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Comparative Analyses: Physiochemical, Textural, Microstructure, and Calcium Bioavailability of Functional Yogurt Supplemented with Different Brans or Dietary Fibers

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Abstract

Wheat, rice, oat, and barley brans, along with wheat and rice dietary fibers and psyllium husk, were incorporated into yogurt formulas. Adding brans and dietary fibers significantly increased viscosity and improved water-holding capacity. Syneresis significantly decreased with the supplementation of wheat, oat, and barley brans, as well as psyllium husk, whereas an increase in syneresis was observed with rice, wheat bran, and rice dietary fibers compared to the control. Most of the tested brans significantly ($p < 0.05$) reduced calcium availability. Yogurt containing barley bran delivered 7.56 mg/50 g more calcium than the control yogurt without bran or dietary fiber supplementation. The inclusion of wheat and rice dietary fibers increased calcium absorption by approximately 21.0 mg/50 g of yogurt. Viable counts of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Bifidobacterium lactis*, and a decrease in *Streptococcus thermophilus* as storage progressed. Fresh yogurt containing psyllium husk exhibited higher hardness, gumminess, and cohesiveness. Samples containing bran or dietary

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fibers had a smooth, compact, and homogeneous microstructure. The overall acceptability of supplemented yogurt was significantly lower ($p < 0.05$), while yogurt containing barley bran received the highest flavor score on day 6 of storage. This study, which provides a comprehensive comparison of yogurt supplementation with various brans and dietary fibers, will provide the industrial sector with valuable information to develop new and acceptable functional yogurts.

Keywords
Yogurt; brans and dietary fibers; physicochemical properties; microstructure; rheology; ca-bioavaliability

1. Introduction

Yogurt is the most popular dairy product in Egypt, with consumption steadily increasing from 2015 to 2020. This rise has positively impacted the yogurt market in Egypt, which recorded a high compound annual growth rate (CAGR) of 18.40% [1]. The growth in the yogurt market can be attributed to increased consumer awareness of yogurt's ingredients, functionality, health benefits, and nutritional value. Yogurt is rich in beneficial microorganisms such as probiotics and lactic acid bacteria (LAB), chiefly *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*, as well as calcium, vitamins, and proteins [2].

Although plain yogurt lacks health-promoting ingredients such as flavonoids, anthocyanins, phenolics, and iron, adding them could enhance its health benefits, potentially contributing to functions such as antidiabetic, anticancer, and anti-obesity effects [2-4]. Recent studies have shown growing demand for health-promoting natural products and an interest in enhancing the functionality of yogurt by incorporating functional ingredients [5-8]. Adding ingredients from vegetables, fruits, and cereals could be a viable solution to modify yogurt formulas, improving health benefits, physicochemical properties, texture, and microstructure [9, 10].

Cereals are the most important source of proteins, minerals, and B vitamins, along with biologically active molecules like dietary fibers and bran. Rice and wheat grains are considered significant sources of dietary fiber [11]. According to the American Association of Cereal Chemists [12], dietary fibers can be defined as "the edible part of plants or analogous carbohydrates that resist digestion and absorption in the human small intestine, undergoing complete or partial fermentation in the large intestine." Dietary fibers are primarily found in the bran, germ fragments, and aleuronic layer, aside from the small portion of starchy endosperm [13]. Brans refer to the outer layer of cereal grains [14].

Brans and dietary fibers can support the human body's health benefits, as their consumption reduces the incidence of various diseases. Several studies have shown that combining bran or dietary fibers with yogurt enhances their health effects. Regular yogurt can increase the bioavailability of vitamins and minerals, enhance the immune modulation system, and improve antioxidant activities [2, 15]. Yogurt supplemented with bran or dietary fibers from wheat, rice, or barley has been shown to enhance liver function and reduce serum lipids in hypercholesterolemic rats [10, 16]. Additionally, dietary fibers in low-fat yogurt can improve human serum lipid profiles

and manage dyslipidemia. This effect is related to the proteolytic activity of lactic acid bacteria during fermentation, which releases bioactive peptides that upregulate genes involved in lipid degradation, inhibit cholesterol synthesis, and reduce circulating cholesterol levels [17]. Furthermore, yogurt combined with dietary fibers can be a therapeutic solution for diabetes mellitus by reducing serum glutamate pyruvate transaminase (SGPT) levels. This effect is due to the high antioxidant levels in bran and yogurt [18]. Yogurt supplemented with long- or short-chain inulin has been shown to effectively increase iron bioavailability and can be used as a therapeutic formula to manage anemia in female rats [4, 19].

On a technological level, brans and dietary fibers could enhance the functional properties of yogurt by serving as fat replacers, texture improvers, and water-binding agents [4, 16, 20]. Therefore, the integration of brans and dietary fibers into a wide range of processed foods as functional ingredients is crucial and has attracted many researchers to develop new forms of functional foods [4]. Incorporating 0.5% psyllium husk into yogurt formulas effectively enhanced physicochemical properties and total bacterial count [21]. Barley bran or barley flour improved overall physicochemical and sensory attributes and increased the viability number of probiotics [10, 22]. Various types of fibers (wheat, oat, pea, and inulin) enhanced the overall characteristics of yogurt [23], with inulin, in particular, increasing the bioavailability of iron and calcium [4, 19].

Generally, the integration of different varieties of brans in ice cream and cheese is extensively studied, with a focus on rice bran, while its application in fermented dairy products is still limited [24, 25]. This limitation may be attributed to the strong taste and flavor of the end product. Therefore, the addition of brans and dietary fibers to various foods and finding out their functional properties and interactions with food ingredients is an ongoing area of research. Additionally, the availability of fermented dairy products supplemented with these functional ingredients is very limited in the Egyptian market. As a result, the current study aimed to assess the impact of incorporating various types of brans and dietary fibers on the physicochemical, texture, microstructure, and sensory properties of yogurt. This research will introduce a new formula of yogurt supplemented with functional ingredients to the Egyptian market and offer consumers a variety of yogurt options.

2. Material and Method

2.1 Material

Fresh full-cream cow's milk was obtained from the pilot farm of Alexandria University (Alexandria, Egypt). Commercial skim milk powder (Dairy Milk Inc., Cdi Fresno, California, US) was used to set the total solids of yogurt milk to 15% (w/w). Wheat bran (WB), rice bran (RB), oat bran (OB), and barley bran (BB), as well as psyllium husk (PsH), were obtained from the local market. Wheat dietary fiber (WDF) was obtained from CFF GmbH & Co. (KG, Gehren, Germany), while rice dietary fiber (RDF) was obtained from AWA Food Additives Company (Alexandria, Egypt). Freeze-dried yogurt starter (YF-L903, Thermophilic Yoghurt Culture-YO-Flex®) composed of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* was provided by Chr. Hansen's Lab., Denmark. *Bifidobacterium lactis* DSM 10140 was obtained from the Egypt Microbial Culture Collection (EMCC), at the Cairo Microbiological Resources Centre (Cairo MIRCEN), Ain Shams University, Cairo, Egypt.

2.2 Brans Manipulation

Various types of bran were dried at 40°C, ground using an electric grinder (Moulinex-Type LM207-500W, France), sifted through a 60-mesh screen using a sieve (mod. A060, Treviolo, Italy), and stored at 6 ± 1°C until use.

2.3 Chemical Composition of Brans and Dietary Fibers

2.3.1 Determination of Moisture, Fat, Protein, and Ash

The AOAC method [26] was used to estimate the protein, ash, fat, and moisture content of brans and dietary fibers. The moisture content was determined by measuring the weight loss after drying the sample in an air oven at 105°C overnight. The fat content was determined using the Soxhlet apparatus with petroleum ether as the extraction agent. The Total protein was determined using the Kjeldahl process (Kjeldahl Analyzer K9840, Jinan Hanon Instruments Co., Ltd., China), with a conversion factor of 6.25. The ash content was determined by incinerating the samples in a muffle furnace at 550°C for 5 hours.

2.3.2 Determination of Dietary Fibers

The levels of acid detergent fiber (ADF), acid detergent lignin (ADL), and neutral detergent fiber (NDF) were analyzed using an ANKOM 220 fiber analyzer (ANKOM Technology Corporation, NY, USA). NDF represents the residue left after digestion in a detergent solution, mainly consists of hemicellulose, cellulose, and lignin. The ADF method measures the residue left after digestion with H_2SO_4 and cetyl trimethylammonium bromide (CTAB), primarily cellulose and lignin. ADL refers to the residue left after digestion with 72% H_2SO_4, which is predominantly lignin [27].

2.4 Preparation of Yogurt and Sample Treatments

Fresh full-fat cow's milk was divided into eight equal batches. One batch served as the control (Cont), while 1.0% bran and dietary fibers were added to batches WB, RB, OB, BB, WDF, and RDF as outlined in Table 1. Psyllium husk was added at 0.2% w/w to batch PsH. We adjusted the total solids of the whole milk batches to 15% using skim milk powder. All batches were heated to 90°C and held for 10 minutes, then cooled to 42°C and inoculated with 0.015% of a commercial yogurt culture and 1% of an activated probiotic culture of *Bifidobacterium lactis* DSM10140. The yogurt preparations were filled in sterilized cups and kept at 42°C until the pH reached 4.4-4.5. Immediately after coagulation, yogurt samples were transferred to a fridge (4 ± 1°C) and stored for 12 days. All yogurt batches were produced twice on the same day at the Alexandria University dairy pilot plant, using the same milk composition. We took two samples from each batch for further analysis.

Table 1 Additives added to different bio-yogurt batches made in this study.

Treatments	Additives		Total solids (%)
	Brans/dietary fibers	Skimmed milk powder (%)	
Cont	None	3.5	15.0
WB	1% Wheat bran	2.5	15.0
RB	1% Rice bran	2.5	15.0
OB	1% Oat bran	2.5	15.0
BB	1% Barley bran	2.5	15.0
WDF	1% Wheat dietary fiber	2.5	15.0
RDF	1% Rice dietary fiber	2.5	15.0
PsH	0.2% psyllium husk	3.3	15.0

Cont = control; WB = wheat bran, RB = rice bran, OB = oat bran, BB = barley bran, WDF = wheat dietary fiber, RDF = rice dietary fiber, PsH = psyllium husk.

2.4.1 Physio-Chemical Analysis of Yogurt

We measured pH using a digital pH meter (Basic20 pH-Meter; Crison Instruments, Barcelona, EU). Titratable acidity was determined following Olugbuyiro & Oseh [28]. Viscosity was measured with a digital rotary viscometer (MYR VR 300-Model L, Viscotech Hispania S.L., El Vendrell, Spain), as stated by Nilsson et al. [29]. We estimated whey syneresis using the method outlined by Tarakçi & Kucukoner [30]. Color measurement was conducted with a high-performance color measurement spectrophotometer (UltraScan® VIS Spectrophotometer, Hunter Associates Laboratory Inc., Va., USA). The instrument was calibrated first with a white tile (high end of the scale) and then with a black tile (low end of the scale). Color values, specifically *L**, *a**, and *b**, were estimated according to Seçkin & Baladura [31].

