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# Evaluating Physicochemical and Sensory Properties of Functional Yogurt Supplemented with *Glycyrrhiza* Polysaccharide as Potential Replacement for Gelatin

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**Abstract:** *Glycyrrhiza* is a well-known plant resource used for the production of extractum-glycyrrhizae; however, large amounts of *Glycyrrhiza* residues containing polysaccharides are produced, and these have not been well utilized until now. The aim of this study was to evaluate the *Glycyrrhiza* polysaccharides obtained from *Glycyrrhiza* residues as a potential gelatin replacer in yogurt. The incorporation of *Glycyrrhiza* polysaccharide (GP) at different concentrations accelerated the growth of lactic acid bacteria. Similar to the effect of adding gelatin (GE), GP could suitably improve the water-holding capacity (WHC) and texture of the yogurt. Moreover, the yogurt prepared with GP showed a higher viscosity and shorter transverse relaxation time of mobile water ($T_{23}$) value than the control group (CG). Moreover, the microstructure analysis indicated that the casein network of yogurt with GP was more compact and cohesive than those of others. Yogurt prepared with 0.1% GPs exhibited the best sensory acceptance. The results indicated that small amounts of GPs can effectively replace gelatin as a thickener in yogurt with good quality.

**Keywords:** polysaccharides; yogurt; texture; sensory; gelatin



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## 1. Introduction

Yogurt is considered a quality dairy product that has high nutritional values and health functions related to lactobacilli and biological components [1]. Gelatin, as a thickener, has been preferred for use in yogurt production to stabilize the system during storage and help prevent syneresis, as well as to create satisfactory appearance, texture, and flavors for better acceptability [2–4]. However, religious beliefs (Jewish and Muslim communities), vegetarian lifestyle choices, and health risks may impact the consumption of yogurt containing beef, pork, or pork-GE [5,6]. Therefore, seeking effective alternatives to GE is important and necessary.

One of the most common approaches used to replace GE in yogurt manufacture is using natural polysaccharides. Polysaccharides are polymeric carbohydrate macromolecules composed of long chains of monosaccharide units that are connected by various glycosidic linkages and have a wide variety of biological activities [7]. Moreover, polysaccharides exert functions such as prebiotic agent as well. The polysaccharides have been added to different dairy products to reinforce the casein network and decrease syneresis [8,9]. Natural polysaccharides, such as pectin, arabic gum locust bean gum, guar gum, tragacanth gum, carrageenan, etc., are regarded as promising candidates for yogurt stabilizers because they can not only control the texture and rheology of yogurt, but can be used to create a functional yogurt that can meet consumer needs for well-being [10]. *Glycyrrhiza* has been

highly valued as a medicinal plant and food worldwide for thousands of years. *Glycyrrhiza* residues are a by-product produced abundantly in mainly *Glycyrrhiza*-producing areas, and they still contain some active components, such as lignin, hemicellulose, and cellulose. However, *Glycyrrhiza* residues are neglected and only used as feed for cattle and flocks or burnt into fertilizer (as fuel), leading to serious waste of biomass in processing plants. In particular, the water-soluble polysaccharides are still in *Glycyrrhiza* residues and can be extracted by acidic or alkaline solutions. Extraction, isolation, structural characterization, pharmacological activities, and medicinal application of licorice polysaccharides have been explored extensively [11]. In our study, *Glycyrrhiza* polysaccharide was obtained from *Glycyrrhiza* residues. No papers on the application of *Glycyrrhiza* polysaccharides to yogurt production have been published so far. In some papers, licorice extract is used [12]. As a natural polysaccharide, GP may the improve texture of the yogurt and provide health benefits that are mainly related to its variety of biological activities [13–15]. Therefore, yogurt is a good candidate to be incorporated with *Glycyrrhiza* polysaccharide.

The aims of this work are to prepare yogurts by fermentation with different concentrations (0.02, 0.06, or 0.1%) of GPs and investigate the effects of GP, in comparison with GE, on the physicochemical (density, WHC, texture, apparent viscosity, water mobility, microstructure, etc.) and sensory characteristics and viable cell count of the yogurt during storage at 4 °C for 48 h. The results may also provide novel insights into the potential commercialization of GP as a functional component of yogurt.

