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Development of Functional Apple Nectar Enriched with Ginger Extract

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ABSTRACT

Consumer demand for functional fruit beverages with improved sensory quality and health benefits is increasing; however, limited research has focused on standardizing ginger-flavored apple nectar under local processing and storage conditions in Afghanistan. Therefore, this study aimed to develop and evaluate ginger-flavored apple nectar and determine the optimum level of ginger extract for physicochemical stability and consumer acceptability during storage. The experiment was conducted in 2025 at the Horticulture Department Laboratory of the Faculty of Agriculture, Kabul University. Apple juice was blended with ginger extract at different concentrations (0–7%) to prepare eight nectar treatments according to Codex standards. The products were pasteurized, bottled, and stored under ambient conditions for 90 days. Physicochemical characteristics and sensory attributes were evaluated at monthly intervals using a factorial completely randomized design with three replications. The experiment was arranged in a factorial completely randomized design (CRD) with three replications, and data were analyzed using STAR software. Results revealed that both ginger concentration and storage period significantly affected the nectar's quality attributes. Moderate incorporation of ginger improved sensory and functional properties, while higher concentrations negatively influenced acceptability. Among all treatments, nectar containing 2% ginger extract exhibited the best overall performance in terms of physicochemical stability and sensory attributes throughout storage. The study concludes that ginger-flavored apple nectar standardized with 2% ginger extract has good storage stability, enhanced quality characteristics, and high consumer acceptability, making it a promising functional beverage with potential for commercial production.

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INTRODUCTION

Apple (*Malus domestica* Borkh.) is a well-known fruit known for its importance to human health. It contains vitamins, minerals, fiber, and phenolic compounds. These nutrients help the body and act as antioxidants, which are beneficial for overall health (Arnold & Gramza-Michalowska, 2024; Asma et al., 2023). Apples are widely used in drinks for their natural sweetness, good taste, and consumer popularity. In addition, apples and their processing by-products contain bioactive compounds, making them suitable for producing functional food products (Asma et al., 2023; Küçükgöz et al., 2025; Szabo et al., 2022; Vandorou et al., 2024).

Ginger (*Zingiber officinale*) On the other hand, ginger is a well-known herb whose rhizome has been used in cooking and medicine since ancient times. Its health benefits come from compounds such as gingerols, shogaols, and other phenolic compounds. These compounds have strong antioxidant, anti-inflammatory, antimicrobial, and anti-cancer effects (Shaukat et al., 2023; Bekkouch et al., 2023; Pali et al., 2020). These properties have increased interest in using ginger in functional foods and health-related drinks. In addition, as people become more aware and prefer natural antioxidants and clean-label products, ginger is now used in many foods, including beverages, dairy, bakery, and meat products (Shaukat et al., 2023; Ayustaningwarno et al., 2024).

In recent years, functional beverages have become more popular because they help increase the intake of beneficial compounds and support overall health. Among them, fruit nectars are widely consumed. They are usually semi-liquid products made by mixing fruit pulp or juice with water and sweeteners, and sometimes adding functional ingredients (Verma et al., 2025). Adding herbs and spices, such as ginger, to fruit-based drinks can enhance their taste and aroma, as well as their nutritional value and shelf life. This is mainly because the bioactive compounds in these ingredients interact synergistically (Okwunodulu et al., 2023; Hussein et al., 2017).

Several studies have shown that adding ginger to fruit drinks has positive effects. For instance, adding ginger extract to apple-based beverages can increase antioxidant activity, total phenolic content, and vitamin C. It can also improve texture (rheological properties) and overall sensory quality (Hassanzadeh et al., 2023; Shaukat et al., 2023). Likewise, drinks made by combining ginger with fruits like apple and pineapple have shown higher levels of phenolic and flavonoid compounds. They also have better oxidation resistance and are generally acceptable in terms of taste, aroma, and overall sensory quality (Ademosun et al., 2025; Ogori et al., 2021). In addition, ginger is known for its natural ability to inhibit microbial growth. This helps reduce the number of microorganisms in juice products and can also increase their shelf life (Ayustaningwarno et al., 2024; Harun & Mohamad, 2023; Olaniran et al., 2020). Apart from improving taste, adding ginger to drinks also increases their health benefits. Ginger-based products are known to have strong antioxidant activity and numerous bioactive compounds. These compounds help reduce oxidative stress in the body and support overall human health (Majeed & Addai, 2025; Okwunodulu et al., 2023; Ishfaq et al., 2022; Shaukat et al., 2023).

The quality and consumer acceptance of functional drinks depend greatly on how the ingredients are mixed and optimized in the formulation. Earlier studies show that ingredient ratios strongly affect important physicochemical properties, such as pH, total soluble solids, acidity, and viscosity. It also influences sensory qualities like taste, smell, and overall acceptability (Mahanandia et al., 2022; Alemayehu et al., 2025; Gupta et al., 2023). In addition, proper blending can reduce drawbacks such as the strong, pungent taste of ginger or the astringent taste of certain fruits. As a result, the overall taste and acceptability of the product are improved (Beer et al., 2024; Rathinasamy et al., 2022; Giri et al., 2025; Maulida et al., 2024; Skąpska et al., 2020).

