

Article

Influence of Guar Gum and Xanthan Gum on the Rheological Behavior, Texture, and Microstructure of Probiotic Low-Fat Yogurt

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Abstract

The aim of this study was to investigate the effects of the addition of guar gum (GG) and xanthan gum (XG) on the proximate composition, texture, viscosity, syneresis, color characteristics, microbiological stability, sensory evaluation, rheological properties, and microstructure of a low-fat yogurt sample. The results showed that adding GG and XG at concentrations of 0.5 and 1% increased the hardness and viscosity of yogurt significantly ($p < 0.05$), with XG having a more pronounced effect. There was no significant difference ($p > 0.05$) in color characteristics between all treatments during the storage period. The viability of probiotics was enhanced in gum-supplemented yogurts, with XG providing better protection for *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Bifidobacterium bifidum* during storage. Sensory evaluation results showed that XG samples gained higher scores as compared to GG samples. Rheological analysis revealed that both the hydrocolloids guar gum (GG) and xanthan gum (XG) significantly increased the parameters such as viscosity and yield stress of low-fat yogurt, with xanthan gum having a more pronounced effect on enhancing the flow behavior. Microstructural analysis using scanning electron microscopy revealed that XG supplementation improved the yogurt gel network, developing a more compact and cohesive structure; however, GG produced a looser and more dispersed network. Overall, both GG and XG enhanced the rheological, textural, and microstructural characteristics of low-fat yogurt, with XG showing superior effects on texture, gel structure, and probiotic stability.

Keywords: low-fat yogurt; guar gum; xanthan gum; rheology; viscosity; microstructure



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1. Introduction

The global dairy industry has experienced significant growth and innovation, with yogurt emerging as a key player in the functional food market [1]. As health-conscious consumers increasingly seek low-fat dairy products that maintain nutritional benefits and sensory appeal, manufacturers face challenges in texture, stability, and overall quality when reducing fat content in yogurt [2].

In this context, the use of hydrocolloids, particularly Guar gum (GG) and Xanthan gum (XG), has gained attention as a potential strategy to enhance the quality and other physicochemical properties of low-fat yogurt [3]. These natural polysaccharides are known for their ability to modify texture, increase viscosity, and enhance water-holding capacity in various food systems [4]. The incorporation of such additives in low-fat yogurt formulations presents an opportunity to address the textural and stability issues often associated with fat reduction, while potentially offering additional functional benefits [5]. Yogurt, a cultured or fermented dairy product, has been consumed for centuries and has always gained attention for its nutritional value and attainable health benefits [6]. Rich in high-quality proteins, calcium, and various essential nutrients, yogurt plays an important role in supporting bone strength, digestive function, and overall well-being. The fermentation process involved in yogurt production not only enhances its digestibility but also introduces beneficial probiotic bacteria, which have been associated with improved gut health and immune function.

With the increasing prevalence of obesity and related health concerns, there has been a shift in consumer preferences towards low-fat dairy options [7]. Low-fat yogurt has emerged as a popular choice for those seeking to reduce calorie intake while still enjoying the nutritional benefits of dairy products [8]. However, the reduction of fat content in yogurt often results in decreased viscosity, increased syneresis (whey separation), and altered texture, which can negatively impact consumer acceptance [9]. To address the challenges associated with fat reduction in yogurt, food scientists and manufacturers have turned to hydrocolloids as potential texture modifiers and stabilizers [10]. Guar gum and xanthan gum, in particular, have shown promise in improving the rheological behavior and stability of yogurt containing low-fat.

Guar gum, obtained from the seeds of the plant *Cyamopsis tetragonoloba*, is a galactomannan polysaccharide known for its good water-binding capacity and thickening properties [11]. In yogurt production, GG has been found to enhance viscosity, reduce syneresis, and improve texture [12]. Xanthan gum, produced by the bacterium *Xanthomonas campestris*, is a heteropolysaccharide with higher stability across different pH and temperature conditions [13]. XG has demonstrated the ability to form strong networks with milk proteins, contributing to increased viscosity and improved stability in dairy products [14].

While previous studies have explored the effects of various hydrocolloids on yogurt properties, there is a need for more comprehensive research examining the long-term impact of GG and XG on low-fat yogurt quality during storage. Understanding how these additives influence physicochemical, textural, and microbiological characteristics over time is crucial for developing stable and high-quality low-fat yogurt products with extended shelf life. The current study aims to investigate the influences of guar gum and xanthan gum addition on the quality and stability of low-fat yogurt over the storage period of 21 days. By investigating various concentrations of these hydrocolloids and their impact on properties such as texture, viscosity, syneresis, and microbial viability, this research seeks to provide valuable insights for the dairy industry.

2. Materials and Methods

2.1. Overall Experimental Design

The current study used a randomized design to examine how adding Guar Gum (GG) and xanthan Gum (XG) affects the quality and properties of low-fat yogurt during 21 days of storage at a temperature of 4 °C. Yogurt samples were divided into a control group, which does not contain any gums, and four treatment groups: Y1 containing 0.5% GG, Y2 with 1% GG, Y3 with 0.5% XG, and Y4 with 1.0% XG. The samples were analyzed at four time points: day 0, 7, 14, and 21 to observe how different concentrations of these gums and storage duration impact yogurt quality, including texture and stability. The objective

was to evaluate the impact of GG and XG on the low-fat yogurt properties during storage or shelf life.

2.2. Low-Fat Yoghurt Manufacturing

Figure 1 shows a schematic of an industrial yogurt manufacturing process. Low-fat yogurt was produced following the method described by [15], with some modifications. Fresh cow milk, sourced from a Farm present in the Faculty of Agriculture, Assiut University, Egypt, was then separated at a temperature of 4 °C to obtain skimmed milk. The skimmed milk was then pasteurized by heating to 95 ± 2 °C for 16 s, and subsequently cooling to 40 ± 1 °C. For studying the impact of different parameters, milk was divided into five treatment groups, as detailed in Table 1, with different ratios of gums added to the skimmed milk. Guar Gum and Xanthan Gum were procured from Loba Chemiel, Mumbai, India, of commercial food-grade quality. A combination of multiple organisms of starter culture, consisting of *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Bifidobacterium bifidum* (from the Egyptian Microbial Culture Collection: EMCC, Cairo MIRCEN, Faculty of Agriculture, Ain Shams University, Cairo, Egypt) in a 1:1:1 ratio, was incorporated at 2% (v/v). The yogurt mixtures were incubated at 40 ± 2 °C for around 3–4 h until obtaining a pH 4.6, after which they were stored at a temperature of 4 ± 2 °C for 21 days.

