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Research Paper / Araştırma Makalesi

Effect of D-Allulose Use as a Sugar Substitute on Some Physicochemical, Textural and Sensory Properties of Cakes

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ABSTRACT

D-allulose is a monosaccharide that belongs to the class of sugars known as rare derivatives of monosaccharides in nature. The aim of this study was to investigate how the sugar substitute D-allulose influenced the physicochemical, textural, and sensory characteristics of cakes. Solvent water retention capacity analysis of flour used in cake production and ash, dry matter, texture, color and reducing sugar analyses of cake dough were carried out in a day while water activity, pH, titratable acidity, antioxidant activity analysis and sensory analyses of cakes were performed in three different days. The average heights of control, AL50 and AL100 cakes were 2.60±0.14, 1.75±0.1 and 1.50±0.0 cm while they had the cake yields of 87.2±1.9, 86.2±4.1 and 87.6±3.2%, respectively. Viscosity analysis results showed that viscosity of dough samples decreased with an increase in spindle speed for all groups. The total dry matter content of control cakes was 76.1±3.0% while AL50 and AL100 cakes had a dry matter content of 76.4±4.6 and 75.0±2.6%, respectively. Total ash contents were 1.2±0.0, 1.3±0.0 and 1.4±0.0% for control, AL50 and AL100 cakes, respectively. The mean radical scavenging activity (RSA) of control cakes on the first day of production was 26.1±5.8, 51.6±1.3 in the AL50 group and 53.9±1.2 in the AL100 group. When evaluating the panelists' overall acceptability scores for the sensory qualities of cakes, the first day yielded the highest AL50 (7.9±1.2), while the 8th day of storage yielded the lowest AL50 (8.5±0.8) for the control group. The 8th day analysis yielded the lowest result (6.7±1.4) for the AL100 group. Results indicated that D-allulose preserved the physicochemical, textural, and sensory characteristics of cakes while increasing their antioxidant capacity, and it could be utilized to create novel products in the food industry because of these qualities.

Keywords: D-Allulose, Cake, Physicochemical analysis, Sensory analysis, Sugar substitutes

Şeker İkamesi Olarak D-Alüloz Kullanımının Keklerin Bazı Fizikokimyasal, Dokusal ve Duyusal Özellikleri Üzerine Etkisi

ÖZ

D-Alüloz, monosakkaritlerin doğada ender türevleri olarak bilinen şekerler sınıfına ait bir monosakkarittir. Bu çalışmanın amacı, şeker ikamesi olan D-alüloz keklerin fizikokimyasal, tekstürel ve duyusal özelliklerine etkilerini araştırmaktır. Kek üretiminde kullanılan unda yapılan çözücü su tutma kapasitesi analizi ve kek hamurunda yapılan kül, kuru madde, tekstür, renk ve indirgen şeker analizleri tek seferde; keklerde yapılan su aktivitesi, pH, titrasyon asitliği, antioksidan aktivite analizi ve duyusal analizler ise üç farklı günde yapılmıştır. Üretilen kontrol, AL50 ve AL100 kek gruplarının yükseklik ortalamaları sırasıyla 2.60±0.14, 1.75±0.1 ve 1.50±0.0 cm'dir. Keklerin kek verimlerinde ise sırasıyla %87.2±1.9, 86.2±4.1 ve 87.6±3.2 olarak saptanmıştır. Viskozite analizi sonuçlarına bakıldığında tüm gruplarda spindle hızının artmasıyla viskozite değerlerinin düştüğü görülmüştür. Toplam kuru madde oranı kontrol grubunda %76.1±3.0, AL50 grubunda %76.4±4.6 ve AL100 grubunda %75.0±2.6; toplam kül oranları kontrol grubu, AL50 ve AL100 grupları için sırasıyla %1.2±0.0, 1.3±0.0 ve 1.4±0.0 olarak bulunmuştur. Kontrol grubunun birinci gün ortalama radikal süpürme aktivitesi (RSA) 26.1±5.8, AL50 grubunda 51.6±1.3 ve AL100 grubunda 53.9±1.2'dir. Panelistlerin keklerin duyusal özelliklerine verdiği genel kabul edilebilirlik puanları incelendiğinde 1. gün en yüksek AL50 (7.9±1.2), 8. gün kontrol grubu (8.5±0.8) almıştır. AL100 grubu 8. analiz gününde en düşük puanı (6.7±1.4) almıştır. D-Alüloz, keklerde fizikokimyasal, tekstürel ve duyusal nitelikleri koruyarak antioksidan kapasitesini artırmıştır. Bu özellikleri nedeniyle gıda endüstrisinde yeni ürünlerin oluşturulmasında kullanılabilir.

Anahtar Kelimeler: D-Alüloz, Kek, Fizikokimyasal analiz, Duyusal analiz, Şeker ikameleri

INTRODUCTION

According to the World Health Organization (WHO), the prevalence of obesity has increased approximately 3 times from 1975 to 2016 worldwide. In 2016, 16% of the world's adult population (11% in men and 15% in women) were obese. The number of obese children under the age of 5 is 39 million, especially in low and middle developed countries; It has been reported that there are 340 million children and adolescents aged 5-19 years [1], and the prevalence of overweight and obese individuals aged 5-19 was 18% in 2016 due to environmental and social changes associated with inadequate health-supporting policies [2]. Sugar (sucrose) is the main sweetener used worldwide and is therefore an important ingredient in the food industry. However, high sugar in the diet leads to many chronic diseases, especially obesity [3]. The World Health Organization stated that the daily consumption amount of added sugars consumed by the consumer should not exceed 10% of the daily energy intake, except for the sugar found naturally in the structure of foods [4]. Studies have found a direct and indirect positive relationship between mild obesity and obesity and the amount of consumption of foods containing sugar [5]. This shows that the prevalence of obesity and obesity-related diseases may reach alarming levels in the coming years [6]. For this reason, it has been suggested in recent years to add taxes to sugar-sweetened foods and beverages in order to reduce the availability of these products [7].

In order to reduce overall sugar and calorie intake, products including natural and artificial sweeteners are now used in the food industry. People with Type 2 diabetes in particular are becoming more interested in maintaining a healthy weight [8]. These foods do not promote satiety, do not increase insulin secretion, and have effects that are similar to addiction by increasing dopamine release while having less energy and a sweeter flavor than sugar [9]. Low sugar and low energy foods are now being made by lowering the sugar level in foods or adding artificial sweeteners due to the detrimental effects of excessive sugar consumption on human health. Natural sweeteners have been recommended as an alternative, however, as evidenced by studies on the harmful effects of artificial sweeteners on health [10].

D-Allulose is a monosaccharide from the group of sugars rarely found in nature, called the rare derivatives of monosaccharides in nature [11]. D-Allulose, originally known as D-psychose (D-ribo 2-hexulose), is a natural sweetener that has essentially no energy and plays a key role in controlling how rapidly glucose and fat are metabolized [12]. It has a 70% relative sweetness when compared to sucrose [13].