## 2. Materials and Methods

### *2.1. Materials*

Full-cream milk powder (fat, 28 g/100 g; protein, 23.5 g/100 g; carbohydrate, 40.0 g/100 g) was purchased from Alar Xinnong Dairy Co. Ltd. (Alar, China). Food-grade GE was purchased from Zhejiang Yinuo Biotechnology Co.Ltd. (Hangzhou, China). Direct vat set (the ratio of *Lactobacillus bulgaricus* to *Streptococcus thermophilus* is 1:1) was obtained from Angel Yeast Co. Ltd. (Yichang, China).

### *2.2. GPs Extraction*

Briefly, 30 g of *Glycyrrhiza* residues (obtained from Xinjiang Alar Xinnong Licorice Industry Co., Ltd., Alar, China) was mixed with 900 mL of 0.1 M HCl solution (1:30 $w/v$) and placed in a water bath at 28 °C for 8 h with simultaneous stirring. The extract was separated from solid residues by filtration, and the pH was adjusted to neutral using 6 M NaOH. Then, 95% ethanol was slowly added at a 3:1 volume ratio to the concentrated extract, and the mixture was precipitated at 4 °C for 12 h. The precipitate was collected and washed with 80% ethanol, then dissolved again with distilled water. The solutions were centrifuged (8000× $g$, 10 min) to separate the residue and collect the supernatant. Soluble polysaccharides were purified using dialysis bags (molecular weight: 3500 Da) for 48 h at 4 °C. Deionized pure water was used in the dialysis methods, which should be changed every 4 h. Finally, the supernatant was concentrated using a rotary evaporator at 55 °C and dried using vacuum freeze-drying to obtain polysaccharides. GP comprised of 58.7% D-glucose, 19.71% D-galactose, 8.86% D-mannose, 8.64% L-arabinose, 1.82% D-galacturonic acid, 1.54% L-rhamnose, 0.52% L-fucose, and 0.21% D-glucuronic acid (Dionex system), and had a molecular weight of 261.2 KDa (High performance size exclusion chromatography). The total sugar contents of GP were 81.5% ($w/w$).

### *2.3. Yogurt Fermentation*

GP or GE were first dissolved in 100 mL pure water with gentle stirring. Three concentration levels (0.02%, 0.06%, 0.1% ($w/v$)) were prepared per sample. Yogurts with added GP or GE were coded as GP 0.02, GP 0.06, GP 0.1, GE0.02, GE0.06, and GE0.1, respectively. Yogurt samples were prepared using the recommended method of Nguyen et al., 2017 [16] and Kieserling et al., 2019 [17]. Whole milk powder (12.5 g) was dissolved in 100 mL pure water containing GP or GE, and the mixtures were homogenized using an Ultra Turrax

blender at 10,000 rpm until all components were completely melted (Shanghai Donghua, China). After that, the reconstituted milk was pasteurized for 30 min at (85 ±1 °C), cooled to the incubation temperature (43 ± 1 °C), and inoculated with a direct vat set (0.1% (*w*/*v*)). Mixtures of 100 mL were divided in a 150 mL cylindrical flask. The inoculated milk was cultivated at (43 ± 1 °C) until pH of 4.6 (within 6 h). Plain yogurt without polysaccharide or GE addition was prepared as a control group (CG) using the aforementioned method. After fermentation, the yogurt samples were analyzed after 48 h at 4 °C.

### *2.4. Determination of Viable Cell Count of Yogurt*

The viable cell count in yogurt samples was enumerated according to Korkmaz et al., 2021 [18]. Analyses were performed after 48 h of storage at 4 °C. First, 25 g of each yogurt was dissolved in 225 mL of 0.85% (*g*/*v*) saline solution and prepared serial dilution. Then, yogurt samples were spread on plates that contained MRS agar (Dehydrated, Thermo Scientific, Waltham, MA, USA) and cultivated at 36 ± 1 °C for 48 ± 2 h under anaerobic conditions. The viable cells were counted and expressed as log colony forming unit (CFU) $mL^{-1}$ of yogurt.

### *2.5. Physical and Chemical Analyses*

The pH of the yogurt samples was tested with a digital pH meter (Mettler Toledo, Shanghai, China). Titratable acidity (expressed as g lactic acid 100 $mL^{-1}$) was investigated according to Sahan et al., 2008 [19]. Total solids (TS) were calculated according to AOAC (version of 2005), and total soluble solids (TSS) were ascertained by a Hand-held Abbe refractometer (ATAGO, Tokyo, Japan).