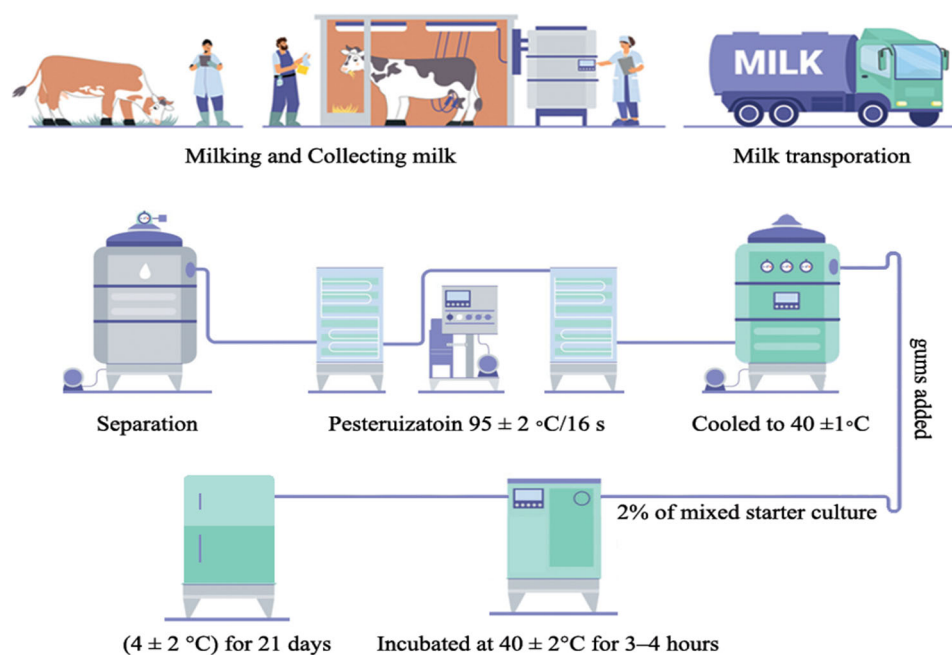


Figure 1. Schematic of a Yogurt manufacturing process.

Table 1. Gum Addition Levels in Low-Fat Yoghurt Manufacturing.

Treatments	GG %	XG %
Control	-	-
Y1	0.5	-
Y2	1	-
Y3	-	0.5
Y4	-	1

2.3. Proximate Composition

The chemicals used for the experiments were obtained from BDH (Mumbai, India), Sigma (New Delhi, India), and Prolab Chemicals (Mumbai, India). In the yogurt samples,

pH measurement was done using a digital pH meter, following the procedure described by AOAC [16]. Parameters, Total protein (TP), total solids (TS), and ash content were analyzed in the yogurt (LFY) samples. The Total Solids (TS) content was measured using a forced-draft oven, following AOAC [17]. Ash content was determined using a muffle furnace set at 550 °C, according to the method outlined by Ling [18]. TP was analyzed with the Kjeldahl method [17] with a conversion factor of 6.38. The chemical composition of the yogurt was monitored at four intervals during storage: 0 days, 7 days, 14 days, and 21 days.

2.4. Textural Analysis

The hardness of the yogurt samples was measured employing a texture analyzer (Stable Micro Systems, Godalming, Surrey, UK) equipped with a back-extrusion plate probe (Probe P-75, 75 mm diameter), as described by Gharibzadeh et al., 2014 [19]. The texture analyzer was operated using Texture Exponent 32 software. The samples were compressed within their containers at a test speed of 0.5 mm/s, with a holding time of 2 s and a data acquisition rate of 200 cps. The parameters assessed included firmness, consistency, cohesiveness, and adhesiveness, offering a detailed textural profile. Measurements were taken at 0, 7, 14, and 21 days of storage.

2.5. Viscosity Determination

A Brookfield LVDVE-230 viscometer (Cole-Parmer Scientific Experts, East Bunker Ct, Vernon Hills, IL, USA) was used to analyze the viscosity of the yogurt samples. The samples were stirred for 40 s prior to performing the analysis. The viscosity was measured at 15 ± 1 °C using spindle number 4 at a speed of 10 rpm, and the results were recorded in centipoise (CPS) units. Viscosity measurements were performed at four time points: 0, 7, 14, and 21 days of storage.

2.6. Syneresis

Yogurt samples were evaluated for syneresis using the method described by Keogh et al., 1998 [20]. To measure, a 30 g of yogurt (LFY) sample was centrifuged at $230 \times g$ for 15 min at 4 °C using a ST Plus series centrifuge (Thermo Fisher, Bremen, Germany). The clear supernatant obtained after centrifugation was weighed and expressed as a percentage of syneresis of the yogurt sample taken. Measurements were taken at four intervals: 0, 7, 14, and 21 days throughout the storage.

2.7. Color Characteristics

The color of the low-fat yogurt (LFY) samples was assessed following the method described by Guler [21] using a Hunter colorimeter with an optical sensor (Momcolor Inc., Columbus, OH, USA), based on the CIE L^* , a^* , and b^* color space. The L^* value indicates lightness, ranging from 0 (black) to 100 (white). The a^* value represents the red-green spectrum, with positive and negative values indicating the degree of redness and greenness, respectively. The b^* value corresponds to the yellow-blue spectrum, with positive and negative values indicating the degree of yellowness and blueness, respectively.

2.8. Microbiological Analysis

One gram of low-fat yogurt (LFY) samples was weighed and transferred to a sterilized jar under aseptic conditions. Then, 9 mL of sterile phosphate buffer was dispensed, and the mixture was properly mixed to prepare a 1:10 dilution, which was used for preparing subsequent dilutions [22]. The total bacterial count (TBC) was determined by plating in duplicate on nutrient agar medium and enumerating colonies using the standard plate count technique [22]. The plates were incubated at 32 °C for 48–72 h before microbial

enumeration. Counts of *Lactobacillus delbrueckii* subsp. *bulgaricus* were determined using MRS agar medium [23], with plates incubated at 37 °C for 48 h under anaerobic conditions. Counts of *Streptococcus thermophilus* were enumerated using M17 agar medium [21]. For *Bifidobacterium bifidum* counts, modified MRS agar medium (m-MRS), supplemented containing 0.05% L-cysteine HCl and 0.3% lithium chloride, was used according to Brewer et al. [24], with these plates also incubated at 37 °C for 48 h anaerobically. Small white colonies were counted as colony-forming units (CFU). Microbiological analyses of LFY samples from different treatments were performed at the intervals: 0, 7, 14, and 21 days of storage.

2.9. Sensory Evaluation

The sensory characteristics of the low-fat yogurt (LFY) samples were assessed by a panel of 10–15 trained panelists from the Dairy Science Department at Assiut University. The evaluation was done following the method described by Hamdy et al. [25], with some modifications. The samples were rated on color and appearance (15 points), flavor (50 points), and body and texture (35 points), for a total of 100 points. The organoleptic characteristics were evaluated weekly when the samples were fresh, and subsequently at 14 and 21 days of storage.

