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ALTERNATIVE SUGAR SUBSTITUTES IN BOZA: EFFECTS ON STORAGE STABILITY AND SENSORY ATTRIBUTES

S u m m a r y

Background. Boza, a traditional cereal-based fermented beverage, is valued for its nutritional qualities, probiotic potential and cultural significance across Eastern Europe, the Balkans and Central Asia. This study examined the substitution of sucrose with alternative carbohydrate sources – glucose syrup, honey, brown sugar and starch – to evaluate their effect on shelf life, physicochemical properties and sensory attributes. Samples were prepared under standardized conditions, stored for 10 days and monitored for pH, acidity, soluble solids (°Brix), density, viscosity and ethanol content. Sensory evaluation assessed taste, aroma, texture and overall acceptability.

Results and conclusions. Honey-based Boza consistently outperformed other formulations, showing superior physicochemical values after 24 hours of fermentation (pH 3.38, acidity 0.78 %, °Brix 18.47, density 1.15 g/mL, viscosity 0.24 P·s, ethanol 0.18 %). It achieved the highest sensory scores for flavor, aroma and mouthfeel, while maintaining desirable texture and storage stability. In contrast, starch and glucose syrup variants yielded weaker sensory outcomes, and brown sugar offered only moderate improvements. These findings highlight the potential of honey as a functional carbohydrate source in Boza, enhancing nutritional and sensory qualities, while preserving authenticity, thereby supporting innovation in functional foods and consumer acceptance.

Key words: boza, sensory quality, honey, sugar, shelf life

Introduction

Fermented foods have long played a critical role in human nutrition, culinary traditions and food preservation, dating back to thousands of years across diverse cultures

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[1, 2]. In recent decades, their significance has resurged due to growing scientific interest in the human microbiome and the health benefits associated with probiotic-rich diets [3]. Fermentation, a biochemical process driven by microorganisms such as bacteria and yeast, not only enhances the shelf life and flavor profile of foods, but also contributes to improving sensory properties and solubility of the product and inhibits the growth of pathogenic microorganisms with low pH values [4, 5].

Boza is a traditional fermented beverage with historical and cultural significance spanning Central Asia, the Balkans and some parts of the Middle East. Characterized by its thick texture and mildly sweet-sour taste, Boza is typically produced through the lactic acid fermentation of cereal grains such as millet, wheat or maize. Its origins trace back to ancient civilizations, where fermentation served both nutritional and preservative purposes. In contemporary times, Boza has gained renewed academic interest due to its probiotic potential, nutritional density and role in promoting gut health [6, 7]. Historically, Boza production has predominantly occurred at the household level; however, recent years have witnessed growing interest in its industrial-scale manufacture. Although production methods may vary, the use of cereal grains remains a fundamental component across all formulations [8]. To ensure consistency in physicochemical and microbiological quality, it is imperative that standardized processing parameters and certified starter cultures are employed during fermentation [9].

Boza possesses a relatively limited shelf life and is unsuitable for storage at temperatures below 10 °C. It remains consumable throughout the fermentation process until the pH reaches approximately 3.5, beyond which quality diminishes [10]. Industrial production often utilizes the Frings fermentation system to maintain controlled microbial activity and product uniformity. Refined sugar (sucrose) serves as the primary carbohydrate source; however, its rapid influence on blood glucose levels has been associated with sudden hunger episodes and the development of leptin resistance, which impairs appetite regulation [11, 12].

Recent scientific literature increasingly highlights the adverse health implications of raffinose sugar consumption, reinforcing the need for alternative sweetening agents in functional beverage formulation [13, 14]. Optimizing the shelf life and storage stability of products is a critical aspect of modern formulation science, particularly in the food, pharmaceutical and cosmetic industries. Prolonged shelf life not only ensures product efficacy and safety over time, but also enhances consumer satisfaction, reduces economic losses due to spoilage and supports sustainable supply chain management. By improving storage stability, manufacturers can maintain the physicochemical integrity, microbiological safety and sensory attributes of products under varying environmental conditions [15, 16]. Furthermore, shelf-life optimization facilitates regulatory compliance, minimizes waste and enables broader market distribution, especially in regions with limited access to controlled storage infrastructure. As such, strategic approaches to extend shelf life are essential for advancing product quality, economic viability and environmental stewardship.

The primary objective of this study is to evaluate the effects of utilizing natural and alternative carbohydrate sources – specifically honey, glucose syrup, brown sugar and starch – as substitutes for refined sugar (sucrose) in the production of Boza. The study further aims to examine how these carbohydrate sources influence the fermentation dynamics, storage stability and physicochemical transformations of the final product. By systematically assessing changes during both fermentation and storage, the study seeks to determine the most suitable alternative capable of enhancing shelf life and sensory quality, while preserving the traditional characteristics of Boza.

Materials and methods

Materials

All raw materials required for Boza production – including corn flour (10 kg), wheat flour Type 800 (20 kg), water (100 dm^3), fresh yeast (125 g), sucrose (100 g in the starter solution and 1 kg per 10 dm^3 for sweetening) and caramelized sugar ('koler') for color adjustment – were procured from local markets in Prizren, Kosovo. The origin of these raw materials was Kosovo and North Macedonia, ensuring representative sourcing conditions consistent with regional production practices. The preparation of the boza matrix was undertaken at the "Banana Split" confectionery production facility, where standardized processing conditions were maintained to ensure reproducibility of the formulation. Subsequent analytical investigations were performed at the laboratories of the UBT Innovation Center (the Republic of Kosovo), which provided controlled environmental conditions and access to calibrated instrumentation. The chemical reagents employed in the analyses included sodium hydroxide (NaOH), obtained from Fluka, Germany (analytical grade). Distilled water utilized throughout the experimental procedures was freshly prepared at the UBT laboratory to minimize potential contamination and variability. Laboratory apparatus and auxiliary equipment necessary for the analyses – including glassware, reaction vessels and measurement tools – were fabricated and assembled within the UBT laboratory facilities at the Prizren branch (the Republic of Kosovo).