2.4.2 Determination of Calcium Bioavailability

Samples of fresh yogurt were digested *in vitro* by simulated gastric and intestinal fluids prepared according to the United States Pharmacopeia [32]. The simulated gastric fluid consisted of 0.7% (v/v) HCl (37%), 0.32% (w/v) pepsin (3200 units/mg protein) (LOBA Chemie, Mumbai, India), 0.25% L-Cysteine-HCl (Oxford, India), and 0.2% (w/v) sodium chloride. Fifty grams of yogurt were mixed with twenty milliliters of gastric fluid and kept at 37°C in a shaking incubator (JSSI-1000T, Korea) at a speed of 30 rpm. The pH gradually decreased during digestion from 4.5 to 1.5 over 2.5 hours [19]. The pH decreased to 2.4, 1.7, 1.6, and 1.5 at 30-minute intervals using a 0.5 M HCl solution.

Intestinal digestion was conducted by adding 20 ml of simulated intestinal fluid to the gastric-digested samples. The simulated intestinal fluid was composed of 19% (v/v) sodium hydroxide 2 N, pancreatin 1% (w/v) (Bio Basic Canada Inc., Ontario, Canada), 0.68% monobasic potassium phosphate (Adwic, El Naser Pharmaceutical, Alex., Egypt), 0.25% L-cysteine, and 0.3% (w/v) porcine bile extract (Biolife, Milano, Italy). The pH of each sample was adjusted to 7-7.2 using 0.2 N $NaHCO_3$ (Adwic). The sample was then placed into a dialysis cellulose membrane with a cut-off of 12,400 Dalton (Sigma-Aldrich Co., St. Louis, Mo., USA). The filled membranes were immersed in 100 ml of Ca^{2+}-free deionized water. To simulate a duodenal medium, the sample-filled dialysis membranes were incubated for two hours at 37°C in a shaker (250 rpm) incubator. Atomic absorption (iCE 3300

AAS Atomic Absorption Spectrometer, Thermo Scientific, Cambridge, United Kingdom) was used to determine the calcium concentrations.

2.4.3 Microbiological Analysis of Yogurt Samples

The International Dairy Federation [33] procedure was followed to prepare yogurt samples for microbial counts. The yogurt samples were diluted tenfold under sterilized conditions in 0.15% (w/v) peptone water. Using the drop plate technique, 20 µl of each dilution was dropped in duplicate into the selective media [34]. The enumeration selective media *Streptococcus thermophilus* agar medium (ST agar), MRS at pH 5.4, and MRS agar supplemented with 0.05% (w/v) L-cysteine-hydrochloride (Sigma Chemical Co., St Louis, MO, USA) were used to enumerate *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Bifidobacterium lactis*, respectively [35]. The incubation conditions were aerobic at 37°C for 24 h, 45°C for 72 h, and anaerobically using Oxoid jars with a mesosphere generation system (Oxoid An aero Gen TM; Oxoid Ltd., Basingstoke, Hampshire, UK) at 37°C for 72 h for streptococci, lactobacilli, and *Bifidobacterium*, respectively.

2.4.4 Texture Measurement

We measured texture in fresh and 12-day-old yogurt samples. The analysis was carried out using a texture analyzer (model TA1000, LabPro (FTC TMS-Pro), USA). The two-bite penetration test was performed at a crosshead speed of 50 mm/sec using a TA60-degree cone Perspex [36].

2.4.5 The Microstructure of Yogurt

The scanning electron microscope (SEM) was used to observe the microstructure. We prepared samples as described by Brooker & Wells [37]. Specimens (1-5 mm^3) were fixed for 1 hour in 3% glutaraldehyde and dehydrated in a graded ethanol series (30, 50, 70, 80, and 90%, 1 hour in each). Drying of samples was done with acetone and amyl acetate, and then they were coated with gold using a Fine Coat JEOL (JFC-1100 E, Ion Sputtering Device, Tokyo, Japan) sputter coater. Samples were examined using the JSM-5300 Jeol Scanning Electron Microscope, Tokyo, Japan.

2.5 Sensory Evaluation

The organoleptic properties of yogurt were evaluated in fresh and 12-day-old samples [38]. The yogurt flavor, texture, and color were examined and rated on scales of 10, 5, and 5 points, respectively. The panel consisted of staff members and postgraduate students from the Dairy Science and Technology Department at the Faculty of Agriculture, Alexandria University.

2.6 Statistical Analysis

The presented data were analyzed using ANOVA through SAS statistical software (SAS, 1998). Significant differences among means were evaluated using Duncan's multiple range tests [39].

2.7 Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

3. Results and Discussion

3.1 Proximate Components of Brans and Dietary Fibers

3.1.1 Chemical Composition

The chemical composition (moisture, ash, raw fat, protein, and carbohydrates) of different brans and dietary fibers tested in this study is presented in Table 2. Wheat bran contained the highest moisture content at 11.85%, while rice bran had the lowest at 5.52%. Previous reports have shown that moisture content varies significantly among brans and dietary fibers from different plants [40, 41]. For example, wheat, oat, and rice brans had moisture contents of 4.8, 4.7, and 5.1%, respectively [41]. However, rice bran and rice dietary fibers had higher moisture contents of 12.12% and 11.73%, respectively [40], compared to the 5.52% and 8.40% found in our study. Barley bran had a moisture content of 9.2%, which is consistent with findings from Amjad et al. [22] and Zafar et al. [10].

Table 2 Proximate composition and fiber composition of different brans and dietary fibers Data are the means ± standard error of two replicates.

Bran and fibre Sources	Moisture (%)	Ash (%)	Crude fat (%)	Crude protein (%)	Fibers composition (%)			
					NDF[*1]	ADF[*2]	ADL[*3]	CHO[*4] (%)
Wheat bran	11.85 ± 0.05^{a}	2.17 ± 0.00^{d}	2.92 ± 0.13^{b}	14.21 ± 0.12^{c}	19.66 ± 0.06^{d}	5.13 ± 0.07^{d}	2.17 ± 0.05^{c}	75.58 ± 0.32^{d}
Rice bran	5.52 ± 0.17^{f}	13.23 ± 0.02^{b}	7.00 ± 0.17^{a}	14.12 ± 0.01^{c}	21.51 ± 0.02^{c}	12.06 ± 0.11^{b}	4.392 ± 0.2^{b}	53.60 ± 0.08^{f}
Oat bran	6.75 ± 0.07^{e}	1.94 ± 0.00^{e}	2.95 ± 0.13^{b}	15.03 ± 0.04^{b}	13.24 ± 0.29^{f}	1.69 ± 0.14^{f}	0.99 ± 0.11^{e}	78.40 ± 0.05^{c}
Barley bran	9.20 ± 0.09^{c}	1.35 ± 0.01^{f}	0.94 ± 0.07^{c}	11.12 ± 0.09^{d}	14.29 ± 0.51^{e}	2.59 ± 0.09^{e}	0.53 ± 0.11^{f}	84.00 ± 0.27^{b}
Wheat dietary fiber	6.69 ± 0.04^{e}	1.08 ± 0.02^{g}	0.13 ± 0.03^{d}	1.28 ± 0.16^{f}	93.10 ± 0.08^{a}	77.56 ± 0.22^{a}	2.13 ± 0.12^{c}	19.96 ± 0.42^{g}
Rice dietary fiber	8.40 ± 0.13^{d}	13.36 ± 0.00^{a}	2.69 ± 0.05^{b}	17.37 ± 0.12^{a}	29.42 ± 0.15^{b}	11.21 ± 0.03^{c}	4.97 ± 0.03^{a}	55.38 ± 0.11^{e}
Psyllium husk	10.60 ± 0.04^{b}	2.52 ± 0.05^{c}	0.99 ± 0.08^{c}	3.04 ± 0.01^{e}	20.39 ± 0.22^{d}	4.89 ± 0.16^{d}	1.68 ± 0.05^{d}	88.57 ± 0.19^{a}

[*1] NDF = Neutral Detergent Fiber. NDF refer to hemicellulose, cellulose and lignin.

[*2] ADF = Acid Detergent Fiber. ADF refer to cellulose and lignin.

[*3] ADL = Acid Detergent Lignin. ADL refer to lignin.

[*4] CHO = Carbohydrate (calculated by difference): 100 - (protein + fat + ash + acid detergent fiber) as mentioned by Claye et al. [41].

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

Ash content varied significantly among the different brans and dietary fibers tested in this study. Rice dietary fibers had the highest ash content (13.36%), followed by rice bran (13.23%). However, wheat dietary fiber (1.08%) showed the lowest content. Similarly, Claye et al. [41] reported that rice bran and dietary fibers had significantly higher ash contents than tomato fiber, oat fiber, and wheat bran. This study reported an ash content of 1.34% for barley bran, which was lower than the 4.09% reported by Zafar et al. [10].

The raw fat content varied from 0.13% for wheat dietary fiber to 7.0% for rice bran. Fat content also differed among different brans. The fat contents of 1.7% for wheat bran and 1.3% for rice bran [41] were lower than the 2.92% and 7% found in the present study. Conversely, the fat contents of 7% for rice bran and 2.69% for rice dietary fibers in this study were lower than the 20.31% and 4.31% reported by Choi et al. [40]. The fat content of 0.94% found in this study for barley bran was lower than the 1.76% reported by Zafar et al. [10].

Protein content varied significantly among the tested brans and dietary fibers. Brans and dietary fibers contained a wide range of proteins, from 1.28 to 17.37. The protein content of the tested brans and dietary fibers was in the following order: rice dietary fiber > oat bran > wheat bran > rice bran > barley bran > psyllium husk > wheat dietary fiber, respectively. Claye et al. [41] evaluated protein contents of 17.2% and 19.3% in wheat and rice brans, respectively. Additionally, Choi et al. [40] reported protein contents of 12.32% and 21.91% in rice bran and dietary fiber, respectively. Zafar et al. [10] noted a protein percentage of 11.74 for barley bran, which is similar to the 11.12% found in this study.

The carbohydrate content of brans and dietary fibers ranged from 19.96% to 88.57%. Carbohydrate content varied widely even within the same group. Average values of carbohydrate content ranged from 19.96 to 88.57% and from 53.60 to 84.00% for the dietary fibers and bran groups, respectively. The amounts of carbohydrate in different brans and dietary fibers were in the following order: psyllium husk > barley bran > oat bran > wheat bran > rice dietary fiber > rice bran > wheat dietary fiber, respectively. The carbohydrate contents were 59.0 and 52.5% in wheat and rice brans, respectively [41], while 75.58 and 53.60% carbohydrate contents were determined for the same brans in this study.

3.1.2 Dietary Fiber Content

The concentrations of acid detergent fibers (ADF), neutral detergent fibers (NDF), and acid detergent lignin (ADL) in different brans and dietary fibers are shown in Table 2. Neutral detergent fibers, also known as cell wall polysaccharides, consist of cellulose, lignin, and hemicelluloses. However, acid detergent fibers consist of cellulose, lignified nitrogen compounds, lignin, and insoluble ash [42]. In general, dietary fibers appeared to contain higher levels of neutral and acid detergent fibers, as well as acid detergent lignin, compared to brans. However, the concentration of such fiber fractions in rice bran was very close to those determined in wheat and rice dietary fibers and psyllium husk. The concentration of neutral detergent fiber was in the following order: wheat dietary fiber > rice dietary fiber > rice bran > psyllium husk > wheat bran > barley bran > oat bran, respectively. The acid detergent fibers accounted for 15.2, 40.5, and 15.1% of total fibers in wheat, oat, and rice brans, respectively [41]. Variations in the concentrations of acid-neutral and detergent fibers, as well as acid-detergent lignin, reported in this study could be attributed to grinding or seasonal operations and/or variety or environmental conditions of the fiber sources [41].

