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Research Article

Effect of Various Hydrocolloid Combinations on the Physicochemical, Bioactive, and Microstructural Properties of Traditional Turkish Milk-Based Desserts

Çeşitli Hidrokolloid Kombinasyonlarının Geleneksel Türk Sütlü Tatlılarının Fizikokimyasal, Biyoaktif ve Mikroyapısal Özellikleri Üzerine Etkisi

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ABSTRACT

This study investigated the effect of different hydrocolloid combinations on the quality characteristics of kazandibi, sütlaç and keşkül, traditional Turkish dairy desserts. The physicochemical properties (total solid, fat and protein contents and pH), total phenolic content (TPC), antioxidant activity (AA), dietary fiber content and microstructures of dessert samples were determined. Statistically significant differences were observed among the dessert types in terms of their physicochemical properties ($p<0.05$). However, the values for hydrocolloid combinations within each specific dairy desserts category were statistically similar ($p>0.05$). Regarding TPC and AA, significant differences were determined among dessert types ($p<0.05$) with the highest TPC in kazandibi, while the highest AA was found in keşkül. Sütlaç desserts exhibited the lowest values for both TPC and AA. Furthermore, the total dietary fiber contents of dairy desserts were found statistically different ($p<0.05$). The use of hydrocolloids had a positive impact on the microstructure of desserts, leading to a reduction in porosity and an enhancement of the overall structural integrity. In conclusion, while the formulation differences among desserts influenced their dietary fiber content, TPC and AA to a certain degree, the overall impact of different hydrocolloid combinations on these properties remained limited.

Keywords: Antioxidant activity, Dairy dessert, Dietary fiber, Hydrocolloids, Microstructure

ÖZ

Bu çalışma, farklı hidrokolloid kombinasyonlarının geleneksel Türk sütlü tatlıları olan kazandibi, sütlaç ve keşkülün kalite özellikleri üzerindeki etkisini incelemiştir. Tatlı örneklerinin fizikokimyasal özellikleri (toplam kuru madde, yağ ve protein içerikleri ile pH), toplam fenolik madde içeriği (TPC), antioksidan aktivitesi (AA), diyet lifi içeriği ve mikroyapıları belirlenmiştir. Tatlı türleri arasında fizikokimyasal özellikleri açısından istatistiksel olarak anlamlı farklılıklar tespit edilmiştir ($p<0,05$). Buna karşın her tatlı türünün kendi içerisindeki hidrokolloid kombinasyonlarına ait değerlerin istatistiksel açıdan benzerlik gösterdiği belirlenmiştir($p>0,05$). TPC ve AA açısından, tatlı türleri arasında anlamlı farklılıklar belirlenmiştir ($p<0,05$). En yüksek TPC kazandibinde görülürken, en yüksek AA keşkülde saptanmıştır. Sütlaç örnekleri hem TPC hem de AA bakımından en düşük değerleri göstermiştir. Ayrıca, sütlü tatlıların toplam diyet lifi içeriklerinin istatistiksel olarak farklı olduğu bulunmuştur ($p<0,05$). Hidrokolloid kullanımı, porozitenin azalmasına ve genel yapısal bütünlüğün iyileşmesine yol açarak tatlıların mikroyapısı üzerinde olumlu bir etki göstermiştir. Sonuç olarak, tatlılar arasındaki formülasyon farklılıkları diyet lifi içeriğini, TPC'yi ve AA'yı belirli ölçüde etkilemiş olsa da farklı hidrokolloid kombinasyonlarının bu özellikler üzerindeki genel etkisi sınırlı kalmıştır.

Anahtar Kelimeler: Antioksidan aktivite, Sütlü tatlılar, Diyet lifleri, Hidrokolloidler, Mikroyapı

INTRODUCTION

Dairy desserts are generally defined as products formulated with primary ingredients such as milk, sugar, starch, flour and eggs often supplemented with additives including colorants, flavorings and various hydrocolloids to enhance flavor and improve structural properties [1, 2]. These desserts are prepared in diverse ways across different cuisines and regions worldwide, resulting in various flavors depending on

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the production methods and the variety of ingredients used [3, 4].

Turkish cuisine is considered one of the oldest and richest in the world, alongside French and Chinese cuisines [5]. In Türkiye, traditional dairy desserts primarily include varieties such as sütlaç (rice pudding), keşkül (almond-based milk pudding), kazandibi (caramelized milk pudding), tavukgöğsü, muhallebi and güllaç [6, 7]. Globally, similar dairy desserts are found under different names: Phirni in India [8], Kheer in the outskirts of the Middle East and India [9], Milchreis in Germany [10], rice pudding in various American and European countries [11]. Additionally, Dulce de leche is a preferred milk jam in Brazil [12] while Natillas in Spain, Vanilla Vla in the Netherlands and Crème dessert in France represent other notable dairy dessert varieties [13].

Dairy desserts exhibit variations in texture, appearance and flavor. These differences arise from the characteristics of the raw materials used, such as milk fat content, starch type and the properties and concentrations of gelling and thickening agents, as well as their interactions and the specific production methods employed [14, 15]. Hydrocolloids stand out as the most critical components affecting the textural properties of dairy desserts [15]. In food systems, hydrocolloids are utilized for gelation, emulsification, stabilization and as fat replacers, anti-caking agents and coating materials [16, 17]. Recently, they have also been incorporated by many manufacturers as low-calorie dietary fibers [16].

Hydrocolloids are a large and heterogeneous group of polymeric materials consisting mainly of carbohydrates and small amounts of proteins. They are long-chain polymers that disperse easily in water, are completely or partially soluble, or exhibit a tendency to swell by absorbing water. They are extensively utilized in the production, processing and optimization of food products [17]. Hydrocolloids such as carrageenan, guar gum and xanthan gum stabilize fat globules in suspensions, support the suspension of solid particles, enhance emulsion stability, increase viscosity and slow down the sedimentation rate [18]. Carrageenan is a sulfated galactose polymer extracted from red seaweed species of the class Rhodophyceae [19, 20]. Its most significant forms are κ-, ι- and λ-carrageenan. Widely used in dairy products, it serves as a gelling agent, thickener and stabilizer [20]. Xanthan gum is an extracellular heteropolysaccharide produced through the fermentation of *Xanthomonas campestris* [15, 21]. It provides high viscosity even at low concentrations in solutions [22] and functions as a binder, thickener and stabilizer in dairy products, while also acting as a water-soluble dietary fiber [23]. Guar gum is a galactomannan extracted from the endosperm of *Cyamopsis tetragonolobus* seeds [24, 25]. It forms strong hydrogen bonds with water, making it an effective thickener and stabilizer in the food industry [22].