Cakes are bakery goods made in a variety of combinations and shapes that are frequently consumed due to their high nutritional value and addition of sugar in various regions of the world. After bread and biscuits, cake production and consumption is third among bakery items [14]. Cakes may have less sugar or have higher quality cakes thanks to the usage of different sugar substitutes. Kim et al. [15] and Hao et al. [16] examined the quality parameters of cakes by using sugar alcohols as sugar substitutes in cakes. Kim and Lee [17] compared the ash syrup by Quiles et al. [18] fruit purees and Shahidi et al. [19] used date syrup as a sugar substitute. On the other hand, Lee et al. [20] and Bolger et al. [21] used D-allulose as a sugar substitute in pancakes and cupcakes and demonstrated its effects.

The aim of this study is to evaluate the physicochemical, textural, and sensory parameters of cakes prepared using D-allulose, a sugar substitute that has nearly no energy compared to sucrose and may be used to make cakes, which are the third most commonly bakery product after bread and biscuits.

MATERIALS and METHODS

Materials

The ingredients for the cakes, wheat flour, sugar, eggs, milk, salt, margarine, vanilla, and baking powder, were bought from local stores in Burdur, Turkey (37.7183°N, 30.2823°E). A specialized Japanese sugar producer provided (Astraea, Matsutani Chemical Industry Co., Ltd.) with D-allulose (Cas No: 551-68-8). Chemical products that were sold commercially and used in the analysis included hydrochloric acid, sodium hydroxide, sodium carbonate, methanol, deionized water, lactic acid, 2,2-diphenyl1-picrylhydrazil (DPPH), Fehling A, Fehling B, phenolphthalein, methylene blue, potassium ferrocyanide, and zinc sulfate. The analysis was performed in the laboratories of the Scientific and Technology Application and Research Center and the Burdur Mehmet Akif Ersoy University Health Sciences Faculty's Food Chemistry and Analysis Department.

Method

Preparation of Cake Dough

Based on trials where D-allulose was utilized as a sugar substitute, the amounts of D-allulose added to the cakes were determined [20, 21]. Three different forms of cakes were prepared in the study using three different ratios of sugar substitutes: 100% sucrose, 0% D-allulose (control), 50% sucrose, 50% D-allulose (AL50), and 100% D-allulose, 0% sucrose (AL100). Goswami et al. [22] modified the cake production method to meet the technique cakes are produced in Turkey when using it for cake production. The final version of the cake recipes was chosen after the preliminary trial phase cakes were assessed for general acceptability. As a result, three times the amount of the recipe from Table 1 was used to make cake recipes, and analyses were based on these ratios

Table 1. Cake recipes

Ingredients	Control	AL50	AL100
Wheat flour (g)	100	100	100
Sugar (g)	80:0	40:40	0:80
Egg (g)	60	60	60
Milk (mL)	65	65	65
Salt (g)	0.5	0.5	0.5
Baking powder (g)	4	4	4
Margarine (g)	60	60	60
Vanilla (g)	9	9	9

Too much heat (>200°C) and/or too much time (35-40 min) in the oven can cause in the crust color of cakes darkening, cracks appearing on the top surface, a weak cake core, and insufficient volume. Preliminary study was conducted to determine the optimum baking temperature and duration for cake recipes, and as a result, it was found that 30 min and 175°C were the most effective conditions. All of the components were kept at room temperature for 60 mins to the study's start. When preparing cakes, baking powder, salt, and wheat flour are first mixed. The egg, sugar, and D-allulose mixtures were mixed well in a separate bowl using an electric mixer on the fifth speed for five minutes. After a minute of beating during which milk and vanilla were added, pre-mixed wheat flour, baking powder, and salt were added and given enough time to thoroughly mix with the batter. All mixtures were homogenized for an extra five min with the addition of room temperature margarine. The cake dough was kept for five minutes after the beating process was completed [23].

Baking and Storage of Cake Dough

The obtained doughs were placed in an oven that had been preheated to 175°C and baked for 30 min on the second level (Arçelik/9620 Mi). The cakes were taken out of the oven at the finish of the baking duration and left to cool for an hour at room temperature. Before being analyzed, they were packaged and kept at room temperature. Solvent water retention capacity of the wheat flour used in the cakes produced and ash, dry matter, texture profile, color and reducing sugar analysis in the cake dough were performed on the first day of cake production. Water activity, pH, antioxidant activity, and sensory analyses of the cakes were performed in duplicate on the first, fourth, and eighth days of storage.

Analyzes

Solvent Retention Capacity

One of the study's key components, wheat, is prepared using the American Association of Cereal Chemists' procedures, and the Solvent Retention Capacity (CTC) analysis method is utilized to assess its quality [24]. Deionized water, 100% sucrose solution, 50% sucrose + D-allulose solution, 100% D-allulose solution, 5% sodium carbonate solution, and 5% lactic acid solution were the six solvents that were prepared using this procedure1 g of flour (±0.05 g) was weighed into 15 mL of centrifuge tubes, and 5 mL of each solvent was then added to each. The centrifuge tubes were shaken with a vortex for 5 seconds after their caps were secured at 0, 5, 10, 15 and 20 minutes. Each centrifuge tube was weighed before being centrifuged at 3000 rpm for 15 minutes. After the tubes were removed from the device, water was poured through them at a 90-degree angle and their weights were recorded once again. The weight of solvent retained by the flour after centrifugation was estimated using the following formula after this procedure was carried out three to four times for each solvent [25].

% Solvent Retention Capacity = [(Gel Weight/Flour weight-1)] x [86/(100-% moisture of flour)] x 100

Dough Density and Volume

The density of the dough used in cake production was measured with a previously weighed and tared container with known volume. Density was calculated by dividing the dough weight by the water weight obtained [26].

Dough Height Measurement

With a stainless steel knife and a plane perpendicular to the cakes' bases (vertical axis), the cakes were sliced. The highest cake center height a digital camera could capture (Xiaomi, POCO X3 Pro, China).

Cake Yield and Weight Loss

Calculations were made to determine the weight reduction based on the difference between the weight of the cake batter and the weight of the baked cakes, as well as the weight of the cake batter to the weight of the baked cakes yield.

Viscosity

Following the preparation of the doughs in the control group and the addition of D-allulose at the specified ratios, the viscosity of the cake batter was measured in a viscometer equipment (Brookfield brand, DV-II pro series) at room temperature (23°C) at various rpms with an RV-07 tip. In mPa.s, viscosities at various speeds were expressed.

Water Activity

The Testo 650 (Germany) equipment was used to measure the water activity values of the cake samples. Prior to measurement, the instrument was calibrated with distilled water. After calibrating, the sample chamber was filled with enough homogenized sample and sealed. After waiting for approximately 15-20 minutes, the value reported on the device's screen stabilized. The device screen was used to read the fixed water activity (aw) value [27].

pH

For pH analysis in cake samples, 10 g of cakes dried for 55 minutes at 130°C were taken and homogenized with 90 mL of distilled water for 10 minutes in a laboratory type homogenizer at high speed, and at the end of this period, pH was determined using a pH meter (704 pH Meter, Metrohm) [28].