3.2 Characterization of Yogurt Supplemented with Brans or Dietary Fibers

3.2.1 Physico-Chemical Characterization

Acid Development During Yogurt Storage.

The initial titratable acidity of different samples, determined in fresh samples, ranged from 0.69 to 0.81% (Table 3). The acidity of the tested yogurt samples increased significantly ($p < 0.05$) over time. After 12 days of storage, the measured acidity values of different yogurt samples ranged from 0.80 to 1.05%. Similarly, titratable acidity in yogurt samples supplemented with rice bran and psyllium husks increased progressively during the cold storage period [43, 44]. The control yogurt had the highest measurement of titratable acidity (1.05%), while yogurt containing psyllium husk had the lowest value (0.80%). The latter sample showed the least evolution of titratable acidity during the storage period, increasing from 0.73% in a fresh sample to 0.80% in the 12-day-aged sample. However, the control yogurt had the highest rate of post-acidification, with titratable acidity increasing from 0.81% in the fresh sample to 1.05% in the 12-day-aged sample. The post-acidification during storage could be related to lactose fermentation to lactic acid via LAB [45].

Table 3 Changes in pH value, titratable acidity, and viscosity during refrigerated storage of bio-yogurt supplemented with various brans and dietary fibers. Data are means ± standard error.

Yogurt treatments	Storage time (days)	pH	Acidity (%)	Viscosity (mPs)
Control	Fresh	$4.60 \pm 0.07^{d-f}$	$0.81 \pm 0.01^{i-k}$	$10450 \pm 400^{m-o}$
	4	$4.49 \pm 0.04^{g-i}$	$0.89 \pm 0.01^{d-f}$	$11650 \pm 345^{k-n}$
	8	4.34 ± 0.07^{kl}	1.01 ± 0.01^{b}	14215 ± 125^{gh}
	12	4.25 ± 0.03^{m}	1.05 ± 0.02^{a}	15290 ± 220^{fg}
Wheat bran	Fresh	4.72 ± 0.00^{bc}	0.77 ± 0.01^{lm}	14150 ± 425^{gh}
	4	$4.64 \pm 0.03^{c-e}$	$0.83 \pm 0.00^{h-j}$	17410 ± 750^{de}
	8	$4.49 \pm 0.03^{g-i}$	$0.88 \pm 0.01^{e-g}$	$17585 \pm 1075^{c-e}$
	12	$4.41 \pm 0.00^{i-k}$	0.92 ± 0.00^{d}	17180 ± 360^{e}
Rice bran	Fresh	4.75 ± 0.01^{b}	0.80 ± 0.02^{jkl}	9910 ± 600^{no}
	4	$4.61 \pm 0.02^{d-f}$	0.86 ± 0.01^{gh}	$12540 \pm 650^{h-l}$
	8	$4.55 \pm 0.01^{e-g}$	0.92 ± 0.00^{d}	$13340 \pm 560^{h-k}$
	12	$4.42 \pm 0.00^{i-k}$	0.95 ± 0.01^{c}	$11995 \pm 525^{j-m}$
Oat bran	Fresh	$4.64 \pm 0.00^{c-e}$	$0.72 \pm 0.01^{n-p}$	$11340 \pm 333^{l-o}$
	4	$4.52 \pm 0.00^{f-h}$	0.77 ± 0.01^{lm}	16880 ± 450^{ef}
	8	$4.44 \pm 0.01^{h-j}$	0.84 ± 0.01^{h}	19645 ± 95^{ab}
	12	4.28 ± 0.04^{lm}	$0.86 \pm 0.01^{e-h}$	$19215 \pm 455^{a-d}$
Barley bran	Fresh	4.79 ± 0.02^{ab}	$0.72 \pm 0.00^{n-p}$	16660 ± 900^{ef}
	4	4.62 ± 0.04^{de}	0.79 ± 0.01^{kl}	$17815 \pm 900^{c-e}$
	8	4.37 ± 0.00^{jk}	0.86 ± 0.01^{gh}	20840 ± 300^{a}
	12	4.25 ± 0.02^{m}	$0.89 \pm 0.01^{e-g}$	$18030 \pm 610^{b-e}$
Wheat dietary fiber	Fresh	4.65 ± 0.02^{cd}	0.69 ± 0.00^{p}	9690 ± 700^{o}
	4	$4.60 \pm 0.02^{d-f}$	0.71 ± 0.01^{po}	$12620 \pm 610^{h-l}$
	8	$4.40 \pm 0.00^{i-k}$	$0.83 \pm 0.00^{h-j}$	$13995 \pm 225^{g-i}$

	12	4.27 ± 0.02^{lm}	$0.86 \pm 0.00^{f-h}$	$11380 \pm 220^{l-o}$
Rice dietary fiber	Fresh	4.77 ± 0.03^{b}	0.78 ± 0.01^{kl}	$13920 \pm 480^{g-i}$
	4	4.65 ± 0.03^{cd}	0.84 ± 0.02^{hi}	$12995 \pm 355^{h-l}$
	8	$4.57 \pm 0.01^{d-g}$	0.90 ± 0.01^{de}	$13610 \pm 70^{g-j}$
	12	$4.42 \pm 0.00^{j-k}$	0.92 ± 0.00^{d}	$12175 \pm 295^{i-m}$
Psyllium husk	Fresh	4.85 ± 0.00^{a}	0.73 ± 0.00^{no}	$19300 \pm 1080^{a-c}$
	4	4.72 ± 0.02^{bc}	0.75 ± 0.00^{mn}	16755 ± 395^{ef}
	8	$4.49 \pm 0.03^{g-i}$	0.79 ± 0.00^{kl}	$18040 \pm 300^{b-e}$
	12	4.33 ± 0.00^{kl}	$0.80 \pm 0.00^{j-l}$	17145 ± 925^{e}

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

The pH values of the different yogurt samples appeared correlated with titratable acidity. Fresh samples had a wide range of pH values from 4.60 to 4.85 (Table 3). Similarly, in terms of titratable acidity, the control sample had the lowest pH, while the samples containing psyllium husk had the highest values. This finding was also reported by Song et al. [20], who found that yogurt samples supplemented with insoluble dietary fiber (IDF) from corn bran had higher ($p < 0.05$) pH values compared to the control. This trend continued over time, with the pH decreasing significantly in all tested samples as they aged. The 12-day-old samples had pH values ranging from 4.25 to 4.44. The control and barley bran-containing samples had the lowest pH values, followed by samples containing wheat dietary fiber, psyllium husk, wheat bran, rice bran, dietary fiber, and oat bran, respectively. Additionally, after 28 days of refrigeration, the pH of yogurt supplemented with IDF from corn bran was significantly higher ($p < 0.05$) than the control [20]. The pH of yogurt supplemented with rice bran decreased significantly during the 21-day cold storage period, with the reduction corresponding to the amount of rice bran added [43]. The authors noted that the pH reduction was greatest in yogurt containing 3% rice bran, at 0.6 units, and lowest in the control yogurt at 0.14 units. The decrease in pH during storage is a common occurrence in fermented foods and is often associated with the growth of microbial starters and the production of lactic acid and other acids [46]. In contrast, an increase in pH was observed for yogurt samples supplemented with rice bran before fermentation [9].

Viscosity of Yogurt During Storage.

The viscosity values for fresh yogurts ranged from 9690 to 17145 mPa·s. (Table 3). Among samples containing bran and fiber, it was observed that psyllium husk produced the highest viscosity, while wheat dietary fiber resulted in the lowest. Overall, samples with added brans or dietary fibers showed significantly higher viscosity compared to the control. The inclusion of fibers in fermented dairy products has been linked to increased viscosity [10]. This phenomenon may be due to the increased concentration of the reducing ingredients in the free space of motion, which encourages collisions during shear. Additionally, the solid bonding of water and other molecules in the gel matrix leads to an increase in viscosity [47]. On the other hand, some reports have suggested that the addition of dietary fibers can actually reduce the apparent viscosity of yogurt [9, 43, 48]. Yogurt supplemented with rice bran, for example, exhibited lower apparent viscosity compared to control samples [9, 43]. This decrease was attributed to polysaccharides like β-glucan and pectin in rice bran, which can stabilize casein aggregates.

On day 12 of storage, yogurt with oat bran had the highest viscosity, followed by those containing barley bran, wheat bran, psyllium husk, control, rice dietary fiber, rice bran, and wheat dietary fiber, respectively. The evolution of viscosity during storage differed significantly among samples. For some samples, the viscosity increased gradually, peaked at day 8, and then decreased, while other samples showed a continuous increase in viscosity until the end of the storage period. Many studies have shown that viscosity changes during storage in yogurt containing dietary fiber. This increase led to a decrease in pH value during storage, resulting in a firmer gel texture [49].

Syneresis.

The most common defect in yogurt is syneresis, which occurs when the curd stability is disrupted, leading to gel separation and potentially causing customers to reject the product [49]. This separation of whey is a key indicator of quality over time [50]. The changes in syneresis (%) during the refrigerated storage of yogurt with different brans or dietary fibers are shown in Figure 1. Among them, yogurt with psyllium husk had the lowest syneresis value, likely due to its high water-holding capacity compared to other bran and fibers. In contrast, yogurt with wheat dietary fiber had the highest syneresis value.

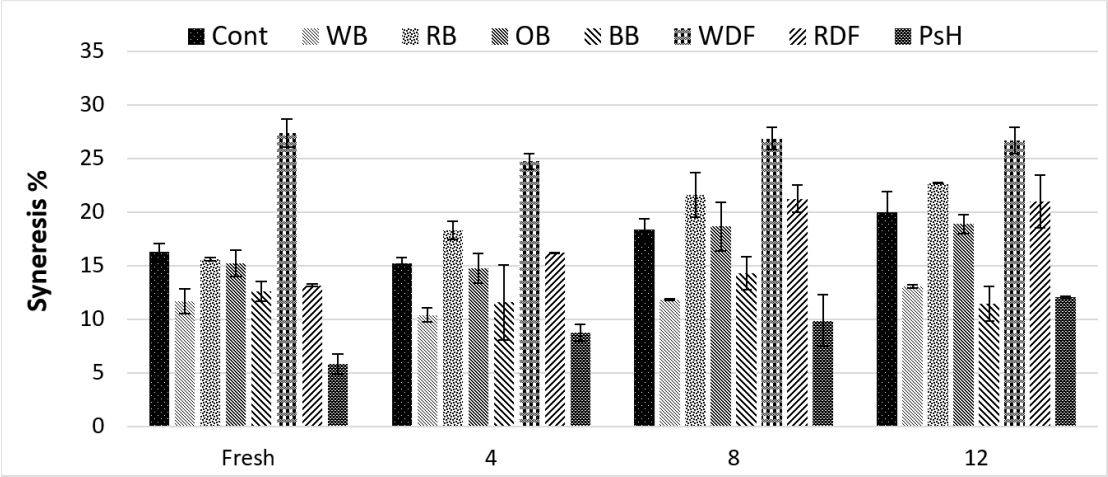


Figure 1 Changes in syneresis during refrigerated storage of the bio-yogurt containing brans or dietary fibers. Columns with different letters are significantly different ($p < 0.05$). Cont = control; WB = wheat bran, RB = rice bran, OB = oat bran, BB = barley bran, WDF = wheat dietary fiber, RDF = rice dietary fiber, and PsH = psyllium husk.