Dietary fiber is defined by the Codex Alimentarius Commission (CAC) as carbohydrate polymers that cannot be hydrolyzed by endogenous enzymes in the human small intestine [26]. While whole grains are sources of insoluble fiber, fruits, vegetables, legumes, pectic substances and hydrocolloids constitute natural sources of soluble dietary fiber [27]. As these dietary fibers cannot be digested or absorbed by the human body, they do not serve as a significant energy source [28]. However, dietary fiber is fermented by the bacterial microbiota in the colon, producing short-chain fatty acids such as acetate, propionate and butyrate, which enter the bloodstream and provide significant health benefits [26, 29, 30]. Insufficient dietary fiber intake is associated with gastrointestinal disorders (constipation, colon cancer and hemorrhoids), cardiovascular diseases (hypercholesterolemia and stroke) and metabolic conditions such as obesity and diabetes [31].

In the food industry, the combined use of two or more hydrocolloids is a frequently employed method to enhance product quality due to their synergistic interactions [32]. Although numerous international studies have examined the use of hydrocolloids in dairy desserts, research on the use of hydrocolloids and hydrocolloid combinations in traditional Turkish dairy desserts remains limited. Accordingly, the effects of hydrocolloids on kazandibi, sütlaç, and keşkül, which represent popular traditional dairy desserts with distinct matrix structures in Türkiye, were investigated. It was expected that the synergistic interactions generated by different hydrocolloid combinations would improve the fundamental physicochemical and microstructural properties of these dairy desserts. In this study, the effect of different hydrocolloid combinations (xanthan gum-guar gum, carrageenan-guar gum and carrageenan-xanthan gum) on the physicochemical properties and microstructural changes in keşkül, kazandibi and sütlaç samples was investigated. Furthermore, the TPC and AA of desserts were determined. This study contributes to the literature by comparatively evaluating these parameters across three traditional Turkish dairy desserts with distinct matrix structures.

MATERIALS and METHODS

Materials

In this study, traditional Turkish dairy desserts (keşkül, kazandibi and sütlaç) were produced in the Department of Food Engineering, Faculty of Engineering, Pamukkale University (Denizli, Türkiye). All ingredients used in the production of the desserts, including UHT milk (3.0% fat content), rice flour, wheat flour, corn starch, rice, vanillin, sugar powder, salt, sucrose and fresh eggs were purchased from local markets in Denizli (Türkiye). Among raw materials, food-grade hydrocolloids (carrageenan, xanthan gum and guar gum) were obtained from Smart Kimya Tic. ve Danışmanlık Şirketi (İzmir, Türkiye). Aluminum containers were used for packaging. A Megazyme assay kit (Megazyme International Ireland Ltd, Wicklow, Ireland) was employed for the determination of the total dietary fiber content, in which technical-grade ethanol (Tekkim, Bursa, Türkiye) and reagent-grade acetone (Carlo Erba Reagents, Val de Reuil Cedex, France) were used. For the determination of TPC, Folin-Ciocalteu phenol (FC) reagent was purchased from Merck (Darmstadt, Germany), gallic acid from Sigma-Aldrich (St. Louis, MO, USA), and sodium carbonate from Isolab Chemicals (Wertheim, Germany). For the AA assay, DPPH (2,2-diphenyl-1-picrylhydrazyl) and Trolox® (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) were obtained from Sigma-Aldrich (St. Louis, MO, USA). All chemicals used in these assays were of reagent-grade, whereas methanol and ethanol were of HPLC plus gradient grade and used as solvents (Carlo Erba Reagents, Val de Reuil Cedex, France).

Production of Kazandibi

Milk, sugar, salt, powdered sugar, wheat flour, rice flour, corn starch and selected hydrocolloids (carrageenan, xanthan gum and guar gum) were used in the production of kazandibi (**Table 1**). In the production process, sugar and salt were added to the milk and the mixture was heated to 40°C. A portion (approximately 25%) of this mixture was transferred to a separate container, where wheat flour, starch, rice flour and hydrocolloids were added to obtain a homogeneous mixture. This mixture was gradually incorporated into the main milk-sugar mixture at 80°C with continuous stirring and boiled for approximately 10 min. To obtain the characteristic caramelized bottom layer of the dessert the bases of heat-resistant trays (25-30 cm in diameter) were slightly moistened and coated with a thin layer of powdered sugar before the mixture was poured. The mixture was then heated on a uniform heat source until the bottom layer reached a caramelization thickness of 1-2 mm. The production flow is shown in **Figure 1**. In this study, the control sample without hydrocolloid addition was coded as Ka, while the sample produced with a guar gum-xanthan gum combination was coded as Ka1. The sample containing a carrageenan-guar gum combination was coded as Ka2 and the sample produced with a carrageenan-xanthan gum combination was designated as Ka3.

Production of Sütlaç

Rice, sugar, rice flour, salt and selected hydrocolloids were used in the production of sütlaç (**Table 1**). In the production process, rice was initially boiled, followed by the addition of milk at ambient temperature (approximately 20°C) and this mixture was heated to 40°C. Simultaneously, rice flour, salt and hydrocolloids were completely dissolved in approximately 25% of the total milk volume preheated to 40°C in a separate container. When the temperature of the main rice mixture reached 80°C, the prepared hydrocolloid solution was incorporated into the system. Subsequently, sugar was added, and this mixture was maintained at 80°C for 10 min until the desired consistency, defined as a soft and dense texture suitable for consumption with a spoon, was achieved. Finally, samples were portioned into bowls. Overall production flow is shown in **Figure 1**. In this study, control sample without hydrocolloid was coded as S, while the sample produced with a guar gum-xanthan gum combination was coded as S1. The sample containing a carrageenan-guar gum combination was coded as S2 and the sample produced with a carrageenan-xanthan gum combination was designated as S3.