Methodology

Production of Boza at the Banana Split Factory, Prizren, Kosovo

Boza was produced at the Banana Split Factory in Prizren, Kosovo, following traditional methods preserved across generations. For a 100 dm^3 batch, the formulation included 10 kg of corn flour, 20 kg of wheat flour (Type 800) and 100 dm^3 of water. The preparation involved boiling 40 dm^3 of water with corn flour for 30 minutes, then combining with a homogenized mixture of wheat flour and 60 dm^3 of cold water. The mass was cooked at 200 ÷ 250 °C for 6 hours with continuous stirring, cooled for 24 hours, and partially homogenized with 25 dm^3 of cold water at 100 rpm/min. Fermentation was carried out in cherry-wood barrels using a starter solution (5 dm^3 of water, 5 kg of wheat flour, 125 g of yeast, 100 g of sucrose), added after 1 hour and maintained for 6 hours at 19 ÷ 21 °C. The fermented product was filtered, diluted to fluid consistency and sweetened at a ratio of 1 kg of sugar per 10 dm^3 boza, with caramelized sugar added for color. Final daily production ranged between 250 ÷ 350 dm^3.

Preparation of unfermented boza samples with different sugar substitutes

The detailed methodology of boza production at the “Banana Split” Factory is provided with a schematic representation presented in Fig. 1. The preparation begins with 2.5 dm^3 of unfermented boza, collected from the “Banana Split” Factory production line. A fermentation starter (starter culture), prepared according to the original recipe (2.5 kg of flour, 2.5 dm^3 of water, and 62.5 g of yeast), is added to a kettle containing boza. The mixture is thoroughly homogenized until the fermentative component settles at the bottom. Once homogenized, the batch is divided into five equal samples of 0.5 dm^3 each. At this stage, each sample contains boza and yeast, but no sugar. Finally, one of the preselected sugar or sugar substitutes is introduced into each of the five samples, ensuring consistent fermentation conditions across all variants.

- Sample 1: unfermented boza with added yeast and 10 g sucrose (white sugar), serving as both flavoring agent and substrate for yeast activity, thereby initiating the fermentation process. The sugar is mixed until completely dissolved, ensuring no undissolved crystals remain. The sample was stored in a dry, shaded environment at room temperature (18 ÷ 19 °C) for 24 hours, during which fermentation comprised an initial industrial stage (6 h) followed by a controlled experimental stage (24 h).
- Samples 2 ÷ 5: prepared identically to sample 1, each containing unfermented boza and yeast. However, instead of sucrose, the following sugar substitutes are added (10 g each):
  - Sample 2: brown sugar;
  - Sample 3: starch (it is not directly fermentable by yeast; its utilization likely depended on endogenous enzymatic hydrolysis);
  - Sample 4: honey;
  - Sample 5: glucose syrup.

These sweeteners act both as flavoring agents and as substrates for yeast metabolism, thereby initiating the fermentation process.

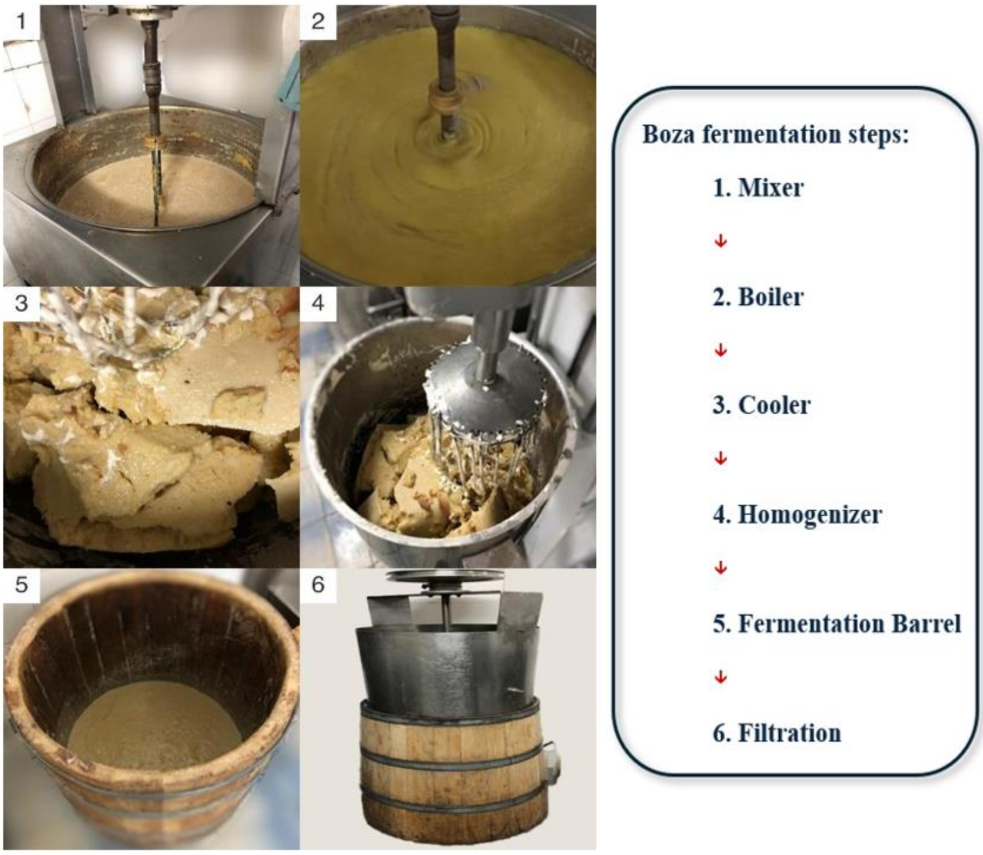

Figure 1. Schematic presentation of Boza fermentation procedure

Experimental design

In this study, five carbohydrate sources – honey, brown sugar, glucose syrup, starch and standard sucrose – were evaluated as independent variables, each incorporated at equal concentrations to substitute conventional sugar in the boza formulation, while all other ingredients and processing conditions were maintained constant to ensure comparability across treatments Table 1.

Sampling was performed at two intervals, day 0 (immediately after production) and day 10, corresponding to the typical refrigerated shelf life of boza (~10 days), as previous studies have confirmed that boza stored at 4 °C undergoes spoilage within 1 ÷ 2 weeks [17]. At each sampling point, stored boza samples were subjected to comprehensive evaluation of physicochemical parameters, including pH, titratable acidity, soluble solids (°Brix) and viscosity, alongside sensory assessment of taste, aroma, mouthfeel and overall acceptability, thereby providing an integrated understanding of both chemical stability and consumer-relevant qualities during refrigerated storage.