Furthermore, using natural ingredients like ginger aligns with the current trend in the food industry of replacing synthetic additives with safer, plant-based alternatives. Although apple and ginger have been widely studied separately, there is still limited research on the standard formulation of ginger-flavored apple nectar. Finding the right balance between taste, nutrition, and storage stability requires careful adjustment of ingredient ratios and processing methods. Therefore, standardization is important to ensure consistent quality, product stability, and consumer acceptance, especially for large-scale production. Based on this, the present study aims to develop a standardized formulation of ginger-flavored apple nectar by optimizing ingredient levels and assessing its physicochemical, sensory, and nutritional properties. The results are expected to support the development of a functional beverage with improved health benefits, a longer shelf life, and strong consumer acceptance, meeting the increasing demand for innovative, value-added food products.

The present study was designed to address the following research questions:

- How do different concentrations of ginger extract affect the chemical and sensory quality of apple nectar during storage?
- What level of ginger extract provides the best balance between physicochemical stability and overall consumer acceptability?

METHODS AND MATERIALS

The study was carried out in 2025 at the Horticulture Department Laboratory, Faculty of Agriculture, Kabul University, Kabul, Afghanistan. The materials used included fresh apple fruits, fresh ginger, sugar, citric acid, sodium benzoate, water, and 250 mL glass bottles. All materials were purchased from the local market.

Nectar Preparation

For juice preparation, apple fruits were first washed properly with clean water, then cut into small pieces using a stainless-steel knife. The seeds and core were removed. After that, the juice was extracted using a juicer, blended well, and filtered through muslin cloth. In the same way, fresh ginger was washed, peeled, and cut into small pieces. It was then crushed in a mixer until smooth and filtered through muslin cloth to obtain ginger juice. For nectar preparation, apple juice and ginger juice were mixed in eight different ratios, as shown in Table 1 below.

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

Treatment	Juice (%)	TSS (°B)	Titratable Acidity (%)
T1	50(100% Pure apple Juice)	14	0.3
T2	50 (99 % apple Juice + 1 % ginger extract)	14	0.3
T3	50 (98 % apple Juice + 2 % ginger extract)	14	0.3
T4	50 (97 % apple Juice + 3 % ginger extract)	14	0.3

T5	50 (96 % apple Juice + 4 % ginger extract)	14	0.3
T6	50 (95 % apple Juice + 5 % ginger extract)	14	0.3
T7	50 (94 % apple Juice + 6 % ginger extract)	14	0.3
T8	50 (93 % apple Juice + 7 % ginger extract)		

According to Table 1, the treatments were prepared by mixing specific proportions of apple and ginger juices. The total soluble solids (TSS) of each sample were adjusted to 14°Brix by adding sugar syrup prepared in warm water, while acidity was set to 0.3% using citric acid. Sodium benzoate (120 ppm) was also added as a preservative. The final nectar was filled into 250 mL glass bottles, sealed, pasteurized in near-boiling water for 25 minutes, and then stored at room temperature. According to Codex standards, the nectar contained 50% fruit juice and 50% sugar syrup.

Parameters Assessment

The samples were analyzed monthly for 3 months to measure pH, TSS, reducing sugars, non-reducing sugars, total sugars, and titratable acidity. TSS was measured with a hand refractometer, and pH was determined with a digital pH meter under controlled temperature conditions. Reducing sugars were measured by diluting 25 mL of nectar with 100 mL distilled water, neutralizing with 1 N NaOH using phenolphthalein as an indicator, adding lead acetate and potassium oxalate solutions, making up the volume to 250 mL, filtering, and then titrating 10 mL of the filtrate with Fehling's solution. Non-reducing sugars were calculated using the formula:

Non-reducing sugars (%) = Total sugars (%) – Reducing sugars (%)

Total sugars were determined by hydrolyzing 100 mL of filtrate with citric acid overnight, neutralizing the filtrate with sodium hydroxide, adjusting the volume to 250 mL, and titrating 10 mL of the filtrate with Fehling's solution. Titratable acidity was measured by diluting the nectar, titrating it with 0.1 N sodium hydroxide using phenolphthalein as an indicator, and expressing the results as % citric acid. The samples were also checked monthly for any mold growth.

Sensory evaluation was carried out by a panel of 10 trained individuals who assessed appearance, color, flavor, taste, aroma, texture, and overall acceptability using a 9-point Hedonic scale (1 = dislike extremely, 9 = like extremely).

Data Analysis

The experiment was designed as a Factorial Completely Randomized Design (CRD) with three replicates. Data were analyzed using the Statistical Tool for Agricultural Research (STAR) software, and treatment means were compared using Least Significant Difference (LSD) at 5% or 1% significance.

FINDINGS

The findings of this study were systematically presented in well-structured tables, with primary emphasis placed on the chemical and sensory characteristics of the nectar. This presentation enabled a clear evaluation and comparison of the measured quality attributes across the different treatments.

Chemical Parameters

The Chemical Parameters section was included to study the changes in the chemical composition and quality of ginger-flavored apple nectar during storage. Parameters such as TSS, Acidity, Reducing Sugar, Non-Reducing Sugar, Total Sugar, and pH were analyzed because they are important indicators of sweetness, taste, stability, and overall beverage quality. The analysis also helped to understand the effect of different levels of ginger extract on the physicochemical properties of the nectar over the storage period.

Total Soluble Solids (TSS)

Statistical analysis showed that storage time (A), treatment (B), and their interaction (A × B) had a highly significant effect ($p \leq 0.01$) on nectar TSS Table 2. This means that both ginger level and storage duration affected the juice's soluble solids content.