Dry Matter and Ash

The gravimetric method was used to calculate the amount of dry matter in cake samples [29]. The cake samples were dried using this procedure in an oven at 105°C for 4 hours after being weighed in a porcelain crucible and brought to a constant weight. By dividing the weight of the cake sample by the weight after drying, the dry matter percentage was computed. The AACC 08.01 technique was used to evaluate the ash. The samples were placed in a porcelain crucible that had been previously been raised to a set weight and burned in the muffle furnace at 550–550°C. By dividing the sample mass still in the crucibles after the burning process by the starting sample mass, the ash content of the cakes was calculated.

Color Analysis

Using a colorimeter (Konica-Minolta), analyze the color of experimental cake batches using the CIE values L* [indicates lightness and ranges from 0 (for black) to 100 (for white)], a* [-a* (for greenness) and +a* (for redness)]. and the color scheme b* [-b* for blueness, +b* for yellowness]. The cake's crust color was measured from the center of the top of the cake using a ceramic-standard color measuring instrument, and the crumb color was examined using a sample taken from the middle point. Using the L*, a*, and b* data obtained from the color measurement device, the browning index was calculated [30]. Below is a formula for calculating the browning index.

$$\text{Browning Index} = [100\,(x-0.31)] / 0.172$$
$$x = a^* + 1.75L^*/[(5.645L^*) + a^* - (0.3012b^*)]$$

Texture Profile Analysis

The TA-XT Plus texture profile analyzer was used to measure instrumental texture profile analysis (Stable Micro Systems, UK). A 35 mm probe was used to apply 2 cm high printing operations to samples with a dimension of 2.5x2.5 that were taken from the cakes stored at room temperature. One mm/s pretest speed, five mm/s test speed, five mm/s post test speed, thirty percent compression force, and five g initial detection force were the conditions for the device's operation. The cakes' values for hardness, stickiness, resilience, adherences, cohesiveness, chewiness, and elasticity were identified. The average of two analyses is used to represent the results.

Antioxidant Activity

Prior to taking the measurements of antioxidant activity, the cakes were extracted. The extract was extracted using the technique used by Çelik [31]. Using this technique, 1 g of the cake samples were weighed, placed in falcon tubes, and mixed with a 70 percent methanol solution. The collected samples were homogenized with the vortex for 1 minute at 12 rpm. The homogenized cake samples were maintained at 50°C for 10 minutes in a water bath with shaking (Thermomac WBS 30). It was then shaken in an orbital shaker (CLS Scientific/CLOS 300) for 15 minutes at 180 rpm. The upper serum portion of the centrifuged cake samples was transferred using a pipette into 150 mL balloon flasks after centrifuge at 8500 rpm and 4°C for 20 minutes (Electro-Mag M 815 A). The serum component was then added to the flasks after repeating the same procedures while adding 10 mL of the methanol solution. The solutions were transferred to amber-colored bottles and kept at -18°C after being filled to a volume of 25 mL with a 70 percent methanol solution in the balloons.

The method developed by Thaipong et al. [32] was modified in order to measure antioxidant activity. During the analysis, the stock solution was produced up to 1000 mL after 24 mg of DPPH had been dissolved in 100 mL of methanol. Using ethanol as a blank solution and ascorbic acid as a reference, the absorbance was measured at 517 nm with a UV-VIS spectrophotometer (PGI brand T60U series). The following equation was used to calculate the percent inhibition (percent I) of the DPPH radical scavenging activity.

$$I\,(\%) = [(A0 - A1) / A0] \times 100$$

A0: Absorbance of control group
A1: Absorbance of sample

Reducing Sugar Analysis

Cake samples were evaluated for reducing sugar, total sugar, and sucrose using the Lane-Eynon method [33]. Only reducing sugar analysis was done on cakes made entirely of D-allulose.

Sensory Analysis

The ISO [34] standard was followed for conducting sensory analyses. A panel of 10 participants, 5 men and 5 women, with a minimum of a master's degree, training in this department, and participation in at least one taste panel-conducted the study. In a room that was well-lit, odor-free, and the optimum temperature (20°C), cake groups were evaluated. Each sample was placed on porcelain dishes for all panel sessions and coded with a letter corresponding to each group. Prior to analysis, all samples were stored for 30 minutes at room temperature (about 20°C). A 9-point hedonic scale was used for evaluation (9 being extremely good and 1 being extremely bad). The cake samples were scored by the panelists based on their appearance (crust appearance, crust thickness, crumb appearance, and volume), color (crumb-crust color), texture (elasticity, pore structure, hardness-softness, chewiness), aroma-flavor (sweetness-bitterness), and general acceptability.

Energy and Macro Nutrient Value

Applying nutrition information systems (BEBIS), all of the baked goods were evaluated for their energy and macronutrient content. The Turkish Nutrition Guide (TUBER) was used to determine the size of one portion of the cakes. One matchbox-sized cake (40–45 g) was accepted as the standard portion sizes for cakes in TUBER, and it was stated that this portion size contained roughly 185 kcal of calories [35]. As a result, the produced cakes were divided into 21 equal portions, and each portion's energy and macronutrient values were calculated.

Statistical Analysis

The statistical package for the social sciences (SPSS) (version 26) package software [36] was used to analyze the data. All data are given as mean (x) and standard deviation, apart from texture profile analysis data (SD). Texture profile analysis data are given as mean and standard error (SE). Non-parametric Mann Whitney U test was used in the analyzes comparing the two groups. To compare the differences between more than two groups, a one-way ANOVA test was used. The difference between groups was assessed using the Tukey Post Hoc Multiple Comparison test. ANOVA analysis with repeated measurements was used to determine differences among days. $p<0.05$ was considered statistically significant.

RESULTS and DISCUSSION

Solvent Retention Capacity

When compared to D-allulose and other solvents, sucrose, which performed as the study's control group, had the highest solvent retention capacity (SRC). Sucrose (control) was determined to have an SRC of 129.7±10.1. The AL50 and AL100 groups' SRC percentages were 115.5±8.5% and 101.4±4.7%, respectively (Table 2). An analysis known as solvent retention capacity is used to assess the characteristics and quality of the flour used as well as the baking performance profile. It also assesses the degree of solvent compatibility for the functional components of wheat flour like gluten, damaged starch, and arabinoxylans (pentosans) [37]. This is conducted to assess the functional impact of each solvent used on the quality of the final product [38]. When compared to D-allulose and other solvents, sucrose, which served as the control group, had the highest level of solvent retention capacity (Table 2). The usage of D-allulose as a sugar substitute in cakes is inferred from the fact that it has an SRC that is close to sucrose. In a study by Lee et al. [20], D-allulose was utilized to make cakes as a sugar substitute, the SRC of sucrose was found to be 130±1.8, 50% of D-allulose, 118±2.5, and 100% of D-determined that allulose was 100±2.3. These results appear to be similar to the results of this study. It is reported that sucrose has a higher effect on gluten complex formation than D-allulose. Due to heat treatment, the resulting gluten complex gives cakes a better rise [39]. This demonstrates that the control group made a large number of cakes.