### *2.6. Water-Holding Capacity (WHC)*

The WHC of the yogurt samples was analyzed and calculated according to Santillán-Urquiza et al., 2017 [20]. The WHC is defined as the weight (g) of the remaining (or drained) yogurt out of the total weight (100 g) of the yogurt.

### *2.7. Textural Characteristics*

Texture Analyzer (Universal TA, Shanghai TengBa Instrument Technology Co., LTD China) was used to analyze the firmness, consistency, and cohesiveness of the yogurt. According to Nguyen et al., 2017 [16] and Zeynep et al., 2021 [21], the test methods were used with small modifications. Briefly, the test was performed directly in a 150 mL wide-mouth glass bottle using a 35 mm piston probe (P/35). The extrusion test was executed in return to Start test mode at a pretest and post speed of 1.00 mm/s to 5 mm at a power of 5.0 g at room temperature.

### *2.8. Low-Field $^1H$ NMR*

Water mobility in the yogurt samples was analyzed by the Low-field $^1H$ NMR method using a benchtop pulsed NMR Analyzer (NMI20-015V-I Suzhou Niumag Analytical Instruments Co., LTD, Suzhou, China) according to Salomonsen et al., 2007 [22] and Xu et al., 2019 [23] with some modifications. It was conducted at 20 MHz (proton resonance frequency). A white sample bottle (1.5 mL) filled with 1.5 g yogurts was placed in a 15 mm glass tube and inserted in the NMR probe. The transverse relaxation time constants ($T_2$) of yoghurt were analyzed with the Carr–Purcell–Meiboom–Gill (CPMG) pulse experiment. $T_2$, which denotes the water retention, is measured using a CPMG sequence with 18,000 echoes and 16 scan repetitions. $T_2$ measurement is made with a τ-value of 4000 ms. The software RINMR 4 (Oxford Instruments, Molecular Biotools Limited Tubney Woods, Abingdon, UK) is used to gather data.

### *2.9. Flow Behaviour Analysis*

Flow behavior characterization of the yogurt samples was conducted in a Rheo-Stress rheometer MCR302 (Anton Paar, Graz, Austria) with a PC50 plane geometry and a 1.00 mm

gap distance at 25 °C, according to the method of Ren et al., 2017, with a small alteration [24]. The samples were equilibrated for 1 h at 25 °C before loading onto the bottom plate of the rheometer. Samples were kept still for 5 min as the equilibration time before viscosity analysis. The plate was programmed to increase the shear rate from 0.1 to 100 $s^{-1}$ at 25 °C. For the oscillation test, the frequency sweep was over 0.1 to 10 Hz and was used to analyze the changes in the storage modulus (G′) and loss modulus (G″) of GPs [25].

### *2.10. Microstructure of Yogurt*

The microstructure of the yogurt samples was observed using confocal laser scanning microscopy (CLSM, Leica, Wetzlar, Germany). The method used was according to those of Laiho et al., 2017 [26] and Xu et al., 2019 [23]. In brief, yogurt was prepared through gentle stirring at room temperature and stained with Rhodamine B (Yeyuan, Shanghai, China) solution (0.1%, *w*/*v*) for 10 min. The stained samples were moved to a microscope slide with a cover. Rhodamine B showed excitation at 543 nm, and the emitted light was recorded with an E570LP emission filter. Duplicate samples from every experiment were examined in four or five areas, and each representative image was obtained.

### *2.11. Sensory Analysis*

Sensory evaluation was conducted for the yogurts stored at 4 °C for 48 h on appearance, flavour, texture, and total acceptance by 14 (7 men and 7 women) trained assessors with an average age of 25 years. All yogurts were served in plastic cups at 10 ± 2 °C. The sample cups were blind-labelled with random three digit-codes and sample order randomized in order to avoid bias due to the order of presentation. Panelists scored the sensory characteristics according to a hedonic scale from 0 (the worst) to 10 (the best) [17].

### *2.12. Data Analysis*

The experiments were performed in triplicate, and the data were presented as means ± standard deviation. Statistical analyses were performed with SPSS (Statistical Package for the Social Sciences) Statistics v.22 (IBM software, New York, NY, USA). One-way analysis of variance (ANOVA) with Duncan's test was used to determine significant differences between means ($p < 0.05$).