Table 1. Quantity of samples prepared for analysis

Type of Material	Quantity
Unfermented Boza	2.5 dm^3
fermentation starter (fermenting yeast) preparation	
flour	2.5 kg
water	2.5 dm^3
yeast	62.5 g
sugar and its substitutes	
refined sugar (sucrose)	10 g
brown sugar	10 g
starch	10 g
honey	10 g
glucose syrup	10 g

Physicochemical analyses

Boza production samples from the "Banana Split" Factory were subjected to physical, chemical, sensory and organoleptic analyses at the IKSHPK laboratory, following protocols outlined in the report on physicochemical and microbiological analysis of samples from Prizren, Kosovo. Results were evaluated against permissible limits defined by food standards. AOAC [18] standards covered parameters such as taste, sugar content, vitamin levels and acidity, while ISO standards [19] addressed general requirements for products intended for human consumption. Samples were collected in sterile glass containers and transported to the laboratory for analysis. An organoleptic evaluation included an assessment of color, foam, aroma and taste. Chemical analyses comprised acidity, pH and Brix measurements, while physical analyses included density and viscosity, determined using a pycnometer and viscometer respectively. Sensory attributes were assessed 24 hours post-fermentation using a nine-point descriptive scale by nine trained panelists from the Department of Food Sciences and Biotechnology, UBT–Higher Education Institution. At each storage interval (day 0 and day 10), physicochemical properties of the boza samples – including pH, titratable acidity, alcohol content and viscosity – were measured using standard food analysis methods to monitor fermentation progress and shelf-life stability. All instrumental analyses were performed in triplicate (n = 3), and mean values were recorded for each sample and time point. Measurements on day 0 (freshly fermented boza) provided a baseline, while subsequent measurements on day 10 indicated howthe properties of each formulation evolved during refrigerated storage.

pH and titratable acidity

The pH electrode was standardized with pH 4.00 and 7.00 buffer solutions before use, and the pH measurements were taken at room temperature by immersing the electrode in the boza sample. Acidity was determined by titration with standardized NaOH solution. An aliquot of each boza sample was diluted with distilled water (1:2 dilution) and titrated with 0.1 M sodium hydroxide until reaching an endpoint of pH 8.2 (phenolphthalein indicator faint pink). It was calculated and expressed as % lactic acid equivalent (g lactic acid per 100 mL of boza), since lactic acid is the predominant organic acid in boza. This assay monitors the accumulation of acidity over time as an indicator of fermentation extent.

Alcohol content and viscosity

A known volume of boza (typically 100 cm^3) was distilled using a glass distillation apparatus to separate ethanol. The distillate was collected and its ethanol content determined by density (pycnometer) readings, following the official AOAC distillation approach for low-alcohol beverages. Results were reported as % alcohol by volume (ABV). A Brookfield-type rotational viscometer was used to determine the apparent viscosity of each boza sample. Measurements were taken at 20 °C using an appropriate spindle and rotation speed to suit the high viscosity of boza. Viscosity (in Pa·s) was recorded at a defined shear rate once the reading stabilized. This parameter reflects the thick, paste-like consistency of boza and was tracked to see if sweetener type or fermentation time influenced the texture of the beverage.

Sensory evaluation

The sensory evaluation of boza samples was conducted by a trained panel of ten experienced assessors, comprising postgraduate students and staff from the field of food science, to monitor organoleptic changes and overall acceptability resulting from the use of different sugar substitutes. The comparative analysis of sensory characteristics was performed after 24 hours of fermentation. Prior to the evaluation, the samples were gently stirred and served chilled (~10 °C, the typical serving temperature for boza [17] in coded plastic cups, with panelists rinsing their palate between tastings to minimize carryover effects. The samples were presented in randomized order using coded labels to minimize bias. Four sensory attributes – taste, aroma, appearance and overall acceptability – were assessed using a structured ten-point scale (1 = extremely poor/disliked, 10 = extremely good/liked). A score of 10 denoted a highly pleasing, characteristic boza flavor, while a score of 1 indicated strong dislike; intermediate scores were interpreted as the acceptable levels of preference. General acceptability encompassed the holistic perception of the beverage, integrating taste, texture and visual characteristics, and served as a general measure of product quality and drinkability. Taste evaluation focused on sweetness, derived from sugar content; sourness, resulting from acidic compounds, and grain flavor, which reflects the aromatic contribution of wheat and corn. The texture assessment included color, rated along a spectrum from light to dark yellow, and intensity–density, which denotes the viscosity and mouthfeel of the product. In addition to scoring, panelists provided brief qualitative comments regarding off-flavors, aroma shifts or texture changes observed during the evaluation. To preserve intrinsic product characteristics, no sugar or cinnamon toppings were added. This sensory evaluation provided descriptive insights into the influence of different sweeteners on the palatability and consumer-relevant qualities of Boza over time.

Data analysis

Physicochemical data were expressed as mean ± standard deviation (SD) based on duplicate measurements for each sample and storage time point. Descriptive statistics were used to summarize the overall trends in pH, titratable acidity, total soluble solids (°Brix), density, viscosity and alcohol content among the different sweetener formulations. Sensory evaluation parameters, including taste, color and density, were also presented as mean ± SD values. Differences among sweetener treatments (refined sugar, brown sugar, starch, honey and glucose syrup) were analyzed using one-way analysis of variance (ANOVA). Separate ANOVA tests were conducted for sensory attributes and for physicochemical parameters measured after 24 hours and after 10 days of fermentation. When significant differences were detected, post-hoc comparisons were performed using Tukey's Honestly Significant Difference (HSD) test to identify pairwise differences among treatments. Differences were considered statistically significant at $p < 0.05$. Statistical grouping indicators (superscript letters a–e) were assigned in the tables, where means sharing the same letter were not significantly different. The interpretation of the results considered both statistical significance and practical relevance, particularly focusing on changes in sensory acceptance, fermentation stability and product quality. Greater emphasis was placed on identifying sweetener formulations that maintained desirable taste, color, density and physicochemical stability throughout storage. Shelf-life termination was considered when the samples showed significant deterioration in sensory quality and physicochemical instability during storage. All results were presented in tables and supported by a graphical representation to facilitate comparison among treatments and storage periods.

Results and discussion

Physicochemical analyses

In this research, the pH measurements, acidity measurements, as well as the determination of °Brix degree, density, viscosity and alcohol content were performed on samples of Boza produced from different carbohydrate sources. Boza produced with refined sugar (sucrose) and glucose syrup exhibited the highest pH level (3.41), whereas Boza prepared using starch showed the lowest pH level (3.35). The Brix degree of Boza produced from various carbohydrate sources was measured using a refractometer, revealing noticeable differences in the resulting Brix values. Boza produced with refined sugar (sucrose) and honey exhibited the highest Brix value (18.5 %), whereas Boza prepared using starch showed the lowest Brix value (18.1 %). Furthermore, the determination of density was done using a pycnometer on the samples of Boza produced from different carbohydrate sources. It was observed that the density of honey syrup Boza (1.16 g/cm^3) was higher than of the other Boza samples. The viscosity determination was also carried out on the samples of Boza produced from different carbohydrate sources using a viscometer. Also, it was noticed that the viscosity of the honey-produced Boza (0.24 P·s) was higher than the other Boza samples. All the results are shown in Fig. 2 and Table 4.

