



The use of stevia (*Stevia rebaudiana*) as a sweetener in fruit yogurts produced with apple powder and the determination of quality parameters

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Abstract

The increasing prevalence of health issues such as obesity, hypertension, and diabetes has heightened consumer interest in healthier dietary choices. In this context, research into natural sugar alternatives has accelerated. This study examined the incorporation of *Stevia rebaudiana* (stevia), a natural sweetener, into fruit yogurt formulations to reduce sugar consumption. Additionally, apples, which are abundant in the Amasya region, were dehydrated into apple powder to enhance the product's shelf life and ease of use. The feasibility of using stevia and apple powder in yogurt production was investigated. In this study, plain yogurt and fruit yogurt containing 5% apple powder and varying levels of sugar (5%, 10%, 15%) or stevia (5%, 10%, 15%) were produced. Subsequently, physicochemical and sensory analyses were performed. The parameters examined included dry matter (10.15–25.38%), color (L*: 71.20–86.25, a*: 3.95–10.66, b*: 16.85–29.93), pH (2.23–2.77), Water-Holding Capacity (37.37–67.73%), acidity (0.42–0.88%), water activity (0.89–0.92), serum separation (4.07–12.40%), and viscosity (143.24–665.42 cP). During storage, all samples showed a decrease in pH values (11.6–16%), an increase in acidity (13.8–95.23%), and an increase in water holding capacity (8–41.01%). Overall acceptability scores decreased by 50% or more, while viscosity values increased (%14.59–192). Sensory evaluations revealed that yogurts containing 10% and 15% stevia received the highest scores in terms of overall liking and purchase intent. The analyses demonstrated that incorporating *Stevia rebaudiana* and apple powder in yogurt production is feasible, yielding a healthy, functional, and consumer-preferred product for modern diets.

Keywords Fermented milk product · Rheology · Sensory · Water holding capacity

Introduction

In recent years, food manufacturers have taken significant steps toward reducing sugar and synthetic additives in their products. This shift is driven not only by the rising incidence of obesity and diabetes but also by increasing consumer demand for healthier and more functional foods [1, 2]. Consequently, the use of plant-based natural additives in the food and beverage industry is steadily increasing [3].

Today, artificial sweeteners such as saccharin, aspartame, and sucralose are used as non-nutritive sugar substitutes [4, 5]. However, these sweeteners have also been linked to various health problems, similar to those associated with sucrose [4, 5]. This has further fueled interest in natural and healthy products, leading to a growing trend of using natural sweeteners in dairy products [4–6].

Stevia, a natural sweetener derived from the *Stevia rebaudiana Bertoni* plant, has gained popularity as an alternative to sucrose and artificial sweeteners [7]. Stevioside, the primary steviol glycoside, is approximately 300 times sweeter than sucrose and is known for its various health benefits, including antihypertensive, anti-inflammatory, antitumor, antidiarrheal, diuretic, and antihyperglycemic effects [4, 5, 8].

Plant-derived phenolic compounds are also among the promising natural additives for the food industry. These

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compounds can extend shelf life and offer numerous health benefits [3]. In the dairy sector, the use of plant extracts is increasing to enhance antimicrobial, antioxidant, and anti-hypertensive properties [3, 9].

Yogurt is a widely consumed fermented dairy product known for its health benefits and variety of flavors [6, 10]. During yogurt production, milk proteins are coagulated by lactic acid-producing bacteria such as *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, forming a gel-like structure [11, 12]. Yogurt can be enriched with probiotics, prebiotics, vitamins, minerals, flavorings, fruits, and sweeteners (including sugar) [13].

Sugar is preferred by consumers in dairy products like yogurt due to its sensory appeal [14]. It also plays an important role in yogurt production, influencing texture, viscosity, color, and shelf life [15]. However, excessive sugar consumption is associated with numerous health issues, including obesity, diabetes, tooth decay, cardiovascular diseases, and kidney disorders [16]. Accordingly, demand for low-sugar or sugar-free products has increased [7].

Many studies have investigated the effects of reducing or replacing sucrose with alternative sweeteners on the characteristics, quality, and consumer acceptance of yogurt [6, 16]. The food industry faces challenges in replacing sugar with natural or artificial sweeteners due to potential impacts on product quality, sensory properties, and consumer preferences. The growing demand for healthier, low-calorie foods has necessitated research into plant-based natural sweeteners [17, 18].

Although natural sweeteners are widely used in products such as baked goods, beverages, and snack bars, their use in dairy products, particularly yogurt remains relatively limited. This study aims to address that gap by producing stevia-enriched yogurt and evaluating quality parameters, including the effects of apple powder addition compared to control and sugar-sweetened yogurts during storage.

Materials and methods

Materials

Apple powder was obtained from a local producer (Köylüm Gurme) in Amasya. The stevia powdered sugar used in yogurt production was 100% pure with prebiotic properties and was procured from the market (Splenda). All chemicals used in sample analyses were supplied by Sigma (St. Louis, MO, USA). The sodium hydroxide used was obtained from Sigma-Aldrich, with CAS number 1310-73-2. The yogurt samples used in this study were produced by factory production stages at Zeki Kuloğlu Dairy Products Industry and Trade Limited Company in Amasya.

Methods

Yogurt

The yogurt samples used in the analyses were produced at Zeki Kuloğlu Dairy Products Industry and Trade Limited Company, located in Amasya. Before the incubation stage, predetermined amounts of apple powder, sugar, and *Stevia rebaudiana* were added. Subsequently, the yogurt cups were sealed and incubated at 43 °C for approximately three (3) hours. Following incubation, the yogurts were stored at +4 °C. Based on the ratios determined through preliminary trials, a total of eight (8) different yogurt samples were prepared. These samples included: plain yogurt, a control group containing 5% apple powder (positive control group), yogurts containing 5% apple powder along with 5%, 10%, and 15% sugar, and yogurts containing 5% apple powder along with 5%, 10%, and 15% stevia. The produced samples were stored at +4 °C in the laboratory of Suluova Vocational School, and the planned analyses were carried out accordingly (Figs. 1 and 2).

Analyses of yogurt samples

Physical and chemical analyses Analyses of the mixtures prepared for yogurts were carried out on days 1, 10, and 20 of storage, for each replicate.

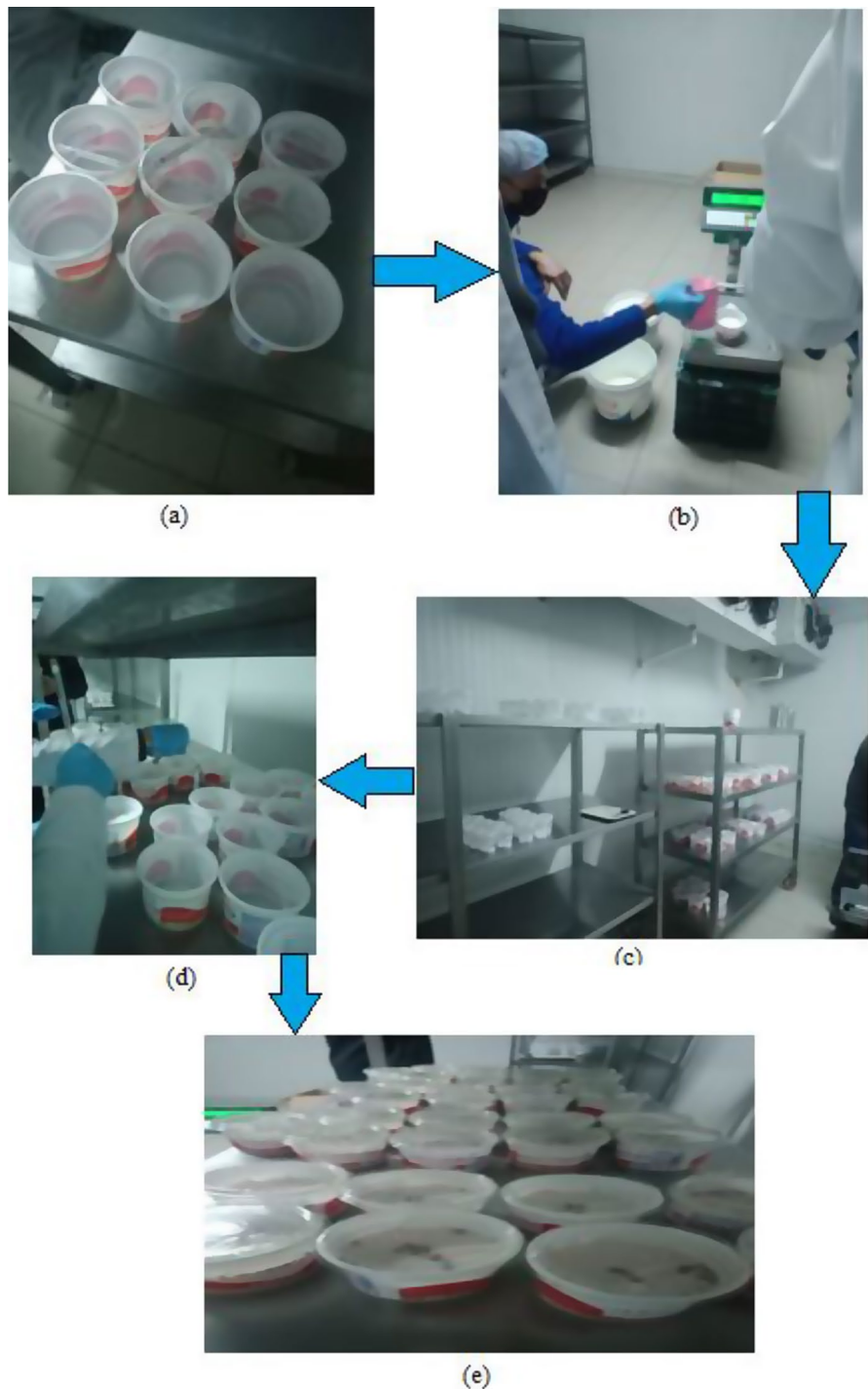
pH determination The pH values of the yogurt samples were measured using a digital pH meter (± 0.01 pH) equipped with a glass electrode (inoLab pH 3110, WTW GmbH, Weilheim, Germany) (Figs. 3, 4 and 5).

Titrateable acidity measurements The titrateable acidity of the yogurt samples was determined using the alkaline titration method, as specified in the International Dairy Federation (IDF) Standard. Results were expressed as a percentage of lactic acid (lactic acid %) [19].