2.10. Rheological Characteristics

The rheological properties of the LFY samples were evaluated using an Anton Paar rheometer (Anton Paar, Graz, Austria) equipped with a cylinder cup (inner diameter 42.01 mm) and a bob (outer diameter 38.69 mm, effective length 60.02 mm, active length 143.8 mm, and positioning length 72.50 mm), following the method of [26] with modifications. The measured samples, 60 mL, were maintained at 25 °C prior to testing. The storage modulus (G'), representing the elastic or 'solid-like' behavior, and the loss modulus (G''), reflecting the viscous or 'liquid-like' behavior, were evaluated at 25 °C. The analyses were conducted at an applied shear strain of 0.5%, over an angular frequency range from 0 to 115 rad/s, with data collected at 5 rad/s intervals. The viscosity (mPa·s) of LFY samples was measured employing the same equipment, applying a shear stress ranging from 1 to 1000 (1/s) at a shear rate of 10 per 3 s. Rheological characteristics were assessed only on freshly prepared samples.

2.11. Microstructure

The morphology of yogurt samples after 24 h of storage at 4 °C was analyzed following the procedure outlined by [27]. The yogurt samples were freeze-dried for 32 h under a pressure of 0.2 millibar using a freeze dryer (Beta 2–8 LD, CHRIST Co., Ltd., Hagen, Germany), with liquid nitrogen. The freeze-dried samples were mounted onto aluminum stubs and coated with a gold layer. Scanning electron microscopy (SEM) observations were conducted using a JSM-6390LV model (NTC, Tokyo, Japan) at a magnification of X3000 (5 µm) and an accelerating voltage of 15 kV.

2.12. Statistical Analysis

All data from the studies were analyzed using Costat 6.303 software [28]. A one-way analysis of variance (ANOVA) was conducted for each variable using a general linear model (GLM) to assess the effects of treatments and storage time on the characteristics of low-fat yogurt (LFY) made with different gums. When significant differences were detected at $p \leq 0.05$, mean separation was performed using the least significant difference (LSD) test.

3. Results and Discussion

3.1. Proximate Composition

The results presented in Table 2 demonstrated the influence of gum supplementation and time of storage on the physicochemical properties of low-fat yogurt samples. Over the 21-day storage period at 4 °C, all yogurt samples exhibited a significant decrease in pH ($p < 0.05$), which is consistent with post-acidification commonly observed during yogurt storage [29]. This pH reduction is likely due to the continued production of lactic acid by starter cultures, particularly *Lactobacillus delbrueckii* subsp. *bulgaricus* [30].

Table 2. Proximate Chemical Composition (n = 3) of Low-Fat Yoghurt Samples Supplemented with Various Gums at Different Ratios Through 21 Days of Storage at 4 °C.

Treatments ¹	Storage ²	pH	TS%	Ash%	Protein%
Control	0	4.60 ± 0.01	11.30 ± 0.05	0.79 ± 0.00	4.54 ± 0.20
	7	4.44 ± 0.03	11.29 ± 0.04	0.76 ± 0.00	4.23 ± 0.08
	14	4.40 ± 0.01	11.32 ± 0.06	0.82 ± 0.00	4.47 ± 0.14
	21	4.03 ± 0.01	11.28 ± 0.05	0.78 ± 0.00	4.54 ± 0.11
Y1	0	4.60 ± 0.01	11.35 ± 0.04	0.87 ± 0.00	4.95 ± 0.01
	7	4.42 ± 0.01	11.33 ± 0.06	0.84 ± 0.00	4.93 ± 0.02
	14	4.30 ± 0.01	11.31 ± 0.05	0.83 ± 0.00	4.88 ± 0.01
	21	3.90 ± 0.01	11.34 ± 0.04	0.88 ± 0.00	4.94 ± 0.01
Y2	0	4.60 ± 0.02	11.38 ± 0.05	0.93 ± 0.00	5.20 ± 0.01
	7	4.39 ± 0.01	11.37 ± 0.04	0.91 ± 0.00	5.14 ± 0.01
	14	4.23 ± 0.01	11.36 ± 0.05	0.94 ± 0.00	5.13 ± 0.01
	21	3.54 ± 0.02	11.34 ± 0.05	0.92 ± 0.00	5.28 ± 0.01
Y3	0	4.60 ± 0.01	11.40 ± 0.05	0.96 ± 0.01	4.56 ± 0.06
	7	4.36 ± 0.01	11.38 ± 0.04	0.98 ± 0.02	4.62 ± 0.10
	14	4.13 ± 0.01	11.36 ± 0.06	0.93 ± 0.00	4.58 ± 0.01
	21	3.37 ± 0.01	11.35 ± 0.05	0.96 ± 0.00	4.61 ± 0.01
Y4	0	4.60 ± 0.02	11.30 ± 0.05	1.08 ± 0.02	4.81 ± 0.10
	7	4.20 ± 0.01	11.29 ± 0.04	1.10 ± 0.10	4.79 ± 0.00
	14	3.60 ± 0.01	11.32 ± 0.06	1.06 ± 0.01	4.84 ± 0.00
	21	3.03 ± 0.01	11.28 ± 0.05	1.10 ± 0.02	4.80 ± 0.00
Treatments		(<0.05) *	NS	(<0.05) *	(<0.05) *
Storage		(<0.05) *	NS	NS	NS
(Treatments × Storage)		(<0.05) *	NS	NS	NS

¹ Treatments: control sample (low-fat yoghurt made without the addition of Gum), Y1 = (low-fat yoghurt made with the addition of 0.50% GG), Y2 = (low-fat yoghurt made with the addition of 1% GG), Y3 = (low-fat yoghurt made with the addition of 0.50% XG), and Y4 = (low-fat yoghurt made with the addition of 1% XG). ² Storage: 0, 7, 14, and 21 of storage at 4 °C. NS = non-significant. (*) = Significant.

The total solids content (TS%) remained relatively stable across all treatments and storage times, indicating that the gum additions did not significantly affect moisture retention. Ash content showed slight increases in samples with higher gum concentrations, especially those containing xanthan gum (Y3 and Y4), suggesting that the gums may contribute to mineral content.

Protein content varied among treatments, with Y2 (1% guar gum) consistently showing the highest levels. This could be due to that guar contains higher protein content as compared to xanthan gum [31]. Interestingly, protein content remained relatively stable throughout storage for all samples, which differs from some studies that have reported protein degradation during yogurt storage [32]. The stability of protein content may be attributed to the protective effects of the added gums.

The statistical analysis revealed significant effects of gum treatments on pH, ash, and protein content ($p < 0.05$), while storage time significantly affected only pH. These results suggest that the addition of gums, particularly xanthan gum at higher concentrations, may accelerate acid production during storage. This could potentially impact the shelf life and sensory properties of low-fat yogurt, as increased acidity can affect texture and flavor [33]. The stability of other parameters during storage indicates that the gums may help maintain the physicochemical properties of low-fat yogurt over time, which is desirable for product quality and consumer acceptance.

3.2. Hardness

The results presented in Table 3 show the effects of gum supplementation and storage time on the hardness of low-fat yogurt samples. Over the 21-day storage period at 4 °C, all yogurt samples exhibited a decrease in hardness, which is consistent with the weakening of the protein network structure during storage [34]. However, the samples containing gums (Y1–Y4) showed higher initial hardness values and maintained greater firmness throughout storage compared to the control. This effect was more pronounced with increasing gum concentration and was particularly evident in samples containing xanthan gum (Y3 and Y4).