At the initial stage, all treatments had the same TSS value (14.00), indicating no differences at this stage. After 30 days of storage, TSS increased in most treatments. The highest value was recorded in T2 (16.93), followed by T3 (16.16) and T4 (15.03), while treatments with higher ginger levels (T7 and T8) showed a slight decrease (13.93–13.60). At 60 days, TSS values showed small changes. T2 still had the highest value (16.16), whereas T7 and T8 decreased further to 13.26 and 13.16. By 90 days, T2 (16.10) and T1 (15.50) maintained relatively higher TSS, while T7 (13.13) and T8 (13.10) recorded the lowest values, showing that higher ginger concentrations tended to reduce soluble solids during longer storage.

The LSD (0.01) values for storage period and treatment were 0.45 and 0.70, confirming that differences among means were statistically significant. The coefficient of variation (CV%) was 1.92, indicating very low experimental variation.

Table. 2. *Effect of Different treatments and Storage duration on the TSS of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	14.00^{a}_{B}	15.50^{b}_{A}	14.43^{bc}_{B}	15.50^{ab}_{A}
T2	14.00^{a}_{C}	16.93^{a}_{A}	16.17^{a}_{B}	16.10^{a}_{B}
T3	14.00^{a}_{B}	15.00^{b}_{A}	14.33^{c}_{B}	14.23^{c}_{B}
T4	14.00^{a}_{B}	15.00^{b}_{A}	15.03^{b}_{A}	15.00^{b}_{A}
T5	14.00^{a}_{B}	15.00^{b}_{AB}	14.60^{bc}_{A}	14.13^{c}_{B}
T6	14.00^{a}_{B}	14.93^{b}_{A}	14.23^{c}_{B}	14.03^{c}_{B}
T7	14.00^{a}_{A}	13.93^{c}_{A}	13.27^{d}_{B}	13.13^{d}_{B}
T8	14.00^{a}_{A}	13.60^{c}_{AB}	13.17^{d}_{B}	13.10^{d}_{B}
Factors	**F-test**	**LSD (0.01)**	**CV (%)**	
Storage period (A)	**	-		
Treatment (B)	**	-	1.92	
Interaction (A×B)	**	0.60		

: P≤0.01; **LSD: Least Significant Difference; **CV**: Coefficient of Variation; **According to LSD**, 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.

Titratable Acidity

Statistical analysis showed that treatment, storage period, and their interaction had a significant effect ($p \leq 0.05$) on acidity (Table 3). The study revealed that the greatest changes in titratable acidity occurred in Treatments 8, 3, and 5. In these treatments, acidity increased from an initial value of 0.30% to 0.497%, 0.390%, and 0.390%, respectively. In contrast, the smallest changes were recorded in Treatments 7 and 4, where acidity changed from 0.30% to 0.270% and 0.330%, respectively. These findings indicate that the response of acidity varied considerably among treatments during the storage period.

The LSD (0.05) value for interaction was 0.084, confirming that the differences among treatments were statistically significant. The coefficient of variation (CV%) was 16.49, indicating acceptable variation in the experimental data.

Table 3. *Effect of Different treatments and storage periods on the Titratable Acidity of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	0.300^{a} A	0.300^{a} A	0.300^{b} A	0.330^{bcd} A
T2	0.300^{a} AB	0.287^{a} AB	0.260^{b} B	0.347^{bc} B
T3	0.300^{a} B	0.330^{a} AB	0.270^{b} B	0.390^{b} A
T4	0.300^{a} AB	0.300^{a} AB	0.240^{b} B	0.330^{bcd} A
T5	0.300^{a} B	0.360^{a} AB	0.390^{a} A	0.390^{b} A
T6	0.300^{a} A	0.287^{a} A	0.260^{b} A	0.257^{d} A
T7	0.300^{a} A	0.300^{a} A	0.300^{b} A	0.270^{cd} A
T8	0.300^{a} BC	0.360^{a} B	0.270^{b} C	0.497^{a} A
Factors	**F-test**	**LSD (0.05)**	**CV (%)**	
Storage period (A)	**	-		
Treatment (B)	**	-	16.49	
Interaction (A×B)	*	0.084		

pH

Statistical analysis showed that storage period had a highly significant effect ($p \leq 0.01$) on pH, indicating that storage time affected the pH of the juice (Table 4). At the initial stage, the pH was 3.33. It decreased after 30 days to 3.10, then remained almost stable at 60 days (3.08) and slightly increased at 90 days (3.12). Overall, this pattern suggests small changes in acidity during storage.

The LSD (0.01) value for storage period was 0.10, confirming significant differences among the means. The coefficient of variation (CV%) was 5.32, indicating acceptable variability in the data.

Table 4. *Effect of Storage Duration and Treatments on the pH of Nectar*

Treatment	Storage period (Days)				
	Initial	**30**	**60**	**90**	**Mean of Treatments**
T1	3.2	2.83	3.04	2.98	**3.01**
T2	3.4	3.22	3.05	3.07	**3.19**
T3	3.16	3.12	3.05	3.09	**3.11**
T4	3.5	3.03	3.13	3.14	**3.20**
T5	3.3	3.14	3.19	3.15	**3.20**
T6	3.65	3.14	2.92	3.17	**3.22**
T7	3.35	3.17	3.2	3.18	**3.23**
T8	3.07	3.16	3.09	3.21	**3.13**
Mean of Storage period	**3.33** $_{A}$	**3.10** $_{B}$	**3.08** $_{B}$	**3.12** $_{B}$	

Factors	F-test	LSD (0.01)	CV (%)
Storage period (A)	Ns	-	
Treatment (B)	**	0.136	5.32
Interaction (A×B)	Ns	-	

Reducing Sugar

Statistical analysis showed that treatment, storage period, and their interaction had a highly significant effect ($p \leq 0.01$) on reducing sugars (Table 5). The results indicated that the greatest changes were observed in Treatments 6 and 7, where the measured values increased from 6.53 and 6.67 to 11.07 and 10.58, respectively. In contrast, the smallest changes were recorded in Treatments 2 and 1, with values changing from 8.33 to 8.88 and 8.81, respectively. These findings suggest that Treatments 6 and 7 exhibited a substantially greater response compared with the other treatments throughout the storage period.