Determination of dry matter content

The dry matter content of yogurt is a significant indicator of quality. A dry matter content of approximately 13–14% is considered ideal for yogurt. Excessively low or high dry matter content may lead to undesirable taste and texture. The dry matter content of the yogurt samples was determined gravimetrically (w/w%) by drying 3–5 g of samples at 100 ± 1 °C until a constant weight was achieved [19]. A 3–5 g yogurt sample was weighed to a precision of ± 0.001 g

Fig. 1 Production of the yogurt process (**a**: preparation of packaging containers; **b**: addition of raw materials to be processed into yogurt, **c**: addition of apple powder, sugar, and *Stevia rebaudiana* in specified proportions, **d**: incubation of prepared samples, **e**: obtained yogurt samples)



into a clean crucible (Shimadzu ATX224). The crucible was placed in an oven at 100 °C (± 1 °C precision, Nüve N 500) and dried until a constant weight was reached. It was then removed from the oven, cooled to room temperature, then reweighed, and the dry matter content was calculated using the following formula:

$$\text{Dry matter content (\%)} : \left(\frac{W_2}{W_1} \right) \times 100 \quad (1)$$

W_2 : Final weight (g).
 W_1 : Initial weight (g).

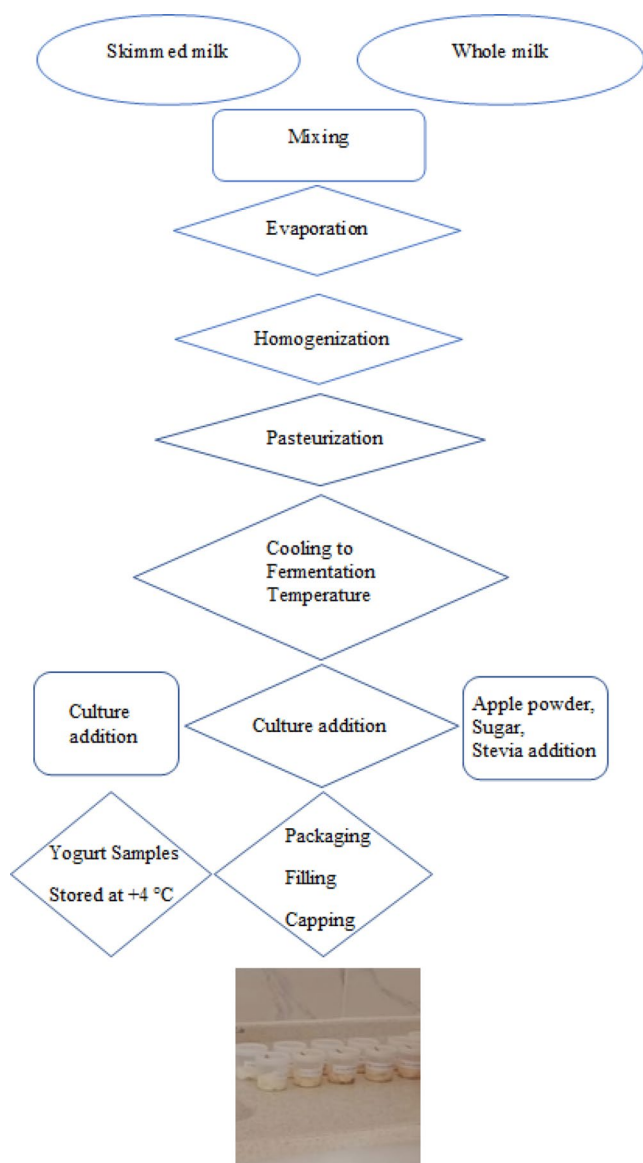


Fig. 2 Yogurt production flow chart (with apple powder, sugar, and stevia addition)

Determination of serum separation

Serum separation is an important indicator of yogurt quality. Excessive serum separation can result in a watery texture and reduced shelf life. The amount of serum separated was determined by filtering 25 g of yogurt through coarse filter paper for 120 min at 4 ± 1 °C, and weighing the collected serum (in grams) [20] (Figs. 6).

A 25 g yogurt sample was weighed with ± 0.001 g precision and placed into a clean centrifuge tube (Shimadzu ATX224). The tube was centrifuged at $1789 \times g$ for 15 min (Hermle Z 206 A). After centrifugation, the separated serum was carefully poured into a pre-weighed beaker. The beaker was reweighed, and serum separation was calculated using the following formula:

$$\text{Serum separation (\%)} : \left(\frac{V_2}{V_1} \right) \times 100 \quad (2)$$

V_2 : Weight of serum (g).

V_1 : weight of the yogurt sample (g).

Determination of Water-Holding capacity (WHC)

Water-holding capacity (WHC) is a critical quality parameter that affects yogurt texture, shelf life, and overall consumer acceptance. A higher WHC indicates that the yogurt retains more water, resulting in a firmer texture and reduced serum separation (syneresis). To evaluate WHC, a 5 g (± 0.001 g) yogurt sample (Shimadzu ATX224) was centrifuged at $2164 \times g$ for 30 min at 10 °C (Hermle Z 206 A). After centrifugation, the supernatant was carefully removed, and the remaining yogurt pellet was weighed. WHC was calculated using the following formula [21]:

$$\text{Water - holding capacity} : \left(\frac{M_2}{M_1} \right) \times 100 \quad (3)$$

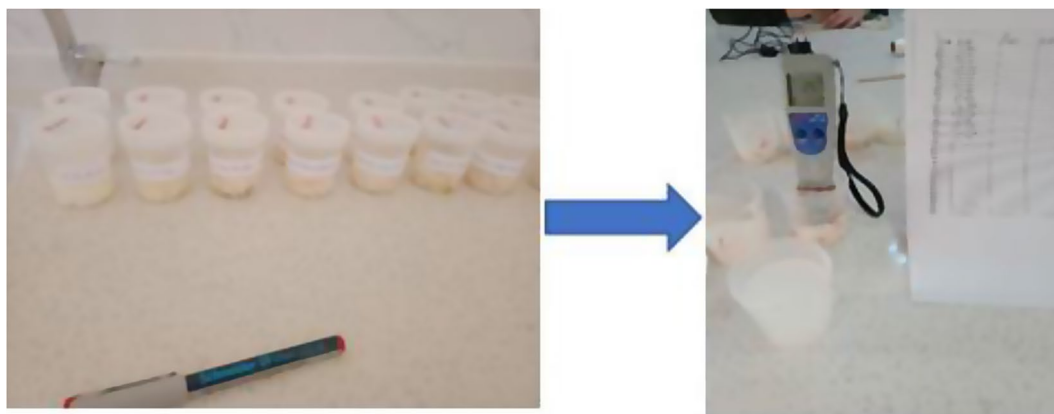


Fig. 3 pH analysis of yogurt samples

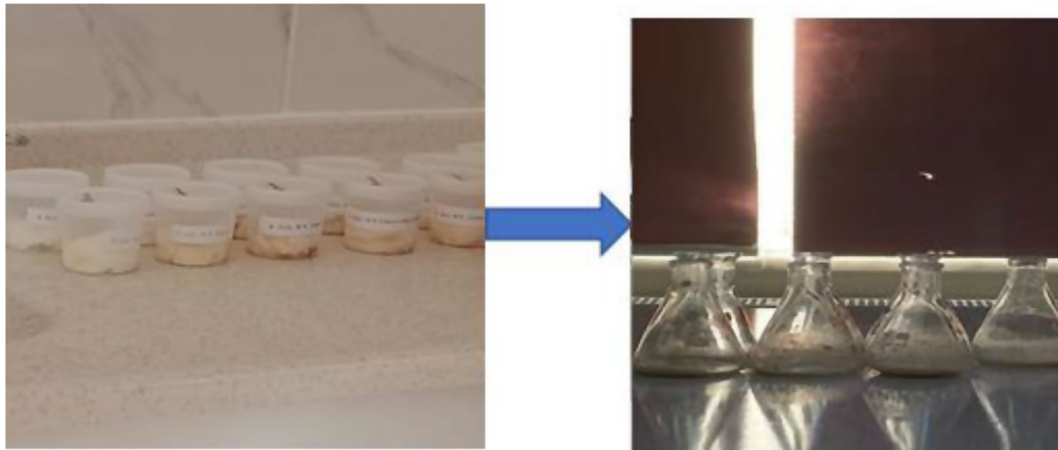


Fig. 4 Acidity analysis of yogurt samples



Fig. 5 a_w analysis of yogurt samples

M_2 : Pellet Weight (g).

M_1 : Initial Weight (g).

Color determination

Color analyses were conducted using a Minolta CR-410 color measurement device (Minolta Co. Ltd., Tokyo, Japan) [22]. Yogurt samples were placed into a clean sample container, which was then positioned in the colorimeter to measure color values. The measured values were recorded, and the yogurt's color was evaluated accordingly. Color is an important quality indicator in yogurt. Consumers generally

prefer yogurts with a bright white appearance, while those with a yellowish or brownish hue may be perceived as stale or spoiled.

Determination of water activity

The water activity (a_w) values of the samples were determined using a water activity measuring device (Nova-sina, LabSwift-aw) located in the laboratory of Suluova Vocational School at Amasya University. The water activity values of the yogurt samples (although the text refers to “ayran”, the context indicates yogurt) were monitored throughout the storage period, and microbiological activity was evaluated accordingly.

Sensory analysis

Sensory analyses were conducted by the academic staff of Suluova Vocational School based on the attributes of appearance, color, texture, odor, taste-aroma, and overall acceptability. The analyses were performed by a panel of 10 trained members on the 1st, 10th, and 20th days of storage. Yogurt samples containing *Stevia rebaudiana* and sugar were compared against each other in terms of changes occurring during storage. The evaluations were carried out using a 9-point hedonic scale, where 1 indicated “very poor” and 9 indicated “very good” acceptability. The sensory evaluation form used in the analysis is provided in Annex 1 [23, 24].

The panel, composed of 10 trained assessors, evaluated the yogurt samples. Panelists were asked to assess the samples based on their appearance, color, texture, odor, taste-aroma, and overall liking. They scored each sample on a 9-point scale, with 1 being the lowest and 9 the highest.