Production of Keşkül

Sugar, rice flour, almonds, ground almonds, egg yolk, salt, vanillin and selected hydrocolloids (carrageenan, xanthan gum and guar gum) were used in the production of Keşkül (**Table 1**). Initially, almonds were held in boiling water briefly and passed through cold water quickly, and then peeled. Whisked egg yolk was added to milk first, followed by the addition of sugar and this mixture was heated to 40°C. Approximately 25% of this mixture was transferred into a separate container, where rice flour and hydrocolloids were added and completely dissolved to obtain a homogeneous mixture. When the main milk mixture reached approximately 80°C, prepared

Table 1. Formulations of traditional Turkish milk-based desserts used in the study

Ingredients	Codes for Kazandibi*				Codes for Sütlaç				Codes for Keşkül			
	Ka	Ka1	Ka2	Ka3	S	S1	S2	S3	K	K1	K2	K3
Milk (L)	1	1	1	1	1	1	1	1	1	1	1	1
Water (L)	0	0	0	0	1	1	1	1				
Sugar (g)	180	180	180	180	250	250	250	250	250	250	250	250
Rice (g)					100	100	100	100				
Fresh eggs (g)									110	110	110	110
Almond (g)									100	100	100	100
Sugar powder (g)	65	65	65	65								
Flour (g)	25	25	25	25								
Rice flour (g)	25	25	25	25	30	30	30	30	50	50	50	50
Vanillin (g)									5	5	5	5
Corn starch (g)	25	25	25	25								
Salt (g)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Carragenan (g)			0.3	0.3			0.25	0.25			0.5	0.5
Guar gum (g)		0.3	0.3			0.25	0.25			0.5	0.5	
Xanthan gum (g)		0.3		0.3		0.25		0.25		0.5		0.5

*Ka, control kazandibi; Ka1, kazandibi with guar gum-xanthan gum; Ka2, kazandibi with carrageenan-guar gum; Ka3, kazandibi with carrageenan-xanthan gum; S, control sütlaç; S1, sütlaç with guar gum-xanthan gum; S2, sütlaç with carrageenan-guar gum; S3, sütlaç with carrageenan-xanthan gum; K, control keşkül; K1, keşkül with guar gum-xanthan gum; K2, keşkül with carrageenan-guar gum; K3, keşkül with carrageenan-xanthan gum.

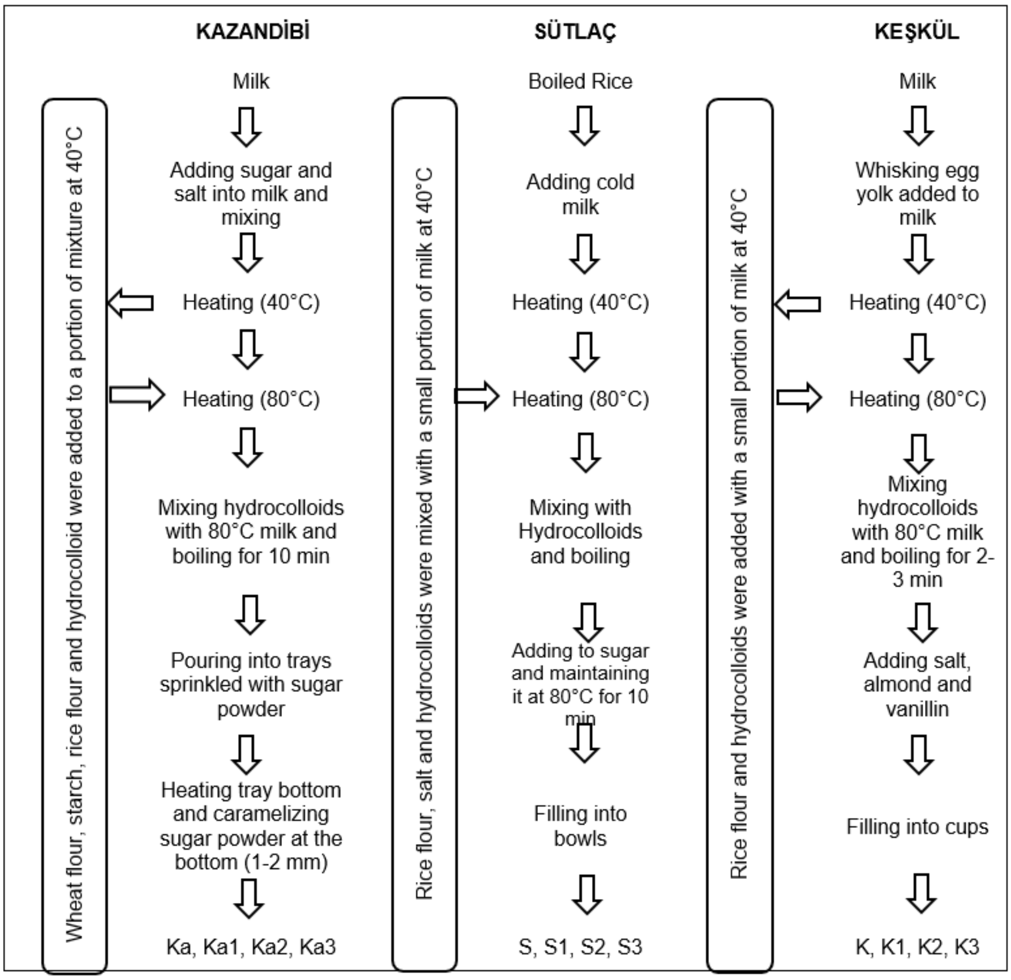

Figure 1. Flow charts for the production of traditional Turkish milk-based desserts (Ka, control kazandibi; Ka1, kazandibi with guar gum-xanthan gum; Ka2, kazandibi with carrageenan-guar gum; Ka3, kazandibi with carrageenan-xanthan gum; S, control sütlaç; S1, sütlaç with guar gum-xanthan gum; S2, sütlaç with carrageenan-guar gum; S3, sütlaç with carrageenan-xanthan gum; K, control keşkül; K1, keşkül with guar gum-xanthan gum; K2, keşkül with carrageenan-guar gum; K3, keşkül with carrageenan-xanthan gum)

rice flour and hydrocolloid mixture was incorporated into the system. After heating for 2-3 min, the almonds, salt and vanillin were added and stirred. Then, keşkül samples were portioned into bowls; the production flow is illustrated in **Figure 1**. In this study, control sample without hydrocolloid was coded as K, while the sample produced with a guar gum-xanthan gum combination was coded as K1. The sample containing a carrageenan-guar gum combination was coded as K2 and the sample produced with a carrageenan-xanthan gum combination was designated as K3.

Physicochemical Analyses

The total solid content (TS, %) of dessert samples was determined gravimetrically according to the AOAC [33] method. Total nitrogen content was measured using the micro-Kjeldahl method [34]. Protein content (%) was calculated by multiplying the total nitrogen value by a conversion factor of 6.38, as specified for milk and dairy products. The pH of samples was determined using a digital pH meter (Hanna HI 8314, Hanna Instruments, Padova, Italy) by immersing the probe directly into samples. The fat content of traditional dairy desserts (%) was determined according to the Folch method [35].