The LSD (0.01) value for treatments was 2.06, confirming significant differences among the means. The coefficient of variation (CV%) was 11.37, indicating acceptable variability in the experimental data.

Table 5. *Effect of Different Treatments and Storage Duration on Reducing Sugar of Nectar (%)*

Treatment	Storage period (Days)			
	Initial	**30**	**60**	**90**
T1	8.33^{a}_{A}	9.26^{a}_{A}	9.83^{a}_{A}	8.88^{bc}_{A}
T2	8.33^{a}_{A}	8.86^{ab}_{A}	9.90^{a}_{A}	8.81^{bc}_{A}
T3	6.69^{ab}_{B}	6.84^{bc}_{B}	9.83^{a}_{A}	7.78^{c}_{AB}
T4	6.70^{ab}_{B}	6.55^{c}_{B}	10.42^{a}_{A}	10.20^{ab}_{A}
T5	6.50^{ab}_{B}	7.29^{abc}_{B}	10.04^{a}_{A}	8.53^{bc}_{AB}
T6	6.53^{ab}_{B}	5.32^{c}_{B}	9.69^{a}_{A}	11.07^{a}_{A}
T7	6.67^{ab}_{B}	7.31^{abc}_{B}	9.81^{a}_{A}	10.58^{ab}_{A}
T8	5.16^{b}_{B}	6.91^{bc}_{B}	9.13^{a}_{A}	10.12^{ab}_{A}

Factors	F-test	LSD (0.01)	CV (%)
Storage period (A)	**	-	
Treatment (B)	**	-	11.38
Interaction (A×B)	**	2.06	

Non-Reducing Sugar

Statistical analysis showed that treatment and storage period had a highly significant effect ($p \le 0.01$) on non-reducing sugars (Table 6). The results revealed that the greatest changes in non-reducing sugar content were observed in Treatments 4 and 6, where the values declined from 5.86 and 5.69 to 1.74 and 1.93, respectively. In contrast, the smallest changes were recorded in Treatments 5 and 3, with values changing from 2.82 and 4.73 to 3.03 and 2.86, respectively. Overall, a decreasing trend in non-reducing sugar content was observed throughout the storage period, indicating progressive utilization or conversion of these sugars.

The LSD (0.01) value for treatments was 1.06 and for storage period was 0.75, confirming significant differences among the means. The coefficient of variation (CV%) was 37.93, indicating relatively higher variability in the experimental data.

Table 6. *Effect of Different Treatments on the Non-Reducing Sugar Content of Nectar (%)*

Treatment	Storage period (Days)				
	Initial	30	60	90	Mean of Treatments
T1	3.96	2.09	2.06	1.61	**2.43^{c}**
T2	3.85	3.43	1.99	1.87	**2.78^{bc}**
T3	4.73	4.49	2.06	2.86	**3.54^{ab}**
T4	5.86	4.43	1.47	1.74	**3.38^{abc}**
T5	2.82	2.93	2.10	3.03	**2.72^{bc}**
T6	5.69	4.57	1.49	1.93	**3.42^{abc}**
T7	3.79	3.56	1.62	1.77	**2.68^{bc}**
T8	5.93	5.31	2.17	2.12	**3.88^{a}**
Mean of Storage period	**4.58** A	**3.85** A	**1.87** B	**2.12** B	

Factors	F-test	LSD (0.01)	CV (%)
Storage period (A)	**	0.75	
Treatment (B)	**	1.06	31.43
Interaction (A×B)	Ns	-	

Total Sugars

The results indicated that both storage duration and ginger concentration had a significant effect on the total sugar content of apple nectar. Moreover, a significant interaction between these two factors was observed (Table 7). The findings further demonstrated that the greatest changes in total sugar content were recorded in Treatments 5 and 7, where the values increased from 9.32 and 10.46 to 11.56 and 12.35, respectively. In contrast, the smallest changes were observed in Treatments 4 and 3, with values changing from 12.56 and 11.42 to 11.94 and 11.39, respectively. Overall, total sugar content tended to increase in most treatments during storage, although the magnitude of change varied among treatments.

The LSD (0.01) values for interaction were 2.13, 1.60, and 2.51, confirming significant differences in storage means and interaction effects. The coefficient of variation (CV%) was 8.50, indicating acceptable variability in the experiment.