Table 2. Solvent retention capacity

Solvents	Solvent Retention Capacity (%) (x±SD)
Sucrose (Control)	129.7±10.1
AL50	115.5±8.5
AL100	101.4±4.7
Distilled water	55.6±7.5
Lactic acid	110.9±13.9
Sodium carbonate	73.4±4.5
p*	0.00

*One Way ANOVA analysis was used. x±SD: mean ± standart deviation

Physicochemical Analysis of Cake Dough and Cakes

As the D-allulose ratio rises, the cake volumes decrease ($p<0.05$).When the specific volume averages of the cakes were examined, it was found that the control, AL50 and AL100 groups were 1.13±0.1, 1.13±0.2 and 1.12±0.0 mL/g, respectively ($p>0.05$). While the average cake yields were 87.2±1.9%, 86.2±4.1% and 87.6±3.2% for the control, AL50 and AL100 groups, respectively ($p>0.05$) (Figure 1). When the water activity values of the cakes produced on the 1st day were examined, it was determined that the control group was 0.83±0.3, the AL50 group 0.82±0.1 and the AL100 group 0.81±0.5 (Table 3). The components of the cake recipe, dough viscosity, solvent retention capacity of the solvents, starch gelatinization, molecular weight, baking temperature and time, and baked cake mold are just a few of the factors that can influence physical analyses of cakes [40, 41]. Cake height and specific volume are related to the increased air retention of the ingredients used in the cake during whipping [42]. Table 3 displays the physical characteristics of the cakes used in this study. The higher viscosity of cake dough containing D-allulose and the fact that sucrose induces swelling in cakes by retaining carbon dioxide and water vapor during baking are also factors that contribute to the lower height values of the AL50 and AL100 groups in cakes. According to Manisha et al. [43], sucrose delays the starch gelatinization process during baking, which results in cakes gaining volume. In their production of cupcakes, Bolger et al. [21] substituted D-allulose for sugar and demonstrated that sucrose produced cakes that were superior to D-allulose at all baking temperatures. They claimed that the cause of this was due to the cakes hardening more quickly as a result of D-allulose and fructose's early induction of egg white and starch denaturation, respectively. In general, the physical qualities of cakes prepared using various sugar substitutes or food additives exhibit similarities to those of typical (control) cakes made using sucrose. According to this study, the effect of D-allulose, a sugar replacement used in baking, on the physical characteristics of cakes is similar to that of sugar. In terms of microbial growth, spoiling reactions, and physical qualities, water activity is a crucial parameter to determine nutrient stability and nutritional security. By regulating the degree of reliance of water in a system, water activity analysis is utilized as a gauge of physical, chemical, and microbiological deterioration [44].

Control AL50 AL100

Figure 1. Images of cake samples (Al50: 50% Sucrose, 50% D-Allulose; AL100:100% D-Allulose)

Table 3 displays the water activity and pH values of the cakes used in this study. The close proximity of the differences between the groups is regarded as indicating that the shelf life of D-allulose-produced cakes will be comparable to that of standard cakes. From a microbiological perspective, it is believed that increased water activity in the cakes for eight days increases the danger. In order to assess the overall amount of carbohydrates in a food, dry matter analysis is a method used to determine the total amounts of protein, fat, and ash [45]. In this study, it was determined that the total dry matter ratio of the control group was 76.1±3.0, the AL50 group was 76.4±4.6, and the AL100 group was 75.0±2.6. That's because the only ingredient in the cake recipe that is modified is sugar, and the sugar substitute D-allulose is also a simple carbohydrate. Although the weight of the cake sample under study and the high dry matter content in the AL50 group are related, the difference is negligible for the food industry.

Table 3. Results of physicochemical analyses in cakes

Physical analyses in cakes		Control (x±SD)	AL50 (x±SD)	AL100 (x±SD)	p*
Height (cm)		2.60±0.14^{a}	1.75±0.1^{b}	1.50±0.0^{b}	0.003
Volume (mL)		1084±19.8^{a}	1106±129.4^{a}	1036±13.4^{a}	0.67
Specific volume (mL/g)		1.13±0.1^{a}	1.13±0.2^{a}	1.12±0.0^{a}	0.99
Cake density (g/mL)		1.01±0.1^{a}	1.03±0.14^{a}	1.01±0.0^{a}	0.95
Cake yield (%)		87.2±1.9^{a}	86.2±4.1^{a}	87.6±3.2^{a}	0.90
Weight loss (%)		12.8±1.9^{a}	13.7±4.1^{a}	12.3±3.2^{a}	0.90
Chemical analyses in cakes	Days				
Water activity	1	0.83±0.3^{Aa}	0.82±0.1^{Aa}	0.81±0.5^{Aa}	0.80
	4	0.83±0.3^{Aa}	0.84±0.0^{Aa}	0.86±0.1^{Aa}	0.39
	8	0.86±0.1^{Aa}	0.87±0.3^{Ba}	0.85±0.0^{Aa}	0.19
	p$^{\#}$	0.51	0.02	0.35	
pH	1	7.5±0.1^{Aa}	6.9±0.0^{Ab}	6.7±0.0^{Ab}	0.00
	4	7.1±0.1^{Ba}	6.8±0.4^{Ab}	6.7±0.2^{Ab}	0.03
	8	7.2±0.0^{Ba}	6.8±0.0^{Ab}	6.7±0.0^{Ac}	0.0
	p$^{\#}$	0.03	0.93	0.29	
Total dry matter (g)		6.4±1.4^{a}	9.1±2.0^{a}	7.7±0.3^{a}	0.21
Total dry matter (%)		76.1±3.0	76.4±4.6	75.0±2.6	0.88
Total ash (g)		0.09±0.0^{a}	0.17±0.03^{b}	0.15±0.01^{a}	0.03
Total ash (%)		1.2±0.0^{a}	1.3±0.0^{b}	1.4±0.0^{c}	0.01

* One Way ANOVA analysis was used. The differences between the groups were identified and displayed using lowercase letters using the Tukey multiple comparison test. # Repeated Measurements ANOVA analysis was used. x±SD: mean ± standard deviation

Viscosity

Viscosity analysis was carried out on cake dough. In all groups, it can be shown that the viscosity values drop as spindle speed rates. The viscosity values of the AL100 group were found to be higher than those of the control and AL50 groups at the same spindle speeds (Figure 2). The viscosity values for the control, AL50, and AL100 groups, respectively, were determined to be 8.000, 6.842, and 8.758 mPa.s in the values recorded at the highest speed. One of the components that influence the final cake volume is the cake batter's viscosity, and the buoyancy force causes the bubble rising rate to be inversely proportional to the viscosity [46]. In order to avoid the added air bubbles from rising to the surface and being lost during early heating, a good cake batter must have enough viscosity [47]. In the amorphous region between the hydroxyl groups of the sugar and the starch, the interaction of the starch molecule and the sugar creates a sugar bridge. Each glucose unit in the -D-glucopyranose unit, which makes up the structure of starch, contains three locations where hydroxyl groups might interact with other molecules. Starch and the hydrogen bond are both impacted by the sugar's hydroxyl group. The starch granule's expansion and granule fragmentation are decreased as a result of the sugar's hydroxyl group replacing for the water molecule [48]. The starch suspension has less viscosity as a result of the addition of sugar [49]. As the study's viscosity analysis findings, it can be noted that all groups' viscosity values drop as spindle speed rises (Figure 2). When compared to sucrose, it may be claimed that D-Allulose makes cakes more viscous. According to Bolger et al. [21], D-allulose had a higher viscosity despite having a similar flow behavior to sucrose and fructose in the cupcakes they made using D-allulose, sucrose, and fructose. Due to its high viscosity qualities, it has been demonstrated in this study that D-allulose has a negative impact on the final cake volume and height.