## 3. Results and Discussion

### *3.1. Viable Cell Count of Yogurt Samples*

The total number of lactic acid bacteria (LAB) was chosen to assess the survivability of viable cells in the yogurt samples. As shown in Figure 1, the viable cells in the yogurt samples with different levels of GPs was higher than that in CG; particularly, the highest count of lactic acid bacteria (8.99 log CFU/g) was detected in GP0.02. This may be due to the appropriate concentration of GPs that can promote LAB to make better use of the nutrients in yogurt. The results are similar to those of the previous reports [27,28].

### *3.2. Physicochemical Characteristics of Yogurt Samples*

As shown in Table 1, yogurt made using GP or GE had no significant effect on the titratable acidity values. The pH values of the yogurt samples ranged from 4.06 ± 0.03 to 4.43 ± 0.05. However, these slight differences in the pH values of yogurt were not statistically significant ($p > 0.05$). Higher pH values were obtained in the CG (4.43 ± 0.05) and GP0.02 had the lowest pH values. This indicated that they had positive influence on the activity of lactic acid bacteria in yogurt, which were consistent with the results obtained from viable cells in the yogurt samples. The results were similar to previous studies [20]. As expected, both TS and TSS of yogurt were increased with higher concentration of polysaccharides. However, the TSS of all yogurt samples was relatively low because of the absence of sucrose in yogurt.

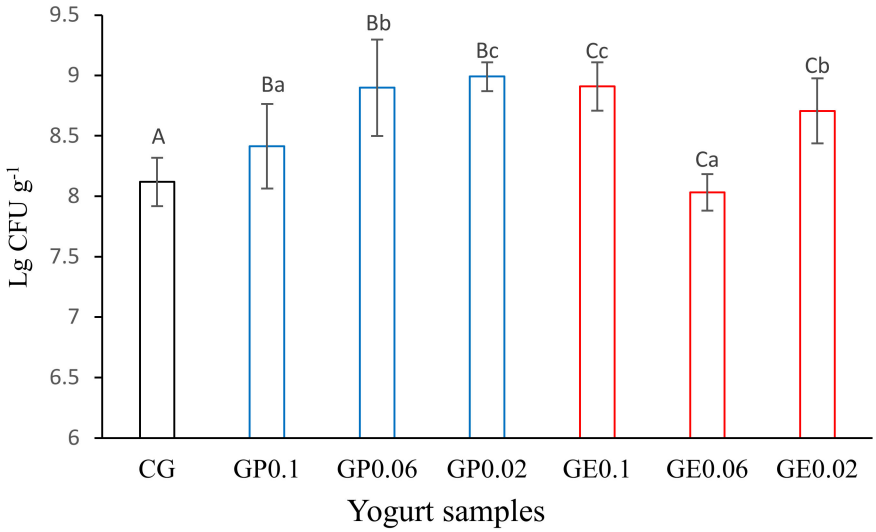


**Figure 1.** Viable cell counts in yogurt. Different capital and small letters indicate significant differences between and within groups, respectively ($p < 0.05$).

**Table 1.** Effects of GP or GE on physicochemical properties of yogurt.

| Samples | Titratable Acidtity (°T) $^{ns}$ | pH $^{ns}$ | TSS (°Brix) | TS (%) | WHC (%) |
|---|---|---|---|---|---|
| CG | 94.33 ± 3.06 | 4.43 ± 0.05 | 6.27 ± 0.15A | 12.69 ± 1.14A | 80.69 ± 0.02A |
| GP0.1 | 94.00 ± 3.60 | 4.23 ± 0.03 | 6.87 ± 0.15Ba | 13.64 ± 0.79Ba | 83.89 ± 0.02Ba |
| GP0.06 | 94.33 ± 4.04 | 4.13 ± 0.02 | 6.77 ± 0.15Ba | 13.06 ± 0.76ABb | 82.79 ± 0.01Ba |
| GP0.02 | 95.00 ± 3.60 | 4.06 ± 0.04 | 6.50 ± 0.20Ba | 12.99 ± 0.83ABbc | 82.66 ± 0.01Bb |
| GE0.1 | 93.33 ± 2.51 | 4.40 ± 0.05 | 6.30 ± 0.265ACa | 12.96 ± 0.92ACa | 85.35 ± 0.02Ca |
| GE0.06 | 93.67 ± 4.16 | 4.37 ± 0.03 | 6.33 ± 0.35ACa | 12.84 ± 0.11ACb | 84.44 ± 0.02Cb |
| GE0.02 | 93.00 ± 1.00 | 4.38 ± 0.04 | 6.23 ± 0.64ACa | 12.70 ± 0.99ACc | 84.85 ± 0.01Cc |

Different capital and small letters in the same column indicate significant differences between and within groups, respectively ($p \leq 0.05$). ns, not significantly different ($p > 0.05$). CG, control group, GP, Glycyrrhiza polysaccharides; GE, mammalian gelatin. TSS, total soluble solids; TS, total solids; WHC, water-holding capacity.