Furthermore, Boza samples were stored for a period of 10 days, after which their pH, acidity and alcohol content were re-evaluated. The relationship between pH, acidity and alcohol levels is shown in Fig. 3. All analyses were performed three times for each sample, and the mean value was obtained. The pH of Boza produced with different sugars decreased over 10 days of fermentation, with sucrose and glucose syrup having a decrease from 3.38 to 3.25 and 3.41 to 3.26 respectively. Thus, the acidity of Boza increased over 10 days of fermentation, with sucrose and glucose syrup having increases from 0.87 to 2.55 % and 0.875 to 2.65 % respectively. The alcohol levels of Boza also increased over 10 days, with sucrose and glucose syrup having increases from 0.22 to 0.88 % v/v and 0.19 to 0.78 % v/v respectively. All the parameters evaluated for another sugar alternatives are presented in Table 4 and Table 5. It is clearly seen from the data obtained after 10 days that the pH values and the acidity measurements of the produced Boza revealed noticeable differences among the samples. These variations in acidity are attributed to the presence of lactic acid, which is a key component in Boza fermentation [20].

The pH of a formulation is a critical determinant of its storage stability, influencing both chemical degradation and microbial susceptibility [21]. Excessive acidity can catalyze degradation reactions in acid-labile compounds, alter organoleptic properties and interact adversely with packaging materials [22]. Thus, as showed by the results

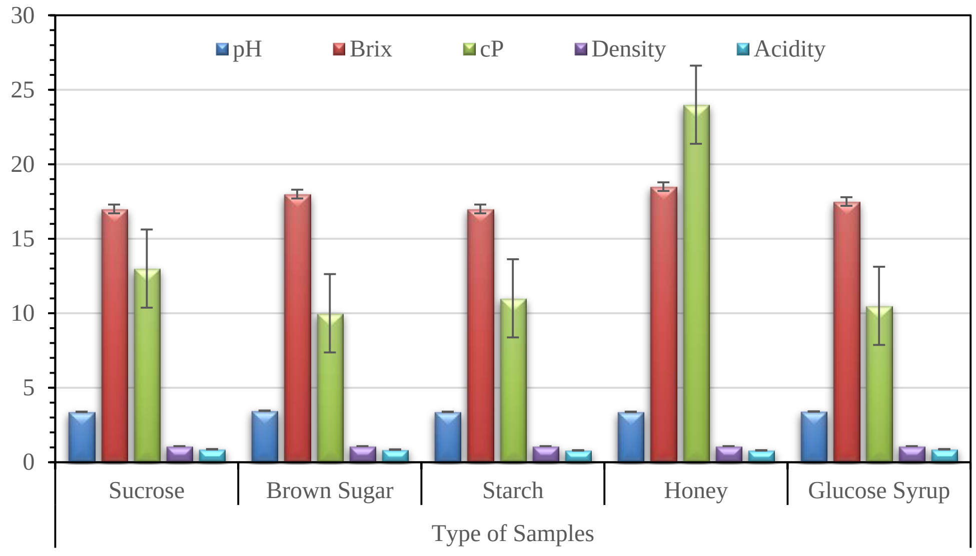

Figure 2. Results of chemical and physical measurements of Boza samples produced with different carbohydrate type

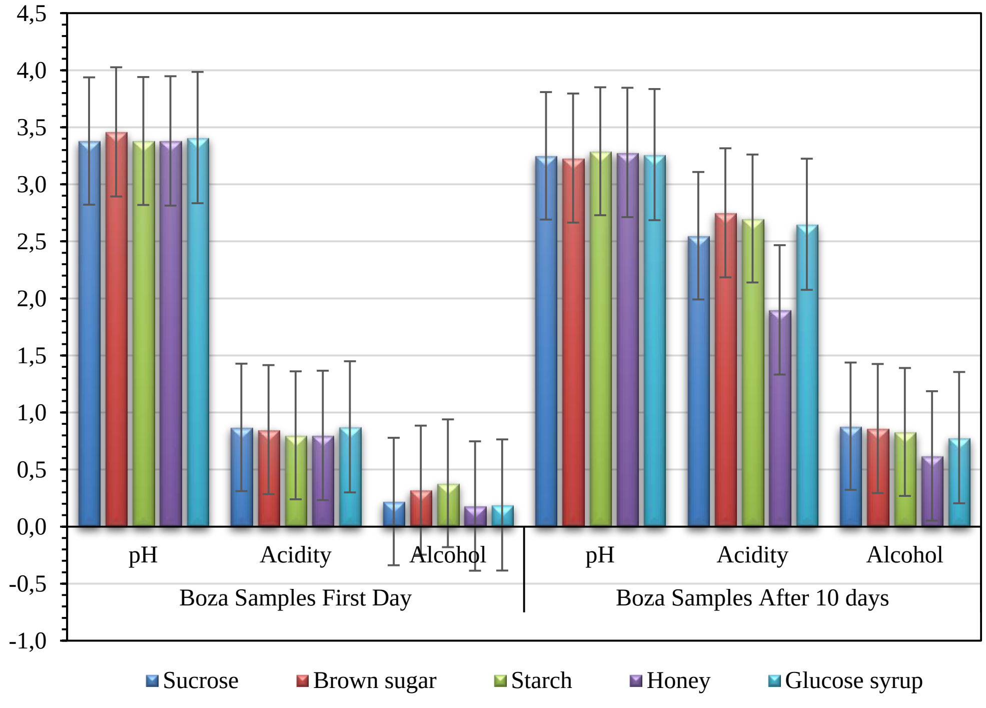

Figure 3. Differences between Boza samples on the first day and after 10 days

obtained, honey-produced Boza was one of the formulations that, after 10 days, showed a lower level of acidity – a result that can be considered highly significant in the context of storage stability. Furthermore, products with higher viscosity often exhibit enhanced resistance to physical instability over time, thus the honey-produced Boza was found to have the highest density and viscosity at 1.16 g/cm^3 and 0.24 Pa·s respectively. The improved stability observed in honey-based samples may be attributed to its antimicrobial compounds, including hydrogen peroxide, phenolic constituents and flavonoids, as well as its lower water activity [23, 24, 25].