During storage, yogurt samples containing wheat bran, oat bran, rice bran, rice fiber, or psyllium husk, as well as the control, showed a continuous increase in syneresis ($p \leq 0.05$) as storage time progressed. However, yogurt containing wheat dietary fiber had the highest syneresis during the storage time, with fluctuating values. Wheat dietary fiber's ability to induce syneresis may relate to its fiber composition, particularly its higher content of neutral and acid detergent fibers compared with other fibers and brans. On the other hand, rice bran and fiber appeared to accelerate whey syneresis since day 4, which could be associated with their high contents of acid detergent lignin, as previously shown in Table 2, classified as water-insoluble fibers [51].

On day 12, the syneresis values of different yogurt samples were as follows: wheat dietary fiber > rice bran > rice dietary fiber > control > oat bran > psyllium husk > barley bran. The lowest syneresis ability of barley found in this study could be related to the presence of β-glucan. β-glucan has been

shown to dramatically decrease whey separation in yogurts [22, 52]. The supplementation of 0.13-0.5% rice berry rice extract to set yogurt significantly reduced syneresis in all supplemented yogurts [53].

Contradictory outcomes have been observed regarding the impact of dietary fiber on yogurt syneresis. Yogurt syneresis appears to be affected differently depending on the type of fiber used. For example, the addition of soy fiber to mistidahi, a popular Indian-style sweetened yogurt, significantly reduced its syneresis, while the addition of oat and inulin fiber produced a slight increase [19, 54]. Additionally, adding inulin and orange fiber significantly increased whey separation in yogurt [55]. The increase in yogurt syneresis due to the supplementation of a certain type of dietary fiber could be attributed to its ability to disturb and break the yogurt gel structure. However, the reduction in syneresis depends mainly on the water-holding ability of the fiber source [56].

Determination of Water Holding Capacity.

Water holding capacity is a crucial factor that influences the success of yogurt retail in the market. It reflects yogurt's ability to keep the serum's gel structure intact [57]. Generally, the results of water holding capacity were complementary to those of water syneresis. Except for barley bran, fresh yogurt samples containing bran or dietary fibers had significantly ($p < 0.05$) higher water holding capacity values compared to the control (Figure 2). Overall, values for water holding capacity ranged from 47.65 to 61.53% and are classified in descending order as follows: rice dietary fiber > wheat dietary fiber > psyllium husk > rice bran > oat bran > wheat bran > control > barley. Throughout the storage period, most samples exhibited a similar trend, with water holding capacity increasing significantly as storage time progressed. By day 12, yogurt containing rice dietary fiber had the highest water-holding capacity (63.95%), while the lowest value was reported for samples containing wheat bran (51.33%). However, the control sample showed a water-holding capacity of 54.13%. Adding rice bran or psyllium husk to the yogurt formula significantly increased the end product's water-holding capacity, depending on the supplementation level [43, 44].

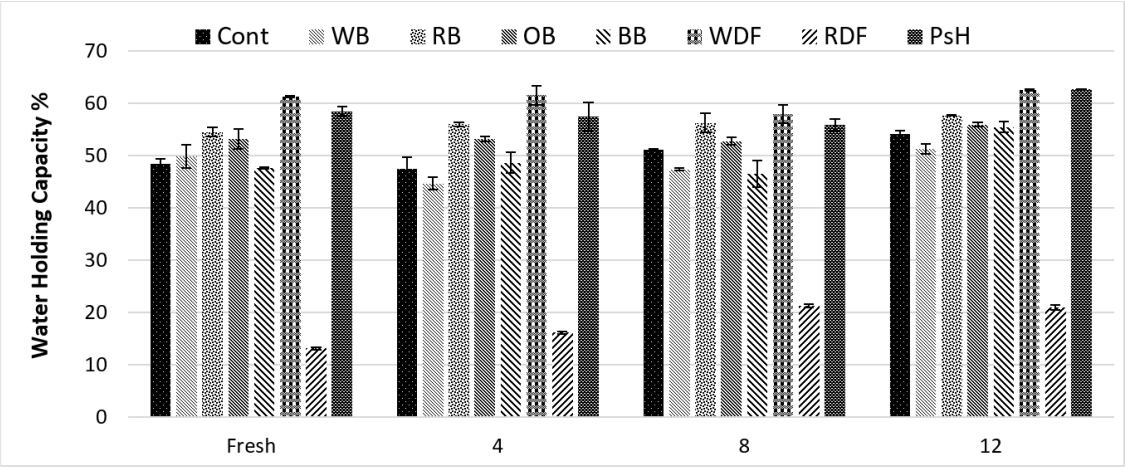


Figure 2 Changes in water holding capacity during refrigerated storage of the bio-yogurt containing brans or dietary fibers. Columns with different letters are significantly different ($p < 0.05$). Cont = control; WB = wheat bran, RB = rice bran, OB = oat bran, BB = barley bran, WDF = wheat dietary fiber, RDF = rice dietary fiber, and PsH = psyllium husk.

Color Evaluation.

The addition of brans and dietary fibers resulted in significant ($p < 0.05$) changes in the contributing color of fresh yogurt (Table 4). These changes depended on the type of bran or dietary fiber added. The *L** values (indicating lightness or whiteness) of fresh yogurts were significantly decreased in samples with added bran or dietary fiber, except for those containing wheat dietary fiber, which showed a significant increase compared to the control. Lightness values were highest in yogurt containing wheat dietary fiber, followed by the control and then samples containing psyllium husk > oat bran > wheat bran > barley bran > rice bran > rice dietary fiber, respectively. Amjad et al. [22] observed an increase in the *L** value of yogurt samples supplemented with barley bran, especially with 1.5% of the added bran. The author attributed this enhancement in color parameters to the blueness of barley bran. In contrast, the addition of rice bran to yogurt significantly reduced the *L** values, with the reduction being proportionally related to the amount of added bran [43]. Tian et al. [58] also observed a significant decrease in *L** value of yogurt with the addition of IDF from soybeans. Many fibers such as soy, oat, and apple fibers have been reported to decrease yogurt lightness [54].

Table 4 Color parameters and calcium bioavailability of fresh bio-yogurt containing brans or dietary fibers Data are means ± standard error.

Yogurt treatments	Parameter of Color			Calcium bioavailability mg/l[*4]
	L^{*1}	a^{*2}	b^{*3}	
Control	87.76 ± 0.03[b]	-0.80 ± 0.0[f]	12.27 ± 0.00[b]	67.87 ± 0.00[c]
Wheat bran	86.92 ± 0.04[d]	-0.34 ± 0.0[c]	12.21 ± 0.01[c]	61.35 ± 0.00[d]
Rice bran	85.68 ± 0.01[f]	-0.15 ± 0.0[b]	11.52 ± 0.00[e]	61.35 ± 0.00[d]
Oat bran	87.18 ± 0.02[c]	-0.61 ± 0.0[e]	11.59 ± 0.00[d]	58.17 ± 0.00[e]
Barley bran	86.63 ± 0.05[e]	-0.36 ± 0.0[d]	11.60 ± 0.00[d]	75.43 ± 0.00[b]
Wheat dietary fiber	87.99 ± 0.02[a]	-0.88 ± 0.0[g]	11.12 ± 0.02[f]	88.75 ± 0.00[a]
Rice dietary fiber	84.68 ± 0.02[g]	0.05 ± 0.0[a]	12.32 ± 0.02[a]	88.89 ± 0.00[a]
Psyllium husk	87.74 ± 0.02[b]	-1.01 ± 0.0[h]	11.52 ± 0.00[e]	65.86 ± 0.00[c]

[*1] L = values (lightness or whiteness).

[*2] a = values (redness).

[*3] b = values (yellowness).

[*4] Bioavailability was determined by *in vitro* digestion of fresh yogurt samples.

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

The values of *a** (redness) and *b** (yellowness) were influenced by the addition of brans and dietary fibers to yogurt. Compared with the control, psyllium husk and wheat dietary fiber decreased the *a** values, while other brans and fibers had the opposite effect. The *a** values of different yogurts ranked as follows: psyllium husk < wheat dietary fibers < control < oat bran < barley < wheat bran < rice bran < rice dietary fiber. Previous studies also found high redness values in yogurts with wheat bran [59], rice bran [43], or asparagus fiber [60]. The type of bran or dietary fiber added significantly impacted *b** (yellowness) values ($p < 0.05$). The *b** values of yogurt samples ranged from 12.32 to 11.12. Yogurt with rice dietary fiber had the highest *b** value, while psyllium

husk had the lowest. The *b** values ranked as follows: rice dietary fiber > control > wheat bran > barley bran > oat bran > rice bran and psyllium husk > wheat dietary fiber. Recently, yogurt supplemented with soybean IDF showed a significant increase in a* and b* values compared to the control [58].

3.2.2 Effect of Brans and Dietary Fibers on Calcium Bioavailability

The ability of yogurts containing bran and dietary fibers to deliver calcium was evaluated *in vitro* under gastrointestinal simulation conditions. Dairy products are generally recognized as excellent sources of calcium. Table 4 presents data on calcium bioavailability from yogurts with various brans and dietary fibers. It was evident that all tested brans (except barley bran) decreased calcium availability by 6.5 to 9.7 mg/50 g of yogurt compared to the control yogurt. Among the tested brans, oat bran showed the highest reduction in calcium availability. However, yogurt with barley bran delivered 7.56 mg/50 g more calcium than the control yogurt. Conversely, the addition of dietary fibers (from rice and wheat) had a positive effect, leading to an increase in calcium absorption by approximately 21.0 mg/50 g of yogurt compared to the control. Psyllium husk showed a slight decrease ($p > 0.05$) in absorbed calcium compared to the control. Overall, the ability of the different yogurt samples to deliver calcium was highest in the sample with rice dietary fiber, followed by those with wheat dietary fiber, barley bran, control, psyllium husk, wheat and rice brans, and oat bran, respectively.

Reports on the impact of dietary fibers on mineral absorption, with few studies focusing on the relationship between brans and mineral absorption. Some studies have shown the improved availability of Ca, Mg, and P from yogurts containing inulin and/or fructo-oligosaccharides [61]. However, there is a decrease in calcium and iron availability in yogurt samples supplemented with long- or short-chain inulin [19]. Locust bean gum and methoxyl pectin reduce the absorption and bioavailability of calcium *in vitro* [62]. This reduction in mineral absorption is believed to be attributed to the presence of certain chemical groups (such as phytic acid) associated with fiber, which bind to important minerals and decrease their availability [63].

3.2.3 Effect of Brans and Dietary Fibers on the Survival of Yogurt Starter and *Bifidobacterium lactis*

The viable numbers of yogurt starter microorganisms (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*) and *Bifidobacterium lactis* during storage under refrigeration conditions of different yogurt samples are presented in Table 5. The average viable counts of *Streptococcus thermophilus* were estimated at 8.77 to 9.00 $\log_{10}$ cfu/g in control samples and from 8.37 to 8.83 $\log_{10}$ cfu/g in yogurt containing bran or dietary fiber (Table 5). Similarly, the viable counts of *Streptococcus thermophilus* in yogurt with rice bran (1, 2, and 3%) ranged from 8.22 to 9.83 $\log_{10}$ cfu/g [43]. The count of *Streptococcus thermophilus* significantly increased in all barley bran yogurt samples, especially those with 6% barley bran or flour, over the control [10]. Yogurts containing brans or dietary fibers in this study showed a significantly lower increase in *Streptococcus thermophilus* counts than the control sample. This was contradictory to the previous results of the viable counts of *Streptococcus thermophilus* in yogurt containing rice bran, which were superior to those determined in the control, and this increment corresponded with the level of added bran [10, 43]. Among samples with brans or fibers tested in this study, yogurt-containing wheat dietary fiber had the lowest viable counts of *Streptococcus thermophilus* throughout the storage period.