The total, soluble and insoluble dietary fiber contents of dairy desserts were determined according to the AOAC 991.43 [36] and AACC 32-07 [37] methods. Initially, starch and proteins were enzymatically removed from 1.000±0.005 g of the sample using heat-stable alpha-amylase (95-100°C) and subsequently protease and amyloglucosidase enzymes (30 min at 60°C). After vacuum filtration through a Gooch crucible, this mixture was washed with ethanol, acetone and distilled water. Residue remaining in a crucible contained insoluble dietary fiber, insoluble salts and indigestible proteins. Ethanol was added to the filtrate containing the soluble dietary fiber and after incubating for 1 hour at room temperature, it was filtered through a Gooch crucible. It was then washed with ethanol (78% and 95%) and acetone. Residue in a crucible contained the soluble fraction of dietary fiber, minerals and indigestible proteins. The Gooch crucibles containing the soluble and insoluble dietary fibers were dried in an oven at 103±2°C until a constant weight was achieved. Following weighing, these samples were subjected to protein and ash analyses to determine residual protein and salts. The amounts of soluble and insoluble dietary fiber were calculated according to the specified methods.

Total Phenolic Content and Antioxidant Activity Analyses

For the extraction of dessert samples, weighed samples were diluted with ethanol at a ratio of 1:1 (w/v) and homogenized using a homogenizer for approximately a minute. This mixture was then processed in an ultrasonic water bath (Elma E 60 H, Singen, Almanya) for 10 min and stirred on a mechanical shaker (WiseShake SHO-1D, Seoul, South Korea) 180 rpm at room temperature for 15 min. After centrifugation (Nüve 1200 R, Ankara, Türkiye) at 8500 rpm for 15 minutes at 4°C, the clear supernatant was collected and stored in a deep freezer at -18°C until analysis [38].

The TPC of samples was determined using the FC method. The FC reagent was diluted 1:10 (v/v) and a 75 g/L sodium carbonate solution was prepared. In the assay, 1 mL of sample or standard was mixed with 5 mL of diluted FC reagent and 4 mL of sodium carbonate solution. After incubating the mixture in the dark at room temperature for 2 h, the absorbance values were measured using a spectrophotometer at a wavelength of 760 nm. A gallic acid stock solution was used for the calibration curve. The TPC of samples was expressed as mg gallic acid equivalent (GAE) per 100 g of dry matter (dm) [38].

Antioxidant activity was determined using the DPPH assay, following the method proposed by Thaipong et al. [39] with slight modifications. A stock solution of DPPH was prepared at a concentration of 24 mg/100 mL in methanol and stored at -24°C before use. A Trolox® solution was prepared for calibration curve. Working solution was obtained by diluting stock solution with methanol to reach an absorbance of 1.1±0.02 at 515 nm. In the experiments, 150 µL of sample was mixed with 2850 µL of DPPH working solution and incubated in the dark for 60 min. Subsequently, the absorbance of colored product was determined at 515 nm. The AA of samples was expressed as µmol Trolox® equivalent (TE) per 100 g of dm.

Microstructure

Light microscopy (Olympus BX50F-3, Olympus Optical Co. Ltd., Tokyo, Japan) was used to examine the microstructure of dairy dessert samples. Samples were spread thinly onto glass slides and analyzed using objectives with 10X and 20X magnification powers. Microstructural images were captured and recorded using a Kameram 21 CMOS camera system. Additionally, the morphological characteristics of dairy desserts were investigated via scanning electron microscopy (SEM) (ZEISS, SUPRA 40VP, Oberkochen, Germany). A substantial number of micrographs were obtained during microstructural analysis and representative images that best reflect the characteristic features of samples were selected for inclusion in the study.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS software package (IBM SPSS Statistics for Windows, Version 23.0, IBM Corp., Armonk, NY, USA). Data were expressed as mean±standard deviation (SD). To determine the statistical differences between parameters, Duncan's multiple range test was applied at the $p<0.05$ level. Dairy dessert varieties were produced in duplicate, and analyses were performed on at least two parallel samples.

RESULTS and DISCUSSION

Physicochemical Properties

Analysis of the TS contents of kazandibi, sütlaç and keşkül samples revealed that the lowest TS levels were in sütlaç, whereas the highest levels were observed in keşkül (**Table 2**). According to the statistical analysis, significant differences were found in the TS contents among the different types of dairy desserts ($p<0.05$). In contrast, the use of different hydrocolloids within the same dessert type did not result in a statistically significant effect on the TS values ($p>0.05$).

Table 2. Physicochemical properties of traditional Turkish milk-based desserts (All values are expressed as mean±standard deviation.)

Products	Codes*	Total Solid (%)	Protein (%)	Fat (%)	pH
Kazandibi	Ka	$38.37\pm1.63^{b**}$	4.46 ± 0.51^{ab}	3.46 ± 0.20^{ab}	6.51 ± 0.03^{ab}
	Ka1	37.28 ± 1.70^{b}	3.85 ± 0.40^{a}	3.57 ± 0.30^{ab}	6.53 ± 0.02^{ab}
	Ka2	38.70 ± 2.77^{b}	3.86 ± 0.40^{a}	3.51 ± 0.40^{ab}	6.55 ± 0.02^{ab}
	Ka3	$37.78\text{-}2.60^{b}$	4.31 ± 0.40^{ab}	3.48 ± 0.39^{ab}	6.56 ± 0.02^{b}
Sütlaç	S	29.18 ± 0.98^{a}	4.57 ± 0.93^{ab}	3.24 ± 0.07^{a}	6.63 ± 0.03^{c}
	S1	27.14 ± 0.12^{a}	4.02 ± 0.03^{ab}	3.24 ± 0.51^{a}	6.68 ± 0.01^{d}
	S2	27.04 ± 0.28^{a}	4.41 ± 0.10^{ab}	3.42 ± 0.40^{ab}	6.66 ± 0.01^{d}
	S3	28.21 ± 0.32^{a}	4.75 ± 0.08^{b}	3.52 ± 0.26^{ab}	6.62 ± 0.02^{c}
Keşkül	K	42.17 ± 2.37^{c}	7.01 ± 0.06^{c}	4.24 ± 0.88^{bc}	6.48 ± 0.02^{a}
	K1	41.99 ± 0.50^{c}	6.46 ± 0.20^{c}	4.92 ± 0.69^{cd}	6.54 ± 0.35^{ab}
	K2	41.77 ± 0.38^{c}	6.52 ± 0.07^{c}	5.33 ± 0.20^{d}	6.56 ± 0.01^{b}
	K3	41.46 ± 0.75^{c}	7.06 ± 0.70^{c}	6.36 ± 0.35^{e}	6.54 ± 0.02^{ab}

*Ka, control kazandibi; Ka1, kazandibi with guar gum-xanthan gum; Ka2, kazandibi with carrageenan-guar gum; Ka3, kazandibi with carrageenan-xanthan gum; S, control sütlaç; S1, sütlaç with guar gum-xanthan gum; S2, sütlaç with carrageenan-guar gum; S3, sütlaç with carrageenan-xanthan gum; K, control keşkül; K1, keşkül with guar gum-xanthan gum; K2, keşkül with carrageenan-guar gum; K3, keşkül with carrageenan-xanthan gum; **Different lowercase superscripts (a-e) in the same column represent statistically significant differences between product types and their formulations ($p<0.05$).