Table 7. *Effect of Different Treatments and Storage Duration on the Total Sugar Content of Nectar (%)*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	$12.29^{a}{}_{A}$	$11.35^{ab}{}_{A}$	$11.89^{a}{}_{A}$	$10.53^{c}{}_{A}$
T2	$12.18^{a}{}_{AB}$	$12.29^{a}{}_{AB}$	$11.89^{a}{}_{B}$	$14.06^{a}{}_{A}$
T3	$11.42^{ab}{}_{A}$	$11.34^{ab}{}_{A}$	$11.89^{a}{}_{A}$	$11.39^{bc}{}_{A}$
T4	$12.56^{a}{}_{A}$	$10.98^{ab}{}_{A}$	$11.89^{a}{}_{A}$	$11.94^{abc}{}_{A}$
T5	$9.32^{b}{}_{B}$	$10.22^{ab}{}_{AB}$	$12.14^{a}{}_{A}$	$11.56^{bc}{}_{A}$
T6	$12.21^{a}{}_{A}$	$9.89^{b}{}_{B}$	$11.18^{a}{}_{AB}$	$13.00^{ab}{}_{A}$
T7	$10.46^{ab}{}_{A}$	$10.87^{ab}{}_{A}$	$11.43^{a}{}_{A}$	$12.35^{abc}{}_{A}$
T8	$11.08^{ab}{}_{A}$	$12.23^{a}{}_{A}$	$10.43^{a}{}_{A}$	$12.24^{abc}{}_{A}$
Factors	**F-test**	**LSD (0.01)**	**CV (%)**	
Storage period (A)	**	-		
Treatment (B)	**	-	8.50	
Interaction (A×B)	**	2.13		

Sensory Evaluation

In this section, data related to sensory attributes, including appearance, color, aroma, flavor, texture, and overall acceptability, are presented in the appropriate tables.

Appearance

The results showed that treatment type, storage time, and their interaction had a significant effect on the appearance of apple juice (Table 8). The results indicated that, on average across the storage period, Treatments 3 and 2 had the highest appearance scores, with mean values of 8.25 and 8.15, respectively. In contrast, Treatment 8 received the lowest appearance score, with a mean value of 6.84.

The LSD (0.0١) values for storage period and treatments were 1.09 and 1.69, confirming significant differences among means. The CV% was 14.63, indicating acceptable data variability.

Table 8. *Effect of Different Treatments and Storage Duration on the Appearance of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	$7.37^{ab}{}_{BC}$	$8.37^{a}{}_{AB}$	$7.00^{a}{}_{C}$	$8.87^{a}{}_{A}$
T2	$7.75^{a}{}_{A}$	$8.37^{a}{}_{A}$	$7.87^{a}{}_{A}$	$8.62^{a}{}_{A}$
T3	$8.12^{a}{}_{AB}$	$8.75^{a}{}_{A}$	$7.50^{a}{}_{B}$	$8.62^{a}{}_{A}$
T4	$7.50^{ab}{}_{BC}$	$8.62^{a}{}_{A}$	$6.87^{a}{}_{C}$	$8.37^{a}{}_{AB}$
T5	$6.75^{ab}{}_{CB}$	$8.12^{ab}{}_{A}$	$7.62^{a}{}_{AB}$	$8.25^{a}{}_{A}$
T6	$5.87^{bc}{}_{C}$	$7.37^{ab}{}_{AB}$	$6.62^{a}{}_{BC}$	$8.37^{a}{}_{A}$
T7	$5.50^{c}{}_{C}$	$6.62^{b}{}_{B}$	$6.75^{a}{}_{B}$	$8.62^{a}{}_{A}$
T8	$5.12^{c}{}_{C}$	$6.62^{b}{}_{B}$	$7.25^{a}{}_{B}$	$8.37^{a}{}_{A}$
Factors	**F-test**	**LSD (0.05)**	**CV (%)**	
Storage period (A)	*	-	14.63	
Treatment (B)	*	-		

Interaction (A×B)	*	1.09	

Color

The results showed that storage duration and ginger concentration had a significant effect on the nectar's color. Furthermore, a significant interaction between these two factors was observed (Table 9). The findings also indicated that, on average during the storage period, Treatment 3 and Treatment 2 obtained the highest color scores, with mean values of 8.15 and 8.12, respectively. In contrast, Treatment 8 received the lowest color score, with a mean value of 6.84.

The LSD (0.05) value for the interaction was 1.02, confirming significant differences among the means. The CV% was 13.57, indicating good precision and reliability of the results.

***Table9.** Effect of Different Treatments and Storage Duration on the Color of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	7.50^{ab}_{B}	8.25^{ab}_{AB}	7.62^{a}_{AB}	8.62^{a}_{A}
T2	7.87^{a}_{AB}	8.25^{ab}_{AB}	7.50^{a}_{B}	8.87^{a}_{A}
T3	8.12^{a}_{AB}	8.75^{a}_{A}	7.12^{a}_{B}	8.62^{a}_{A}
T4	7.62^{ab}_{AB}	8.37^{ab}_{A}	7.12^{a}_{B}	8.62^{a}_{A}
T5	7.12^{abc}_{A}	8.12^{ab}_{A}	7.37^{a}_{A}	8.00^{a}_{A}
T6	6.12^{bcdC}	7.50^{ab}_{AB}	7.25^{a}_{B}	8.37^{a}_{A}
T7	5.87^{cd}_{C}	7.25^{ab}_{B}	6.62^{a}_{BC}	8.37^{a}_{A}
T8	5.12^{d}_{C}	6.87^{b}_{B}	7.12^{a}_{A}	8.25^{a}_{A}
Factors	**F-test**	**LSD (0.05)**	**CV (%)**	
Storage period (A)	*	-		
Treatment (B)	*	-	13.57	
Interaction (A×B)	*	1.02		

Flavor

The results showed that storage duration and ginger concentration had a significant effect on the nectar's flavor. However, no significant interaction between these two factors was observed (Table 10). On average throughout the storage period, Treatment 3 and Treatment 2 received the highest flavor scores, with mean values of 7.97 and 7.66, respectively. In contrast, Treatment 8 obtained the lowest flavor score, with a mean value of 5.84. The LSD (0.05) value for treatments was 0.88 and for storage periods was 0.40, confirming significant differences among treatments. The coefficient of variation (CV%) was 16.83, indicating acceptable variability in the data.