During the evaluation process, panelists were provided with a list of descriptive terms to guide their assessments. All evaluations were performed in individual booths, and

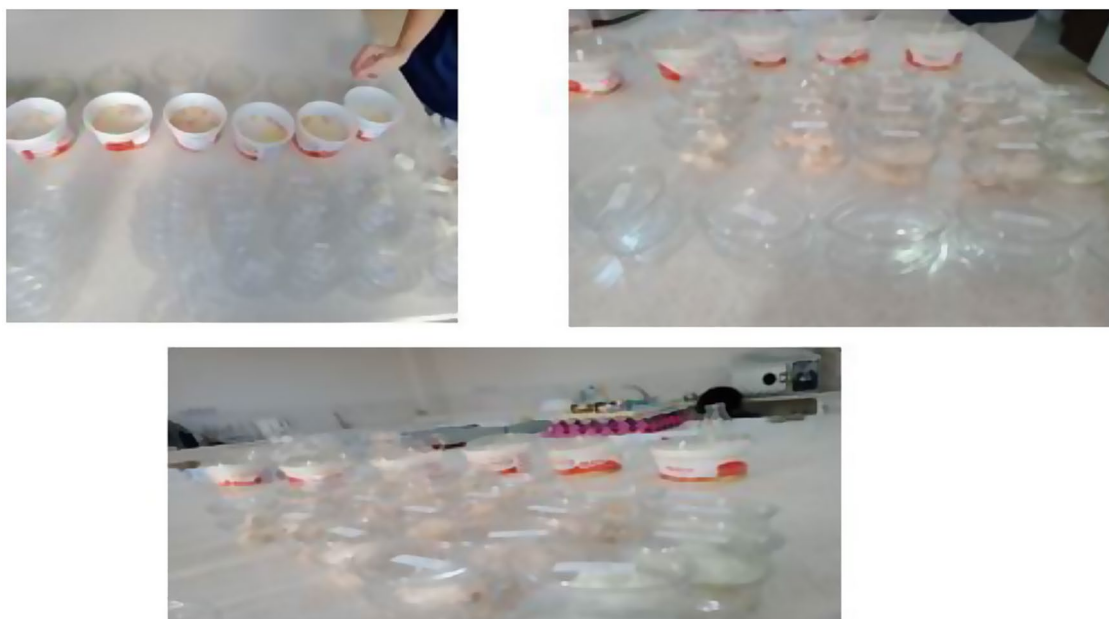


Fig. 6 Sensory analysis of yogurt samples

panelists rinsed their mouths with water between each sample to prevent flavor carryover. The sensory data were analyzed using statistical methods.

Sensory analysis is an important tool for evaluating the quality of food products. It is used to assess characteristics such as appearance, color, texture, odor, taste, and overall acceptability. The results obtained from sensory analyses can be used to identify areas where the product may be improved.

Rheological measurements of yogurt samples

The rheological properties of the yogurt samples were evaluated using a HAAKE RheoStress 600HP viscometer operating at a constant temperature of 5 °C. A Z20 DIN cylinder geometry was used for the measurements. A 2 mL portion of each yogurt sample was collected and transferred onto the rheometer plate. To ensure repeatability, independent repeated measurements were conducted for each sample. Data analysis was performed using RheoWin Pro software (version 2.94, Thermo HAAKE).

A thixotropy test was applied to describe the flow behavior of the yogurt samples. The degree of thixotropy was determined by calculating the hysteresis loop area (ΔA) formed between the upward and downward flow curves [25].

Statistical analysis

All experiments were repeated at least twice, and mean standard deviations were calculated. One-way analysis of

Table 1 Physicochemical analysis of milk used in yogurt production

Properties	Fat milk	Skimmed milk
Fat (%)	3.7	0.1
Dry matter (%)	11.25	10.5
SH	6.8	7
pH	6.78	6.72
Brix	9.8	10

variance (ANOVA) was used to evaluate the effects of different samples on physicochemical, and sensory properties. To compare the effects of storage time, Tukey's multiple comparison test was applied. Other data were analyzed using the ANOVA method with SPSS 16.0 statistical software. The level of statistical significance was set at 0.05 using the Tukey test.

Results and discussion

Milk data used in yogurt analysis

The milk data used in yogurt production are presented in Table 1. The production was carried out by the manufacturing process of Kuloğlu Dairy Products Industry and Trade Limited Company.

Dry matter content in yogurt samples

In this study, the effects of apple powder, sugar, and stevia addition on the dry matter content of yogurt samples were evaluated. The findings revealed that both the type of

ingredients used in the formulation and the storage period had a statistically significant effect on the dry matter content ($p < 0.05$). Throughout the storage period, the control group exhibited the lowest dry matter content, whereas the EYC sample containing 5% apple powder and 15% sugar demonstrated the highest dry matter content (24.60%) on day 10. This result can be attributed to the direct contribution of sugar to the total dry matter. Similarly, the EYZ sample, which contained 15% stevia and 5% apple powder, also showed high dry matter values on days 1 and 20 of measurement Table 2, 3 and 4.

Comparable findings have been reported in previous studies. For instance, while the total dry matter content in fruit yogurts has been reported as 16.58%, this value ranged between 14.32% and 14.37% in yogurts containing apple fiber [26–28]. The dry matter values obtained in this study are consistent with the literature and indicate that the addition of apple powder can enhance this content. The inclusion of apple powder in yogurt formulations increases the total dry matter content, resulting in a denser, creamier, and more stable yogurt structure. The dietary fiber and natural sugars in apple powder enhance the product's Water-Holding Capacity, reduce syneresis (serum separation), and positively affect textural attributes [29]. In a study, the addition of 2–5% apple powder increased the total dry matter content by 8–12%, depending on the concentration and processing conditions [30]. This effect was also observed in this study, particularly in samples where the contribution of apple powder was pronounced Table 5, 6.

On the other hand, the contribution of stevia to the dry matter content is limited. This can be explained by the fact

that stevia is used in very low concentrations compared to sugar [31]. However, the combined use of stevia and apple powder may lead to structural interactions between milk proteins and apple-derived pectins, resulting in a more stable gel network. This can indirectly enhance the texture characteristics associated with dry matter content [32]. This synergistic effect not only improves the mouthfeel but also helps maintain compliance with regulatory requirements for product composition. Some losses in dry matter content were observed during the storage period, which were attributed to moisture loss, changes in protein structure, or compositional variations due to microbial activity. Similarly, previous studies on yogurts enriched with stevia reported an increase in total dry matter content on day 1; however, this content remained stable throughout storage ($p > 0.05$) [33].

These findings support the results of our study and emphasize the need to carefully evaluate the impact of plant-based ingredients on the yogurt matrix during storage. The use of plant-based ingredients such as apple powder and stevia in yogurt formulations may not only enhance nutritional value but also improve physicochemical and structural properties. Such natural additives hold significant potential for the development of functional food products. Further studies are recommended to explore different concentrations and combinations in more detail.

Color characteristics of yogurt samples

This study evaluated the effects of apple powder, sugar, and stevia added at different concentrations on the color parameters (L^* , a^* , b^* , and Δh) of yogurt samples. Color is one of the first sensory attributes assessed by consumers and directly influences product acceptability. The findings revealed that the color properties of the yogurts were significantly affected by the type of additive used and the storage period.

The L^* value (lightness) showed significant differences among the samples. Statistically significant differences ($p < 0.05$) were observed particularly on days 1 and 10; however, these differences diminished by day 20. The control group exhibited the highest L^* values throughout the storage period, indicating that the addition of ingredients caused a darkening of the yogurt color. This can be attributed to the Maillard reactions triggered by components such as apple powder and sugar during fermentation. These results are consistent with previous studies reporting that apple powder reduces L^* values [29, 30]. Rich in polyphenols and carotenoids, apple powder caused noticeable darkening in yogurt through oxidative browning reactions.

Regarding the a^* value (red-green axis), the highest values were observed in the EYX sample (5% apple powder + 5% stevia) on days 1 and 10, and in the EY sample on

Table 2 Dry matter content in the yogurt samples

Properties	Samples	Storage Days		
Dry matter (%)	First day	10th day	20th day	
K	10.49 ^{Ea} ± 0.14	10.15 ^{Eb} ± 0.78	10.21 ^{Fb} ± 0.69	
EY	14.40 ^{Db} ± 0.51	15.15 ^{Da} ± 0.27	13.59 ^{Ec} ± 0.62	
EYA	21.15 ^{Ba} ± 0.49	18.18 ^{Cb} ± 0.32	18.00 ^{Cb} ± 0.50	
EYB	20.43 ^{Bb} ± 0.56	21.57 ^{Ba} ± 0.66	19.04 ^{Cc} ± 0.30	
EYC	20.16 ^{Bb} ± 2.87	24.60 ^{Aa} ± 0.62	19.44 ^{Cc} ± 0.10	
EYX	16.66 ^{Cb} ± 0.68	18.31 ^{Ca} ± 0.13	15.89 ^{Dc} ± 0.87	
EYY	22.14 ^{Ba} ± 0.15	22.07 ^{Ba} ± 0.44	21.38 ^{Bb} ± 0.55	
EYZ	24.42 ^{Aa} ± 1.76	24.30 ^{Aa} ± 0.61	23.52 ^{Ab} ± 0.43	

*: Mean ± standard deviation. A-E: Capital letters within a column indicate significant differences ($p < 0.05$) between different yogurt types. a-d: Lowercase letters within a row indicate significant differences ($p < 0.05$) between different storage times