Table 5 Changes in the viable count (log_{10} cfu/g) of *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. Bulgaricus, and *Bifidobacterium lactis* during refrigerated storage of bio-yogurt containing bran or dietary fibers. Data are means ± standard error.

Yogurt treatments	Storage time (days)	*Streptococcus thermophiles*	*Lactobacillus delbrueckii* subsp. *bulgaricus*	*Bifidobacterium lactis*
Control	Fresh	8.77 ± 0.03^{a-c}	8.76 ± 0.12^{a-d}	8.50 ± 0.11^{c-i}
	4	8.72 ± 0.07^{a-e}	8.41 ± 0.11^{f-k}	8.53 ± 0.00^{c-i}
	8	8.87 ± 0.10^{ab}	8.09 ± 0.09^{lm}	8.94 ± 0.01^{ab}
	12	9.00 ± 0.11^{a}	8.96 ± 0.06^{a}	9.21 ± 0.18^{a}
Wheat bran	Fresh	8.61 ± 0.01^{b-f}	8.55 ± 0.07^{c-i}	8.60 ± 0.13^{c-g}
	4	8.60 ± 0.02^{b-f}	8.38 ± 0.09^{g-k}	8.31 ± 0.13^{g-j}
	8	8.68 ± 0.08^{a-f}	8.66 ± 0.01^{b-h}	8.75 ± 0.02^{bc}
	12	8.79 ± 0.03^{ab}	8.62 ± 0.02^{b-h}	8.74 ± 0.13^{bc}
Rice bran	Fresh	8.61 ± 0.09^{b-f}	8.67 ± 0.01^{b-g}	8.58 ± 0.04^{c-g}
	4	8.74 ± 0.00^{a-d}	8.09 ± 0.09^{lm}	8.19 ± 0.10^{ij}
	8	8.83 ± 0.17^{ab}	8.66 ± 0.04^{b-h}	8.71 ± 0.06^{b-d}
	12	8.82 ± 0.06^{ab}	8.83 ± 0.10^{abc}	8.65 ± 0.05^{b-g}
Oat bran	Fresh	8.59 ± 0.10^{b-f}	8.63 ± 0.07^{b-h}	8.33 ± 0.06^{f-j}
	4	8.64 ± 0.00^{b-f}	8.49 ± 0.11^{d-j}	8.43 ± 0.04^{c-j}
	8	8.74 ± 0.09^{a-d}	8.42 ± 0.05^{e-k}	8.63 ± 0.06^{b-g}
	12	8.68 ± 0.02^{a-f}	8.72 ± 0.02^{a-e}	8.56 ± 0.17^{c-h}
Barley bran	Fresh	8.73 ± 0.04^{a-d}	8.18 ± 0.18^{k-m}	8.65 ± 0.12^{b-g}
	4	8.74 ± 0.21^{a-d}	8.05 ± 0.06^{m}	8.23 ± 0.06^{g-j}
	8	8.71 ± 0.13^{a-e}	8.63 ± 0.14^{b-h}	8.67 ± 0.10^{b-f}
	12	8.73 ± 0.11^{a-d}	8.51 ± 0.00^{d-i}	8.62 ± 0.07^{b-g}
Wheat dietary fiber	Fresh	8.38 ± 0.20^{ef}	8.44 ± 0.04^{e-k}	8.47 ± 0.13^{c-j}
	4	8.43 ± 0.13^{c-f}	8.08 ± 0.08^{m}	8.34 ± 0.04^{e-j}
	8	8.63 ± 0.02^{b-f}	8.66 ± 0.07^{b-g}	8.45 ± 0.05^{c-j}
	12	8.37 ± 0.02^{f}	8.71 ± 0.01^{a-e}	8.19 ± 0.19^{ij}
Rice dietary fiber	Fresh	8.61 ± 0.04^{b-f}	8.18 ± 0.18^{k-m}	8.47 ± 0.00^{c-j}
	4	8.43 ± 0.13^{c-f}	8.08 ± 0.08^{lm}	8.39 ± 0.00^{d-j}
	8	8.71 ± 0.06^{a-e}	8.69 ± 0.04^{a-f}	8.42 ± 0.12^{c-j}
	12	8.79 ± 0.05^{ab}	8.87 ± 0.08^{ab}	8.68 ± 0.01^{b-e}
Psyllium husk	Fresh	8.54 ± 0.11^{b-f}	8.37 ± 0.02^{h-l}	8.39 ± 0.00^{d-j}
	4	8.41 ± 0.12^{d-f}	8.23 ± 0.02^{j-m}	8.15 ± 0.15^{j}
	8	8.56 ± 0.09^{b-f}	8.31 ± 0.13^{i-m}	8.39 ± 0.09^{d-j}
	12	8.69 ± 0.09^{a-f}	8.65 ± 0.02^{b-h}	8.60 ± 0.04^{c-g}

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

Lactobacillus delbrueckii subsp. *bulgaricus* exhibited varying trends in viable counts during the storage period of different yogurt samples (Table 5). The viable numbers of *Lactobacillus delbrueckii*

subsp. *bulgaricus* determined in the control were 8.09 to 8.96 $\log_{10}$ cfu/g but ranged from 8.05 to 8.87 $\log_{10}$ cfu/g in yogurts containing bran or dietary fibers. Overall, all samples showed a progressive increase in viable counts of *Lactobacillus delbrueckii* subsp. *bulgaricus* as the storage time progressed. Similar results have been reported for rice bran- or barley bran-containing yogurt [10, 22, 43]. The authors also reported an increase in viable cells of *Lactobacillus delbrueckii* subsp. *bulgaricus* as the level of added rice bran increased from 1 to 3% and barley bran increased to 6%.

The viable counts of *Bifidobacterium lactis* during storage ranged from 8.50 to 9.21 $\log_{10}$ cfu/g in the control group (Table 5). This range was higher than the 8.15-8.75 $\log_{10}$ cfu/g counts found in yogurt samples containing bran or dietary fibers. Between days 3 and 12, most samples showed a slight increase in *Bifidobacterium lactis* viable counts. Additionally, a significant increase in *Bifidobacterium lactis* viable counts was observed during the storage of non-dairy probiotic beverages based on oat bran up to 14 days after fermentation, followed by a sharp decrease in viable bacteria after 21 days of storage [64]. On day 14, supplementing stirred-type yogurt with blue pea extract increased the viable count of *Bifidobacterium animalis* over the control samples [65].

3.2.4 Influence of Brans and Dietary Fibers on the Textural Attributes of Yogurt

Hardness (g) is the most critical criterion for evaluating the texture of yogurt. In fresh samples, the yogurt sample containing psyllium husk had the maximum hardness value, followed by the control sample. Similar results showing an increase in hardness were reported for yogurt samples supplemented with psyllium husk up to 0.7% over the control [21]. Additionally, yogurt samples supplemented with corn IDF showed increased hardness, and hardness increased significantly ($p < 0.05$) with higher IDF content [20]. Yogurts containing other brans and dietary fibers had significantly lower hardness values compared with control yogurt (Table 6). This may be related to the ability of brans and dietary fibers to disrupt rearrangement of the casein matrix, reducing firmness values [66]. Furthermore, rice bran-supplemented yogurt samples showed reduced hardness values [9]. The modification of texture in yogurt samples supplemented with barley bran was previously observed [10]. On day 12 of storage, higher hardness values were determined in all samples compared with the fresh samples. The same finding of high hardness values for yogurt samples with IDF of corn bran increased with a longer refrigeration period, and yogurt hardness reached a maximum level by 21 days of refrigeration storage [20]. It has also been previously reported that hardness values increased significantly during the cold storage of yogurt [67]. This increase is due to the formation of protein-protein interactions that might take place during cold storage. At the final period of storage, the control had the highest hardness value, followed by yogurt samples with added psyllium husk, wheat bran, wheat dietary fiber, rice bran, oat bran, rice dietary fiber, and barley bran, respectively.

Table 6 Changes in the textural parameters during refrigerated storage of bio-yogurt containing brans or dietary fibers.

Yogurt treatments	Storage time (days)	Textural parameters				
		Hardness (g)	Adhesiveness (g·mm)	Cohesiveness	Springiness (mm)	Gumminess (N)
Control	0	141.0 ± 4.0^{c-e}	60.69 ± 0.34^{cd}	0.42 ± 0.01^{gh}	4.73 ± 0.01^{e-g}	59 ± 2.0^{cd}
	12	186.5 ± 11.5^{a}	86.02 ± 4.13^{a}	0.44 ± 0.01^{d-g}	6.23 ± 0.47^{a}	81 ± 6.0^{b}
Wheat bran	0	130.0 ± 5.0^{d-g}	67.16 ± 1.63^{b}	0.42 ± 0.01^{g}	5.28 ± 0.23^{bd}	55 ± 4.0^{cd}
	12	145.0 ± 0.0^{c}	83.86 ± 0.34^{a}	0.43 ± 0.02^{fg}	5.34 ± 0.17^{bc}	62 ± 1.5^{c}
Rice bran	0	130.0 ± 1.0^{d-g}	57.86 ± 0.03^{de}	0.42 ± 0.01^{gh}	4.82 ± 0.02^{d-g}	55 ± 0.5^{cd}
	12	139.0 ± 2.0^{c-f}	47.92 ± 1.75^{gh}	0.45 ± 0.01^{cd}	5.26 ± 0.05^{bcd}	62 ± 0.0^{c}
Oat bran	0	117.5 ± 3.5^{g-i}	65.06 ± 0.83^{bc}	0.46 ± 0.01^{cd}	4.42 ± 0.01^{g}	54 ± 1.5^{c-e}
	12	125.0 ± 4.0^{f-h}	53.67 ± 0.42^{ef}	0.48 ± 0.01^{c}	4.85 ± 0.03^{c-g}	59 ± 1.0^{cd}
Barley bran	0	106.0 ± 0.0^{i}	60.71 ± 0.52^{cd}	0.43 ± 0.01^{e-g}	4.50 ± 0.04^{fg}	46 ± 1.0^{ef}
	12	114.5 ± 3.5^{hi}	58.28 ± 0.12^{de}	0.45 ± 0.01^{d-f}	5.06 ± 0.04^{b-e}	51 ± 1.0^{d-f}
Wheat dietary fiber	0	113.5 ± 4.5^{hi}	56.46 ± 2.20^{d-f}	0.40 ± 0.01^{h}	4.79 ± 0.02^{d-g}	45 ± 0.5^{f}
	12	143.0 ± 2.0^{cd}	51.92 ± 2.65^{fg}	0.41 ± 0.00^{gh}	5.07 ± 0.07^{b-e}	58 ± 1.0^{cd}
Rice dietary fiber	0	127.5 ± 5.5^{e-h}	55.68 ± 0.23^{d-f}	0.43 ± 0.01^{e-g}	5.04 ± 0.09^{b-e}	55 ± 4.0^{cd}
	12	125.0 ± 1.0^{f-h}	53.54 ± 0.86^{ef}	0.45 ± 0.01^{de}	5.16 ± 0.04^{b-e}	57 ± 1.5^{cd}
Psyllium husk	0	160.0 ± 4.0^{b}	39.81 ± 0.37^{i}	0.56 ± 0.01^{b}	5.41 ± 0.08^{b}	89 ± 3.5^{b}
	12	184.0 ± 2.0^{a}	44.90 ± 0.57^{h}	0.61 ± 0.01^{a}	4.97 ± 0.05^{b-f}	112 ± 2.5^{a}

Data are means ± standard error.