Considering the adverse health effects of refined sugar (sucrose) on human health [26, 27], the parameters evaluated in this study suggest that substituting sugar with honey may represent a beneficial alternative – both from a health perspective and in terms of storage stability.

Sensory Evaluation

The sensory evaluation of Boza samples, summarized in Table 2, revealed several characteristic observations. The panelists consistently described the beverage as sweet, reflecting its sugar content, while dryness was associated with acidity levels. The aroma was noted for its distinct wheat-like character and the color was uniformly perceived as dark yellow. Comparative assessment of sensory attributes was performed after 24 hours of fermentation. Results are presented in Fig. 4.

Table 2. Sensory characteristics and definitions defined in the descriptive sensory analysis

SENSORY ANALYSIS	UNDERSTANDING
General Acceptability	The assessment of Boza considering all their characteristics
TASTE	
Sweetness	The taste caused by sugar in the product content
Sourness	The taste caused by acid in the product
Grain Flavor	Aroma from wheat and corn
TEXTURE	
Color	Rating of the color of the bottle from light to dark yellow
Intensity – Density	Viscosity of the product

Furthermore, the sensory analysis revealed statistically significant differences among sweeteners across all evaluated parameters (taste, color and density), as confirmed by one-way ANOVA ($p < 0.001$). Tukey’s HSD post-hoc test further clarified the grouping of treatments, highlighting clear consumer preferences.

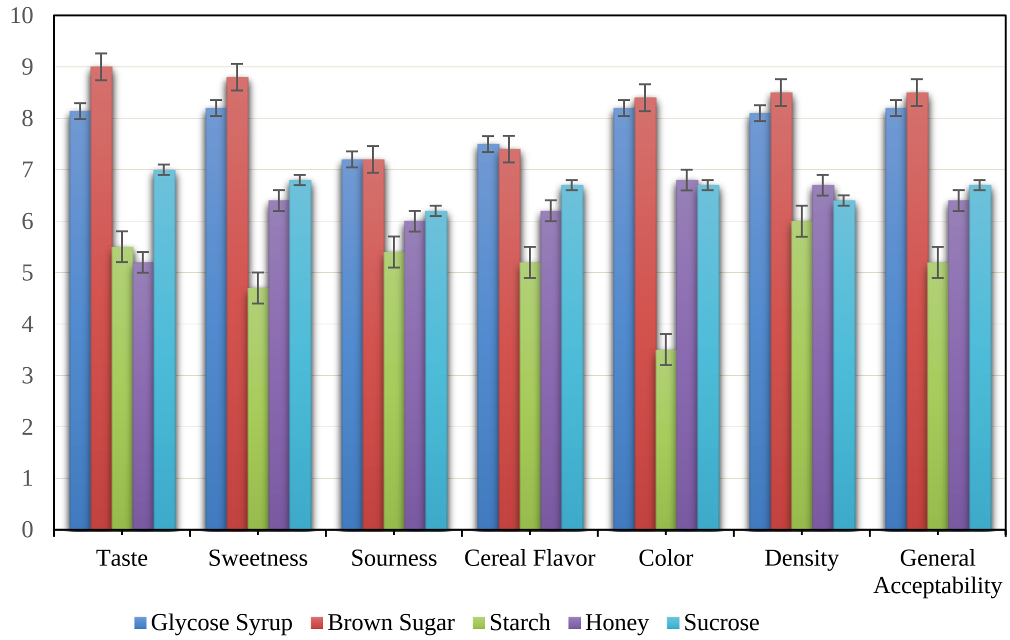

Figure 4. Sensory characteristics results given by the panelists

Refined sugar (7.40 ± 0.10) and honey (7.27 ± 0.15) were statistically indistinguishable (group a), indicating that both sweeteners deliver comparable taste acceptability. Brown sugar (6.98 ± 0.015, group b) was moderately preferred, while glucose syrup (6.53 ± 0.15, group c) and starch (5.30 ± 0.10, group d) scored significantly lower. These findings suggest that sucrose-based sweeteners maintain superior palatability, consistent with Codex Alimentarius standards emphasizing consumer acceptability in sweetener substitution. The reduced scores for starch highlight its limited suitability in the formulations where taste is a critical determinant of quality.

Color evaluation yielded the highest F-value (420.5), underscoring strong panel discrimination. Refined sugar and honey (8.30 ± 0.10, group a) achieved the highest scores, reflecting desirable visual attributes. Brown sugar (7.63 ± 0.15, group b) was acceptable but significantly lower, while glucose syrup (6.67 ± 0.15, group c) and starch (3.40 ± 0.10, group d) were less appealing. The poor performance of starch aligns with WHO sensory guidelines, which emphasizes visual quality as a determinant of consumer acceptance. The superior color of refined sugar and honey may be attributed to their clarity and absence of undesirable pigments, whereas starch likely introduced turbidity or opacity.

Honey (8.37 ± 0.15, group a) achieved the highest density score, surpassing refined sugar (7.93 ± 0.15, group b). Brown sugar (7.40 ± 0.10, group c) was moderately acceptable, while glucose syrup (6.23 ± 0.15, group d) and starch (5.98 ± 0.015, group e) were significantly less preferred. The superior density of honey may be linked to its natural viscosity and complex carbohydrate composition, which enhance mouthfeel. This finding is consistent with Codex recommendations that highlight texture and body as critical sensory attributes in sweetened products.

Across parameters, refined sugar and honey consistently ranked the highest, confirming their suitability as preferred sweeteners in sensory-driven formulations. Brown sugar provided moderate acceptability, while glucose syrup and starch were consistently inferior. The strong statistical significance ($p < 0.001$) across all attributes underscores the robustness of panel evaluations and validates the discriminatory capacity of the methodology (Table 3).

Table 3. Descriptive Statistics, One-Way ANOVA and Tukey HSD grouping of sensory analysis

Parameter	Sweetener	Mean ± SD	F-value	*p*-value	Significance
Taste	Refined Sugar	7.40 ± 0.10^{a}	82.3	<0.001	Significant
	Honey	7.27 ± 0.15^{a}			
	Brown Sugar	6.98 ± 0.015^{b}			
	Glucose Syrup	6.53 ± 0.15^{c}			
	Starch	5.30 ± 0.10^{d}			
Color	Refined Sugar	8.30 ± 0.10^{a}	420.5	<0.001	Significant
	Honey	8.30 ± 0.10^{a}			
	Brown Sugar	7.63 ± 0.15^{b}			
	Glucose Syrup	6.67 ± 0.15^{c}			
	Starch	3.40 ± 0.10^{d}			
Density	Honey	8.37 ± 0.15^{a}	75.6	<0.001	Significant
	Refined Sugar	7.93 ± 0.15^{b}			
	Brown Sugar	7.40 ± 0.10^{c}			
	Glucose Syrup	6.23 ± 0.15^{d}			
	Starch	5.98 ± 0.015^{e}			

Explanatory notes: Means sharing the same letter are not significantly different at $p < 0.05$ according to Tukey's HSD test.