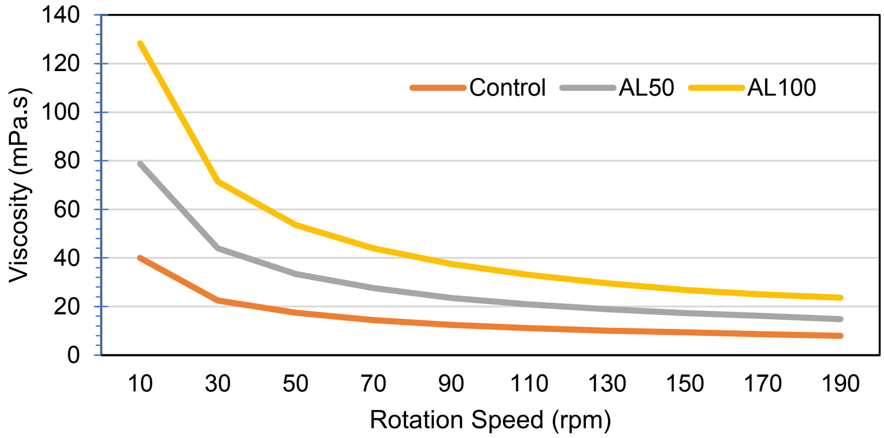


Figure 2. Viscosity analysis of cake dough samples (Al50: 50% Sucrose, 50% D-Allulose; AL100:100% D-Allulose; rpm: Revolutions per minute)

Color Analysis

The mean L*, a*, b* color values of the crust part of the control group were 57.5±0.4, 18.1±0.3, and 38.5±0.6, respectively. The mean L*, a*, b* values of the AL50 group were determined as 53.6±0.7, 20.6±0.2 and 40.6±2.4, respectively. In the AL100 group, these values were 47.9±1.3, 21.9±0.2 and 35.9±1.4, respectively. When the crumb color analyzes were examined, the mean L*, a* and b* values of the control group were determined as 84.4±0.5, -2.6±0.3 and 26.1±0.6, respectively. The mean crumb color values of the AL50 group were 77.8±1.5, 0.98±0.6 and 30.5±0.3, respectively; In the AL100 group, these rates were 65.4±2.7, 6.3±0.8, and 33.3±1.7 (Table 4). Melanoidin, a substance produced by the maillard reaction between the amino groups of proteins and carbohydrates in cake components, has an impact on the crust and crumb color characteristics of cakes [50]. After heat treatment, cakes contain more melanoid, which darkens the color of the crumb and crust. According to Hossain et al. [11] and O'Charoen et al. [51], D-allulose shows a better Maillard reaction than other monosaccharides, which enhances functional characteristics. Table 4 displays the findings of the analysis of the cakes made for this study's crust and crumb colors. The color values of the crust and crumb portions of the cakes produced were investigated in a study that used D-Allulose as a sugar substitute. Mean crust L*, a*, b* and ΔE values of cakes produced from 50% and 100% D-allulose were 35.3±0.8, 6.2±0.7, 5.5±0.9, and 17.7±0.6 ve 34.5±0.6, 4.8±0.8, 3.7±0.8, 19.8±0.3, respectively. The browning index of cakes was reported in the same study to be 0.10±0.0, 0.12±0.0, and 0.23±0.0, respectively [20]. The browning index and color values of cake samples increased in direct proportion to the D-allulose ratio and baking time, according to Bolger et al. [21] investigation with D-allulose substitution. Although there have only been a few studies with D-Allulose, Lee et al. [20] found that the findings of their investigation were comparable to those of this study. The browning index and other color parameters were greater in the D-allulose group, and D-allulose provided a better Maillard reaction than sucrose, according to Lee et al. [20] and Bolger et al. [21]

Texture Profile Analysis

As a result of the texture profile analysis of the cakes produced as control, AL50 and AL100, the mean hardness values were found to be 1657.2±157.3 g, 2486.4±122.8 g and 3721.8±244.1 g, respectively ($p<0.05$). Chewiness values of the cakes produced as control, AL50 and AL100 were found 87.8±45.1, 89.0±37.5, and 299.6±11.0 respectively. The statistical significance of the differences in the stickiness, resilience, adherences, and elasticity values of the generated cake groups was not determined ($p>0.05$) (Table 5). Food's textural qualities play a significant role in how well it is received by consumers [52]. Table 5 displays the outcomes of this study's analysis of the texture profile. According to Lee et al. [20], the cakes prepared using D-allulose as a sugar substitute had the highest hardness value compared to the cakes in the control group, and the hardness value increased as the D-allulose ratio increased. The same study found that the resilience value increased as the D-allulose ratio increased, with the control group having the lowest resilience valueIt was found that the control group had the highest gumminess value, and that this value increased as the D-allulose ratio increased. It is believed that the differences in the cake recipe are what caused the difference in these study outcomes. Similar findings were made in the study by Bolger et al. [21], which suggested that the retrograding starch network in D-allulose-containing cakes may be responsible for the cakes' firmness. According to Gao et al. [53], a decrease in sugar concentration may result in an increase in hardness and flexibility values. Karaoğlu and Bedir [54] also concluded that the partial baking method was effective in increasing the chewiness and elasticity values of the cakes and decreasing the cohesiveness value, and that 20 minutes of partial baking and up to 14 days of intermediate storage could be used in cake production.