The observed increase in hardness with gum addition can be attributed to the water-binding and gel-forming properties of these hydrocolloids, which contribute to a more stable and firmer yogurt structure [35]. Xanthan gum, in particular, demonstrated a superior ability to enhance yogurt firmness, likely due to its strong interaction with milk proteins and its ability to form a more rigid network [15].

Table 3. Physical and Color Characteristics ($n = 3$) of Low-Fat Yoghurt Samples Supplemented with Various Gums at Different Ratios Through 21 Days of Storage at 4 °C.

Treatments ¹	Storage ²	Hardness (g)	Viscosity (cp)	Syneresis%	L*	b*	a*
Control	0	0.66 ± 0.03	1659.80 ± 3.05	38.50 ± 0.45	62.78 ± 0.30	22.35 ± 0.32	12.40 ± 0.26
	7	0.61 ± 0.07	1690.21 ± 2.07	40.50 ± 0.10	63.10 ± 0.07	22.45 ± 0.24	12.60 ± 0.19
	14	0.58 ± 0.01	1730.23 ± 4.71	44.50 ± 0.10	61.85 ± 0.16	21.75 ± 0.30	12.10 ± 0.15
	21	0.56 ± 0.02	1810.25 ± 4.12	51.50 ± 0.10	62.40 ± 0.20	22.50 ± 0.27	12.55 ± 0.35
Y1	0	0.71 ± 0.05	2026.32 ± 7.88	35.50 ± 0.10	68.90 ± 0.01	22.50 ± 0.08	12.80 ± 0.44
	7	0.70 ± 0.04	2094.05 ± 6.17	36.80 ± 0.10	60.15 ± 0.28	21.70 ± 0.31	12.85 ± 0.14
	14	0.65 ± 0.08	2130.55 ± 4.12	39.50 ± 0.10	59.70 ± 0.12	23.05 ± 0.04	13.15 ± 0.11
	21	0.62 ± 0.01	2153.45 ± 5.37	46.50 ± 0.10	61.20 ± 0.60	21.90 ± 0.40	11.75 ± 0.25
Y2	0	0.79 ± 0.01	2174.21 ± 4.47	33.50 ± 0.10	64.45 ± 0.12	22.60 ± 0.05	12.45 ± 0.03
	7	0.75 ± 0.04	2194.25 ± 10.47	35.00 ± 0.90	61.55 ± 0.55	22.05 ± 0.95	11.15 ± 1.00
	14	0.71 ± 0.07	2203.98 ± 3.16	37.50 ± 0.10	64.10 ± 0.25	23.00 ± 0.40	13.35 ± 0.25
	21	0.68 ± 0.03	2240.55 ± 10.87	43.50 ± 0.10	63.00 ± 0.15	22.15 ± 0.30	12.25 ± 0.10
Y3	0	0.85 ± 0.02	2359.21 ± 12.84	30.50 ± 0.10	59.50 ± 0.60	22.15 ± 0.20	11.80 ± 0.45
	7	0.83 ± 0.12	2403.25 ± 13.67	32.50 ± 0.45	60.50 ± 0.45	23.00 ± 0.50	13.50 ± 0.35
	14	0.79 ± 0.05	2426.97 ± 5.32	35.00 ± 0.10	63.40 ± 0.20	22.20 ± 0.70	12.15 ± 0.40
	21	0.75 ± 0.01	2457.65 ± 2.97	40.50 ± 0.10	62.20 ± 0.25	21.50 ± 0.30	12.60 ± 0.20
Y4	0	0.91 ± 0.05	2537.28 ± 8.54	24.50 ± 0.90	63.00 ± 0.45	22.30 ± 0.90	13.20 ± 0.50
	7	0.91 ± 0.09	2602.09 ± 10.87	26.50 ± 0.10	61.75 ± 0.10	21.40 ± 0.20	12.10 ± 0.12
	14	0.87 ± 0.01	2624.85 ± 7.83	30.00 ± 0.10	59.70 ± 0.30	22.05 ± 0.25	12.15 ± 0.60
	21	0.81 ± 0.02	2680.05 ± 6.08	32.00 ± 0.10	62.75 ± 0.50	22.20 ± 0.50	12.70 ± 0.45
Treatments		(<0.05) *	(<0.05) *	(<0.05) *	NS	NS	NS
Storage		(<0.05) *	(<0.05) *	(<0.05) *	NS	NS	NS
(Treatments × Storage)		(<0.05) *	(<0.05) *	(<0.05) *	NS	NS	NS

¹ Treatments: control sample (low-fat yoghurt made without the addition of Gum), Y1 = (low-fat yoghurt made with the addition of 0.50% GG), Y2 = (low-fat yoghurt made with the addition of 1% GG), Y3 = (low-fat yoghurt made with the addition of 0.50% XG), and Y4 = (low-fat yoghurt made with the addition of 1% XG). ² Storage: 0, 7, 14, and 21 days of storage at 4 °C. NS = non-significant. (*) = Significant.

The statistical analysis revealed significant effects of both treatments and storage time on hardness ($p < 0.05$), as well as a significant interaction between these factors. This interaction suggests that the gums not only increase initial hardness but also help maintain firmness during storage, potentially by reducing syneresis and stabilizing the protein network [36]. These findings are in line with previous studies that have reported improved textural properties of yogurt with the addition of hydrocolloids. The enhanced firmness and stability provided by gum supplementation, especially xanthan gum, could lead to improved consumer acceptance and extended shelf life of low-fat yogurt products [37].

3.3. Viscosity

The results presented in Table 3 illustrate the effects of gum supplementation (Figure 2) and time of storage on the viscosity of LFY samples. Over the 21-day storage period at 4 °C, all yogurt samples demonstrated an increase in viscosity, with the gum-supplemented samples (Y1–Y4) exhibiting significantly higher viscosity values compared to the control throughout the storage period. This trend was more pronounced with increasing gum concentration and was particularly evident in samples containing xanthan gum (Y3 and Y4).

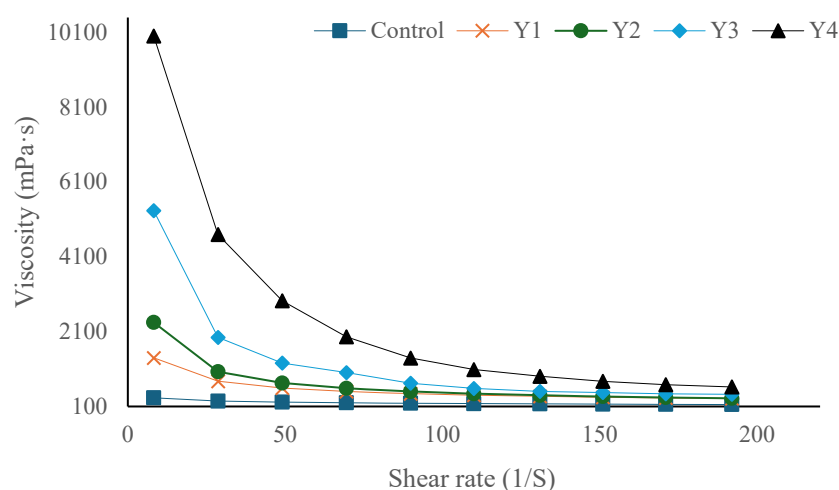


Figure 2. Viscosity (mPa·s) of the LFY samples at fresh time.