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

Adhesiveness is the force required to remove adhered material from the mouth while eating. It measures the stickiness of yogurt and is inversely related to jogurt eating quality [68]. The adhesiveness (g·mm) of yogurt samples showed varied responses to brans and dietary fibers added to yogurt (Table 6). Fresh samples with wheat or oat bran had significantly higher adhesiveness compared to the control sample. Rice and barley bran, as well as rice and wheat dietary fiber, significantly reduced adhesiveness values. However, adding psyllium husk produced yogurt with the lowest adhesiveness values. The type of added dietary fiber affects yogurt adhesiveness. Partially hydrolyzed guar gum and oat-maltodextrin appeared to increase yogurt adhesiveness [66-68], while cellulose fibers had the opposite effect [67].

Refrigerated storage appeared to significantly affect the adhesiveness of the yogurt samples, primarily based on the type of added bran and dietary fiber. The yogurt samples could be categorized into two groups depending on the type of supplemented bran and fibers. The first group, including the control sample and yogurts with wheat bran and psyllium husk, showed an increase in adhesiveness during storage. The second group, consisting of samples with rice, oat, and barley brans as well as wheat and rice dietary fibers, exhibited a notable decrease in adhesiveness as the storage time progressed. Additionally, the adhesiveness values of yogurt containing cellulose fiber decreased during storage [67].

Cohesiveness is an important textural measurement that influences consumer acceptance of yogurt. The inclusion of bran and dietary fibers had little impact on the cohesiveness values of yogurt samples (Table 6). Psyllium husk was found to significantly increase cohesiveness values. Also, the yogurt cohesiveness increased with the inclusion of IDF from corn [20]. Conversely, a significant decrease in cohesiveness was noted in yogurt samples with added rice bran [9]. Refrigerated storage led to a slight increase in cohesiveness values for all samples. Notably, samples with psyllium husk had the most remarkable increase. Additionally, refrigerated storage may have contributed to the slight rise in yogurt cohesiveness [68].

Springiness, or elasticity, is a textural parameter that describes the rate at which the sample returns to its original dimensions after a deforming force is removed. The springiness of the yogurt was greatly affected by the addition of bran and fibers as well as refrigerated storage (Table 6). Bran and dietary fibers appeared to have varying effects on springiness values. Oat and barley bran decreased springiness values in fresh samples compared to the control yogurt, although this difference was not statistically significant ($p > 0.05$). Yogurt samples with corn IDF exhibited lower elasticity values compared to the control, but this difference was also not statistically significant ($p > 0.05$) [20]. However, wheat and rice bran as well as dietary fibers, like psyllium husk, significantly increased springiness values. Cellulose fiber significantly increased the springiness of supplemented yogurt [68]. After refrigeration storage, springiness values increased significantly in all samples except the psyllium husk samples, where springiness decreased significantly. The control yogurt had the highest springiness values, followed by yogurt samples with wheat bran, rice bran, rice fiber, wheat dietary fiber, barley bran, and psyllium husk oat bran, respectively.

Gumminess, a textural parameter derived from hardness and cohesiveness, is presented in Table 6 for yogurts containing various brans or dietary fibers. In fresh samples, it was evident that the gumminess of yogurt decreased with the supplementation of different brans or dietary fibers, except for psyllium husk, which significantly increased gumminess values compared to the control yogurt. This trend in gumminess aligned with the reported hardness and cohesiveness values of the yogurt samples. Storage noticeably increased gumminess values for all samples, consistent with

findings in yogurt supplemented with cellulose fiber [68]. By day 12, psyllium husk-containing samples had the highest gumminess values, followed by the control, wheat and rice brans, oat bran, barley bran, wheat dietary fiber, and rice dietary fiber, respectively.

3.2.5 Effect of Brans and Dietary Fibers on the Microstructural Attributes of Yogurt

Scanning electron microscopy (SEM) was utilized to analyze the overall and microstructural characteristics of yogurt samples supplemented with various brans and dietary fibers. During sample preparation for SEM, water (whey) and fat were removed, resulting in spherical voids among casein aggregates and tiny pores in the protein network [69, 70]. As a result, only the protein matrix and bacterial cells could be visualized.

Scanning electron microscopy micrographs showing the microstructure (magnification 5000×) of fresh yogurt samples containing different brans and dietary fibers are presented in Figure 3. The control sample appeared to have a compact structure with a granular and coarse surface, and no whey pockets could be seen within its structure (Figure 3A). The sample showeed a microstructure similar to that of fermented milk, described as a network of casein micelles, which appeared as gray zones in the electron microscopy photo [69]. On the other hand, the yogurt microstructure was remarkably modified by the supplementation of bran and dietary fibers (Figure 3B-3H). The microstructures of yogurt samples with wheat, oat, and barley brans or psyllium husk (Figure 3C-3E, 3H, respectively) could be described as an extended open protein matrix in which large whey pockets were embedded. The largest whey pockets were observed in the sample containing barley bran (Figure 3E), which may explain the lowest firmness values recorded for the sample by the texture profile analyzer. Similar microstructure features were reported for yogurt made with 0.25% and 0.5% pectin [71]. They showed that yogurt containing 0.25% and 0.5% pectin had large voids in the microstructure, showed a plus serum phase in the network, and consequently had a weak structure. In contrast, the addition of IDF from soybean dregs effectively reduced the pore network structure of yogurt [58]. On the other hand, larger microscopic particles (clusters of aggregates) could be seen in yogurt samples containing oat bran (Figure 3D) or wheat dietary fiber (Figure 3F), which could be attributed to the formation of protein clusters either alone or in combination with added bran or fiber. A similar cluster was observed in yogurt samples containing 0.05% pectin or 0.25% to 0.50% insoluble soybean fiber, as previously described by Chen et al. [47], Tian et al. [58], and Wang et al. [71].

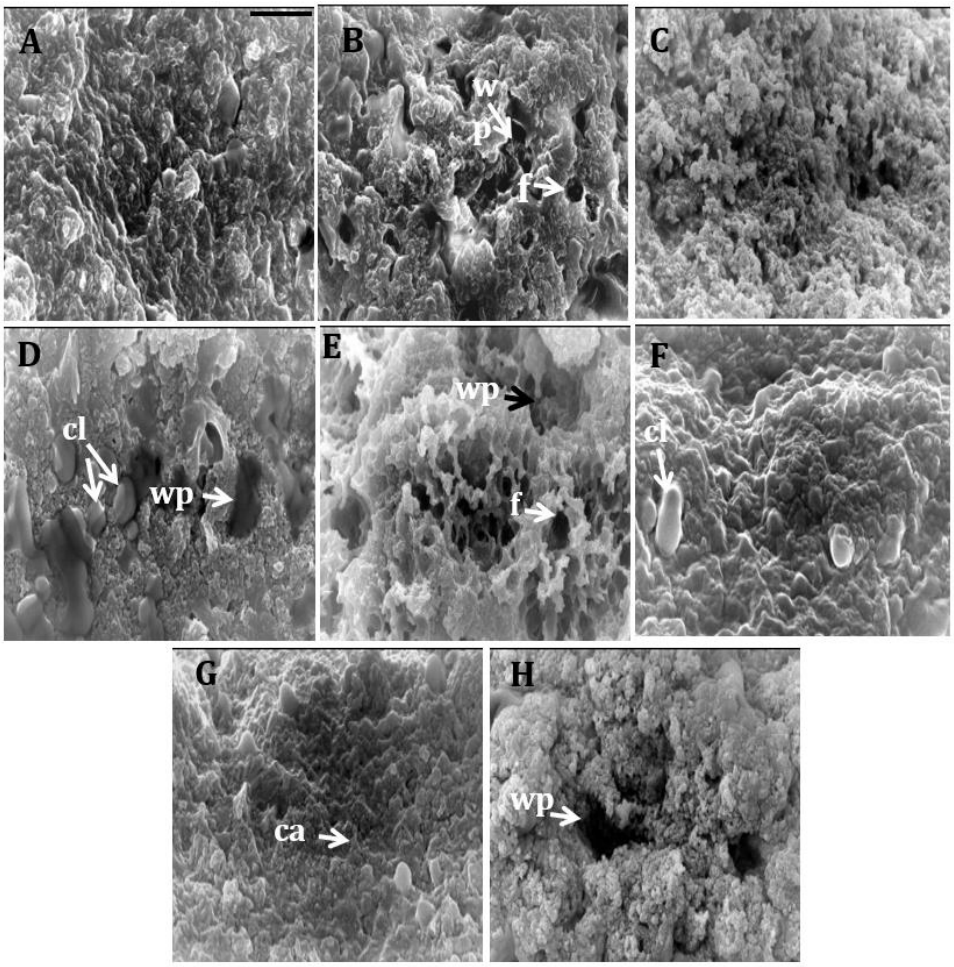


Figure 3 Scanning electron micrographs of the effect of brans and dietary fibers on the microstructure of bio-yogurt. A = control sample. Letters B to H represent yogurts containing wheat bran (B), rice bran (C), oat bran (D), barley bran (E), wheat dietary fiber (F), rice dietary fiber (G), and psyllium husk (H), respectively. Void of fat globule (f), whey pocket (wp), casein matrix (ca), cluster of aggregates (cl). Magnitude 5000×; at 20 kV. Bar = 5 µm.

Yogurt samples containing rice bran or dietary fiber (Figure 3C, 3G, respectively) developed a narrower microstructure compared to samples with wheat, oat, and barley brans or psyllium husk. Yogurt samples supplemented with rice bran showed a similar compact texture [9]. The presence of microscopic aggregates entrapped within the microstructure of the yogurt sample containing rice fiber was also evident, but with less frequency compared to samples containing oat bran or wheat dietary fiber.

3.2.6 Effect of Brans and Dietary Fibers on Sensory Attributes of Yogurt

Sensory and appearance characteristics of yogurt, including color, flavor, odor, and texture, are important criteria that govern overall consumer acceptance and marketing prosperity [5]. The addition of various brans and dietary fibers significantly decreased ratings for color and appearance, body texture, flavor, and overall acceptability of fresh yogurt samples compared to the control yogurt. Among the samples containing brans or dietary fibers, yogurt with barley bran had the

highest flavor score on day 6 of storage. However, wheat dietary fiber had the highest score, surpassing the control sample, on day 12 of storage (Table 7).

Table 7 Sensory evaluation of the bio-yogurt with brans or dietary fibers during cold storage. Data are means ± standard error.

