higher ginger levels may be attributed to pigment dilution, oxidation of phenolic compounds, and non-enzymatic browning reactions during storage. Despite this, moderate ginger levels maintained acceptable color characteristics, indicating their suitability for product formulation. These findings are consistent with the reports of Thakre et al. (2026) and Raupsha et al. (2025). Flavor was significantly affected ($P \leq 0.01$) by ginger concentration, with higher levels resulting in lower sensory scores due to the strong, pungent, and slightly bitter taste imparted by ginger. Moderate concentrations (1–3%) maintained a balanced, acceptable flavor profile, suggesting that optimal levels of ginger can enhance the nectar's functional properties without compromising sensory quality. Similar trends have been reported by Thakre et al. (2026), Mishra and Sangma (2017), Selvi et al. (2018), and Hayat et al. (2019). Aroma scores declined with increasing ginger concentration, as higher levels introduced a dominant odor that masked the natural fruity aroma of pomegranate nectar. Lower concentrations (1–3%) maintained a more pleasant, balanced aroma, indicating their suitability for consumer acceptance. These results are in agreement with those reported by Muslim et al., (2026), Raupsha et al. (2025), and Rajpoot et al. (2025). Texture improved significantly during short-term storage, likely due to enhanced homogenization and interactions among juice components. The gradual increase in texture scores, with the highest value recorded on Day 4 (7.67), suggests enhanced mouthfeel and consistency as storage progressed. Overall acceptability increased during short-term storage, reaching its peak at Day 4 (7.83), reflecting the combined effects of improved texture, balanced flavor, and acceptable aroma. However, higher ginger concentrations negatively

affected overall acceptability by affecting sensory attributes. Moderate levels of ginger (1–3%) were found to be optimal for maintaining overall product quality. These findings are consistent with previous studies by Thakre et al. (2026), Raupsha et al. (2025), Patel et al. (2025), Selvi et al. (2018), and Hayat et al. (2019).

CONCLUSION

The study confirms that adding ginger extract to pomegranate nectar improves its quality, stability, and sensory properties. Moderate levels (1–3%) were optimal, maintaining better chemical balance and higher consumer acceptability, while higher concentrations offered no added benefit. The product remained microbiologically safe over three months, demonstrating effective preservation. The ginger-flavored pomegranate nectar is a promising value-added beverage with strong potential for commercial production, especially in pomegranate-producing regions.

Authors Contributions

- Sadiquallah Shaoon conceptualized the study, conducted the field research, collected the raw data, and drafted the manuscript.
- Hamid Salari contributed to the study methodology, analyzed the data, and supervised the research.
- All authors reviewed and approved the final manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding authors upon reasonable request.

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