The observed increase in viscosity can be attributed to the thickening and water-binding properties of the added hydrocolloids, which contribute to a more viscous and stable yogurt structure [10]. Xanthan gum showed a superior ability to enhance yogurt viscosity, likely due to its unique rheological properties and strong interaction with milk proteins [15,20].

Statistical analysis revealed significant effects of both treatments and storage time on viscosity ($p < 0.05$), as well as a significant interaction between these factors. This interaction suggests that the gums not only increase initial viscosity but also contribute to a continued increase in viscosity during storage. The progressive increase in viscosity during storage for all samples, including the control, can be explained by the ongoing rearrangement of the protein network and the formation of new bonds between casein particles [38]. However, the more pronounced increase in gum-supplemented samples indicates that these hydrocolloids play a role in enhancing this process, possibly by promoting protein-polysaccharide interactions and reducing syneresis [39].

The enhanced viscosity provided by gum supplementation, especially xanthan gum, could lead to improved texture, mouthfeel, and overall consumer acceptance of low-fat yogurt products. Additionally, the increased viscosity may contribute to better stability and reduced syneresis during storage, potentially extending the shelf life of the product [40].

These findings align with previous studies that have reported improved rheological properties of yogurt with the addition of hydrocolloids [41,42].

3.4. Syneresis

The results presented in Table 3 demonstrate the influence of gum supplementation and storage time on syneresis in low-fat yogurt samples. Over the 21-day storage period at 4 °C, all yogurt samples exhibited an increase in syneresis, with the control sample showing the highest levels throughout the storage period. However, the gum-supplemented samples (Y1–Y4) displayed significantly lower syneresis percentages, with the effect being more pronounced at higher gum concentrations and particularly evident in samples containing xanthan gum (Y3 and Y4).

The observed reduction in syneresis with gum addition can be attributed to the water-binding properties of these hydrocolloids, which help to stabilize the yogurt structure and prevent whey separation. Xanthan gum demonstrated superior performance in reducing syneresis, likely due to its excellent water-holding capacity and ability to form a strong network with milk proteins [15].

The statistical analysis revealed significant effects of both treatments and storage time on syneresis ($p < 0.05$), as well as a significant interaction between these factors. This interaction suggests that the gums not only reduce initial syneresis but also help mitigate its progression during storage. The increasing trend in syneresis during storage for all samples can be explained by the ongoing rearrangement of the protein network and the contraction of casein micelles, which leads to the expulsion of whey [38]. However, the lower syneresis rates in gum-supplemented samples indicate that these hydrocolloids effectively interfere with this process, possibly by occupying interstitial spaces in the protein network and immobilizing free water [39].

The reduction in syneresis provided by gum supplementation, especially xanthan gum, could lead to improved texture, appearance, and overall consumer acceptance of low-fat yogurt products. Reduced syneresis is particularly important in low-fat yogurts, which are more prone to whey separation due to their lower total solids content [9]. These findings align with previous studies that have reported improved water retention and reduced syneresis in yogurt with the addition of hydrocolloids [41]. The results also suggest that higher concentrations of gums, particularly xanthan gum, may be more effective in controlling syneresis throughout the shelf life of low-fat yogurt. This could potentially extend the product's shelf life and maintain its quality for longer periods, which is beneficial for both producers and consumers [43].

3.5. Color Characteristics

The results presented in Table 3 demonstrate the effects of gum supplementation and storage time on the color characteristics (L^* , a^* , b^*) of low-fat yogurt samples over a 21-day storage period at 4 °C. Interestingly, the statistical analysis revealed no significant effects of treatments of the LFY samples, storage time, or their interaction on any of the color parameters (L^* , a^* , b^*). The L^* value, representing lightness, showed some fluctuations across treatments and storage times, but without a clear trend. For instance, the control sample ranged from 61.85 to 63.10, while Y1 (0.50% guar gum) showed more variation, ranging from 59.70 to 68.90. Similarly, the a^* (redness) and b^* (yellowness) values exhibited minor variations without consistent patterns across treatments or storage times. The lack of significant changes in color parameters suggests that the supplementation of gums (Guar gum and Xanthan gum) at the tested concentrations did not substantially alter the visual appearance of the yogurt samples during storage. This stability in color is generally desirable from a consumer perspective, as it indicates consistent product appearance

throughout the shelf life. These findings are in contrast with some previous studies that have reported changes in yogurt color during storage. For example, Coggins et al., [29] observed significant changes in color attributes of conventional milk yogurt over storage time, including increases in color intensity and brightness. However, their study did not involve gum additives, which may explain the difference in results [29].

The stability of color parameters in gum-supplemented yogurts could be attributed to the stabilizing effects of the hydrocolloids. Gums can potentially reduce syneresis and maintain a more stable protein network, which might contribute to preserving the original color of the yogurt [39]. Additionally, the lack of significant color changes could indicate minimal chemical reactions or microbial activities that might affect pigmentation during storage. It's worth noting that while color stability is generally positive, some subtle changes in appearance might be expected or even desirable in fermented dairy products. The absence of such changes in this study might guarantee further investigation to ensure that the product maintains other quality attributes associated with normal yogurt aging processes.

3.6. Microbiological Characteristics

The results presented in Table 4 demonstrated the effects of gum supplementation and storage time on the bacterial content and hence the microbiological properties of yogurt samples throughout a 21-day storage period at 4 °C. The statistical analysis revealed significant effects ($p < 0.05$) of treatments, storage time, and their interaction on all measured microbial populations.

Total bacterial counts showed varying trends across treatments. The control and Y1-Y3 samples generally exhibited an increase in total counts up to day 14, followed by a decrease at day 21. However, Y4 (1% xanthan gum) showed consistently lower total counts compared to other treatments, with a marked decrease on day 21. This could be attributed to the fact that as storage time progressed, the increase in acidity likely inhibited overall bacterial growth [25,44–46]. *Lactobacillus delbrueckii* subsp. *bulgaricus* counts were significantly higher in all gum-supplemented samples compared to the control. Y3 and Y4 (xanthan gum treatments) maintained the highest *L. bulgaricus* counts throughout storage, indicating that xanthan gum may provide a more favorable environment for this species [15]. *Streptococcus thermophilus* counts showed a similar trend to *L. bulgaricus*, with gum-supplemented samples showing higher counts compared to the control. Y3 (0.5% xanthan gum) exhibited the highest *S. thermophilus* counts for most of the storage period, suggesting an optimal concentration for this species. *Bifidobacterium bifidum* counts were markedly higher in all gum-supplemented samples compared to the control. Y3 and Y4 (xanthan gum treatments) maintained the highest *B. bifidum* counts throughout storage, with Y3 showing the best overall performance. This indicates that xanthan gum may be particularly effective in supporting the growth and survival of this probiotic species [15].