Yogurt treatments	Storage time (days)	Flavor (10 points)	Body and texture (5 points)	Appearance and color (5 points)	Overall acceptability (20 points)
Control	Fresh	9.00 ± 0.38^{a}	4.68 ± 0.14^{a}	4.36 ± 0.20^{ab}	18.05 ± 0.53^{a}
	6	8.15 ± 0.34^{a-e}	4.00 ± 0.19^{a-d}	4.00 ± 0.10^{ab}	16.15 ± 0.53^{a-c}
	12	8.33 ± 0.67^{a-c}	4.25 ± 0.31^{a-c}	4.33 ± 0.21^{ab}	16.92 ± 1.00^{a-c}
Wheat bran	Fresh	7.09 ± 0.49^{b-e}	4.05 ± 0.24^{a-d}	4.00 ± 0.33^{ab}	15.14 ± 0.88^{a-e}
	6	7.07 ± 0.38^{b-e}	4.07 ± 0.14^{a-d}	4.00 ± 0.16^{ab}	15.14 ± 0.57^{a-e}
	12	7.50 ± 0.72^{a-e}	4.67 ± 0.21^{a}	4.75 ± 0.17^{ab}	16.92 ± 1.02^{a-c}
Rice bran	Fresh	6.91 ± 0.43^{b-e}	4.00 ± 0.22^{a-d}	3.59 ± 0.35^{bc}	14.50 ± 0.89^{b-f}
	6	6.77 ± 0.28^{c-e}	3.58 ± 0.31^{c-f}	3.54 ± 0.22^{bc}	13.88 ± 0.65^{c-f}
	12	7.16 ± 1.08^{b-e}	4.50 ± 0.34^{a-c}	4.50 ± 0.22^{ab}	16.17 ± 1.30^{a-c}
Oat bran	Fresh	7.77 ± 0.44^{a-e}	3.86 ± 0.23^{a-e}	4.32 ± 0.27^{a}	15.95 ± 0.69^{a-c}
	6	7.00 ± 0.41^{b-e}	3.66 ± 0.28^{b-f}	4.04 ± 0.23^{ab}	14.71 ± 0.84^{b-f}
	12	7.33 ± 0.61^{a-e}	4.42 ± 0.33^{a-c}	4.67 ± 0.21^{a}	16.42 ± 0.99^{a-c}
Barley bran	Fresh	7.91 ± 0.39^{a-e}	4.23 ± 0.26^{a-c}	4.41 ± 0.28^{ab}	16.55 ± 0.79^{a-c}
	6	8.38 ± 0.40^{a-c}	4.08 ± 0.23^{a-d}	4.19 ± 0.14^{ab}	16.65 ± 0.70^{a-c}
	12	8.17 ± 0.75^{a-d}	4.75 ± 0.17^{a}	4.50 ± 0.22^{ab}	17.42 ± 1.04^{ab}
Wheat dietary fiber	Fresh	8.09 ± 0.62^{a-e}	4.59 ± 0.15^{ab}	4.59 ± 0.20^{a}	17.27 ± 0.74^{ab}
	6	7.85 ± 0.42^{a-e}	3.92 ± 0.21^{a-e}	3.88 ± 0.20^{ab}	15.65 ± 0.76^{a-d}
	12	8.66 ± 0.76^{ab}	4.75 ± 0.17^{a}	4.67 ± 0.21^{a}	18.08 ± 1.07^{a}
Rice dietary fiber	Fresh	6.77 ± 0.52^{c-e}	4.00 ± 0.26^{a-d}	4.09 ± 0.21^{ab}	14.86 ± 0.83^{b-f}
	6	7.15 ± 0.41^{b-e}	3.23 ± 0.23^{d-g}	3.62 ± 0.30^{bc}	14.00 ± 0.73^{c-f}
	12	7.67 ± 0.67^{a-e}	4.42 ± 0.33^{a-c}	4.42 ± 0.33^{ab}	16.50 ± 1.24^{a-c}
Psyllium husk	Fresh	6.50 ± 0.64^{de}	3.09 ± 0.45^{e-g}	2.86 ± 0.44^{cd}	12.45 ± 1.33^{ef}
	6	6.33 ± 0.50^{e}	2.88 ± 0.25^{fg}	2.88 ± 0.33^{cd}	12.08 ± 0.89^{f}
	12	7.83 ± 0.40^{a-e}	2.50 ± 0.41^{g}	2.58 ± 0.45^{d}	12.92 ± 0.99^{d-f}

Superscript letters following numbers in the same column denote significant differences ($p \leq 0.05$).

Except for barley bran, adding different brans and dietary fibers also had a negative impact on the appearance and color of the tested yogurt. In contrast, yogurt samples with 0.5%, 1%, and 1.5% barley bran received lower evaluations in terms of appearance and color compared to the control [22]. Bran- and dietary fiber-supplemented yogurt samples also showed poorer body and texture characteristics, especially in fresh samples. However, by day 12 of storage, samples with various brans or dietary fibers, except those containing psyllium husk, had higher body and texture scores than the control. This suggests that the brans and dietary fibers tested in this study may be suitable for long-term use as body and texture enhancers. Adjusting the amount of bran or fiber used in

yogurt production and adding flavoring agents may help mitigate any negative effects on the sensory quality of the supplemented yogurt. Data from the sensory evaluation of the different yogurts produced in this study indicated that yogurt containing barley bran had the most acceptable sensory characteristics compared to samples made with other brans and dietary fibers.

Our results contribute to previous research on how brans and dietary fibers affect the sensory attributes of yogurt. The addition of barley bran (at levels of 0.3, 0.6, 0.9, and 1.2%) to yogurt was found to have a negative impact on the organoleptic quality of the yogurt samples [72]. Similarly, incorporating rice bran (at levels of 1, 2, and 3%) into set-type yogurt resulted in a decrease in overall acceptance of the final products [43]. Furthermore, supplementing yogurt with 1.5%, 3%, and 4.5% date fiber, from dates as well as 1.5% wheat bran did not improve the sensory ratings or overall acceptance of the yogurts [59]. In contrast, yogurt samples supplemented with 0.5% psyllium husk received the highest acceptability scores compared to the control yogurt [21].

4. Conclusion

Wheat, rice, oat, and barley brans, as well as wheat and rice dietary fibers, along with psyllium husk, have been included in yogurt formulas. Adding brans or dietary fibers significantly decreased syneresis and acidity while increasing viscosity and water-holding capacity compared with control yogurt. Most tested brans reduced the availability of calcium, except yogurt containing barley bran, which increased calcium delivery. The inclusion of dietary fibers also increased calcium absorption. Throughout storage, all samples exhibited a gradual increase in viable numbers of probiotic *Bifidobacterium lactis*. Fresh yogurt with psyllium husk had high hardness, gumminess, and cohesiveness. Samples containing brans or dietary fibers (except barley bran) appeared smoother, more compact, and more homogeneous than the control yogurt. Adding various brans and dietary fibers significantly decreased scores for color and appearance, body texture, flavor, and overall acceptance of fresh yogurt. Notably, yogurt with barley bran received the highest flavor score on day 6 of storage. This study offers valuable insights for the Egyptian market on incorporating local brans or dietary fibers into yogurt production to create functional yogurt supplemented with health-promoting ingredients.

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Author Contributions

Hamedy S: Methodology (equal), and formal analysis (equal). Kheadr E: conceptualization (equal), formal analysis (equal), investigation (lead), methodology (lead), project administration (lead), validation (lead), and writing-review & editing (equal). El-Ziney M: formal analysis (equal), and conducting a research and investigation process. Shoukry E: formal analysis (equal); Methodology (equal), and conducting a research and investigation process. Elsaadany K: Data curation management activities to produce the data scrub and maintain the research data for use. Dabour N: conceptualization (equal), writing-original draft (lead), data analysis (lead), and writing-review & editing (equal).

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AI-Assisted Technologies Statement

The authors used AI programs for improving the text quality and proofreading programs such as Free Online Proofreader (https://www.scribbr.com/proofreading-editing/online-proofreader/). All scientific content, data interpretation, and conclusions were developed independently by the author. The authors have thoroughly reviewed and edited the AI-assisted text to ensure its accuracy and accept full responsibility for the content of the manuscript.

References

1. Leading Market Research. Yogurt (Dairy & Soy Food) Market in Egypt - Outlook to 2022: Market Size, Growth and Forecast Analytics [Internet]. Paris, France: Leading Market Research; 2022. Available from: https://www.leadingmarketresearch.com/yogurt-dairy-and-soy-food-market-in-egypt-outlook-to-2022-market-siz.
2. Rashwan AK, Osman AI, Chen W. Natural nutraceuticals for enhancing yogurt properties: A review. Environ Chem Lett. 2023; 21: 1907-1931.
3. Britos S, González AF, Flax Marcó F, Katz M, Schuldberg J, Torresani ME, et al. Yogurt, in the context of a healthy diet, for the prevention and management of diabetes and obesity: A perspective from Argentina. Front Nutr. 2024; 11: 1373551.
4. Mohammed O, Dyab N, Kheadr E, Dabour N. Effectiveness of inulin-type on the iron bioavailability in anemic female rats fed bio-yogurt. RSC Adv. 2021; 11: 1928-1938.
5. Huang K, Liu Y, Zhang Y, Cao H, Luo DK, Yi C, et al. Formulation of plant-based yoghurt from soybean and quinoa and evaluation of physicochemical, rheological, sensory and functional properties. Food Biosci. 2022; 49: 101831.
6. Liu L, Jiang S, Xie W, Xu J, Zhao Y, Zeng M. Fortification of yogurt with oyster hydrolysate and evaluation of its *in vitro* digestive characteristics and anti-inflammatory activity. Food Biosci. 2022; 47: 101472.
7. Shori AB. Storage quality and antioxidant properties of yogurt fortified with polyphenol extract from nutmeg, black pepper, and white pepper. Electron J Biotechnol. 2022; 57: 24-30.
8. Tang PL, Cham XY, Hou X, Deng J. Potential use of waste cinnamon leaves in stirred yogurt fortification. Food Biosci. 2022; 48: 101838.
9. Wu T, Deng C, Luo S, Liu C, Hu X. Effect of rice bran on properties of yogurt: Comparison between addition of bran before fermentation and after fermentation. Food Hydrocoll. 2023; 135: 108122.