***Table 10.** Effect of Different Treatments and Storage Periods on the Flavor of Nectar*

Treatment	Storage period (Days)				
	Initial	30	60	90	Mean of Treatments
T1	7.25	7.75	7.00	7.25	**7.31^{ab}**
T2	7.75	7.75	7.38	7.75	**7.66^{a}**
T3	7.75	8.25	7.63	8.25	**7.97^{a}**
T4	7.13	7.88	7.25	6.50	**7.19^{abc}**
T5	6.63	7.63	6.38	5.75	**6.59^{bcd}**
T6	6.00	6.88	6.63	5.88	**6.34^{cd}**

T7	5.38	6.13	6.00	6.13	**5.9[1d]**
T8	4.75	6.38	6.25	6.00	**5.84[d]**
Mean of Storage period	**6.58B**	**7.33A**	**6.8B**	**6.69B**	
Factors		**F-test**		**LSD (0.05)**	**CV (%)**
Storage period (A)		*		0.40	
Treatment (B)		*		0.88	16.83
Interaction (A×B)		Ns		-	

Aroma

The results showed that varying concentrations of ginger significantly affected the aroma of the nectar. However, no significant interaction was observed between the studied factors (Table 11). On average across the storage period, Treatments 3 and 2 had the highest aroma scores, with mean values of 7.78 and 7.38, respectively. In contrast, Treatment 8 obtained the lowest aroma score, with a mean value of 5.59.

The LSD (0.05) value for treatments was 0.57, confirming significant differences among the means. The coefficient of variation (CV%) was 17.8, indicating acceptable experimental variability.

Table. 11. *Effect of Different Treatments on the Aroma of Ginger-Flavored Apple Nectar*

Treatment	**Storage period (Days)**				
	Initial	**30**	**60**	**90**	**Mean of Treatments**
T1	7.00	7.25	7.00	6.88	**7.03ab**
T2	7.30	8.13	7.25	8.00	**7.38a**
T3	7.75	7.50	7.50	6.88	**7.78a**
T4	7.12	7.50	6.00	5.75	**7.25ab**
T5	6.62	5.63	5.50	5.63	**6.47bc**
T6	5.37	5.63	5.75	5.88	**5.53d**
T7	4.75	5.63	6.13	6.00	**5.50d**
T8	7.00	7.25	7.00	6.88	**5.59cd**
Factors		**F-test**		**LSD (0.05)**	**CV (%)**
Storage period (A)		Ns		-	
Treatment (B)		*		0.57	17.80
Interaction (A×B)		Ns		-	

Texture

The results showed that storage duration and ginger concentration had a significant effect on the nectar's texture. Furthermore, a significant interaction between these two factors was observed (Table 12). On average throughout the storage period, Treatment 3 and Treatment 2 received the highest texture scores, with mean values of 7.87 and 7.87, respectively. In contrast, Treatment 8 obtained the lowest texture score, with a mean value of 5.75.

The LSD (0.05) value for the interaction was 1.01, confirming significant differences among the means. The CV% was 14.98, indicating good precision and reliability of the results.

Table. 12. *Effect of Different Treatments and Storage Duration on the Texture of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	7.62^{ab}_{AB}	8.12^{ab}_{A}	6.87^{ab}_{B}	7.75^{a}_{AB}
T2	7.75^{a}_{A}	8.25^{ab}_{A}	7.50^{ab}_{A}	7.87^{a}_{A}
T3	7.62^{ab}_{AB}	8.62^{a}_{A}	7.25^{ab}_{B}	7.87^{a}_{AB}
T4	7.25^{ab}_{A}	8.12^{ab}_{A}	7.75^{a}_{AB}	7.12^{ab}_{A}
T5	6.12^{bc}_{B}	7.62^{abc}_{A}	6.75^{ab}_{AB}	6.37^{ab}_{B}
T6	5.37^{cd}_{B}	6.75^{bcd}_{A}	6.00^{b}_{AB}	6.37^{ab}_{AB}
T7	4.50^{d}_{B}	6.50^{cd}_{A}	6.75^{ab}_{A}	5.87^{b}_{A}
T8	4.37^{d}_{B}	5.87^{d}_{A}	6.62^{ab}_{A}	5.75^{b}_{A}
Factors	**F-test**	**LSD (0.05)**	**CV (%)**	
Storage period (A)	*	-		
Treatment (B)	*	-	14.98	
Interaction (A×B)	*	1.01		

Overall Acceptance

The results showed that storage duration and ginger concentration had a significant effect on the nectar's texture. Furthermore, a significant interaction between these two factors was observed (Table 12). On average throughout the storage period, Treatment 3 and Treatment 2 received the highest texture scores, with mean values of 8.62 and 7.87, respectively. In contrast, Treatment 6 obtained the lowest texture score, with a mean value of 5.62.

The LSD (0.05) value for the interaction was 1.01, confirming significant differences among the means. The CV% was 15.25, indicating acceptable variability in the experiment.