When the protein contents of samples were considered, the lowest values were observed in kazandibi, while the highest were observed in keşkül samples. The fat contents of sütlaç and kazandibi were found remarkably similar. The fat content of keşkül samples was significantly higher than that of other desserts ($p<0.05$). The elevated protein and fat levels in keşkül samples are attributed to the inclusion of egg yolk, which had a high protein content (15.7-16.6%) [40] and the use of almonds, which contain approximately 20% protein [41]. Furthermore, unlike other dairy desserts, the presence of non-milk fat sources, specifically almonds and egg yolk, contributed to the increase in total fat content. The fat content of almonds may range from 43.4% to 47.5% [42], whereas the fat content of egg yolk is approximately 32–35% [40]. Among keşkül samples, K3 had the highest fat content. The uneven distribution of fat contents in keşkül samples might arise from the non-homogeneous distribution of almonds during production. Additionally, basic ingredients used in dairy dessert production, such as milk, rice and flour, may also influence variations in the final protein content.

Karimidastjerd et al. [43] utilized various commercially available plant-based milks (almond, oat, soy, coconut and peanut milk) as well as whole and low-fat cow's milk for the production of vegan rice pudding. The chemical composition of the desserts varied depending on the type of milk used. Specifically, the total solid content of these desserts ranged from 14.13% to 22.66%, while the protein and fat contents varied between 0.73–5.05% and 1.89–3.29%, respectively. Similarly, in a study on pudding conducted by Vatthanakul et al. [44], the pH values of the samples were determined between 6.13 and 6.54. In another research on rice pudding by Papageorgiou et al. [45] the average total solid content was reported as 25.88%, with an average fat content of 3.05%, a total protein content of 3.31% and pH values ranging from 6.60 to 6.67. Furthermore, in dairy desserts formulated with milk, figs and carboxymethyl cellulose (CMC) by Jahromi and Niakousari [46], the TS varied between 20.66% and 27.10%, while the pH values ranged from 6.21 to 6.42. In a study on keşkül conducted by Cinar et al. [47], TS content were found to range between 28.93% and 30.64%. Similarly, Aytaç [48] reported that TS content ranged from 25.85% to 34.47% for muhallebi samples and from 25.93% to 38.71% for tavukgöğsü samples. As demonstrated by these studies, physicochemical properties such as TS, fat, protein and pH levels vary across different types of desserts. These variations in results are attributed to differences in the fat content of milk used, the addition of milk powder, whey powder or whey protein concentrate [49], as well as the varying ratios and compositions of other ingredients such as starch, type and concentration of hydrocolloids and sugar [32]. Furthermore, regional variations in the proportions of ingredients and the use of different substitutes during production lead to distinct differences in the appearance, flavor and texture of dairy desserts.

The total dietary fiber contents of kazandibi, sütlaç and keşkül samples were found statistically different ($p<0.05$) (**Table 3**). The highest total dietary fiber content was detected in keşkül samples, which contain almonds in their formulation. Depending on the distribution of almonds, the amounts of soluble and insoluble dietary fiber led to statistically significant differences among the keşkül samples ($p<0.05$). Almonds are a highly rich source of both insoluble (10.10 g/100g edible portion) and soluble (1.10 g/100g edible portion) dietary fiber [24].

Kazandibi samples had a higher total dietary fiber content than sütlaç samples but lower than keşkül samples. No statistically significant difference was detected among the insoluble dietary fiber contents of kazandibi samples ($p>0.05$). However, statistically significant differences were observed in the soluble dietary fiber content ($p<0.05$), which could stem from the type of hydrocolloid utilized. Sütlaç samples were determined to have the lowest total dietary fiber content, with no insoluble dietary fiber detected in these samples. When the soluble dietary fiber contents of sütlaç samples were compared with one another, statistically significant differences were observed ($p<0.05$).

Table 3. Dietary fiber contents of traditional Turkish milk-based desserts (All values are expressed as mean±standard deviation.)

Products	Sample Codes*	Insoluble Dietary Fiber (%)	Soluble Dietary Fiber (%)	Total Dietary Fiber (%)
Kazandibi	Ka	$0.42±0.04^{b**}$	$1.56±0.06^{cd}$	$1.98±0.10^{c}$
	Ka1	$0.43±0.02^{b}$	$1.87±0.10^{de}$	$2.30±0.10^{cd}$
	Ka2	$0.41±0.02^{b}$	$1.81±0.10^{de}$	$2.22±0.10^{cd}$
	Ka3	$0.26±0.04^{b}$	$2.12±0.13^{e}$	$2.38±0.16^{d}$
Sütlaç	S	-	$1.21±0.22^{bc}$	$1.21±0.22^{b}$
	S1	-	$0.88±0.13^{a}$	$0.88±0.13^{a}$
	S2	-	$1.26±0.15^{bc}$	$1.26±0.15^{b}$
	S3	-	$0.85±0.25^{a}$	$0.85±0.25^{a}$
Keşkül	K	$1.75±0.12^{d}$	$1.35±0.35^{c}$	$3.10±0.23^{e}$
	K1	$1.41±0.10^{c}$	$1.76±0.24^{d}$	$3.17±0.30^{e}$
	K2	$1.44±0.10^{c}$	$1.81±0.18^{de}$	$3.15±0.21^{e}$
	K3	$1.86±0.11^{d}$	$1.17±0.16^{ab}$	$3.03±0.24^{e}$

*Ka, control kazandibi; Ka1, kazandibi with guar gum-xanthan gum; Ka2, kazandibi with carrageenan-guar gum; Ka3, kazandibi with carrageenan-xanthan gum; S, control sütlaç; S1, sütlaç with guar gum-xanthan gum; S2, sütlaç with carrageenan-guar gum; S3, sütlaç with carrageenan-xanthan gum; K, control keşkül; K1, keşkül with guar gum-xanthan gum; K2, keşkül with carrageenan-guar gum; K3, keşkül with carrageenan-xanthan gum; **Different superscripts (a-e) in the same column represent statistically significant differences between product types and their formulations ($p<0.05$). (-) not detected

A review of studies on dairy desserts reveals that various sources of dietary fiber are commonly added alongside hydrocolloids to enhance the fiber content of the products. In a study conducted by Staffolo et al. [50], bamboo, inulin, wheat, apple, *Psyllium* and chitosan were utilized as fiber sources. Cruz et al. [51] incorporated Baru almonds while Zheng et al. [52] used bamboo shoots in their research. Furthermore, Maya et al. [29] utilized sago starch as a fiber source, whereas Estevam et al. [53] included guava, lemon, inulin, apple and wheat in their formulations. In puddings produced by Maya et al. [29] with the addition of sago starch and tempeh, carrageenan was utilized at a concentration of 1%. The dietary fiber content in the resulting pudding samples was determined to be 3.95%, a value attributed to the use of sago starch (*Metroxylon sp.*), which inherently contains 3.69-5.96% dietary fiber. In another study comparing the properties of dairy desserts prepared using two different species of the seaweed genus Gracilaria, the total dietary fiber content was found to be 1.14% (4.61 g/100 g TS) and 2.23% (9.02 g/100 g TS) for the respective species. Furthermore, the incorporation of guava, which is rich in dietary fiber, was effective in increasing the overall dietary fiber content in that study [53].