Data Analysis

Initial Chemical and Physical Properties (24 h)

The comparative analysis of sweeteners revealed statistically significant differences across all measured parameters (pH, acidity, °Brix, density, viscosity and alcohol content), as confirmed by one-way ANOVA ($p < 0.001$ for most parameters). Tukey's HSD post-hoc test provided clear groupings, enabling the interpretation of the relative performance of each sweetener (Table 4). Refined sugar (3.41 ± 0.01) and glucose syrup (3.41 ± 0.01) were statistically similar (group *a*), maintaining the highest pH values. Brown sugar (3.38 ± 0.01) and honey (3.38 ± 0.01) formed group *b*, while starch (3.35 ± 0.01) was significantly lower (group *c*). These results suggest that sucrose-based sweeteners stabilize acidity better than starch, consistent with Codex Alimentarius guidelines that emphasize pH stability as a determinant of product safety and quality. Furthermore, refined sugar, brown sugar and glucose syrup (0.87 ± 0.02; group *a*) exhibited the highest acidity, while starch (0.84 ± 0.01; group *b*) and honey (0.78 ± 0.02; group *c*) were significantly lower. Reduced acidity in honey may be attributed to its buffering capacity and organic acid composition. This aligns with WHO recommendations that highlight acidity as a critical factor influencing microbial stability and shelf life [28].

Refined sugar (18.60 ± 0.25; group *a*) achieved the highest soluble solids content, followed closely by honey (18.47 ± 0.15; group *ab*). Glucose syrup (18.30 ± 0.10; group *b*), brown sugar (18.20 ± 0.10; group *bc*) and starch (18.13 ± 0.15; group *c*) were progressively lower. These findings confirm that sucrose-based sweeteners contribute more effectively to soluble solids, enhancing sweetness intensity and product consistency. For instance, honey (1.15 ± 0.01; group *a*) exhibited the highest density, followed by glucose syrup (1.14 ± 0.015; group *ab*). Brown sugar (1.12 ± 0.01; group *b*) was moderate, while refined sugar and starch (1.11 ± 0.01; group *c*) were the lowest. The superior density of honey reflects its natural viscosity and carbohydrate complexity, contributing to desirable mouthfeel and product body. Honey (0.24 ± 0.01; group *a*) again ranked the highest, followed by brown sugar and glucose syrup (0.21 ± 0.01; group *b*). Refined sugar (0.20 ± 0.01; group *c*) and starch (0.18 ± 0.01; group *d*) were significantly lower. Viscosity is a critical sensory and functional attribute, influencing texture and stability. The performance of honey underscores its potential as a natural thickening agent in formulations.

Brown sugar (0.23 ± 0.01; group *a*) yielded the highest alcohol content, followed by refined sugar (0.21 ± 0.01; group *b*). Starch (0.20 ± 0.01; group *bc*), glucose syrup (0.19 ± 0.01; group *c*) and honey (0.18 ± 0.01; group *d*) were progressively lower. Elevated alcohol levels in brown sugar may reflect higher fermentable substrate availability, while the lower values of honey suggest reduced microbial fermentation potential, consistent with its antimicrobial properties.

Overall, refined sugar and honey consistently demonstrated superior performance across multiple parameters. Refined sugar excelled in pH, acidity and °Brix, while honey dominated density and viscosity. Brown sugar showed moderate performance but was associated with higher alcohol production, which may limit its stability. Glucose syrup performed adequately but was inferior to sucrose-based sweeteners, while starch consistently ranked the lowest, indicating limited suitability for maintaining chemical and physical quality.

Table 4. Descriptive Statistics, One-Way ANOVA and Tukey HSD Grouping of chemical and physical analysis after 24 hours

Parameter (24 h)	Sweetener	Mean ± SD	F-value	*p*-value	Significance
pH	Refined Sugar	3.41 ± 0.01^{a}	18.9	<0.001	Significant
	Glucose Syrup	3.41 ± 0.01^{a}			
	Brown Sugar	3.38 ± 0.01^{b}			
	Honey	3.38 ± 0.01^{b}			
	Starch	3.35 ± 0.01^{c}			
Acidity (%)	Refined Sugar	0.87 ± 0.02^{a}	45.2	<0.001	Significant
	Brown Sugar	0.87 ± 0.015^{a}			
	Glucose Syrup	0.87 ± 0.02^{a}			
	Starch	0.84 ± 0.01^{b}			
	Honey	0.78 ± 0.02^{c}			
Brix (°Bx)	Refined Sugar	18.60 ± 0.25^{a}	12.5	<0.001	Significant
	Honey	18.47 ± 0.15^{ab}			
	Glucose Syrup	18.30 ± 0.10^{b}			
	Brown Sugar	18.20 ± 0.10^{bc}			
	Starch	18.13 ± 0.15^{c}			
Density (g/cm^3)	Honey	1.15 ± 0.01^{a}	8.9	0.002	Significant
	Glucose Syrup	1.14 ± 0.015^{ab}			
	Brown Sugar	1.12 ± 0.01^{b}			
	Refined Sugar	1.11 ± 0.01^{c}			
	Starch	1.11 ± 0.01^{c}			
Viscosity (Pa·s)	Honey	0.24 ± 0.01^{a}	11.0	<0.001	Significant
	Brown Sugar	0.21 ± 0.01^{b}			
	Glucose Syrup	0.21 ± 0.01^{b}			
	Refined Sugar	0.20 ± 0.01^{c}			
	Starch	0.18 ± 0.01^{d}			
Alcohol (% v/v)	Brown Sugar	0.23 ± 0.01^{a}	28.6	<0.001	Significant
	Refined Sugar	0.21 ± 0.01^{b}			
	Starch	0.20 ± 0.01^{bc}			
	Glucose Syrup	0.19 ± 0.01^{c}			
	Honey	0.18 ± 0.01^{d}			

Explanatory notes: Means sharing the same letter are not significantly different at $p < 0.05$ according to Tukey's HSD test.