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

Table 3 Color values of the yogurt samples

Properties	Samples	Storage days		
		First day	10th day	20th day
L*	K	84.02 ^{Aa} ±2.73	86.25 ^{Aa} ±2.25	82.76 ^{Aa} ±1.13
	EY	81.11 ^{Ba} ±1.59	81.47 ^{Ba} ±2.91	76.36 ^{Aa} ±1.17
	EYA	78.16 ^{Da} ±3.12	80.92 ^{Ba} ±1.22	74.01 ^{Aa} ±2.49
	EYB	79.18 ^{Ca} ±0.86	80.49 ^{Ba} ±1.03	72.12 ^{Ab} ±1.24
	EYC	72.38 ^{Gb} ±1.13	80.83 ^{Ba} ±1.74	76.10 ^{Aab} ±0.60
	EYX	71.20 ^{Hc} ±2.76	81.00 ^{Ba} ±1.51	75.40 ^{Ab} ±1.72
	EYY	76.27 ^{Eb} ±2.05	79.46 ^{Ba} ±1.34	79.37 ^{Aa} ±1.32
	EYZ	75.43 ^{Fa} ±1.71	75.32 ^{Ca} ±1.38	75.52 ^{Aa} ±1.23
a*	K	4.08 ^{Ga} ±0.50	4.06 ^{Aa} ±0.07	3.95 ^{Aa} ±0.44
	EY	8.73 ^{Fa} ±0.86	9.93 ^{Aa} ±1.20	10.1 ^{Aa} ±1.68
	EYA	9.76 ^{Ca} ±0.91	9.62 ^{Aa} ±0.58	9.29 ^{Aa} ±1.26
	EYB	9.72 ^{Da} ±0.25	10.10 ^{Aa} ±1.16	7.93 ^{Aa} ±1.08
	EYC	9.91 ^{Ba} ±0.94	9.94 ^{Aa} ±1.74	5.28 ^{Ab} ±1.38
	EYX	10.66 ^{Aa} ±0.82	10.52 ^{Aa} ±0.78	5.48 ^{Ab} ±0.94
	EYY	9.94 ^{Ba} ±0.47	10.29 ^{Aa} ±0.55	9.25 ^{Aa} ±1.30
	EYZ	9.66 ^{Ea} ±0.55	9.92 ^{Aa} ±1.02	5.52 ^{Ab} ±0.16
b*	K	19.61 ^{Aa} ±1.23	19.15 ^{Ba} ±0.74	16.85 ^{Ab} ±1.13
	EY	23.82 ^{Aa} ±1.30	24.42 ^{Aa} ±1.12	23.28 ^{Aa} ±0.89
	EYA	22.64 ^{Aa} ±1.02	24.24 ^{Aa} ±0.95	24.04 ^{Aa} ±0.18
	EYB	24.78 ^{Aa} ±0.13	24.26 ^{Aa} ±0.80	20.90 ^{Ab} ±1.20
	EYC	24.84 ^{Aa} ±1.74	24.75 ^{Aa} ±0.87	17.75 ^{Ab} ±1.60
	EYX	29.93 ^{Aa} ±1.36	26.18 ^{Aa} ±1.29	18.20 ^{Aa} ±1.33
	EYY	23.59 ^{Aa} ±0.87	24.65 ^{Aa} ±0.39	23.54 ^{Aa} ±1.64
	EYZ	24.31 ^{Aa} ±1.31	24.10 ^{Aa} ±1.07	18.36 ^{Ab} ±1.48
Δh	K	78.25 ^{Aa} ±1.22	77.99 ^{Aa} ±0.65	76.82 ^{Aa} ±0.72
	EY	69.92 ^{Ba} ±1.14	67.92 ^{Ba} ±1.43	68.45 ^{Aa} ±1.24
	EYA	66.72 ^{Da} ±1.53	68.36 ^{Ba} ±0.56	69.85 ^{Aa} ±1.25
	EYB	68.57 ^{BCa} ±0.60	67.44 ^{Ba} ±1.65	69.82 ^{Aa} ±1.37
	EYC	68.27 ^{BCDb} ±1.12	68.22 ^{Bb} ±1.64	73.77 ^{Aa} ±1.68
	EYX	67.04 ^{CDb} ±1.45	68.12 ^{Bb} ±0.60	73.33 ^{Aa} ±1.58
	EYY	67.15 ^{CDa} ±0.51	67.35 ^{Ba} ±0.78	68.62 ^{Aa} ±1.41
	EYZ	68.34 ^{BCDa} ±0.64	67.66 ^{Ba} ±1.37	66.94 ^{Aa} ±1.34

*: Mean ± standard deviation. A-E: Capital letters within a column indicate significant differences ($p < 0.05$) between different yogurt types. a-d: Lowercase letters within a row indicate significant differences ($p < 0.05$) between different storage times

L* value: lightness-darkness, a* value: Position between green and red, b* value: Position between blue and yellow

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

day 20. This suggests that the natural pigments (particularly anthocyanins and certain polyphenolic compounds) present in apple powder contributed to the red hues [34]. The increase in a* values can be explained by the presence of these pigments and reactions occurring during fermentation. Since stevia does not directly contain color pigments, its effect on a* values is considered limited. However, Maillard reactions resulting from protein-sugar interactions during extended storage also caused slight color changes in the presence of stevia [35].

The b* value (yellow-blue axis) did not show statistically significant differences among the samples ($p > 0.05$). However, the increased yellowness observed in some samples

may be associated with the carotenoid compounds found in apple powder. This increase in b* values can be viewed as a factor enhancing the visual appeal of yogurt. Additionally, some studies have linked changes in the yellow-blue axis to fermentation-related pH fluctuations, pigment degradation, and modifications in protein structure [31, 35].

The Δh value (color difference) varied over the storage period. Statistically significant differences were observed on days 1 and 10, but these differences disappeared by day 20. This can be explained by the reduced pigment stability over time and the eventual equilibrium of color parameters. The addition of stevia and sugar was found to influence Δh values, although this effect declined over time.

Table 4 Physical and chemical analyses of the yogurt samples

Properties	Samples	Storage days		
		First day	10th day	20th day
pH	K	2.77 ^{Aa} ±0.04	2.58 ^{Ab} ±0.01	2.41 ^{Ac} ±0.00
	EY	2.54 ^{Da} ±0.01	2.35 ^{ABb} ±0.03	2.25 ^{Cc} ±0.01
	EYA	2.50 ^{Ea} ±0.00	2.36 ^{ABb} ±0.01	2.23 ^{Dc} ±0.00
	EYB	2.57 ^{Ca} ±0.01	2.34 ^{ABb} ±0.01	2.25 ^{Cc} ±0.01
	EYC	2.57 ^{Ca} ±0.01	2.58 ^{Aa} ±0.48	2.29 ^{Ba} ±0.00
	EYX	2.51 ^{DEa} ±0.00	2.28 ^{Bb} ±0.00	2.24 ^{CDc} ±0.01
	EYY	2.57 ^{Ca} ±0.00	2.37 ^{ABb} ±0.00	2.24 ^{CDc} ±0.00
	EYZ	2.66 ^{Ba} ±0.01 2.29 ^{Bb} ±0.00 2.23 ^{Dc} ±0.00		
Water holding capacity	K	40.83 ^{Cb} ±0.95	39.36 ^{Fb} ±0.35	49.76 ^{Fa} ±1.64
	EY	44.26 ^{Ab} ±0.37	42.12 ^{Eb} ±1.13	52.26 ^{CDEa} ±1.20
	EYA	43.54 ^{ABb} ±1.31	45.91 ^{Db} ±2.04	55.86 ^{Ca} ±1.39
	EYB	37.37 ^{Dc} ±1.47	51.34 ^{Bb} ±0.76	63.35 ^{Ba} ±1.10
	EYC	37.52 ^{Dc} ±0.30	57.81 ^{Aa} ±1.37	54.86 ^{CDb} ±2.72
	EYX	40.92 ^{Cc} ±0.54	49.22 ^{Cb} ±0.93	51.21 ^{EFa} ±1.28
	EYY	41.30 ^{Cc} ±1.26	47.55 ^{CDb} ±1.45	51.21 ^{EFa} ±1.28
	EYZ	41.94 ^{BCc} ±0.90 47.21 ^{Db} ±0.91 67.73 ^{Aa} ±2.08		
Acidity	K	0.72 ^{Ab} ±0.01	0.76 ^{Aa} ±0.02	0.82 ^{Cb} ±0.00
	EY	0.75 ^{Aa} ±0.00	0.64 ^{Ac} ±0.02	0.64 ^{Ac} ±0.02
	EYA	0.65 ^{Bb} ±0.00	0.66 ^{Ab} ±0.02	0.77 ^{Ba} ±0.00
	EYB	0.42 ^{Dc} ±0.01	0.57 ^{Aa} ±0.41	0.68 ^{Db} ±0.00
	EYC	0.58 ^{Cc} ±0.07	0.71 ^{Ab} ±0.00	0.77 ^{Ba} ±0.01
	EYX	0.60 ^{Cb} ±0.01	0.76 ^{Aa} ±0.01	0.85 ^{Ba} ±0.00
	EYY	0.65 ^{Bc} ±0.00	0.83 ^{Ab} ±0.01	0.88 ^{Aa} ±0.02
	EYZ	0.42 ^{Db} ±0.02	0.72 ^{Aa} ±0.00	0.82 ^{Ca} ±0.01
Water activity	K	0.91 ^{Aa} ±0.00	0.90 ^{ABa} ±0.00	0.92 ^{Aa} ±0.02
	EY	0.91 ^{Aa} ±0.00	0.90 ^{ABb} ±0.00	0.89 ^{Bc} ±0.00
	EYA	0.90 ^{Bb} ±0.00	0.90 ^{Aa} ±0.00	0.89 ^{Bc} ±0.00
	EYB	0.90 ^{Ba} ±0.00	0.89 ^{Da} ±0.00	0.89 ^{Ba} ±0.00
	EYC	0.91 ^{Aa} ±0.00	0.89 ^{Db} ±0.00	0.89 ^{Bb} ±0.00
	EYX	0.90 ^{Aa} ±0.00	0.89 ^{Da} ±0.00	0.89 ^{Bb} ±0.00
	EYY	0.89 ^{Cc} ±0.00	0.89 ^{Da} ±0.00	0.89 ^{Bb} ±0.00
	EYZ	0.89 ^{Cc} ±0.00 0.90 ^{Ca} ±0.00 0.89 ^{Bb} ±0.00		
Serum separation	K	9.05 ^{Fb} ±0.05	10.92 ^{Ba} ±0.09	11.00 ^{Aa} ±0.08
	EY	12.40 ^{Aa} ±0.11	10.47 ^{Cb} ±0.12	8.50 ^{Fc} ±0.08
	EYA	12.00 ^{Ba} ±0.08	10.07 ^{Eb} ±0.15	9.50 ^{Dc} ±0.08
	EYB	11.15 ^{Ca} ±0.12	10.25 ^{Db} ±0.05	9.77 ^{Bc} ±0.05
	EYC	10.07 ^{Da} ±0.09	9.15 ^{Gb} ±0.05	8.97 ^{Ec} ±0.05
	EYX	5.55 ^{Hc} ±0.05	9.47 ^{Fb} ±0.05	9.65 ^{Ca} ±0.05
	EYY	9.50 ^{Eb} ±0.08	11.07 ^{Aa} ±0.09	4.07 ^{Hc} ±0.09
	EYZ	7.97 ^{Gb} ±0.05	8.35 ^{Ha} ±0.12	8.27 ^{Ga} ±0.05

*: Mean ± standard deviation. A-E: Capital letters within a column indicate significant differences ($p < 0.05$) between different yogurt types. a-d: Lowercase letters within a row indicate significant differences ($p < 0.05$) between different storage times

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

According to the literature, yogurt samples containing stevia typically exhibit L^* values between 70.86 and 73.58, a^* values between (-3.11) and (-2.51), and b^* values between 6.72 and 8.23 [36]. Higher a^* and b^* values observed in this study can be attributed to the contribution of apple powder. Due to its high natural pigment content, apple powder increased the red and yellow tones in yogurt.

Similar color shifts have also been reported in yogurts formulated with plant-based additives such as beetroot or Aloe vera [32, 35].