Table 4. Color analysis results for cake groups

Color value	Crust			p*	Crumb			p*
	Control (x±SD)	AL50 (x±SD)	AL100 (x±SD)		Control (x±SD)	AL50 (x±SD)	AL100 (x±SD)	
L*	57.5±0.4[a]	53.6±0.7[b]	47.9±1.3[c]	0.00	84.4±0.5[a]	77.8±1.5[b]	65.4±2.7[c]	0.04
a*	18.1±0.3[a]	20.6±0.2[b]	21.9±0.2[c]	0.00	-2.6±0.3[a]	0.98±0.6[b]	6.3±0.8[c]	0.02
b*	38.5±0.6[a]	40.6±2.4[a]	35.9±1.4[a]	0.13	26.1±0.6[a]	30.5±0.3[b]	33.3±1.7[b]	0.01
ΔL*	-37.2±0.4[a]	-41.1±0.7[b]	-46.8±1.3[c]	0.04	-10.3±0.5[a]	-16.9±1.5[b]	-29.3±2.7[c]	0.00
Δa*	18.2±0.3[a]	20.7±0.2[b]	21.9±0.2[c]	0.01	-2.5±0.3[a]	1.1±0.6[b]	6.4±0.8[c]	0.00
Δb*	35.7±0.6[a]	37.8±2.4[a]	33.1±1.4[a]	0.13	23.3±0.6[a]	27.8±0.3[b]	30.6±1.7[b]	0.01
ΔE	54.7±0.6[a]	59.6±1.1[b]	61.4±0.3[b]	0.00	25.6±0.7[a]	32.5±1.1[b]	42.8±3.1[c]	0.00
BI	28.2±0.1[a]	33.6±0.3[b]	38.1±0.9[c]	0.00	0.8±0.3[a]	4.8±0.7[a]	11.9±1.6[c]	0.00

BI: Browning index, x±SD: mean ± standart deviation, Al50: 50% Sucrose, 50% D-Allulose), AL100: (100% D-Allulose)
* One Way ANOVA analysis was used. With the Tukey multiple comparison test, the differences among the groups were determined and shown with lowercase letters.

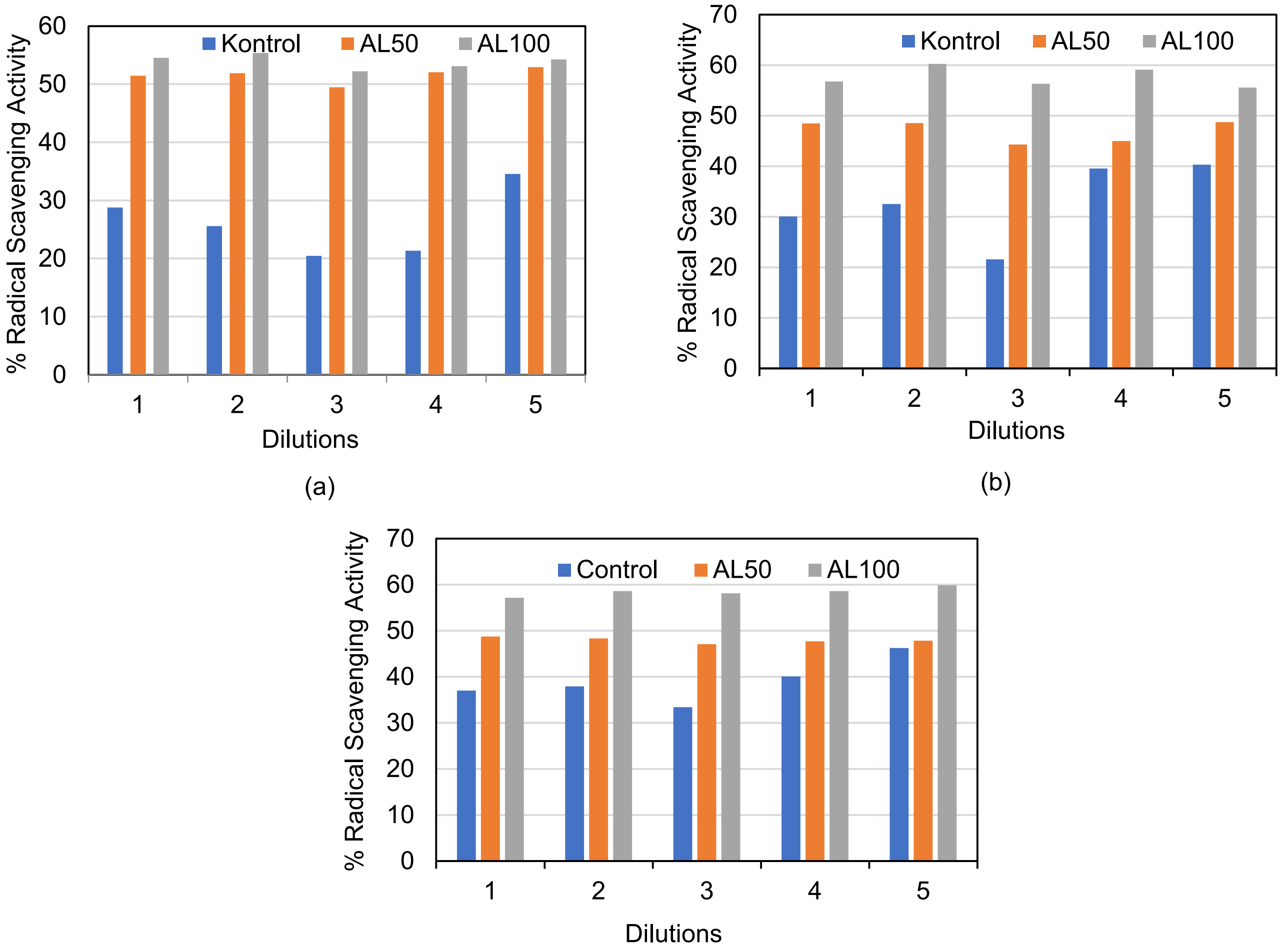
Table 5. Texture Profile Analysis experimental cake groups

Parameter	Control (x±SE)	AL50 (x±SE)	AL100 (x±SE)	p*
Hardness (g)	1657.2±157.3[a]	2486.4±122.8[a]	3721.8±244.1[c]	0.00
Stickiness	-37.2±4.9[a]	-24.3±7.6[a]	-6.0±4.7[a]	0.07
Resilience	0.34±0.2[a]	0.21±0.1[a]	0.62±0.0[a]	0.14
Adherences (%)	0.15±0.0[a]	0.16±0.0[a]	0.13±0.0[a]	0.31
Cohesiveness	251.6±9.1[a]	403.6±34.1[a]	481.5±31.9[c]	0.02
Chewiness	87.8±45.1[a]	89.0±37.5[a]	299.6±11.0[c]	0.03
Elasticity (%)	0.058±0.01[a]	0.059±0.01[a]	0.052±0.0[a]	0.76

SE: Standart Error, Al50: 50% Sucrose, 50% D-Allulose), AL100: (100% D-Allulose). *One Way ANOVA analysis was used. With the Tukey multiple comparison test, the differences between the groups were determined and shown with lowercase letters.