Polysaccharides such as guar gum, xanthan gum, locust bean gum, sodium alginate and sodium carboxymethyl cellulose, which are soluble fibers used as gelling and thickening agents in dairy desserts, provide a relatively low contribution to daily fiber intake due to their low usage concentrations (0.1-0.5%) [54]. According to Viebke et al. [55], the average soluble dietary fiber content of carrageenan, xanthan gum and guar gum is reported as 80-90%, 80-95% and 80-85%, respectively. The approximate usage levels for these hydrocolloids are provided as 1.5%, 1.0% and 1.5%, respectively.

Total Phenolic Content and Antioxidant Activity

The TPC and AA values of kazandibi, keşkül and sütlaç samples are presented in **Table 4**. These data indicate that TPC was generally high in kazandibi samples and low in sütlaç samples. Statistical analyses revealed significant differences among the dessert types and formulations ($p<0.05$). Sütlaç samples formed a statistically distinct group by exhibiting the lowest TPC across all formulations. In contrast, statistical similarities were observed between certain kazandibi formulations (Ka2 and Ka3) and keşkül samples ($p>0.05$). The highest TPC was determined in the Ka and Ka1 formulations.

Antioxidant values differed significantly among all three dessert types (kazandibi, sütlaç and keşkül) across all formulations ($p<0.05$). Statistical analysis regarding the effect of hydrocolloid usage within each dessert type revealed no significant differences for sütlaç and keşkül samples ($p>0.05$); however, significant differences were observed among kazandibi samples ($p<0.05$).

While rice and rice flour were utilized in sütlaç formulations, distinct raw materials in kazandibi and keşkül formulations might contribute to variations in the TPC of these desserts. Furthermore, it was observed that hydrocolloid combinations did not exert a significant effect on the TPC of sütlaç and keşkül samples; differences in kazandibi samples, on the other hand, are thought to be associated with processes such as cooking and caramelization.

The variations in the TPC of the dairy dessert samples are thought to arise from the raw materials utilized and the manufacturing processes applied. While Ertan et al. [56] reported that the TPC in UHT milk ranged between 505.46±16.66 and 982.14±168.42 mg GAE/L, Sönmez et al. [57] determined this value to be 1030.10±19.31 mg GAE/L.

Table 4. Total phenolic content and antioxidant activity of traditional Turkish milk-based desserts (All values are expressed as mean±standard deviation.)

Products	Sample Codes*	Total phenolic content (mg GAE/ 100 g dm)	Antioxidant activity (µmol TE/100 g dm)*
Kazandibi	Ka	$65.72\pm26.70^{c**}$	5.10 ± 2.96^{b}
	Ka1	75.03 ± 22.59^{c}	5.96 ± 2.19^{bc}
	Ka2	50.60 ± 19.43^{b}	5.02 ± 0.67^{b}
	Ka3	49.02 ± 12.87^{b}	6.92 ± 1.00^{c}
Sütlaç	S	20.03 ± 4.75^{a}	3.15 ± 0.65^{a}
	S1	19.95 ± 4.70^{a}	3.25 ± 0.75^{a}
	S2	19.03 ± 5.87^{a}	3.71 ± 0.58^{a}
	S3	18.37 ± 5.30^{a}	3.60 ± 0.78^{a}
Keşkül	K	49.65 ± 0.48^{b}	13.75 ± 0.78^{d}
	K1	52.71 ± 1.79^{b}	14.02 ± 0.92^{d}
	K2	49.47 ± 3.11^{b}	14.38 ± 0.13^{d}
	K3	49.40 ± 0.84^{b}	14.30 ± 0.03^{d}

*Ka, control kazandibi; Ka1, kazandibi with guar gum-xanthan gum; Ka2, kazandibi with carrageenan-guar gum; Ka3, kazandibi with carrageenan-xanthan gum; S, control sütlaç; S1, sütlaç with guar gum-xanthan gum; S2, sütlaç with carrageenan-guar gum; S3, sütlaç with carrageenan-xanthan gum; K, control keşkül; K1, keşkül with guar gum-xanthan gum; K2, keşkül with carrageenan-guar gum; K3, keşkül with carrageenan-xanthan gum; **Different superscripts (a-d) in the same column represent statistically significant differences between product types and their formulations ($p<0.05$).

In addition to the milk used in dairy dessert production, cereal and starch products incorporated into the formulation also contribute to the TPC of the matrix. Indeed, the TPC of rice flour was reported as 21.38 mg GAE/100 g by Runt Kütük and Özgören Çapraz [58] and 16.25 mg GAE/100 g dm by Çelik [59].

In rice grains, this value was determined to be 45.29 mg GAE/100 g dm [60]. On the other hand, Vaher et al. [61] reported the TPC of wheat flour to range between 0.044 and 0.14 mg GAE/g, while Yüksel [62] determined this amount as 53.79±0.5 mg GAE/1000 mL in corn starch.

In addition to raw material composition, the thermal processes applied play a decisive role in phenolic compounds. Demir [63] reported that phenolic compounds in foods are affected by high-temperature applications; while reductions in TPC occur as a result of the degradation and oxidation of phytochemicals during thermal processing, several studies have also observed increases in phenolic compounds depending on the product type, processing method, and application conditions.

The TPC and AA of sütlaç samples were lower than those of kazandibi and keşkül samples. In contrast, the total AA of keşkül samples was the highest among all groups. The ranking of the samples in terms of AA, from highest to lowest, is as follows: keşkül, kazandibi and sütlaç. Notably, keşkül samples exhibited AAs 3.5 times higher than sütlaç samples and approximately 2 times higher than kazandibi samples.