Yogurts produced with freeze-dried blackcurrant, beetroot, or Aloe vera have also exhibited similar color changes. In these cases, the type of additive, its pigment content, and the concentration used in the formulation were the

Table 5 Sensory analysis values of the yogurt samples

Properties	Samples	Storage days		
		First day	10th day	20th day
Color and appearance	K	4.75 ^{Aa} ±0.50	4.50 ^{Aa} ±0.57	3.75 ^{Aa} ±1.50
	EY	4.75 ^{Aa} ±0.50	4.50 ^{Aa} ±0.57	4.00 ^{Aa} ±0.81
	EYA	4.25 ^{Aa} ±0.50	4.00 ^{ABa} ±0.81	3.25 ^{Aa} ±1.70
	EYB	4.50 ^{Aa} ±0.57	4.75 ^{Aa} ±0.50	2.50 ^{Ab} ±1.00
	EYC	4.50 ^{Aa} ±0.57	4.25 ^{ABa} ±0.50	3.25 ^{Aa} ±1.50
	EYX	5.00 ^{Aa} ±0.00	3.50 ^{Bab} ±0.57	2.25 ^{Ab} ±1.25
	EYY	5.00 ^{Aa} ±0.00	4.50 ^{Aa} ±0.57	2.25 ^{Ab} ±1.89
	EYZ	4.50 ^{Aa} ±0.57	4.25 ^{ABab} ±0.50	2.50 ^{Ab} ±1.91
Structure consistency (with a spoon)	K	4.75 ^{Aa} ±0.50	4.00 ^{ABa} ±0.00	4.25 ^{Aa} ±0.47
	EY	4.75 ^{Aa} ±0.50	4.50 ^{ABa} ±1.00	3.25 ^{Aa} ±0.62
	EYA	4.75 ^{Aa} ±0.50	4.50 ^{ABa} ±0.57	3.50 ^{Aa} ±0.64
	EYB	4.25 ^{ABa} ±0.95	4.75 ^{Aa} ±0.50	3.00 ^{Ab} ±0.40
	EYC	4.50 ^{Aa} ±0.57	4.25 ^{ABab} ±0.50	3.50 ^{Ab} ±0.28
	EYX	4.75 ^{Aa} ±0.50	3.75 ^{Ba} ±0.50	2.50 ^{Ab} ±0.50
	EYY	4.75 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	2.25 ^{Ab} ±0.94
	EYZ	5.00 ^{Aa} ±0.00	4.50 ^{ABa} ±0.57	2.75 ^{Ab} ±0.85
Structure consistency (by mouth)	K	5.00 ^{Aa} ±0.00	4.50 ^{ABa} ±0.57	4.00 ^{Ab} ±0.81
	EY	4.75 ^{Aa} ±0.50	4.50 ^{Aa} ±0.57	3.75 ^{Aa} ±0.95
	EYA	5.00 ^{Aa} ±0.00	4.50 ^{Aa} ±0.57	3.00 ^{Ab} ±1.41
	EYB	4.75 ^{Aa} ±0.50	4.50 ^{Aa} ±0.57	2.25 ^{Ab} ±1.25
	EYC	4.75 ^{Aa} ±0.50	4.50 ^{Aa} ±1.00	3.00 ^{Ab} ±0.81
	EYX	4.50 ^{Aa} ±0.57	4.00 ^{Aa} ±0.81	2.50 ^{Ab} ±1.00
	EYY	4.75 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	2.50 ^{Ab} ±1.73
	EYZ	5.00 ^{Aa} ±0.00	4.50 ^{Aa} ±0.57	2.50 ^{Ab} ±1.73
Taste-aroma	K	4.75 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	3.75 ^{Ab} ±0.50
	EY	4.25 ^{Aa} ±1.50	4.00 ^{Aa} ±0.81	2.25 ^{ABb} ±0.50
	EYA	4.50 ^{Aa} ±0.57	4.00 ^{Aa} ±1.15	2.25 ^{ABb} ±1.25
	EYB	4.50 ^{Aa} ±0.57	4.75 ^{Aa} ±0.50	1.50 ^{Bb} ±1.00
	EYC	4.25 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	2.50 ^{ABb} ±1.00
	EYX	3.50 ^{Aa} ±1.00	3.75 ^{Aa} ±0.50	1.75 ^{Bb} ±1.50
	EYY	4.75 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	1.25 ^{Bb} ±0.50
	EYZ	4.75 ^{Aa} ±0.50	4.75 ^{Aa} ±0.50	2.50 ^{ABb} ±0.73
Sweetness	K	4.00 ^{ABa} ±0.00	4.00 ^{ABa} ±0.00	2.75 ^{Ab} ±0.50
	EY	3.75 ^{ABa} ±1.25	3.75 ^{ABa} ±0.95	2.00 ^{Ab} ±0.81
	EYA	4.25 ^{ABa} ±0.95	4.25 ^{ABa} ±0.95	2.25 ^{Ab} ±0.95
	EYB	4.25 ^{ABa} ±0.95	4.75 ^{Aa} ±0.50	1.25 ^{Ab} ±0.50
	EYC	4.25 ^{ABa} ±0.95	4.25 ^{ABa} ±0.50	2.50 ^{Ab} ±0.29
	EYX	3.50 ^{Ba} ±1.00	3.50 ^{Ba} ±0.57	1.75 ^{Ab} ±0.95
	EYY	5.00 ^{Aa} ±0.00	4.50 ^{ABa} ±0.57	1.75 ^{Ab} ±0.95
	EYZ	4.75 ^{ABa} ±0.50	4.00 ^{ABab} ±0.00	2.50 ^{Ab} ±0.91
General appreciation	K	4.50 ^{ABa} ±0.57	4.25 ^{ABCa} ±0.50	3.25 ^{Ab} ±0.50
	EY	3.50 ^{Bab} ±1.00	4.00 ^{BCa} ±0.81	2.25 ^{Ab} ±0.50
	EYA	4.75 ^{Aa} ±0.50	4.25 ^{ABCa} ±0.50	2.25 ^{Ab} ±0.25
	EYB	4.25 ^{ABa} ±0.50	4.75 ^{ABa} ±0.50	1.50 ^{Ab} ±1.00
	EYC	4.50 ^{ABa} ±0.57	4.50 ^{ABa} ±0.57	2.75 ^{Ab} ±0.50
	EYX	3.50 ^{Ba} ±1.00	3.50 ^{Ca} ±0.57	1.75 ^{Aa} ±0.50
	EYY	4.75 ^{Aa} ±0.50	5.00 ^{Aa} ±0.00	1.50 ^{Ab} ±0.57
	EYZ	5.00 ^{Aa} ±0.00	4.25 ^{ABCab} ±0.50	2.50 ^{Ab} ±0.91

*: Mean±standard deviation

A-E: Capital letters within a column indicate significant differences ($p<0.05$) between different yogurt typesa-d: Lowercase letters within a row indicate significant differences ($p<0.05$) between different storage times

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

Table 6 Purchase probabilities for yogurt samples

Properties	Samples	Storage days		
		First day	10th day	20th day
Possibility of purchase	K	1.00 ^{Bb} ±0.00	1.00 ^{Bb} ±0.00	2.00 ^{Aa} ±0.81
	EY	2.00 ^{Aa} ±0.81	1.75 ^{ABa} ±0.50	1.50 ^{Aa} ±0.57
	EYA	1.25 ^{ABa} ±0.50	1.50 ^{ABa} ±0.57	2.25 ^{Aa} ±0.95
	EYB	1.50 ^{ABab} ±0.57	1.25 ^{ABb} ±0.50	2.25 ^{Aa} ±0.50
	EYC	2.00 ^{Aab} ±0.00	1.50 ^{ABb} ±0.57	2.75 ^{Aa} ±0.95
	EYX	2.00 ^{Aa} ±0.81	2.00 ^{Aa} ±0.81	2.25 ^{Aa} ±0.95
	EYY	1.25 ^{ABb} ±0.50	1.00 ^{Bb} ±0.00	2.75 ^{Aa} ±0.50
	EYZ	1.25 ^{ABa} ±0.50	1.75 ^{ABa} ±0.50	2.25 ^{Aa} ±0.95

*: Mean±standard deviation. A-E: Capital letters within a column indicate significant differences ($p<0.05$) between different yogurt types. a-d: Lowercase letters within a row indicate significant differences ($p<0.05$) between different storage times

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

determining factors [30, 31]. For example, yogurts with high isomalt content show increased L^* values, resulting in a lighter product appearance, whereas apple powder-containing samples exhibit decreased L^* values due to the browning tendency of pigments [37].

In another study involving the addition of Aloe vera and stevia, a decrease in lightness (L^*), an increase in green tones, and a reduction in yellowness were reported [38]. Many studies have shown that pigment stability deteriorates with pH changes in the yogurt matrix, leading to variations in color parameters [39–41]. Increasing acidity during storage causes degradation of natural pigments such as anthocyanins and betalains, resulting in decreased L^* and b^* values, especially in fruit yogurts. Similarly, in this study, pigment degradation initiated by the addition of apple powder and stevia before fermentation continued throughout the storage period and contributed to the reduction in L^* values.

Significant changes in the color characteristics of yogurts formulated with apple powder, sugar, and stevia were observed in this study. The pigment profile of natural additives (especially apple powder), the chemical reactions occurring during fermentation (notably Maillard reactions), and storage conditions directly influenced the color stability of the product. The decrease in L^* value, in particular, is a key factor affecting the visual perception of yogurt. Therefore, optimizing the concentrations of additives and maintaining appropriate storage conditions are crucial for improving consumer acceptance of functional yogurts.

Physical and chemical analysis of yogurt

In this research, the effects of adding apple powder, stevia, and sugar on the pH values and acidic properties of yogurts were investigated. The results showed a significant decrease in pH values and an increase in acidity, particularly during the storage period. As storage time increased, a decline in pH and a rise in acidity were observed in all samples. This trend is commonly seen in fermented dairy products and results from the utilization of sugars and organic acids by microorganisms present in the medium [42, 43]. These findings are consistent with previous studies. Similarly, a decrease in pH during storage was reported in yogurts produced with apple and strawberry [42].

Furthermore, components such as stevia and apple powder may indirectly affect pH and alter the acidic profile of yogurt, thus influencing product quality. In this study, the lowest pH values were observed in certain samples on days 1, 10, and 20, and these samples had lower pH values than the control group. While all samples showed a decreasing trend in pH under controlled storage conditions, the control group exhibited the highest pH values. Similarly, significant pH differences were detected in yogurts supplemented with “Andiz molass” and grape pomace, with variations attributed to the types of fruit, usage ratios, and compositions [43, 44].

When explaining the effect of apple powder, stevia, and sugar on pH, the buffering capacities of these ingredients should also be considered. Various studies have shown that stevia does not cause a significant direct change in pH or acidity [45, 46]. Since stevia is a non-fermentable sweetener, it has an indirect effect on pH. In yogurts containing stevia, lactic acid bacteria cannot access fermentable carbohydrates, and as a result, these yogurts generally exhibit slightly higher pH values compared to those with sugar [35].

On the other hand, organic acids such as malic acid found in apple powder can lower the pH and increase the sourness of yogurt [29]. These effects may allow the desired pH level to be maintained by balancing apple powder and stevia. In addition to fruit components, the fiber and polyphenols in apple powder affect the yogurt’s buffering capacity. Pectin in apple powder interacts with milk proteins, influencing acidification dynamics and slowing down the pH decrease. This effect can help maintain structural integrity and sensory quality, limiting pH changes during storage [47].