Antioxidant Activity

The total radical scavenging activity (RSA) of the cakes is calculated by taking the average of five dilutions (0.1-0.5 mL/mg), and Figure 3a, 3b, and 3c shows the total RSA at various dilutions. The mean RSA on the first day was found to be 26.1±5.8% in the control group, 51.6%±1.3% in the AL50 group and 53.9%±1.2% in the AL100 group (Figure 3a). The mean RSA of the cakes on the fourth day were 32.8%±7.7%, 47.0±2.2% and 47.9±0.6% (Figure 3b), respectively; the mean RSA on the eighth day were 53.9%±1.2%, 57.6%±2.0% and 58.5±1.0% ($p<0.05$) (Figure 3c). Compounds known as antioxidants work to counteract the effects of free radicals in the body and prevent the oxidation of lipids, particularly in foods. Natural antioxidant components isolated from plants have started to replace synthetic antioxidants like butylated hydroxyanisole and butylated hydroxytoluene, which are commonly utilized in the food industry today [55]. D-Allulose has reportedly been linked to increased antioxidant activity in food as a result of its high Maillard reaction products [56]. O'Charoen et al. [51] in a study investigating the nutritional properties of albumen modified by rare ketohexoses by Maillard reaction, reported that D-allulose showed higher antioxidant activity compared to fructose. On the other hand, Kim and Han [57] reported that the RSA value of D-allulose varied between 54.2% and 47.0%, but the decrease in RSA was not statistically significant as the D-allulose ratio increased. In addition, in this study, it was emphasized that D-allulose showed high antioxidant activity. No study was found that investigated the effect of D-allulose on antioxidant activity in cakes. Therefore, this study is the first study in the literature with this aspect.



(c)

Figure 3. Results of the total radical scavenging activity assay on the first day (a), the fourth day (b) and the eigth day (c) (Dilution 1: 1 mL/mg, Dilution 2: 2 mL/mg, Dilution 3: 3 mL/mg, Dilution 4: mL/mg, Dilution 5: 5 mL/mg; Al50: 50% Sucrose, 50% D-Allulose, AL100: 100% D-Allulose)

Reducing Sugar Analysis

The reducing sugar ratios of the control group were 0.46%, the AL50 group was 4.20% and the AL100 group was 7.0%. The ratio of total reducing sugar increases positively with the ratio of D-allulose ($p<0.05$). Since the AL100 group does not contain sucrose, the ratio of total sugar and sucrose was not analyzed. Total sugar ratios of the control group and AL50 group were found to be 22.7% and 15.8%, respectively. The sucrose ratios of the control and AL50 group cakes were 21.1% and 11.0%, respectively. The Lane-Eynon method is frequently preferred for reducing sugar analysis even if there are several methods available. Based on the reduction of copper-II-oxide in Fehling's solution to water-insoluble copper-I-oxide by inverting sugar in an alkaline medium at boiling temperature, the Lane-Eynon method analyzes sugar [33]. Reducing sugars are substances used in the baking of cakes in the bakery industry that affect the color and texture of the cake's crust and crumbs [58]. According to reports [59], the Maillard reaction creates carbohydrates with reducing abilities. These compounds impact the flavor, aroma, and color of food, and some, such hydroxymethyl furfural, acrylamide, and heterocyclic amines, have been linked to cancer. Because it lacks free aldehyde or ketone groups in its chemical composition, sucrose, which is extensively used to sweeten food, does not exhibit reducing activities [60]. However, sucrose is converted into glucose and fructose and gains reducing characteristics through actions like strong acid or heat treatment [61]. Because of this, the increased amount of reducing sugar created by the breakdown of sucrose and its enhanced Maillard reaction is what gives bakery products like bread and cake their characteristic brown color [62]. Because it has a free ketone group in its chemical structure, D-allulose exhibits direct reducing activities [11]. There aren't many research that indicate functional foods made with D-allulose have reducing sugar activity. There were not enough resources available to report the findings because these research did not focus on baked products. When this study is compared to studies that investigate the reducing sugar content of cakes, it becomes clear that D-allulose has a higher reducing property than sweet potato flour and a lower reducing property than molasses prepared from different fruits. To demonstrate similar results to those in the literature, it is crucial to note that the reducing sugar ratio in the cakes made with D-allulose was higher than in the control group.

Sensory Analysis

On the first day of the sensory analysis, the control group's mean general acceptability value was 7.8±1.5, the AL50 group's mean general acceptability was 7.9±1.2, and the AL100 group's mean general acceptability value was 7.3±1.0 ($p>0.05$). The AL100 group cakes received lower scores in terms of volume (swelling), elasticity, pore structure, and hardness-softness values after the sensory analysis was carried out on the first day, and this was statistically significant ($p<0.05$). According to the findings of the sensory analysis conducted on the fourth day, the control group's mean general acceptability score was 8.2±0.8, while the scores for the AL50 and AL100 groups were 8.2±0.8 and 7.4±0.9, respectively ($p<0.05$) and the overall acceptability scores were higher than the 1st day (Table 6). In order to evaluate new product designs, improve product quality, assess acceptability of the product, and identify quality-control and assurance issues, sensory analysis is a scientific discipline that uses the senses of hearing, touching, tasting, smelling, and seeing [63]. An significant factor in establishing consumer preference is the sensory qualities of the newly created product or one or more of its components [64]. Lee et al. [20] found that the general acceptability score of cake products containing D-allulose at different rates in pancake samples, in which D-allulose was used as a sugar substitute at different rates, was 6.7±1.4, 6.1±1.6, and 5.3±1.8 respectively. The overall acceptability score of the control (sucrose) group was reported to be 7.0±1.2. In cakes made with D-allulose utilized in a variety of ratios, it is seen that the product's acceptance score decreases as the D-allulose ratio increases. Because D-allulose tastes less sweet than sucrose, the decline in sweetness levels and the D-Allulose ratio can be attributed to this. In compared to the other groups, cakes containing 25% D-allulose were found to be more palatable at the conclusion of the study. In a study by Bolger et al. [21], D-allulose was compared to sucrose and fructose in cupcakes baked at 20°C. It was shown that D-allulose had similar physical and textural characteristics to fructose and sucrose. Additionally, he said that D-allulose might be used in the bakery industry when combined with extended baking durations or other items that need less volume enhancement and have lower moisture contents. When compared to studies using various sugar substitutes, the decreased D-Allulose scores compared to the control group indicate similar outcomes. This lends support to the idea that the panelists are more appreciative of the flavours they are familiar to.