The variations in AA among dessert types are considered to arise from differences in formulation components and raw material profiles. Indeed, compared to sütlaç samples exhibiting the lowest AA, distinct ingredients are incorporated into the production of keşkül and kazandibi. In particular, the presence of almonds - which possess an AA of 1.78±0.03 μM TE/g [64] - in the keşkül formulation is regarded as one of the primary reasons for its superior AA. When the ingredients commonly used in dairy dessert production are examined in the literature, data obtained regarding the AAs of these raw materials also support this situation

The primary components exhibiting antioxidant properties in milk and dairy products are sulfur-containing cysteine amino acids [65] and casein among milk proteins [65, 66]. In addition, lactoferrin, conjugated linoleic acid (CLA), coenzyme Q10, uric acid, carotenoids, and vitamins C, E, A, and D_3 are among the prominent antioxidant compounds found in milk. In previous studies, the AA of UHT milk was determined to range from 12.0 to 14.5 μmol TE/mL [66].

When studies on the AAs of cereal products in the literature are examined, it has been reported that the AA of wild rice ranges from 0.85 to 1.12 mM TE/100 g dm, whereas this value remains at 0.20-0.80 mM TE/100 g dm in white rice [67]. Regarding raw materials in flour form, while the AA of rice flour was determined to be 6.36 μmol TE/100 g dm [58], the antioxidant capacity of whole wheat flour was 193.04 μmol TE/100 g dm [68].

Similarly, in a study conducted by Yüksel [62], AA of corn starch was determined as 0.08±0.02%.

In addition to these raw material-derived contributions, Maillard reaction products formed during thermal processing through interactions between reducing sugars and the free amino groups of proteins and peptides have been reported to possess antioxidant properties [69].

In a study [70] on the production of high-protein and low-fat dairy desserts using specific ratios of whey protein concentrate, antioxidant activity values were measured between 2.7 and 38 μmol TE/100 g. Values obtained in our study were found to be within the range reported in that research. When compared with two different studies examining the TPC of desserts produced by traditional methods, it was observed that the literature values were higher than our sütlaç samples but lower than our kazandibi and keşkül samples. In these studies, TPCs were reported as 35.10 mg GAE/100 g dm [71] and 27 mg GAE/100 g dm [72].

In a study [73] on probiotic dairy desserts supplemented with date extract and enriched with various additives, TPC was found to be lower than the values observed in our study. That same research noted that while date extract is rich in phenolics, the whey used in the formulation is also significantly effective in contributing to AA. Interactions between casein and phenolic compounds can either enhance or diminish antioxidant properties. Consequently, the incorporation of different additives in the preparation of dairy desserts directly influences the overall AA level.

Microstructural Properties

The light microscopy images of kazandibi samples are presented in **Figure 2** (A). Samples supplemented with hydrocolloids exhibited a denser and more compact structure compared to the control sample. Furthermore, the microstructural appearances of the samples coded Ka2 and Ka3 were highly similar to each other.

The SEM images of kazandibi samples are provided in **Figure 2** (B). Control sample (Ka) exhibited a crystalline-like structure with distinct intermolecular spaces. In contrast, sample Ka1 showed a denser and more homogeneous structure characterized by spherical formations, with significantly fewer intermolecular voids compared to the control. Sample Ka2 also displayed a more compact structure and reduced intermolecular spaces compared to the control, although it contained more crystalline structures than sample Ka1. Sample Ka3 exhibited a dense structure similar to Ka2, featuring a combination of crystalline and spherical formations, maintaining a tighter matrix than control sample.

The light microscopy images of sütlaç samples are presented in **Figure 3** (A). The microstructural appearances of these samples were highly similar to one another. The SEM images of sütlaç samples in **Figure 3** (B) reveal a brittle and porous structure in the control (S) sample. In sample S1, which contained guar gum and xanthan gum, voids were fewer and more circular, although some brittle formations persisted.

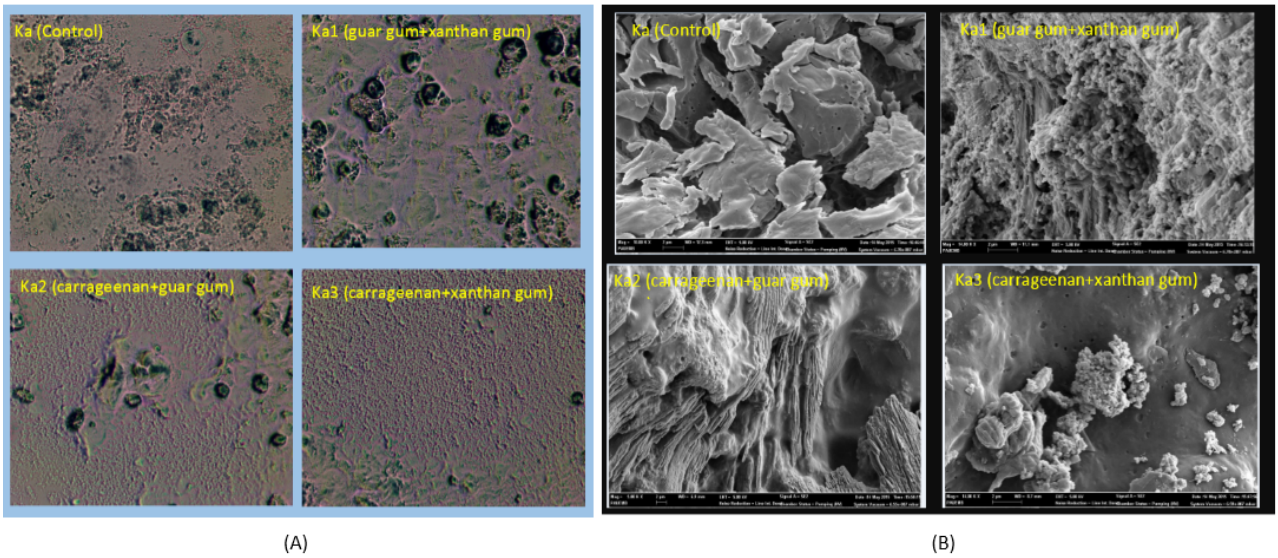

Figure 2. Microstructural analysis of kazandibi samples: (A) Light microscopy images at 20× magnification (B) Scanning electron microscopy (SEM) images