Moreover, the buffering capacity of apple powder helps preserve the quality of yogurt throughout its shelf-life by preventing excessive pH drops, thereby contributing to the maintenance of the product’s sensory and microbial quality. This indicates that polyphenols and fibers in apple powder play a critical role in controlling pH variations. The optimization achieved between stevia and apple powder helps

maintain the yogurt's sensory attributes while preventing excessive sourness. The combined use of these two ingredients preserves the refreshing acidic taste of yogurt while preventing excessive sourness that could reduce consumer acceptance [31].

Stevia is a non-fermentable sweetener that helps balance the acidic effect provided by sugar, while the organic acids in apple powder can achieve the desired acidity level, thereby stabilizing pH changes [32].

In addition, this study examined the effects of apple powder and stevia on the Water-Holding Capacity (WHC) of yogurt samples and found that both storage time and sample type had significant effects on WHC. The findings revealed that the addition of apple powder and stevia increased the WHC of yogurt, particularly during the storage period. This result demonstrates that WHC, which plays a critical role in the textural properties, stability, and overall quality of yogurt, can be optimized through formulation components.

The increase in WHC over the storage period also highlights the synergistic effect of fruit addition and natural sweeteners (stevia and apple powder). In this study, all samples showed an increase in WHC as storage time progressed. This finding aligns with studies conducted on yogurts made with pomegranate and sour cherry and contradicts some reports in the literature suggesting that WHC decreases over time [48].

Additionally, the increased Water-Holding Capacity (WHC) observed in yogurt samples containing apple powder and stevia throughout the storage period demonstrates the positive effects of these components. Notably, a significant increase in WHC was observed in samples where both apple powder and stevia were used. These findings suggest that, despite some literature reporting a decrease in WHC with increasing fruit content, the addition of apple powder and stevia can counterbalance this effect.

Apple powder, a component rich in pectin, enhances the Water-Holding Capacity of yogurt. Pectin interacts with milk proteins to form a gel-like structure, which increases viscosity and reduces syneresis (whey separation) [29]. Studies have shown that using 2–5% apple powder can increase WHC by 10–20% [30]. This improvement contributes to a firmer and more stable yogurt texture and prevents excessive whey separation. The pectin content in apple powder strengthens the gel structure through its interaction with milk proteins, thereby enhancing yogurt stability.

Although stevia does not directly influence WHC, it may affect the microstructure of yogurt. Since stevia does not contain fermentable sugars, its interaction with milk proteins and microbial activity may alter protein network formation. Some studies have suggested that yogurt sweetened with stevia may have lower WHC compared to yogurt sweetened with sucrose, because stevia does not provide

carbohydrates that support fermentation, potentially affecting protein aggregation and gel formation [35].

Nevertheless, when stevia is used in combination with apple powder, pectin–protein interactions may counteract these effects, leading to a stable gel structure that enhances WHC [32]. This indicates a synergistic effect between stevia and apple powder, contributing positively to WHC. Additionally, some researchers have reported that the addition of fruit increases the dry matter content in yogurt, which in turn raises pectin levels and WHC. In a study involving probiotics and apricots, WHC values were observed to increase with extended storage time [49].

Similarly, in the present study, an increase in WHC was observed across all samples throughout the storage period. The highest stevia concentration resulted in the maximum WHC. High sugar concentrations also increased Water-Holding Capacity. The addition of a natural sweetener such as stevia improved WHC by contributing to the product's total solids. Consistent with other studies, the inclusion of stevia led to an increase in WHC, pointing to a synergistic effect of sugar content and potential probiotic activity [50].

The impact of storage conditions on WHC is also significant. The polyphenolic compounds in apple powder contribute to oxidative stability, preventing the degradation of the yogurt matrix and helping maintain WHC over time [47]. Research indicates that yogurts containing apple powder and stevia can better preserve WHC during 14–28 days of cold storage compared to traditional formulations [30]. These findings suggest that the properties of polyphenols in apple powder and stevia are effective in preserving yogurt quality during extended storage. Optimizing the concentrations of apple powder and stevia is crucial to achieving an ideal WHC balance. This ensures reduced whey separation, a creamier texture, and an acceptable mouthfeel for consumers [31]. When used in appropriate ratios, apple powder and stevia enhance the structural quality of yogurt, allowing for the production of more stable and higher-quality products. These ingredients are expected to play a significant role in maintaining the desirable quality of yogurt by preserving water-holding capacity (WHC) throughout the storage period. This study demonstrates that the addition of apple powder and stevia effectively increases WHC and helps maintain it over time. Apple powder enhances WHC through its pectin content, while stevia influences the formation of the protein network and alters the microstructure. The combination of these two ingredients produces a synergistic effect in increasing water-holding capacity (WHC). The observed increase in WHC over the storage period highlights the potential of these components to improve yogurt stability and quality. Using optimal concentrations of apple powder and stevia improves the textural characteristics of yogurt, enabling the production of high-quality and stable

products. These findings can guide yogurt manufacturers in developing new formulations and contribute to the production of superior products.

One of the key findings of this study relates to the acidity values of the yogurt samples. Both storage period and sample type had a significant effect on acidity. Notably, clear differences were observed among the samples on days 1 and 20, whereas these differences were less pronounced on day 10. Acidity increased in all samples as the storage period progressed. This supports the well-established notion that acidity increases over time due to the activity of microorganisms during yogurt fermentation [51]. The combination of apple powder and stevia particularly 5% apple powder and 10% stevia resulted in the highest acidity values. This highlights the potential of natural organic acids such as malic acid found in apple powder to increase yogurt acidity [29]. According to the Turkish Food Codex, the acidity level of fermented dairy products should be within the range of 0.6–1.5% lactic acid, and the findings of this study were consistent with this range.

Furthermore, studies involving different fruit and sweetener combinations have reported consistently high acidity levels in yogurts containing apple powder and stevia. For example, in apple-flavored yogurts sweetened with sugar, acidity levels ranged from 0.89 to 1.22%, while in those sweetened with stevia, acidity ranged from 0.84 to 1.05% [52].

These differences may be attributed to the use of apple powder instead of fresh apple and to variations in the type and amount of sweeteners used. The type of fruit (fresh or dried), its concentration, and the type and concentration of sweeteners/acids used are all factors that directly influence the acidity of yogurt.

Another study reported that the acidity developed after fermentation and during cold storage plays an important role in stabilizing the yogurt gel [38]. Moreover, although stevia does not directly contribute to acidity, it may exert an indirect effect by modulating the activity of lactic acid bacteria. Yogurts sweetened with stevia have been reported to exhibit slightly lower titratable acidity levels compared to those sweetened with sucrose, stevia does not provide fermentable sugars, which can influence LAB metabolism differently [35].

However, when used in combination with apple powder, the natural sugars found in apples can compensate for this effect, helping to stabilize acidity levels [32]. After 24 h of cold storage, the lowest pH value was observed in the sample containing *Aloe vera* gel and stevia. The potential effects of stevia on bacterial growth and pH profiles have been explained in previous studies. On the final day of storage, the highest acidity levels were detected in yogurt samples

containing stevia. This increase may be attributed to the use of stevia as a substrate by microbial organisms [5].

The polyphenolic compounds in apple powder interact with microorganisms, preventing excessive acidification and thus ensuring a balanced structure [47]. The increase in acidity throughout the storage period was a result of continuous bacterial activity. Yogurts containing apple powder and stevia maintained stable acidity levels for 14–28 days, which helped prevent excessive sourness and ensured microbial safety [30]. These findings indicate that the combination of apple powder and stevia has the potential to enhance acidity and improve quality in yogurt production.

Ingredients such as apple powder and stevia significantly affect yogurt acidity, and these interactions become more pronounced over time. While apple powder contains natural acidity enhancers, stevia contributes to maintaining acidity by modulating the activity of lactic acid bacteria rather than directly affecting it. The findings of this study suggest that yogurts containing apple powder and stevia may offer advantages over traditional yogurt formulations in terms of shelf life and microbial safety.

In this study, the effects of adding apple powder and stevia on serum separation (syneresis) values in yogurts were investigated. Serum separation values varied depending on the sample type and storage period, and these changes were found to be statistically significant ($p < 0.05$). On the 1st, 10th, and 20th days, the lowest levels of serum separation were recorded in the EYX, EYZ, and EYY samples, respectively, while the highest serum separation values were observed in the control group and other samples.

The study revealed that sugar increased serum separation on the first day; however, the combination of sugar and stevia reduced serum separation on the 10th and 20th days. This result indicates an inverse relationship between serum separation and yogurt quality, suggesting that reducing syneresis enhances overall product quality.

Several factors, such as dry matter content (DMC), fat and protein composition, heat treatment, protein denaturation, temperature rise, microbial activity, and increased acidity significantly influence serum separation [53]. Studies have shown that the addition of sugar and stevia significantly reduces serum separation throughout storage, enabling the production of yogurt with functional properties targeted toward consumers. Furthermore, storage conditions and structural degradation of proteins are also known to contribute to increased syneresis [54].

The role of the apple powder and stevia combination in reducing syneresis aligns with findings from similar studies in the literature. For instance, lower levels of whey separation were observed in yogurts enriched with beetroot, where the Water-Holding Capacity of beet pulp was reported to increase firmness and viscosity, thereby reducing syneresis

[52, 55]. Additionally, numerous studies have confirmed that the addition of fruits and vegetables improves Water-Holding Capacity by increasing the dry matter and fiber content of yogurt, thereby reducing whey separation [50, 56].

Apple powder, which is rich in pectin and fiber, reduces syneresis by enhancing the Water-Holding Capacity of yogurt. Studies have shown that yogurts containing 2–5% apple powder exhibited a 15–30% reduction in syneresis compared to control samples without apple powder [47]. The gel-like structures formed through the interaction of pectin with milk proteins help prevent the release of free water and contribute to the formation of a more stable structure [30]. This mechanism explains how the incorporation of apple powder strengthens the yogurt matrix and reduces whey separation.

When stevia is used as a sugar substitute, it may result in higher levels of syneresis due to its lower contribution to gel network formation compared to sucrose, and the reduced total solids content [35]. However, the combined use of stevia and apple powder improves structural integrity and compensates for the absence of sucrose, minimizing syneresis [32]. This study also, it was observed that the use of apple powder together with stevia enhanced the stability of yogurt and maintained low levels of whey separation.

Storage time is a significant factor affecting the degree of syneresis in yogurt. Yogurts containing apple powder exhibited reduced syneresis compared to traditional formulations. The polyphenols and fibers in apple powder stabilize the protein matrix, prevent excessive whey release, and support the maintenance of a stable gel structure [29]. Additionally, apple powder contributes to reduced syneresis during storage by improving the microbial stability and textural properties of yogurt.