Stability Over 10 Days

The extended storage period (10 days) revealed significant shifts in chemical parameters across sweeteners, as confirmed by one-way ANOVA ($p < 0.05$ to < 0.001). Tukey's HSD grouping highlighted distinct trends in pH, acidity and alcohol production, reflecting both compositional differences and microbial activity (Table 5).

Brown sugar (3.28 ± 0.015; group a) maintained the highest pH, while honey (3.26 ± 0.025) and glucose syrup (3.25 ± 0.01) were statistically similar (group ab). Refined sugar (3.24 ± 0.01; group b) and starch (3.22 ± 0.02; group c) were significantly lower. These results suggest that brown sugar provides greater buffering capacity, possibly due to mineral and molasses content, while starch exhibited the lowest stability. According to Codex Alimentarius, pH stability is critical for microbial safety, and the observed decline in starch-based formulations may predispose them to spoilage. Furthermore, glucose syrup (2.64 ± 0.01) and starch (2.63 ± 0.015) formed group a, showing the highest acidity. Refined sugar (2.54 ± 0.01; group b) and brown sugar (2.50 ± 0.015; group c) were moderately acidic, while honey (1.89 ± 0.01; group d) was significantly lower. Elevated acidity in glucose syrup and starch may reflect microbial fermentation and organic acid accumulation. The reduced acidity of honey aligns with its antimicrobial properties and enzymatic composition, which limits acidification. WHO guidelines emphasize acidity as a determinant of shelf stability, suggesting honey may offer longer preservation potential compared to starch-based formulations.

Table 5. Descriptive Statistics, One-Way ANOVA and Tukey HSD grouping after 10 Days

Parameter (10 Days)	Sweetener	Mean ± SD*	F-value	*p*-value	Significance
pH	Brown Sugar	3.28 ± 0.015^{a}	5.12	0.015	Significant
	Honey	3.26 ± 0.025^{ab}			
	Glucose Syrup	3.25 ± 0.01^{ab}			
	Refined Sugar	3.24 ± 0.01^{b}			
	Starch	3.22 ± 0.02^{c}			
Acidity (%)	Glucose Syrup	2.64 ± 0.01^{a}	210.3	<0.001	Significant
	Starch	2.63 ± 0.015^{a}			
	Refined Sugar	2.54 ± 0.01^{b}			
	Brown Sugar	2.50 ± 0.015^{c}			
	Honey	1.89 ± 0.01^{d}			
Alcohol (% v/v)	Starch	0.91 ± 0.01^{a}	150.7	<0.001	Significant
	Refined Sugar	0.87 ± 0.01^{b}			
	Brown Sugar	0.84 ± 0.01^{c}			
	Glucose Syrup	0.77 ± 0.01^{d}			
	Honey	0.61 ± 0.01^{e}			

Explanatory notes: Different letters indicate statistically significant differences among sweetener treatments according to Tukey's HSD test at $p < 0.05$.

Alcohol content increased markedly after 10 days, with starch (0.91 ± 0.01; group a) producing the highest levels. Refined sugar (0.87 ± 0.01; group b) and brown sugar (0.84 ± 0.01; group c) were moderate, while glucose syrup (0.77 ± 0.01; group d) and honey (0.61 ± 0.01; group e) were the lowest. Elevated alcohol in starch and refined sugar indicates higher fermentable substrate availability, consistent with microbial activity during storage. Minimal alcohol production in honey reinforces its inhibitory effect on fermentation, a property well-documented in Codex Alimentarius standards for honey quality.

After 10 days, honey remains the most stable sweetener, minimizing undesirable chemical changes. Brown sugar provides buffering but moderate fermentation, while starch and glucose syrup are the least stable, showing high acidity and alcohol production. Refined sugar performs moderately but is less stable than honey. These findings reinforce a dual role of honey as a natural sweetener and preservative, aligning with WHO and Codex Alimentarius standards for product safety and quality.

Comparison of pH, °Brix and Viscosity values with reported literature data

Since pH values play a significant role in predicting storage stability, a comparative analysis was conducted between the measured pH levels and those reported in the existing literature. The relevant data is given in Table 6. Arici et al. [29] conducted research focusing on the microbiological aspects and both steady and dynamic rheological behavior of Boza, including temperature sweep experiments and the relevance of the Cox-Merz rule. Goncu et al. [30] explored the physicochemical characteristics and sensory attributes of gluten-free Boza made with chia and quinoa flours. The pH value reported in this study were found to be lower than present study. However, it should be emphasized that chia and quinoa flours have a considerably high price compared to wheat flour.

Furthermore, Tornuk et al. [31] examined the rheological and selected physicochemical characteristics of probiotic Boza fermented with Lactobacillus casei Shirota, utilizing a principal component analysis for its evaluation. Arslan et al. investigated the microbiological and chemical profile of probiotic Boza, along with its acceptance among consumers [32]. Additionally, Akpinar-Bayizit et al. [8] studied how raw materials and fermentation influence the organic acid composition of Boza. Higher pH values reported in previous studies compared to the present work suggest that those formulations created a more favorable environment for microbial growth, including bacteria, yeasts and molds. Elevated pH levels reduce the natural inhibitory effect of acidity, thereby accelerating spoilage processes and shortening shelf life. In contrast, lower pH observed in the current study indicates a more acidic environment, which is less hospitable to microbial proliferation and contributes to improved product stability during storage. This highlights the critical role of pH as a determinant of both microbial safety and shelf life in Boza production. By maintaining lower pH values, formulations can achieve extended preservation, while simultaneously supporting desirable sensory attributes, positioning acidity control as a key strategy in optimizing the balance between tradition, quality and modern food safety standards [33].

In addition to pH values, °Brix levels were also evaluated in comparison with previous studies to provide a broader perspective on Boza quality. Duven et al. [34] reported that chia and quinoa can be successfully incorporated into Boza production, yielding psychobiotic LAB and yeast with promising probiotic characteristics. The Brix values obtained in their study were the most comparable to those measured in the present work, supporting the consistency of results across different raw materials. In contrast, Pulatsu et al. reported that the fortification of Boza with 10 % non-fat dry milk significantly increased protein content, while maintaining fermentation performance and gel-like rheology [35]. Sucrose-based Boza represents the traditional benchmark, delivering high Brix values that reflect elevated sugar content and a characteristic sweetness profile. However, this formulation aligns less with modern health-conscious preferences due to its reliance on refined sugar. In contrast, honey-based Boza not only preserves the sensory appeal of sweetness and aroma, but also introduces bioactive compounds such as antioxidants and enzymes, thereby enhancing nutritional value, while moderating fermentation dynamics. Milk-enriched Boza, on the other hand, shifts the balance toward protein and mineral supplementation, resulting in lower Brix values and a reduced sugar load. This compositional reorientation favors nutritional density and controlled fermentation, but produces milder sweetness compared to sucrose or honey formulations. Taken together, these comparisons illustrate how different sweetening and enrichment strategies can tailor the physicochemical and sensory profile of Boza to diverse consumer expectations – ranging from traditional indulgence to functional innovation – while positioning the beverage within broader health and wellness trends.