Table 13. *Effect of Different Treatments and Storage Duration on Overall Acceptance of Nectar*

Treatment	Storage period (Days)			
	Initial	30	60	90
T1	7.12^{a}_{A}	7.50^{abc}_{A}	7.00^{ab}_{A}	7.25^{ab}_{A}
T2	7.62^{a}_{A}	8.25^{ab}_{A}	7.50^{a}_{A}	7.87^{a}_{A}
T3	8.00^{a}_{AB}	8.62^{a}_{A}	7.25^{ab}_{B}	8.62^{a}_{A}
T4	7.12^{a}_{A}	7.62^{abc}_{A}	7.12^{ab}_{A}	5.87^{bc}_{B}
T5	6.62^{ab}_{AB}	7.37^{abcd}_{A}	6.50^{ab}_{AB}	5.75^{bc}_{B}
T6	5.50^{bc}_{B}	6.75^{bcd}_{A}	6.37^{ab}_{AB}	5.62^{c}_{B}
T7	4.75^{c}_{B}	6.25^{cd}_{A}	5.75^{b}_{AB}	6.25^{bc}_{A}
T8	4.62^{c}_{B}	5.87^{d}_{A}	6.12^{ab}_{A}	6.00^{bc}_{A}
Factors	**F-test**	**LSD (0.05)**	**CV (%)**	
Storage period (A)	*	-		
Treatment (B)	*	-	15.25	
Interaction (A×B)	*	1.01		

DISCUSSION

The TSS content of the nectar was significantly affected by varying concentrations of ginger during storage. An increase in TSS was observed during the initial stage of storage, which may be attributed to the hydrolysis of complex carbohydrates such as starch and other polysaccharides into simpler soluble sugars. However, after 30 days of storage, some treatments showed a decline in TSS. This reduction could be associated with the formation of precipitates in the juice, as dissolved constituents may interact during storage and form insoluble complexes, thereby decreasing the concentration of soluble solids.

Similar findings have been reported in previous studies, which indicated that the increase in TSS during storage was mainly due to the breakdown of starch and other complex carbohydrates, as well as various biochemical reactions. These studies also reported that the subsequent decrease in TSS could be attributed to the formation of insoluble precipitates during storage, resulting in a reduction in soluble solids content (Hassanzadeh et al., 2023; Okwunodulu et al., 2023; Verma et al., 2025; Ahmed et al., 2023; Herawati et al., 2021; Rajpoot et al., 2025; Wang et al., 2022). The decrease in TSS at higher ginger concentrations may be attributed to the dilution effect of added ginger extract and possible precipitation of soluble solids over time (Shaukat et al., 2023; Ademosun et al., 2025).

The acidity of apple nectar was significantly affected during storage. In general, acidity increased in some treatments while decreasing in others. These variations may be attributed to the formation of organic acids and to the degradation and utilization of existing organic acids during storage. Changes in metabolic and chemical reactions during storage can alter the balance of acidic compounds, thereby influencing the product's overall acidity. Similar findings have been reported in previous studies, which demonstrated that the acidity of fruit nectars changes during storage as a result of ongoing biochemical and physicochemical processes (Hassanzadeh et al., 2023; Shaukat et al., 2023; Muslim et al., 2026; Stanikzai et al., 2026; Shi et al., 2024).

Different concentrations of ginger did not exert a significant effect on the acidity of apple nectar during the first 30 days of storage. However, after 30 days, significant differences in acidity emerged among the treatments, indicating that the effect of ginger concentration became more pronounced with prolonged storage. The changes in acidity did not follow a consistent trend with increasing ginger concentration, suggesting that the response was treatment-specific rather than concentration-dependent. This variation may be attributed to differences in the proportions of apple juice and ginger extract in the formulations, which could influence the balance of organic acids and other biochemical reactions occurring during storage. The smallest changes in acidity were observed in Treatment 1, whereas the greatest changes were recorded in Treatment 8. Similar findings have been reported in previous studies, which demonstrated that different ginger concentrations can have variable effects on nectar acidity. These differences have been primarily attributed to variations in the natural acid content of ginger and apple, as well as their interactions during storage (Alemayehu et al., 2025; Rathinasamy et al., 2022; Okwunodulu et al., 2023; Rajpoot et al., 2025; Skąpska et al., 2020).

Different concentrations of ginger did not significantly affect the pH of apple nectar during storage. However, storage duration significantly affected pH, with a gradual decline over time. This reduction in pH may be attributed to the formation and accumulation of organic acids, changes in total soluble solids (TSS), and alterations in the balance between sugars and acids during storage. Such physicochemical changes can increase the nectar's acidity, thereby lowering its pH. Similar findings have been reported in previous studies, which also observed a decline in pH during the storage of fruit nectars and beverages. These changes were primarily associated with ongoing biochemical reactions and the production of acidic compounds throughout the storage period (Dippong et al., 2025; Gupta et al., 2025; Rajpoot et al., 2025).

Treatments with higher ginger levels (T7 and T8) exhibited lower reducing sugar content compared to pure apple juice (T1) and lower ginger treatments, indicating that increasing ginger incorporation may dilute or interact with inherent sugars in apple juice (Asma et al., 2023; Shaukat et al., 2023). During storage, the sugar content decreased from 6.86% at day 0 to a peak of 12.34% at 60 days, then declined slightly to 11.40% by day 90. This trend may be attributed to enzymatic breakdown of polysaccharides into simpler sugars and subsequent Maillard or other oxidative reactions during prolonged storage (Hassanzadeh et al., 2023; Okwunodulu et al., 2023). Similar dynamic changes in sugar composition have been reported in fruit-based functional beverages enriched with herbal extracts, reflecting interactions between fruit and bioactive compounds over time (Verma et al., 2025; Pali et al., 2020).