This study revealed that the addition of apple powder and stevia significantly affected syneresis values in yogurts. Apple powder, due to its pectin and fiber content, reduced syneresis by enhancing Water-Holding Capacity, while stevia tended to increase syneresis when used as a sugar substitute. However, this effect was balanced when used in combination with apple powder. Storage conditions and the ingredients used are critical factors that enhance the functional properties and quality of yogurt. These findings indicate that sweeteners and additives used in yogurt production should be carefully selected and that the combination of apple powder and stevia offers an effective approach to controlling syneresis levels.

Sensory analysis of yogurt samples

The sensory attributes of yogurt samples including color and appearance, texture-consistency, mouthfeel, taste and

aroma, sweetness, and overall acceptability were significantly affected by the addition of apple powder, stevia, and sugar, as well as by the storage duration. These sensory properties are critically important in determining consumer preferences, in addition to the nutritional and functional characteristics of the product [38].

The yogurt samples received similar scores in terms of color and appearance. No significant differences were observed among sample types on days 1 and 20. However, a significant difference was detected on day 10. Storage duration did not significantly affect the color and appearance of the K, EY, EYA, and EYC samples, but it impacted the EYB, EYX, EYY, and EYZ samples. The highest color and appearance scores were recorded in the EYY and EYZ samples on day 1, EYB on day 10, and EY on day 20. In contrast, the lowest scores were observed for EYB on day 1, EYX on day 10, and EYX and EYY on day 20. Notably, yogurt samples containing 10–15% stevia received higher scores than the control group on day 1. On day 10, the sample containing 10% stevia achieved scores similar to the control. However, by day 20, scores had decreased across all sample groups, with only the yogurt containing 5% apple powder receiving the highest scores. These findings suggest that stevia, at certain concentrations, may initially enhance visual appeal, while apple powder may contribute more significantly to preserving color and appearance during extended storage.

As with color and appearance, no significant differences in texture-consistency were found between sample types on days 1 and 20, whereas significant differences emerged on day 10. By day 20, storage duration had a significant effect on this attribute. On day 1, the sample with 15% stevia received the highest score, followed by the 10% stevia sample on day 10. However, on day 20, the highest score was obtained by the control group. This suggests that stevia initially contributed positively to the spoonability of the yogurt, but its effect diminished over time, with the control sample eventually exhibiting better texture-consistency in the later stages of storage.

Regarding mouthfeel, yogurt type did not have a statistically significant effect, but storage time did. A clear difference was observed by Day 20. The sample with 15% stevia received the highest mouthfeel scores on days 1 and 10, while the control group received the highest score on day 20. Scores declined in all other groups. This indicates that although stevia may initially improve perceived texture, after extended storage, the control yogurt offers a more desirable mouthfeel.

In terms of taste and aroma, neither yogurt type nor storage time caused significant differences between days 1 and 10. However, on day 20, both factors had a statistically significant effect. Samples containing 10–15% stevia received the highest scores on days 1 and 10, whereas the control

group scored highest on day 20. Scores declined across all other groups. This trend aligns with the mouthfeel results and suggests that while stevia may enhance taste and aroma initially, the control sample is preferred in the long term for its flavor profile.

For sweetness, yogurt type had a statistically significant effect on days 1 and 10, but not on day 20. In contrast, storage time had a statistically significant effect on sweetness. Samples containing 5–10–15% sugar and 10–15% stevia received the highest sweetness scores on days 1 and 10. However, by day 20, the highest sweetness score was attributed to the control group, with decreased scores in all other groups. This indicates that sugar and stevia initially enhance sweetness perception, but their effect diminishes over time, with the control group maintaining a desirable sweetness level.

In terms of overall acceptability, the type of yogurt showed a significant difference on days 1 and 10, but not on day 20. Storage duration had a significant impact on overall acceptability. On day 1, samples with 5% sugar and 15% stevia received the highest scores, while on day 10, samples with 10% sugar and 10% stevia scored the highest. These samples even outperformed the control group. However, by day 20, the control group received the highest overall acceptability score, while scores declined in all other groups.

These results suggest that combining sugar and stevia in specific proportions can enhance the initial overall acceptability of yogurt compared to the control. Nevertheless, after prolonged storage, the control yogurt becomes the preferred option among consumers. Considering all sensory attributes, yogurt samples containing 10% and 15% stevia generally received higher scores than the control sample, especially in the early stages, reflecting initial consumer preferences. This finding is consistent with the results of a study that reported the addition of stevia extract had a significant impact on taste, aroma, mouthfeel, and acceptability, but no notable effect on appearance or color [45]. A low-calorie yogurt sweetened with 0.5% stevia extract achieved the highest acceptability score. These results suggest that stevia leaf can be used as a sugar substitute in yogurt and, in some cases, may even enhance its nutritional value. Specifically, the addition of 0.5% stevia extract has been found to be effective in developing a low-calorie product with high consumer appeal.

Conversely, in another study, yogurt sweetened with sucrose was perceived as the sweetest, followed by a sucrose-stevia blend, and finally, yogurt sweetened only with stevia. The highest sensory scores were awarded to the sucrose-stevia blend, followed by sucrose-sweetened yogurt, while stevia-only samples received the lowest scores. These conflicting findings indicate that stevia's perceived sweetness

and overall acceptability can vary depending on its concentration and the presence of other sweeteners [57].

In our current study, a decrease in sensory scores for stevia-containing samples was observed on day 20, during which the control group was preferred more. In a different study, it was reported that stevia-containing samples were perceived as sweeter but less fermented, exhibiting a lower acetaldehyde aroma intensity. These samples were also found to have lower hardness and viscosity values. Despite these differences, no significant difference in overall sensory acceptability was found between the samples, as all samples received high and comparable scores ($p < 0.01$) [58]. This suggests that stevia may alter certain sensory attributes, but the overall acceptability can remain high. However, it also indicates that consumer preferences may change over time, as observed in our study.

In the time-dependent sensory profiling study of sweeteners (sucrose, xylitol, and stevia) and fruit purée concentrations, the complex interaction between these components is further clarified. Yogurts sweetened with sucrose exhibited a more pronounced sourness with higher purée concentrations. In contrast, yogurts sweetened with lower concentrations of xylitol and stevia showed reduced aftertaste. Across all sweeteners, a decrease in sweetness, sourness, creaminess, and fruitiness was observed from the first to the third sip. However, yogurts sweetened with sucrose developed stronger licorice and bitter notes over time, an increase in aftertaste was noted in xylitol-sweetened samples, and these effects were also evident in stevia-containing yogurts. Overall, yogurts with lower sucrose or xylitol content and low purée concentrations were preferred. This highlights the need to optimize both sweetener and fruit ratios to achieve an ideal sensory profile and consumer acceptance [59].

The study evaluating sugar-free probiotic milk gels produced using stevia and inulin provides important insights into the potential of stevia in functional dairy products [60]. This research demonstrated that the combination of stevia with inulin significantly enhanced probiotic bacterial viability and postbiotic short-chain fatty acid (SCFA) production compared to using stevia alone. Additionally, higher fermentation rates were observed in yogurts containing *Lactobacillus acidophilus*, which could be associated with the development of acidity and bacterial survival. Stevia concentrations ranging from 0.5 to 3.5% were tested, with 0.5% consistently achieving the highest sensory acceptability scores [45, 61]. These findings suggest that stevia is a promising prebiotic substrate for functional foods and may help probiotic bacteria thrive in the gastrointestinal tract, thereby improving gut health. The sensory characteristics of yogurt, such as taste, texture, aroma, and overall acceptability, are significantly influenced by the addition of apple powder and stevia. Studies have shown that apple powder

enhances fruity aroma and natural sweetness, resulting in higher consumer preference scores [62]. Stevia, on the other hand, provides sweetness without the caloric impact of sucrose, though excessive use may introduce a slight aftertaste [31]. A balanced formulation of these two ingredients can enhance sensory acceptability by offering a creamy texture and refreshing flavor. However, in this study, a decline in sensory scores was observed in most samples, including those containing stevia by the 20th day of storage. This suggests the need for further investigation into the long-term stability of these sensory attributes and the interactions between the yogurt matrix and added components. The sensory evaluation shows that the inclusion of stevia and apple powder has a significant impact on consumer perception of yogurt. While stevia may enhance sweetness and overall acceptability in the early stages, its interaction with other components particularly apple powder, should be carefully considered over time. Although the control yogurt initially received lower scores in some attributes, it maintained better sensory quality throughout the 20-day storage period. These findings emphasize the importance of optimized formulations that balance the advantages of natural sweeteners and fruit components to ensure sustained consumer preference for functional yogurt products.

Purchase probabilities of yogurt samples

The sensory analysis conducted in this study was not limited to hedonic evaluation but also examined consumers' purchase intentions, providing valuable insights into the market potential of the formulated yogurt samples. Consumers evaluated their willingness to purchase the products using a three-point scale: (1) definitely would buy, (2) might buy, (3) definitely would not buy. On the first day of storage, consumers showed the highest purchase intention for the control group and yogurt samples containing 5% sugar and 10–15% stevia, rating them as “definitely would buy.” This finding indicates that both traditional formulations (control) and yogurts sweetened with low sugar or higher levels of stevia initially held strong appeal for consumers. The positive response toward stevia-sweetened yogurts also aligns with the increasing consumer demand for reduced-sugar alternatives and supports the findings of the study which reported high acceptability of low-calorie, stevia-sweetened yogurts [45].

By the tenth day of storage, a slight shift in purchase intentions was observed. Consumers now rated the control sample along with the samples containing 10% sugar and 10% stevia as “definitely would buy.” This suggests that the appeal of the 5% sugar sample slightly declined in the short term, while formulations with 10% sugar and 10% stevia maintained high purchase interest similar to the control

group. These results imply that minor changes in sensory properties during this period may influence consumer preference. A more notable shift occurred by the twentieth day of storage. At this stage, only the yogurt sample containing 5% apple powder received the response “definitely would buy” from consumers. This is a critical finding, revealing that apple powder provides a significant advantage in maintaining consumer acceptance during long-term storage. The decline in purchase intent for the control and stevia/sugar-sweetened samples suggests a perceived reduction in quality or sensory appeal over extended shelf life.

The positive purchase tendency toward the sample containing 5% apple powder may be associated with previously discussed factors such as increased Water-Holding Capacity (WHC), enhanced textural stability, preservation of flavor profile, or reduced effects of spoilage. The purchase intentions observed throughout the storage period provide preliminary market data for functional yogurt products. While the initial appeal of stevia-sweetened yogurts reflects consumer interest in sugar alternatives, the sustained interest in the yogurt containing apple powder by the end of the 20 days demonstrates the potential benefits of this ingredient in maintaining long-term consumer acceptance. These findings support the idea that apple powder, by improving WHC, can help make the product more stable and palatable [30].