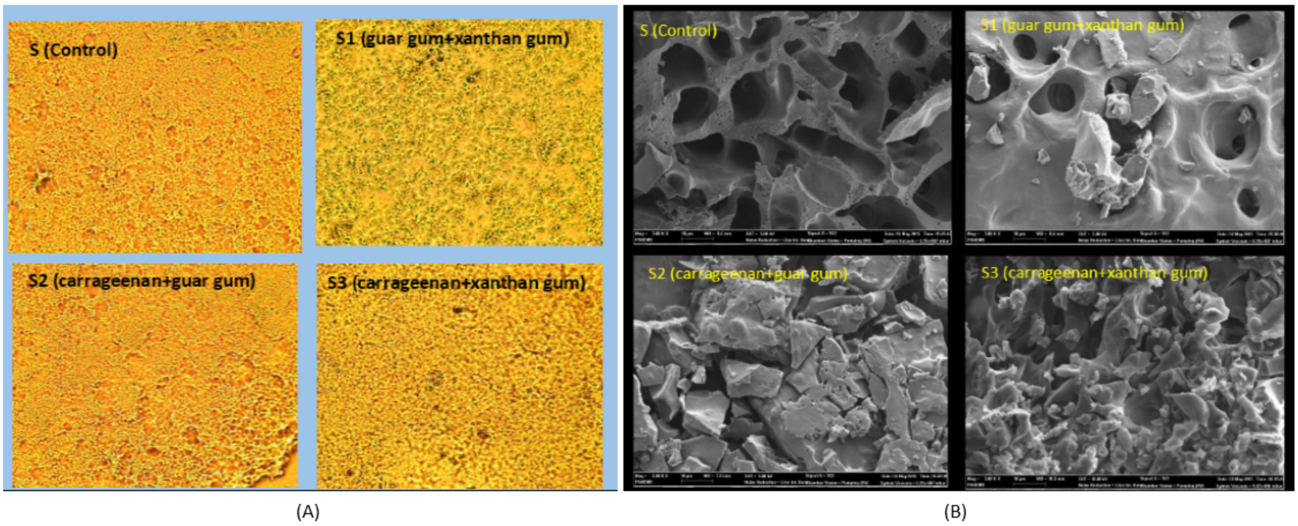

Figure 3. Microstructural analysis of sütlaç samples: (A) Light microscopy images at 20× magnification (B) Scanning electron microscopy (SEM) images

In sample S2 containing carrageenan and guar gum, voids were significantly reduced compared to samples S and S1, exhibiting a denser and more crystalline appearance. For sample S3 (with carrageenan and xanthan gum), a dense structure similar to S2 was observed, albeit with a more pronounced brittle character.

Similar results were reported by Majzoobi et al. [74] in a study where roasted wheat germ was added to pudding at specific ratios and particle sizes. In that study, while control samples exhibited large voids and pores surrounded by milk protein and gelatin, samples containing roasted wheat germ were found to have smaller pores, a reduced number of holes and a more compact structure.

Unlike other desserts, egg yolk and almonds were utilized in the production of keşkül samples. The light microscopy images of keşkül samples are presented in **Figure 4** (A). The SEM images of keşkül samples are presented in **Figure 4** (B). Control sample (K) exhibited a more crystalline and fragile appearance.

The microstructures of K1, K2 and K3 samples were similar to each other with more spherical formations observed in these images compared to control sample. Djaoud et al. [72] investigated the microstructure of commercial dairy desserts (consisting of milk, corn starch, carrageenan and sugar) and compared them with dairy desserts sweetened with date syrup and date powder as sugar substitutes. Commercial dairy desserts possessed a homogeneous structure with small and uniformly distributed pores. In samples where sugar was replaced with date derivatives, pores were observed to be slightly larger. In a study examining the microstructure of gels composed of pea proteins, carrageenan and starch, Nunes et al. [75] observed the formation of a protein aggregate network and a carrageenan network, where the swollen starch granules functioned as filler materials.

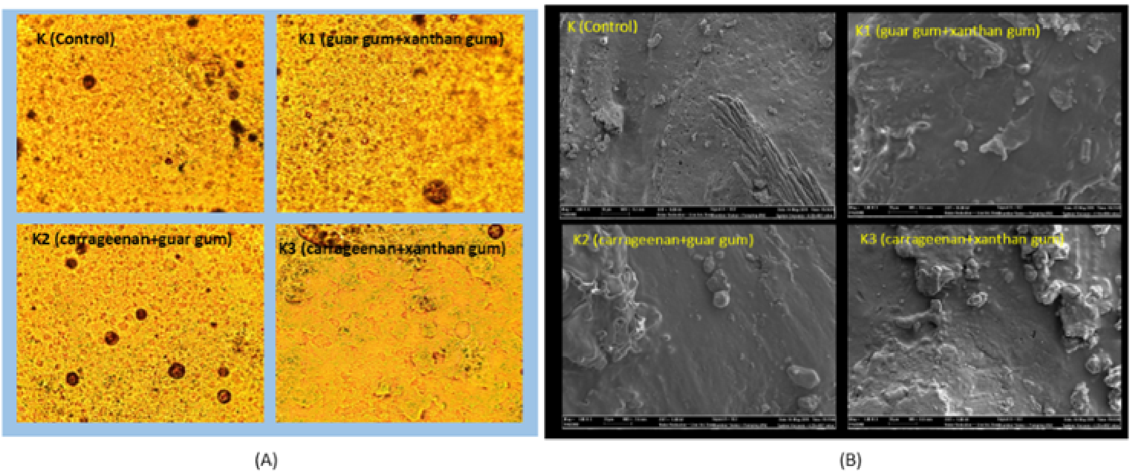

Figure 4. Microstructural analysis of keşkül samples: (A) Light microscopy images at 20× magnification (B) Scanning electron microscopy (SEM) images

CONCLUSION

In this study, the physicochemical properties of kazandibi, sütlaç and keşkül samples exhibited statistically significant differences depending on the type of dessert ($p<0.05$). These variations are attributed to the diversity and proportions of raw materials used in the formulations. When evaluating hydrocolloid combinations within each dessert type, different combinations did not have a decisive impact on the physicochemical properties, as results indicated statistically insignificancy ($p>0.05$). Regarding bioactive properties, the highest TPC was determined in kazandibi samples, while the highest AA was recorded in keşkül samples. Statistical analyses revealed that rice sütlaç, keşkül and kazandibi samples exhibited significant variations from each other in terms of both TPC and AA ($p<0.05$). The total dietary fiber contents of dessert samples were statistically different ($p<0.05$). Unlike other dessert types, no insoluble dietary fiber was detected in sütlaç samples. Based on these results, the dietary fiber content of samples was derived not only from hydrocolloids but also from other ingredients within the formulations. The low usage rates of hydrocolloids resulted in a limited effect on the total dietary fiber content of the dairy desserts. Upon evaluation of both light microscopy and SEM images for kazandibi, sütlaç and keşkül, it was observed that due to interactions between milk proteins and hydrocolloids, hydrocolloid-added samples exhibited a less porous, denser and more integrated microstructure compared to control samples.

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