These findings align with previous studies that have reported improved viability of probiotic bacteria in yogurt supplemented with hydrocolloids. For instance, Sahan et al. [40] observed enhanced survival of probiotic bacteria in yogurt containing β -glucan. Similarly, Aziznia et al. [41] reported improved viability of probiotic strains in yogurt supplemented with gum tragacanth. The observed enhancement in bacterial viability with gum supplementation can be attributed to several factors. Hydrocolloids like guar gum and xanthan gum can act as prebiotics, providing a substrate for bacterial growth [47]. They may also create a protective environment for the bacteria by improving the texture and water-holding capacity of the yogurt matrix, thereby shielding the microorganisms from adverse conditions. The significant interaction between treatments and storage time suggests that the effects of gum supplementation on microbial viability are not constant throughout

the storage period. This highlights the importance of considering both gum type and concentration, as well as storage duration, when optimizing probiotic yogurt formulations.

Table 4. Microbiological Analysis (n = 3) of Low-Fat Yoghurt Samples Supplemented with Various Gums at Different Ratios Through 21 Days of Storage at 4 °C.

Treatments ¹	Storage ²	Total Bacterial Counts (log CFU/g)	<i>Lactobacillus dlebreuckii</i> subsp. <i>bulgaricus</i> (log CFU/g)	<i>Streptococcus thermophilus</i> Counts (log CFU)	<i>Bifidobacterium bifidum</i> Counts (log CFU)
Control	0	7.77 ± 0.05	5.62 ± 0.05	6.95 ± 0.03	3.94 ± 0.08
	7	8.17 ± 0.12	6.82 ± 0.06	7.23 ± 0.04	4.07 ± 0.05
	14	8.27 ± 0.02	5.51 ± 0.02	6.64 ± 0.03	4.23 ± 0.06
	21	7.38 ± 0.14	5.47 ± 0.02	6.45 ± 0.06	3.77 ± 0.05
Y1	0	8.23 ± 0.07	8.32 ± 0.03	8.28 ± 0.01	5.95 ± 0.03
	7	8.31 ± 0.12	8.52 ± 0.04	8.71 ± 0.03	6.26 ± 0.02
	14	8.43 ± 0.02	7.17 ± 0.02	8.23 ± 0.06	6.37 ± 0.05
	21	8.07 ± 0.03	8.21 ± 0.02	7.94 ± 0.03	5.71 ± 0.04
Y2	0	8.37 ± 0.07	8.57 ± 0.05	8.37 ± 0.05	6.47 ± 0.02
	7	8.50 ± 0.03	8.71 ± 0.03	8.82 ± 0.07	6.75 ± 0.02
	14	8.72 ± 0.10	7.51 ± 0.01	8.05 ± 0.04	6.82 ± 0.04
	21	7.86 ± 0.06	8.48 ± 0.05	7.88 ± 0.08	7.17 ± 0.05
Y3	0	8.49 ± 0.07	8.80 ± 0.06	9.03 ± 0.02	8.07 ± 0.04
	7	8.63 ± 0.11	8.93 ± 0.03	9.05 ± 0.06	8.08 ± 0.05
	14	8.82 ± 0.10	8.86 ± 0.02	8.93 ± 0.04	8.21 ± 0.03
	21	8.26 ± 0.12	8.61 ± 0.05	7.67 ± 0.05	7.66 ± 0.05
Y4	0	6.94 ± 0.09	8.88 ± 0.02	8.32 ± 0.05	7.18 ± 0.03
	7	6.91 ± 0.04	9.17 ± 0.07	8.68 ± 0.08	7.30 ± 0.02
	14	6.91 ± 0.08	8.95 ± 0.02	8.22 ± 0.02	7.56 ± 0.01
	21	5.74 ± 0.15	8.73 ± 0.01	8.16 ± 0.06	7.16 ± 0.08
Treatments		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *
Storage		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *
(Treatments × Storage)		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *

¹ Treatments: control sample (low-fat yoghurt made without the addition of Gum), Y1 = (low-fat yoghurt made with the addition of 0.50% GG), Y2 = (low-fat yoghurt made with the addition of 1% GG), Y3 = (low-fat yoghurt made with the addition of 0.50% XG), and Y4 = (low-fat yoghurt made with the addition of 1% XG). ² Storage: 0, 7, 14, and 21 of storage at 4 °C. (*) = Significant.

3.7. Sensory Analysis

The results presented in Table 5 demonstrate the effect of gum supplementation and storage time on the sensory attributes of low-fat yogurt samples during the 21-day storage period at 4 °C. The statistical analysis revealed significant effects ($p < 0.05$) of treatments, storage time, and their interaction on all sensory parameters evaluated.

Scores obtained in color and appearance test showed a clear trend of improvement with gum addition, particularly for xanthan gum treatments (Y3 and Y4). Y4 (1% xanthan gum) consistently received the highest scores throughout storage, indicating that xanthan gum at higher concentrations enhances the visual appeal of low-fat yogurt. This improvement could be attributed to the gum's ability to stabilize the yogurt structure and prevent syneresis, resulting in a more appealing appearance [9,15]. Body and texture scores followed a similar pattern, with gum-supplemented samples receiving higher scores than the control. Y4 (1% xanthan gum) again showed the best performance, followed closely by Y3 (0.5% xanthan gum). This suggests that xanthan gum is particularly effective in improving

the textural properties of low-fat yogurt, likely due to its strong water-binding and gel-forming capabilities [48]. Flavor scores showed more complex trends. While xanthan gum treatments (Y3 and Y4) generally received higher scores, there was a notable decrease in flavor scores for guar gum treatments (Y1 and Y2), especially at higher concentrations. This indicates that while xanthan gum may enhance or preserve flavor, higher concentrations of guar gum might negatively impact the taste of low-fat yogurt. Total sensory scores, which combine all attributes, clearly favored the xanthan gum treatments, with Y4 (1% xanthan gum) consistently achieving the highest overall scores throughout storage. This suggests that xanthan gum at 1% concentration provides the best overall sensory improvement for low-fat yogurt.

Table 5. Sensory Analysis (n = 3) of Low-Fat Yoghurt Samples Supplemented with Various Gums at Different Ratios Through 21 Days of Storage at 4 °C.

Treatments ¹	Storage ²	Color and Appearance (15)	Body and Texture (35)	Flavor (50)	Total (100)
Control	0	6.765	20.975	36.385	64.125
	14	5.885	18.625	35.785	60.295
	21	5.885	16.805	34.445	57.135
Y1	0	7.485	24.825	30.385	62.695
	14	6.885	21.825	32.085	60.795
	21	6.885	14.825	28.785	50.495
Y2	0	9.385	27.825	25.135	62.345
	14	8.685	25.825	27.635	62.145
	21	7.885	20.825	21.085	49.795
Y3	0	10.885	30.625	41.845	83.355
	14	10.885	28.725	44.505	84.115
	21	9.885	22.925	37.085	69.895
Y4	0	14.385	32.225	42.885	89.495
	14	13.885	30.825	45.885	90.595
	21	13.685	26.825	40.235	80.745
Treatments		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *
Storage		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *
(Treatments × Storage)		(<0.05) *	(<0.05) *	(<0.05) *	(<0.05) *

¹ Treatments: control sample (low-fat yoghurt made without the addition of Gum), Y1 = (low-fat yoghurt made with the addition of 0.50% GG), Y2 = (low-fat yoghurt made with the addition of 1% GG), Y3 = (low-fat yoghurt made with the addition of 0.50% XG), and Y4 = (low-fat yoghurt made with the addition of 1% XG). ² Storage: 0, 7, 14, and 21 days of storage at 4 °C. (*) = Significant.