10. Zafar U, Hameed A, Amjad A, Javed MS, Afzal MI, Umer M, et al. Potential of barley enriched yogurt to improve probiotic growth for the management of hypercholesterolemia. Int J Food Prop. 2023; 26: 1177-1189.
11. Food and Agriculture Organization. World Food Situation [Internet]. Rome, Italy: FAO; 2026. Available from: https://www.fao.org/worldfoodsituation/csdb/en/.
12. American Association of Cereal Chemists. The Definition of Dietary Fiber. St. Paul, MN: AACC; 2001; no. W-2001-0222-01O. Available from: https://www.cerealsgrains.org/resources/definitions/Documents/DietaryFiber/DFDef.pdf.
13. Fardet A. New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre? Nutr Res Rev. 2010; 23: 65-134.
14. Lattimer JM, Haub MD. Effects of dietary fiber and its components on metabolic health. Nutrients. 2010; 2: 1266-1289.
15. Šeregelj V, Pezo L, Šovljanski O, Lević S, Nedović V, Markov S, et al. New concept of fortified yogurt formulation with encapsulated carrot waste extract. LWT. 2021; 138: 110732.
16. Dabour N, Elsaadany K, Shoukry E, Hamdy S, Taïbi A, Kheadr E. The ability of yoghurt supplemented with dietary fibers or brans extracted from wheat or rice to reduce serum lipids and enhance liver function in male hypercholesterolemic rats. J Food Biochem. 2022; 46: e14499.
17. Sarfraz F, Farooq U, Shafi A, Hayat Z, Akram K, Rehman HU. Hypolipidaemic effects of synbiotic yoghurt in rabbits. Int J Dairy Technol. 2019; 72: 545-550.
18. Putri I, Haskito A, Permana D. Effect of goat milk yogurt fortified with red rice bran flour on SGPT levels of rats (*Rattus norvegicus*) model diabetes mellitus induced streptozotocin. J Phys Conf Ser. 2020; 1430: 012008.
19. Dabour N, Dyab N, Kheadr E. Iron fortification of reduced-fat bioyoghurt containing either short-or long-chain inulin. Int J Dairy Technol. 2019; 72: 229-239.
20. Song Z, Dai H, Bo L, Song C, Liu X, Ren J. Set yogurt incorporated with insoluble dietary fiber maintains non-sedimentation: Combined alkaline hydrogen peroxide modification and high-pressure homogenization process. LWT. 2024; 206: 116617.
21. Bhat SV, Deva AM, Amin T. Physicochemical and textural properties of yogurt fortified with psyllium (*Plantago ovate*) husk. J Food Process Preserv. 2018; 42: e13425.
22. Amjad A, Javed MS, Hameed A, Khan AA, Amjad MR, Ali SA, et al. Improving the probiotics viability and quality characteristics of yoghurt enriched with barley bran. Int J Innov Approach Agric Res. 2021; 5: 362-380.
23. Dabija A, Codină GG, Gâtlan AM, Rusu L. Quality assessment of yogurt enriched with different types of fibers. CyTA J Food. 2018; 16: 859-867.
24. Tolve R, Zanoni M, Ferrentino G, Gonzalez-Ortega R, Sportiello L, Scampicchio M, et al. Dietary fibers effects on physical, thermal, and sensory properties of low-fat ice cream. LWT. 2024; 199: 116094.
25. Eng HY, Mohd Rozalli NH. Rice bran and its constituents: Introduction and potential food uses. Int J Food Sci Technol. 2022; 57: 4041-4051.
26. Association of Official Analysis Chemists. Official methods of analysis of the AOAC. 15th ed. Washington, D.C.: AOAC; 1990.
27. Van Soest Pv, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci. 1991; 74: 3583-3597.

28. Olugbuyiro JA, Oseh JE. Physico-chemical and sensory evaluation of market yoghurt in Nigeria. Pak J Nutr. 2011; 10: 914-918.
29. Nilsson L, Lyck S, Tamime A. Production of drinking products. In: Fermented Milks. Oxford, UK: Blackwell Science; 2006. pp. 95-127.
30. Tarakçı Z, Küçüköner E. Physical, chemical, microbiological and sensory characteristics of some fruit-flavored yoghurt. YYÜ Vet Fak Derg. 2003; 14: 10-14.
31. Seçkin AK, Baladura E. Effect of using some dietary fibers on color, texture and sensory properties of strained yogurt. GIDA. 2012; 37: 63-69.
32. The United States Pharmacopeial Convention. USP pharmacists' pharmacopeia. Rockville, MD: The United States Pharmacopeial Convention; 2009.
33. International Dairy Federation. IDF 122:2001(E). Milk and milk products—General guidance for the preparation of test samples, initial suspensions and decimal dilutions for microbiological examination [Internet]. ISO Standard; 2002. Available from: https://cdn.standards.iteh.ai/samples/27062/0c0f5617e36e456ea69119d180b51eef/ISO-8261-2001.pdf.
34. Kleessen B, Sykura B, Zunft HJ, Blaut M. Effects of inulin and lactose on fecal microflora, microbial activity, and bowel habit in elderly constipated persons. Am J Clin Nutr. 1997; 65: 1397-1402.
35. Tharmaraj N, Shah N. Selective enumeration of *Lactobacillus delbrueckii* ssp. *bulgaricus*, *Streptococcus thermophilus*, *Lactobacillus acidophilus*, bifidobacteria, *Lactobacillus casei*, *Lactobacillus rhamnosus*, and propionibacteria. J Dairy Sci. 2003; 86: 2288-2296.
36. Bourne MC. Texture profile analysis. Food Technol. 1978; 32: 62-66.
37. Brooker BE, Wells K. Preparation of dairy products for scanning electron microscopy: Etching of epoxy resin-embedded material. J Dairy Res. 1984; 51: 605-613.
38. Askary N, Bolandi M. Assessment of iron fortiifiicatiion inflluence on organolleptiics and physiico-chemiicall propertiies of yogurt. J Chem Health Risks. 2013; 3: 1-8.
39. Duncan DB. Multiple range and multiple F tests. Biometrics. 1955; 11: 1-42.
40. Choi YS, Choi JH, Han DJ, Kim HY, Lee MA, Kim HW, et al. Effects of rice bran fiber on heat-induced gel prepared with pork salt-soluble meat proteins in model system. Meat Sci. 2011; 88: 59-66.
41. Claye SS, Idouraine A, Weber CW. Extraction and fractionation of insoluble fiber from five fiber sources. Food Chem. 1996; 57: 305-310.
42. Ghodrat A, Yaghobfar A, Ebrahimnezhad Y, Aghdam Shahryar H, Ghorbani A. *In vitro* binding capacity of organic (wheat bran and rice bran) and inorganic (perlite) sources for Mn, Zn, Cu, and Fe. J Appl Anim Res. 2017; 45: 80-84.
43. Demirci T, Aktaş K, Sözeri D, Öztürk Hİ, Akın N. Rice bran improve probiotic viability in yoghurt and provide added antioxidative benefits. J Funct Foods. 2017; 36: 396-403.
44. Sakr HS. A study on supplementation of non-fat yoghurt with psyllium. J Food Dairy Sci. 2019; 10: 303-308.
45. Ramirez-Santiago C, Ramos-Solis L, Lobato-Calleros C, Peña-Valdivia C, Vernon-Carter E, Alvarez-Ramírez J. Enrichment of stirred yogurt with soluble dietary fiber from *Pachyrhizus erosus* L. Urban: Effect on syneresis, microstructure and rheological properties. J Food Eng. 2010; 101: 229-235.

46. Lucey JA. Cultured dairy products: An overview of their gelation and texture properties. Int J Dairy Technol. 2004; 57: 77-84.
47. Chen B, Zhao X, Cai Y, Jing X, Zhao M, Zhao Q, et al. Incorporation of modified okara-derived insoluble soybean fiber into set-type yogurt: Structural architecture, rheological properties and moisture stability. Food Hydrocoll. 2023; 137: 108413.
48. El-Said MM, Haggag H, El-Din HMF, Gad A, Farahat AM. Antioxidant activities and physical properties of stirred yoghurt fortified with pomegranate peel extracts. Ann Agric Sci. 2014; 59: 207-212.
49. Arab M, Yousefi M, Khanniri E, Azari M, Ghasemzadeh-Mohammadi V, Mollakhalili-Meybodi N. A comprehensive review on yogurt syneresis: Effect of processing conditions and added additives. J Food Sci Technol. 2023; 60: 1656-1665.
50. Zare F, Boye J, Orsat V, Champagne C, Simpson B. Microbial, physical and sensory properties of yogurt supplemented with lentil flour. Food Res Int. 2011; 44: 2482-2488.
51. Dai FJ, Chau CF. Classification and regulatory perspectives of dietary fiber. J Food Drug Anal. 2017; 25: 37-42.
52. Ozcan T, Kurtuldu O. Influence of dietary fiber addition on the properties of probiotic yogurt. Int J Chem Eng Appl. 2014; 5: 397-401.
53. Anuyahong T, Chusak C, Thilavech T, Adisakwattana S. Postprandial effect of yogurt enriched with anthocyanins from riceberry rice on glycemic response and antioxidant capacity in healthy adults. Nutrients. 2020; 12: 2930.
54. Raju PN, Pal D. Effect of dietary fibers on physico-chemical, sensory and textural properties of *Misti Dahi*. J Food Sci Technol. 2014; 51: 3124-3133.
55. Guven M, Yasar K, Karaca O, Hayaloglu A. The effect of inulin as a fat replacer on the quality of set-type low-fat yogurt manufacture. Int J Dairy Technol. 2005; 58: 180-184.
56. Aryana KJ. Probiotic, fibre fortified, fat free plain set yoghurt. Milchwissenschaft. 2006; 61: 312-315.
57. Bong D, Moraru C. Use of micellar casein concentrate for Greek-style yogurt manufacturing: Effects on processing and product properties. J Dairy Sci. 2014; 97: 1259-1269.
58. Tian Y, Sheng Y, Wu T, Wang C. Effect of modified okara insoluble dietary fibre on the quality of yoghurt. Food Chem X. 2024; 21: 101064.
59. Hashim IÁ, Khalil A, Afifi H. Quality characteristics and consumer acceptance of yogurt fortified with date fiber. J Dairy Sci. 2009; 92: 5403-5407.
60. Sanz T, Salvador A, Jimenez A, Fiszman S. Yogurt enrichment with functional asparagus fibre. Effect of fibre extraction method on rheological properties, colour, and sensory acceptance. Eur Food Res Technol. 2008; 227: 1515-1521.
61. Rani KS, Srividya N. Effect of inulin, fructooligosaccharides and *L. acidophilus* in formulating a synbiotic yoghurt. Asian J Dairy Food Res. 2016; 35: 37-40.
62. Bosscher PD, Van Cauwenbergh R, Deelstra PH. Availabilities of calcium, iron, and zinc from dairy infant formulas is affected by soluble dietary fibers and modified starch fractions. Nutrition. 2003; 19: 641-645.
63. Dongowski G, Ehwald R. Properties of dietary preparations of the cellan-type. In: Proceeding of the PROFIBRE Symposium, Functional properties of non-digestible carbohydrates. Nantes, France: Imprimerie Parentheses; 1998. pp. 52-54.

64. Asadzadeh A, Jalali H, Azizi MH, Mohammadi Nafchi A. Production of oat bran functional probiotic beverage using *Bifidobacterium lactis*. J Food Measure Charact. 2021; 15: 1301-1309.
65. Wijesekara A, Weerasingha V, Jayarathna S, Priyashantha H. Quality parameters of natural phenolics and its impact on physicochemical, microbiological, and sensory quality attributes of probiotic stirred yogurt during the storage. Food Chem X. 2022; 14: 100332.
66. Prasanna P, Grandison A, Charalampopoulos D. Microbiological, chemical and rheological properties of low fat set yoghurt produced with exopolysaccharide (EPS) producing *Bifidobacterium* strains. Food Res Int. 2013; 51: 15-22.
67. Akın MB. Some properties of bio-yogurt enriched with cellulose fiber. Adv Microbiol. 2018; 8: 54-64.
68. Mudgil D, Barak S, Khatkar B. Texture profile analysis of yogurt as influenced by partially hydrolyzed guar gum and process variables. J Food Sci Technol. 2017; 54: 3810-3817.
69. Gilbert A, Turgeon SL. Studying stirred yogurt microstructure and its correlation to physical properties: A review. Food Hydrocoll. 2021; 121: 106970.
70. Wang L, Wu T, Zhang Y, Yang K, He Y, Deng K, et al. Comparative studies on the nutritional and physicochemical properties of yoghurts from cows', goats', and camels' milk powder. Int Dairy J. 2023; 138: 105542.
71. Wang H, Wang C, Wang M, Guo M. Chemical, physiochemical, and microstructural properties, and probiotic survivability of fermented goat milk using polymerized whey protein and starter culture Kefir Mild 01. J Food Sci. 2017; 82: 2650-2658.
72. Hasani S, Sari AA, Heshmati A, Karami M. Physicochemical and sensory attributes assessment of functional low-fat yogurt produced by incorporation of barley bran and *Lactobacillus acidophilus*. Food Sci Nutr. 2017; 5: 875-880.