Viscosity values were further evaluated in relation to previous studies. Ozturk et al. [36] reported that *Lb. casei* Shirota adapted well in Boza, conferring probiotic potential, and that predictive modelling (ANFIS) best described its pseudoplastic viscosity changes during storage; their formulations exhibited relatively high viscosity. In contrast, Pulatsu et al. [35] reported the lowest viscosity values when fortifying Boza with non-fat dry milk, reflecting the impact of protein enrichment on flow behavior. The intermediate viscosity observed in the present study represents a critical balance between tradition and innovation in Boza production. High viscosity is often associated with the characteristic spoonable texture of the beverage, which reinforces its cultural authenticity and consumer recognition. However, excessively thick formulations can hinder drinkability and reduce sensory acceptance, particularly among modern consumers seeking lighter texture. Conversely, very low viscosity compromises mouthfeel, diminishing the perception of richness and quality. By achieving an intermediate viscosity, the current formulation maintains desirable rheological properties that support microbial activity during fermentation, while ensuring consumer preference for both texture and palatability. This equilibrium suggests that viscosity is not merely a physical parameter, but a functional attribute that integrates sensory appeal, microbial dynamics and product identity, making it a pivotal factor in optimizing the physicochemical and sensory profile of Boza.

Table 6. Comparison of pH, °Brix and Viscosity values with reported literature data

	This study (honey-based formulation)	Arıcı et al. 2014 [29]	Göncü et al. 2023 [30]	Tornuk et al. 2014 [31]	Arslan et al. 2025 [32]	Akpınar-Bayazıt et al. 2010 [8]
pH	3.28 ÷ 3.38	3.19 ÷ 3.99	3.13 ÷ 3.24	4.08 ÷ 4.21	<4.50	3.43 ÷ 3.86
	This study (honey-based formulation)	Öztürk 2013 [36]	Pulatsu et al. 2023 [35]	Tornuk et al. 2014 [31]	Düven 2024 [34]	
°Brix	18.5	14.67 ÷ 15.30	11.8 ÷ 12.7	16.75 ÷ 17.82	15.10 ÷ 18.05	
	This study (honey-based formulation)	Öztürk 2013 [36]	Pulatsu et al. 2023 [35]	Tornuk et al. 2014 [31]	Arıcı et al. 2014 [29]	
Viscosity (Pa·s)	0.24	0.651 ÷ 2.481	0.11	0.49 ÷ 0.63	0.425 ÷ 0.683	

Conclusions

1. The study systematically investigated the incorporation of alternative sweeteners – glucose syrup, honey, brown sugar and starch – into Boza formulations as substitutes for sucrose, with the aim of evaluating their impact on sensory quality, physicochemical properties and overall product stability.
2. Among the tested options, honey emerged as the most promising candidate, achieving the highest sensory evaluation scores across taste, aroma, mouthfeel and overall acceptability, thereby demonstrating its superior ability to enhance consumer appeal.
3. Honey-based Boza exhibited favorable physicochemical changes, including a lower pH and reduced titratable acidity, which contributed to a milder flavor profile and created conditions less conducive to microbial spoilage, ultimately supporting longer shelf life.
4. The formulation also showed decreased ethanol content, indicating a more controlled fermentation process that minimized undesirable by-products, while maintaining the characteristic qualities of the beverage.

5. Beyond sensory and physicochemical improvements, honey contributed additional nutritional value through its natural bioactive compounds, such as antioxidants and enzymes, which enriched the functional properties of the beverage.
6. Overall, honey supplementation enhanced product stability during storage, while simultaneously improving consumer acceptance, positioning it as a multifunctional ingredient that strengthens both quality and marketability.
7. Incorporating honey into Boza formulations aligns with contemporary health-conscious trends, while preserving the traditional essence of the beverage, offering a balanced fusion of cultural heritage and modern innovation in fermented beverage development.

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ALTERNATYWNE ZAMIENNIKI CUKRU W BOZA: WPŁYW NA STABILNOŚĆ PRZECHOWALNICZĄ I WŁAŚCIWOŚCI SENSORYCZNE

S t r e s z c z e n i e

Wprowadzenie. Boza, tradycyjny fermentowany napój zbożowy, jest ceniony ze względu na swoje właściwości odżywcze, potencjał probiotyczny i znaczenie kulturowe w Europie Wschodniej, na Bałkanach i w Azji Środkowej. W niniejszym badaniu przeanalizowano zastąpienie sacharozy alternatywnymi źródłami węglowodanów – syropem glukozowym, miodem, cukrem brązowym i skrobią – w celu oceny ich wpływu na okres przydatności do spożycia, właściwości fizykochemiczne i właściwości sensoryczne. Próbki przygotowano w standaryzowanych warunkach, przechowywano przez 10 dni i monitorowano pod kątem pH, kwasowości, zawartości rozpuszczalnych substancji stałych (°Brix), gęstości, lepkości i zawartości etanolu. Ocena sensoryczna obejmowała ocenę smaku, aromatu, tekstury i ogólnej akceptowalności.

Wyniki i wnioski. Boza na bazie miodu konsekwentnie przewyższała inne receptury, wykazując lepsze wartości fizykochemiczne po 24 godzinach fermentacji (pH 3,38, kwasowość 0,78 %, °Brix 18,47, gęstość 1,15 g/cm^3, lepkość 0,24 P·s, etanol 0,18 %). Uzyskała najwyższe oceny sensoryczne za smak, aromat i wrażenie w ustach, zachowując jednocześnie pożądaną teksturę i stabilność podczas przechowywania. Z kolei warianty ze skrobią i syropem glukozowym dały słabsze wyniki sensoryczne, a brązowy cukier przyniósł jedynie umiarkowaną poprawę. Wyniki te podkreślają potencjał miodu jako funkcjonalnego źródła węglowodanów w napoju Boza, poprawiającego walory odżywcze i sensoryczne przy jednoczesnym zachowaniu autentyczności, wspierając tym samym innowacje w żywności funkcjonalnej i akceptację konsumentów.

Słowa kluczowe: boza, jakość sensoryczna, miód, cukier, okres przydatności do spożycia