Interestingly, all samples showed some degree of sensory quality decline over the storage period, but the rate of decline was less pronounced in the xanthan gum treatments. This indicates that xanthan gum may help maintain sensory quality during storage, potentially extending the shelf life of low-fat yogurt. These findings align with previous studies that have reported improved sensory properties of yogurt with the addition of hydrocolloids. For instance, (Alsalem & Hamouda, 2024a) observed enhanced sensory attributes in yogurt containing xanthan gum [15]. Similarly, (Aziznia et al., 2008) reported improved texture and overall acceptability in yogurt supplemented with gum tragacanth [41]. The significant interaction between treatments and storage time for all sensory attributes highlights the complex dynamics between gum supplementation and storage duration. This interaction suggests that the sensory benefits of gum addition are not constant throughout the storage period and may vary depending on the specific attribute and gum type/concentration.

3.8. Rheological Properties

The rheological properties of low-fat yogurt samples (control, Y1, Y2, Y3, and Y4) as depicted in Figures 3 and 4, provide valuable insights into the effects of gum addition on the yogurt's structure and texture. The analysis of loss modulus (G''), storage modulus (G'), and viscosity across different angular frequencies and shear rates reveals significant differences between the control and gum-supplemented samples. In both the G'' and G' , the control sample consistently exhibits the lowest values across the range of angular frequencies, indicating weaker viscoelastic properties. This is typical for low-fat yogurts, which often lack the structural integrity provided by fat globules [38]. The addition of guar gum (GG) and xanthan gum (XG) significantly improved these properties, with Y4 (1% XG) consistently showing the highest values in both G' and G'' . This suggests that XG at higher concentrations is particularly effective in forming a stronger gel network within the yogurt matrix. The enhancement in moduli with XG, especially at 1% concentration, indicates its superior role in strengthening the yogurt structure compared to GG. This can be attributed to XG having a unique molecular structure and its ability to form a more rigid network through interactions with milk proteins [4]. The higher G' values for XG-supplemented samples suggest more elastic behavior, which is often associated with improved texture and mouthfeel in yogurt products. In the viscosity graph, all samples exhibit shear-thinning behavior, which is characteristic of yogurt and many other semi-solid dairy products. However, the control sample has the lowest viscosity across all shear rates, reflecting its weaker structure. Y4 (1% XG) shows the highest viscosity, further indicating that higher XG concentrations effectively enhance the yogurt's thickness and body. This increased viscosity can contribute to improved sensory properties and reduced syneresis in low-fat yogurts. The superior performance of XG, particularly at 1% concentration, in improving the textural and structural properties of low-fat yogurt can be explained by its unique rheological properties. XG forms a weak gel structure in aqueous systems, which can interact synergistically with milk proteins to create a more stable and viscoelastic network. This interaction is more pronounced than that of GG, which primarily acts as a thickening agent without significantly contributing to gel formation. These results demonstrate that XG, particularly at 1% concentration, is more effective than GG in improving the textural and structural properties of low-fat yogurt. The enhanced rheological properties observed with XG addition suggest potential improvements in product stability, mouthfeel, and overall consumer acceptance of low-fat yogurt products. However, it's important to note that while these rheological improvements are generally desirable, the optimal gum concentration should be determined in conjunction with sensory evaluations to ensure a balance between textural enhancement and flavor acceptability.

3.9. Microstructure

The microstructural images of low-fat yogurt samples obtained by scanning electron microscopy (SEM) (Figure 5) provide clear visual evidence of the effect of gum addition on yogurt structure. The control sample (C) exhibited a loose and irregular microstructure with numerous open spaces, indicating a weak gel network. In contrast, the addition of guar gum led to noticeable structural improvements, where Y1 (0.5% guar gum) and Y2 (1% guar gum) displayed denser and more compact matrices. This trend continued with xanthan gum addition, as Y3 (0.5% XG) and Y4 (1% XG) revealed the most compact and homogeneous structures, with Y4 presenting the tightest and most cohesive network. These morphological observations are consistent with the rheological results, confirming that xanthan gum, particularly at higher concentrations, significantly strengthens the yogurt matrix by forming a more stable and uniform gel [15].

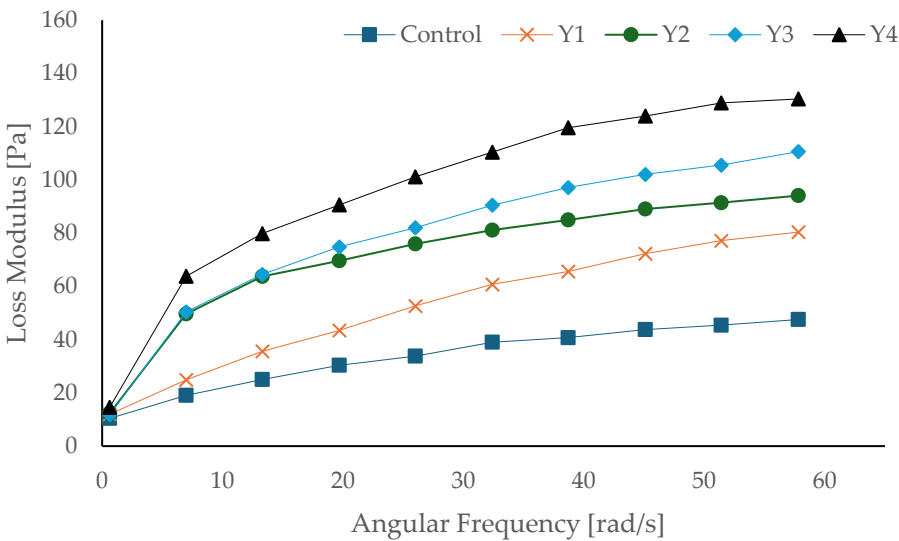


Figure 3. Loss modulus (Pa) of LFY samples at fresh time.