Higher ginger levels (T6 and T8) tended to increase non-reducing sugar content compared to pure apple juice, suggesting that ginger incorporation may contribute additional oligosaccharides or complex sugars, enhancing overall sugar diversity (Asma et al., 2023; Shaukat et al., 2023). During storage, non-reducing sugar content declined. This pattern indicates progressive hydrolysis of non-reducing sugars into reducing sugars, consistent with enzymatic activity and chemical conversion occurring in fruit-herb beverages during storage (Hassanzadeh et al., 2023; Okwunodulu et al., 2023; Verma et al., 2025). Similar trends have been observed in functional fruit beverages enriched with bioactive plant extracts, where shifts in sugar composition over time affect sweetness, stability, and nutritional value (Pali et al., 2020; Ademosun et al., 2025).

This indicates that changes in sugar composition were primarily driven by storage-related biochemical transformations rather than ginger concentration alone (Shaukat et al., 2023; Hassanzadeh et al., 2023). The results indicated that increasing the ginger concentration reduced total sugar content for up to 60 days of storage. However, beyond 60 days, total sugar content increased with increasing ginger concentration. This shift may be attributed to various biochemical changes in nectar during storage, including the hydrolysis of complex carbohydrates and the transformation of sugar compounds. The dynamic nature of these reactions can influence sugar accumulation and utilization at different stages of storage. Similar trends have been reported in previous studies, which also observed significant changes in total sugar content in response to varying ginger concentrations and storage duration (Debnath et al., 2022; Hayat et al., 2019; Lanjhiyana et al., 2010).

During storage, total sugars generally increased, suggesting partial hydrolysis of non-reducing sugars into reducing sugars and the breakdown of polysaccharides, a common phenomenon in fruit-based beverages during extended storage (Okwunodulu et al., 2023; Verma et al., 2025). Minor fluctuations across treatments further indicate that higher ginger concentrations may slightly modulate sugar stability, likely due to interactions between bioactive compounds and enzymatic activity (Asma et al., 2023; Pali et al., 2020).

The sensory characteristics of ginger-flavored apple nectar, including appearance, color, flavor, aroma, texture, and overall acceptability, were significantly influenced by ginger concentration, storage duration, and their interaction. Generally, lower to moderate ginger levels (1–2%) resulted in higher sensory scores, enhancing the visual quality, color stability, flavor, aroma, texture, and consumer acceptance of the nectar. In contrast, higher ginger concentrations initially reduced sensory quality due to darker color, increased particulate matter, stronger pungency, and altered mouthfeel (Shaukat et al., 2023; Ademosun et al., 2025; Pali et al., 2020).

During storage, most sensory attributes improved, particularly in treatments containing moderate levels of ginger, likely due to interactions between apple constituents and ginger bioactive compounds, including phenolics and antioxidants, which contributed to color stabilization, browning inhibition, flavor integration, and texture maintenance (Asma et al., 2023; Okwunodulu et al., 2023; Verma et al., 2025). Although prolonged storage caused slight declines in some sensory attributes, formulations containing 1–2% ginger consistently maintained the highest overall acceptability. These findings suggest that moderate incorporation of ginger can improve the sensory quality and storage stability of apple nectar while preserving consumer preference (Hassanzadeh et al., 2023; Olaniran et al., 2020).

Although precipitate formation was observed during the study, its underlying causes and formation mechanisms were not systematically investigated. This represents an important knowledge gap, as precipitate development may influence product quality, stability, and consumer acceptability. Future studies should therefore focus on elucidating the factors governing precipitate formation and their interactions under various storage and processing conditions.

CONCLUSION

The present study successfully standardized the formulation of ginger-flavored apple nectar and demonstrated that both ginger concentration and storage duration significantly influence its physicochemical and sensory properties. Among the different treatments, the formulation containing 2% ginger extract (T3) was found to be the most suitable, as it consistently exhibited superior quality attributes, including optimal TSS, balanced acidity, desirable sugar composition, and enhanced sensory characteristics such as flavor, aroma, texture, color, and overall acceptability.

Higher levels of ginger extract negatively affected sensory quality due to increased pungency and changes in color and texture, although slight improvements were observed during prolonged storage. Storage duration also significantly influenced quality parameters, with moderate storage enhancing flavor integration and product stability.

Overall, the optimized formulation with 2% ginger extract demonstrated good stability, improved functional properties, and high consumer acceptability. Therefore, ginger-flavored apple nectar standardized to this level can be considered a promising functional beverage with potential for commercial production, meeting the increasing demand for natural, health-oriented products.

Recommendations

Based on the findings, 2% ginger extract is recommended for ginger-flavored apple nectar, as it provides the best balance between physicochemical quality and sensory acceptability. Future studies should focus on shelf-life extension, suitable packaging materials, and the evaluation of nutritional and functional properties. Further research may also explore additional natural ingredients and conduct large-scale consumer sensory evaluations to support product commercialization.

Authors contributions

Nasir Ahmad Omari conducted the research, analyzed the data with the assistance of Dr. Hamid Salari, and wrote the manuscript while incorporating feedback from the co-author. Dr. Hamid Salari proposed the research concept, supervised the overall study, and contributed to the research work. All authors reviewed and approved the final version of the manuscript.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Data Availability Statement

All data generated or analyzed during this study are included in this published article and its supplementary files. Additional raw data related to chemical and sensory evaluations of ginger-flavored apple nectar can be made available from the corresponding author upon reasonable request, subject to ethical approval.

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