Table 6. Sensory analysis of cake groups

		1st day				4th day				8th day			p*
		Control (x±SD)	**AL50 (x±SD)**	**AL100 (x±SD)**	**p***	**Control (x±SD)**	**AL50 (x±SD)**	**AL100 (x±SD)**	**p***	**Control (x±SD)**	**AL50 (x±SD)**	**AL100 (x±SD)**	
Appearance	Crust appearance	7.6±1.6^{Aa}	7.9±1.1^{Aa}	7.5±1.2^{Aa}	0.50	7.8±1.6^{Aa}	8.2±0.8^{Aa}	7.7±1.0^{Aa}	0.45	7.9±1.6^{Aa}	8.0±0.9^{Aa}	7.1±1.1^{Aa}	0.14
	Crust thickness	7.6±1.7^{Aa}	7.9±0.7^{Aa}	7.8±1.0^{Aa}	0.79	7.7±1.4^{Aa}	8.2±0.8^{Aa}	7.7±0.8^{Aa}	0.20	8.3±1.1^{Aa}	8.0±1.0^{Aa}	6.9±1.5^{Ac}	0.02
	Crumb appearance	8.1±1.2^{Aa}	7.8±1.0^{Aa}	7.3±1.1^{Aa}	0.06	8.0±1.1^{Aa}	7.9±0.9^{Aa}	7.2±1.0^{Ab}	0.03	8.1±1.2^{Aa}	7.8±0.9^{Aa}	6.7±1.6^{Ac}	0.02
	Volume (swelling)	8.4±1.0^{Aa}	7.6±0.9^{Aa}	7.0±1.3^{Ab}	0.00	8.2±0.7^{Aa}	8.1±0.7^{Aab}	7.1±1.0^{Ac}	0.00	8.7±0.7^{Aa}	7.7±1.2^{Ab}	6.5±1.4^{Ac}	0.00
Color	Crumb color	7.6±1.7^{Aa}	7.9±0.9^{Aa}	7.2±1.1^{Aa}	0.24	7.9±1.2^{Aa}	8.1±0.8^{Aa}	7.5±0.9^{Aa}	0.15	7.9±1.3^{aA}	8.0±1.2^{Aa}	6.9±1.6^{Aa}	0.11
	Crust color	7.5±1.7^{Aa}	8.0±0.9^{Aa}	7.3±1.1^{Aa}	0.22	7.9±1.1^{Aa}	8.1±0.7^{Aa}	7.4±0.9^{Ac}	0.05	7.9±1.2^{Aa}	8.0±0.9^{Aa}	7.2±1.2^{Aa}	0.14
Texture	Elasticity	8.5±0.6^{Aa}	7.8±1.1^{Aa}	7.3±1.5^{Ab}	0.00	8.2±0.6^{Aa}	7.7±1.0^{Aa}	7.2±1.2^{Ac}	0.00	8.5±0.9^{Aa}	7.6±1.2^{Aa}	6.9±1.6^{Ac}	0.01
	Pore structure	8.3±0.7^{Aa}	7.5±1.2^{Aa}	7.2±1.4^{Ab}	0.01	8.2±0.8^{Aa}	7.9±0.9^{Aa}	7.4±1.0^{Ac}	0.04	8.5±0.7^{Aa}	8.0±1.2^{Aa}	7.1±1.5^{Ac}	0.01
	Hardness-Softness	8.4±0.7^{Aa}	7.7±1.1^{Aa}	7.3±1.2^{Ab}	0.00	8.3±0.8^{Aa}	7.9±0.8^{Aa}	7.4±0.9^{Ac}	0.00	8.6±0.9^{Aa}	7.8±1.1^{Aa}	6.6±1.9^{Ac}	0.00
	Chewiness	8.4±1.1^{Aa}	7.8±1.3^{Aa}	7.7±1.2^{Aa}	0.15	8.2±0.9^{Aa}	8.3±0.7^{Aa}	7.7±0.8^{Aa}	0.05	8.7±0.7^{Aa}	8.3±1.0^{Aa}	7.3±1.4^{Ac}	0.00
Aroma-Flavor	Sweetness-Bitterness	7.8±1.3^{Aa}	7.5±1.3^{Aa}	7.1±1.4^{Aa}	0.31	8.1±0.9^{Aa}	7.9±0.9^{Aa}	7.2±1.2^{Ac}	0.03	8.4±0.9^{Aa}	8.0±1.2^{Aa}	6.6±1.8^{Ac}	0.00
General acceptability		7.8±1.5^{Aa}	7.9±1.2^{Aa}	7.3±1.0^{Aa}	0.39	8.2±0.8^{Aa}	8.2±0.8^{Aa}	7.4±0.9^{Ac}	0.00	8.5±0.8^{Aa}	7.8±1.3^{Aa}	6.7±1.4^{Ac}	0.00

* One Way Anova analysis was used. With the Tukey multiple comparison test, the differences between the groups were determined and shown with lowercase letters.

x±SD: mean ± standart deviation, Al 50: 50% Sucrose, 50% D-Allulose), AL100: (100% D-Allulose)

Energy and Macro Nutrient Value of a Portion of Cake

The total energy values of the cakes in the control, AL50 and AL100 groups included 3654.4 kcal, 3191.6 kcal and 2728.9 kcal energy, respectively. Although it was not statistically examined, it was found that the energy value of the cakes containing D-Allulose decreased. Without any variation between the groups, the cakes included 469.2 g of carbohydrates, 58.4 g of protein, and 170.7 g of fat. One portion of the baked cakes had energy values of 174.0, 152.0, and 130.0 kcal/45 g, respectively. Cakes prepared with AL100 have a lower energy content per portion than cakes made with AL50 or the control group. According to the WHO, free or added sugar consumption should not account for more than 10% of daily calorie intake [4]. Due to these findings and suggestions, the food industry has seen an increase in requests for the rearrangement of goods that contain free or added sugar [25]. As shown in this study, one portion of the cakes prepared with control (sucorse), AL50, and AL100, each had 174.0, 152.0, and 130.0 kcal/45 g of energy, respectively. One of the limitations of this study is the absence of total nitrogen/protein, total fat, and total fiber analyses in the energy and macronutrient analyses. It is clear that the cakes produced in this study using D-allulose as a sugar substitute had less calories than those produced in the studies. Low-glycemic index D-allulose, which has also demonstrated anti-diabetic effects [65], is believed to be a potential ingredient for low-energy cakes. D-allulose is preferred by the consumer when used in cake production, according to the panelists' ratings of the baked products.

CONCLUSION

The impact of D-allulose, a sugar substitute, on the physicochemical, textural, and sensory characteristics of cakes were examined in this study. These analyses show that it can be used in the development of new products in this field. The positive health effects, such as antidiabetic, antihyperlipidemic, and antioxidant effects when consumed, seem to make it better than regular cake samples in addition to these effects on cake quality attributes. In order to assess the quality of the items generated, other analyses such as total protein, total fat, acrylamide, hydroxymethylfurfural, and dietary fiber could not be carried out. The study's limitations can be attributed to the lack of these analyses. In addition, the cost and selling price of the cake selection of participants in the sensory analyses presented to the panelists, as well as the fact that their health effects were also mentioned, may give the cakes a higher score in terms of general acceptance. At the same time, it is thought that D-allulose will be used more frequently in the food industry by conducting studies that include the analyzes specified as the limitations of this study. On the other hand, D-allulose should be used in a lot more food-related products, and both human and experimental animal studies should be conducted to show what effects it has on health. As a result, D-allulose is a natural sweetener that has positive effects on health and increases the quality of the food it is used in. Cakes from bakery products can be recommended as snacks in diets where the added sugar content does not exceed 10%. Cakes produced by using D-allulose as a sugar substitute can be used as an alternative snack in diets where the added sugar content exceeds 10% or in individuals where daily added sugar consumption is limited.

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