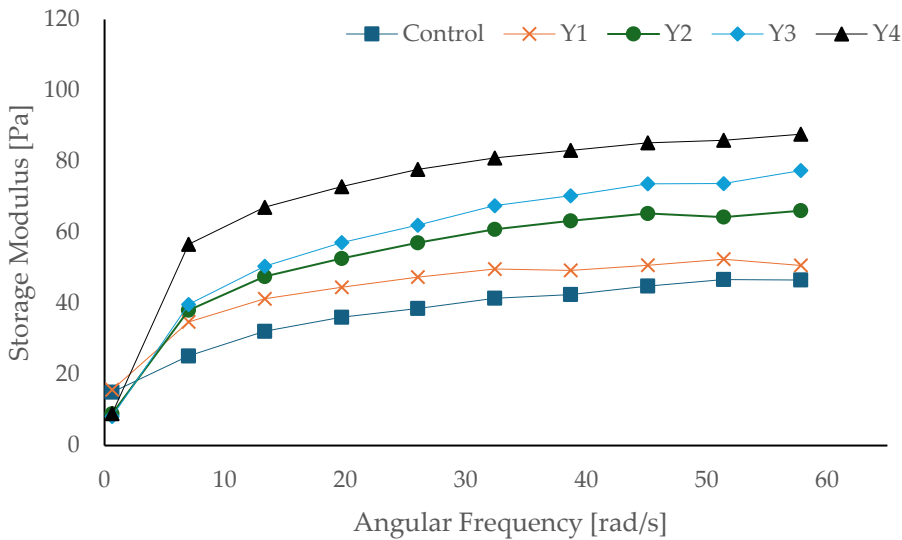


Figure 4. Storage modulus (Pa) of LFY samples at fresh time.

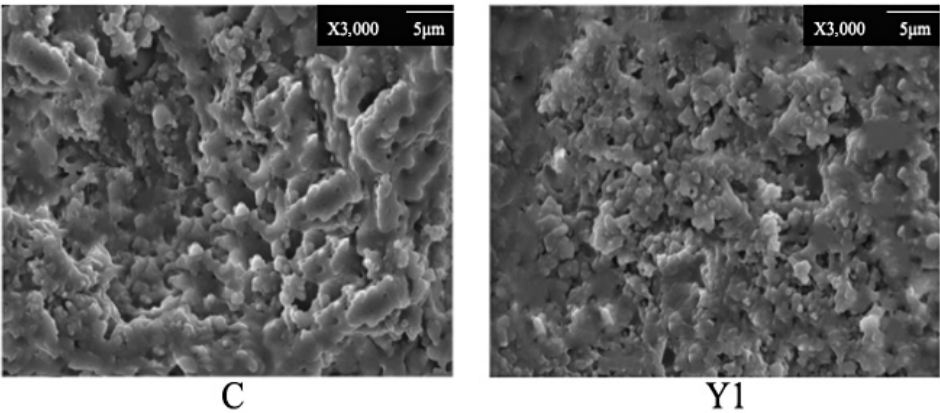


Figure 5. Cont.

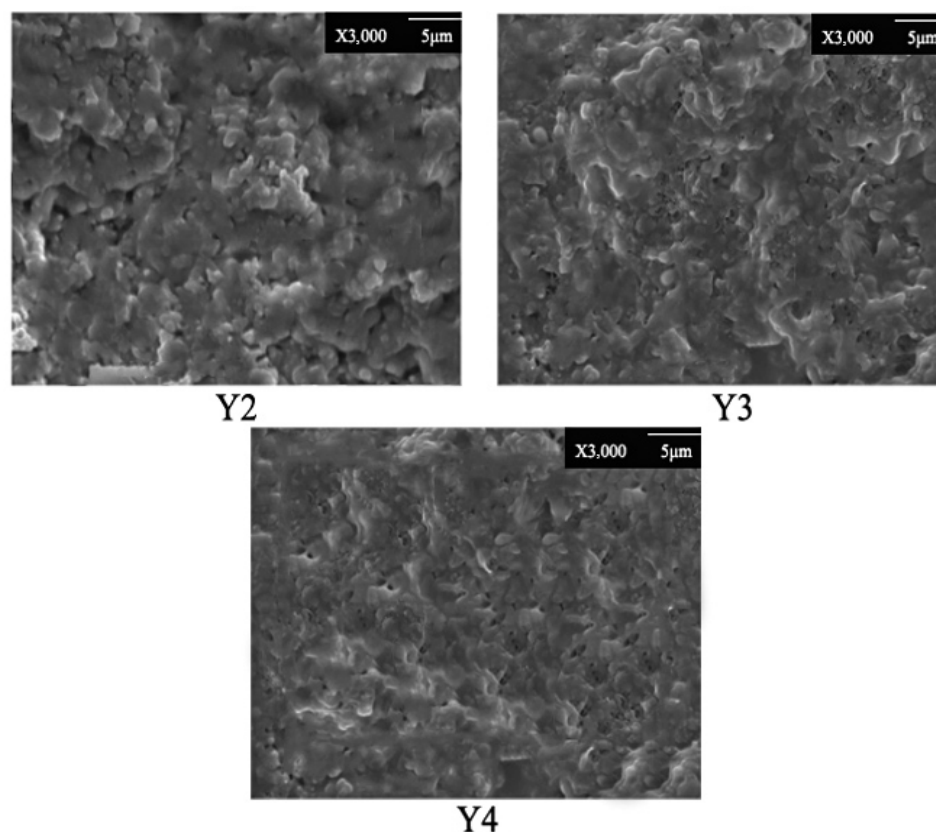


Figure 5. Scanning electron micrographs (SEM) of low-fat yogurt samples at 3000 $\times$ magnification (scale bar = 5 μ m). Treatments: (C) control yogurt without gum; (Y1) yogurt with 0.50% guar gum; (Y2) yogurt with 1% guar gum; (Y3) yogurt with 0.50% xanthan gum; and (Y4) yogurt with 1% xanthan gum. Images were obtained at 0, 7, 14, and 21 days of storage at 4 $^{\circ}$ C.

4. Conclusions

In conclusion, the supplementation of low-fat yogurt with guar and xanthan gums significantly influenced its physicochemical, textural, and microbiological properties during the period of 21 days of storage at 4 $^{\circ}$ C. The gums, particularly xanthan gum, effectively enhanced yogurt texture by increasing hardness, viscosity, and reducing syneresis, which contributed to improved stability and consumer acceptance. The gums also supported the growth and survival of probiotic bacteria, especially *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Bifidobacterium bifidum*, demonstrating their potential to enhance yogurt's probiotic content. Additionally, the gums did not significantly affect the yogurt's color, indicating their stability in maintaining product appearance. Overall, gum supplementation, especially with xanthan gum, shows promise in improving the quality, texture, and shelf life of low-fat yogurt while supporting the viability of beneficial probiotic strains.

5. Study Limitations

The study has some limitations, including the relatively short storage period of 21 days, reliance on trained panel scores for sensory evaluation, and the absence of large-scale industrial validation.

6. Future Research

Future research should therefore explore longer storage durations, incorporate consumer-based sensory testing, investigate additional hydrocolloids, and evaluate the feasibility of application under industrial-scale production conditions.

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Abbreviations

The following abbreviations are used in this manuscript:

XG	Xanthan Gum
GG	Guar Gum
EMCC	Egyptian Microbial Culture Collection
LFY	Low-fat yogurt
TP	Total Protein
TS	Total Solids
CPS	Centipoise
TBC	Total Bacterial Count
CFU	Colony Forming Unit
ANOVA	Analysis of variance
GLM	General Linear Model
LSD	Least Significant Difference

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