The decline in purchase intent for the initially popular control group by day 20 may be explained by factors such as texture changes (e.g., increased syneresis) or subtle flavor alterations perceived over time, which were not directly addressed in this study. This partial market analysis based on purchase intent offers valuable insights for future product development efforts. While stevia presents an attractive alternative for sugar reduction strategies, the inclusion of apple powder contributes to preserving the long-term appeal of yogurt. To validate these preliminary findings, broader consumer studies and detailed monitoring of physicochemical and microbiological changes during storage are needed. The shift in consumer preference toward the apple powder-containing sample at the end of the storage period highlights the importance of considering the long-term stability and sensory evolution of functional food products.

Rheological properties in yogurt samples

Table 7 presents the viscosity values of the yogurt samples, which range from 143.24 to 665.42 cP, and reflect various structural characteristics resulting from different formulations and storage durations. This discussion focuses on the effect of apple powder and stevia addition on viscosity, a key rheological parameter that determines yogurt texture and mouthfeel. In samples K, EY, EYA, EYB, and EYZ, viscosity values increased by the final day of storage. In contrast,

Table 7 Rheological properties of yogurt samples

Properties	Samples	Storage days		
		First day	10th day	20th day
Viscosity	K	232.52 ^{Bb} ±25.48	470.91 ^{Aa} ±46.38	473.10 ^{BCa} ±63.76
	EY	370.31 ^{Aab} ±32.70	284.40 ^{Bb} ±28.95	424.69 ^{Ca} ±44.76
	EYA	258.61 ^{Bb} ±27.45	260.60 ^{Bb} ±27.56	438.75 ^{Ca} ±63.15
	EYB	220.11 ^{Bb} ±25.01	143.24 ^{Db} ±20.67	610.39 ^{ABa} ±65.06
	EYC	254.29 ^{Ba} ±32.90	158.79 ^{CDb} ±19.56	180.04 ^{Db} ±21.09
	EYX	363.38 ^{Aab} ±58.72	401.66 ^{Aa} ±43.47	245.24 ^{Db} ±31.35
	EYY	265.17 ^{Ba} ±31.17	205.84 ^{BCDab} ±25.95	169.25 ^{Db} ±25.20
	EYZ	227.33 ^{Bb} ±29.68	240.13 ^{BCb} ±26.73	665.42 ^{Aa} ±63.88

*: Mean±standard deviation. A-E: Capital letters within a column indicate significant differences ($p<0.05$) between different yogurt types. a-d: Lowercase letters within a row indicate significant differences ($p<0.05$) between different storage times

K: Control Group. EY: Yogurt added with 5% apple powder. EYA: Yogurt added with 5% apple powder and 5% sugar; EYB: Yogurt added with 5% apple powder and 10% sugar; EYC: Yogurt added with 5% apple powder and 15% sugar; EYX: Yogurt added with 5% apple powder and 5% stevia; EYY: Yogurt added with 5% apple powder and 10% stevia; EYZ: Yogurt added with 5% apple powder and 15% stevia

a decrease in viscosity was observed in samples EYC, EYX, and EYY by the end of the storage period. The addition of apple powder generally led to an increase in viscosity, aligning with literature findings suggesting that apple powder, rich in pectin and fiber, can form gel-like structures with milk proteins, thereby enhancing yogurt viscosity [32, 34]. This increase contributes to the desirable creamy texture in fruit-based yogurt products. The impact of stevia concentration on viscosity demonstrated a more complex pattern. As the stevia ratio increased, viscosity initially decreased on the first day of storage but then increased by the final day. This initial reduction may be due to stevia not contributing as much of the volumetric solid content as sugar [35]. However, the subsequent increase over time may point to interactions with the protein matrix or effects on microbial activity.

No clear linear relationship was observed between sugar content and viscosity. The highest viscosity value was measured in the EYZ sample on day 20, while the lowest was recorded in the EYB sample on day 10. This suggests complex interactions among the additives and changes occurring during storage. Throughout the storage period, samples K, EYA, and EYZ exhibited an increasing trend in viscosity, whereas samples EYC and EYY showed a decreasing trend. In EY and EYB samples, viscosity initially dropped and then increased, while in EYX, it initially rose and later decreased. The combination of 5% sugar and 15% stevia resulted in increased viscosity during storage while increasing sugar content and reducing stevia concentration led to a decrease in viscosity.

The viscosity index of yogurt is associated with gel formation, which is influenced by casein micelle aggregation and the physicochemical and biochemical changes occurring during fermentation [63]. In a study evaluating the viscosity indices of probiotic yogurts enriched with stevia, values of viscosity index ranged from -84.51 to -199.06 g/s, with

the lowest average value observed on day 14 and the highest on day 7 [36]. Interestingly, samples containing stevia, and with or without inulin, showed similar viscosity indices, suggesting that stevia's potential role as a prebiotic substrate and inulin's bifidogenic effects may influence WHC and viscosity through hydrophilic interactions between protein and water. However, the study, as mentioned earlier, reported no statistically significant change in the viscosity index, which contrasts with the dynamic viscosity changes observed in the present study. This discrepancy may be attributed to the inclusion of apple powder in our formulations, which introduces additional complexity through pectin-protein interactions and Water-Holding Capacity.

The pseudoplastic behavior of yogurt, defined by a decrease in viscosity with increasing shear rate, was likely observed in all samples in this study, although not directly measured [64, 65]. A transient increase in viscosity was noted in skim milk samples at shear rates of 0.16–0.2 s⁻¹, explained by structural breakdown [64]. A similar pattern may have occurred in our study, depending on formulation and duration of storage.

In another study, inulin and GOS were found to have no significant effect on viscosity, whereas pectin and beta-glucan significantly increased it [64, 66–69]. This increase was attributed to the formation of passive pectin-filling systems within the protein network [70]. These findings support the viscosity-enhancing effect of apple powder, which is rich in pectin. In another study comparing low-fat yogurts formulated with alternative sweeteners (including stevia) and various protein types, it was reported that protein content significantly affects rheological and textural properties; higher protein levels consistently yielded firmer yogurts [51]. The same study also reported increased syneresis in yogurts sweetened with stevia, attributed to lower Water-Holding Capacity (WHC) caused by reduced solid content. The process created significant effects on rheological

and textural parameters, emphasizing the need to carefully evaluate the interactions between sweeteners and other solid ingredients like apple powder concerning yogurt texture and stability.

Although literature on yogurt viscosity exists, studies focusing specifically on yogurts produced with stevia and apple powder, and the characteristic effects of this particular combination remain limited. This study fills that gap by providing a comprehensive evaluation of viscosity values across different formulations and storage durations and reveals quality parameters for a novel functional product.

The synergistic effect on viscosity observed in our study through the combination of stevia and apple powder aligns with findings from different research, indicating that apple powder increased the viscosity of stevia-sweetened yogurt by approximately 10–15% [32]. The fact that apple powder contributes to viscosity even in the presence of stevia via its water-binding properties points to a complex interaction that warrants further research to optimize the textural attributes of functional yogurts. The dynamic viscosity changes observed in various samples during storage in this study highlight the complex interactions among the yogurt matrix, apple powder, and sweeteners (sugar and stevia). These findings demonstrate that the careful selection and optimization of these ingredients can shape the textural properties of yogurt in ways that significantly influence consumer acceptance.

In addition to their physicochemical, sensory, and rheological properties, yogurt samples enriched with stevia also stand out in terms of their nutritional value and microbiological characteristics. The non-caloric nature of stevia and its content of natural antioxidant compounds make these products especially suitable for individuals requiring sugar-restricted diets, while also supporting their classification as functional foods. Moreover, the antimicrobial properties of stevia have been reported to enhance the microbial stability of yogurt and potentially extend its shelf life. This is significant not only for ensuring product safety but also for optimizing industrial production processes. Accordingly, yogurts formulated with stevia may be considered promising functional and safe dairy products due to their health-promoting composition and ability to maintain microbiological quality. Similar results have been reported in previous studies, supporting the findings of the present research. The use of stevia and apple powder in this study not only contributes to sensory and nutritional qualities but may also enhance the functional and microbial safety aspects of the yogurt. Contaminants such as aflatoxin M1, commonly found in dairy products, pose significant health risks to consumers [71]. In this context, the incorporation of natural additives can improve both the safety and the functional value of fermented dairy products. Stevia, in particular, has been

shown to provide oral health benefits, which supports the functional food potential of the stevia-enriched yogurt produced in this study [72]. Furthermore, the microbial diversity and biogenic amine content are highly influenced by post-fermentation conditions, especially cold fermentation processes [73]. The combination of stevia and apple powder may help maintain microbial stability during storage, contributing to extended shelf life and product safety.

Finally, the use of plant-based bioactive compounds, such as broccoli sprout extract, has demonstrated antimicrobial effects in dairy matrices [74]. Similarly, the natural components used in this study may also play a role in improving microbial safety. Therefore, yogurts enriched with stevia and apple powder can be considered a functional, safe, and consumer-friendly alternative in the growing market of health-oriented dairy products.

Conclusions

In this study, the effects of stevia and apple powder on the physicochemical, sensory, and rheological (viscosity) properties of fruit-flavored yogurt were investigated. Eight different yogurt samples containing a fixed 5% apple powder and varying levels of sugar and stevia (5%, 10%, and 15%, for either sweetener) were prepared using standard yogurt starter cultures. The characteristics of the yogurts were evaluated over a 20-day storage period, and consumer acceptance tests were conducted. Significant differences were observed among the samples containing apple powder and varying amounts of sugar and stevia in terms of dry matter content, L^* , a^* , and b^* color values, pH, Water-Holding Capacity, acidity, serum separation, sensory attributes such as purchase preference, and viscosity. The use of stevia at different concentrations significantly affected these quality parameters. Particularly, the use of stevia at 10–15% was found to be highly suitable in terms of sensory attributes and purchase preferences. As a result, this study supports the use of *Stevia rebaudiana* and apple powder in yogurt production, highlighting their potential to offer consumers a healthier and more functional product. The findings demonstrate that stevia and apple powder can be viable alternatives in this field, especially in guiding new product development efforts in the dairy industry. Stevia emerges as a natural alternative to sugar and artificial sweeteners in the production of fruit yogurts. This combination offers a functional product that aligns with the preferences of health-conscious consumers. Although the study focused on stevia, the use of apples in yogurt production may provide a synergistic effect by enhancing product appeal through natural sweetness and dietary fiber content. The apple can balance stevia's sweetness, contributing to a more complex flavor profile and

enhanced nutritional value. This combination is in line with the growing consumer demand for natural and healthy food options. Future research could explore the inclusion of different fruit types and probiotics to diversify product offerings. In addition, in-depth studies on the long-term effects of stevia use and its stability under various storage conditions are recommended.

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Declarations

Conflicts of interest No conflicts of interest were reported by the authors.

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