WHC represents the water retention capacity of the yogurt protein gel network, reflecting the compactness of the gel network and the texture of the yogurt. The yogurt samples prepared with GP or GE showed that WHC was higher than CG (Table 1). One probable reason is the high hydrophilicity of GP; another explanation may be the interaction between protein molecules and polysaccharides, which can form compounds with positively charged protein clusters in yogurts to improve the structure of protein gels [29,30]. The addition of GE also increased the WHC of yogurts, possibly due to the stronger water-absorbing properties of GE.

### *3.3. Texture Analysis*

Texture property is a vital measure for assessing the structure and quality of yogurt. Table 2 summarizes the textural parameters (firmness, adhesiveness, cohesiveness, springing, etc.) of all yogurt samples analyzed after storage at 4 °C for 24 h. The effects of GP or GE on these parameters were found to be statistically significant ($p < 0.05$). The samples with GP or GE showed more firmness than the CG (120.02 g), which gradually increased with the concentration of GP or GE. This was probably due to the high WHC of yogurt with GP or GE. Similarly, Xu et al. reported an improvement in yogurt firmness by adding of okra polysaccharides [23]. The adhesiveness of the yogurt samples made using GP or GE was higher than that of CG; however, the adhesiveness of GP0.1 was relatively low at 44.68 Nm. Higher firmness and adhesiveness may be associated with structural modification in yogurt with a profit of firmness of protein matrix [31,32]. The cohesiveness values changed from 0.30 to 0.60 in yogurts. GP or GE noticeably affected cohesiveness values

of yogurts with the highest value acquired in GP 0.1, whereas the lowest was in GE0.06. Springiness and resilience values of sample GP 0.02 were higher than the CG. Improvement in firmness and significant variation in adhesiveness, cohesiveness, springiness, and resilience may be contributing to changes occurring in the pore structure, which may be due to extensive polysaccharide–protein interactions or cross-linking between polysaccharide, casein micelles, and whey proteins that enhance three-dimensional gel network.

**Table 2.** Textural properties of yogurts.

| Samples | Firmness (gf) | Adhesiveness (Nm) | Cohesiveness | Springiness (mm) | Resilience |
|---|---|---|---|---|---|
| CG | 120.02 ± 5.00A | 38.81 ± 1.50A | 0.47 ± 0.02A | 0.37 ± 0.01A | 0.52 ± 0.01A |
| GP0.02 | 124.02 ± 3.40Ba | 79.26 ± 3.40Ba | 0.35 ± 0.01Ba | 0.87 ± 0.02Ba | 1.03 ± 0.02Ba |
| GP0.06 | 130.02 ± 6.50Bb | 82.87 ± 4.32Bb | 0.39 ± 0.01Bb | 0.67 ± 0.05Bb | 0.20 ± 0.01Bb |
| GP0.1 | 134.02 ± 8.01Bc | 44.68 ± 0.56Bc | 0.60 ± 0.03Bc | 0.32 ± 0.02Bc | 0.46 ± 0.02Bc |
| GE0.02 | 138.02 ± 4.10Ca | 95.23 ± 2.50Ca | 0.36 ± 0.02Ca | 1.79 ± 0.04Ca | 2.26 ± 0.01Ca |
| GE0.06 | 144.02 ± 5.30Cb | 109.33 ± 3.50Cb | 0.30 ± 0.01Cb | 0.97 ± 0.01Cb | 0.35 ± 0.01Cb |
| GE0.1 | 158.02 ± 7.35Cc | 90.18 ± 1.80Cc | 0.31 ± 0.15Cb | 1.17 ± 0.01Cc | 1.2 ± 0.02Cc |

Different capital and small superscript letters in the same column indicate significant differences between and within groups, respectively ($p \leq 0.05$). CG, control group, GP, Glycyrrhiza polysaccharides; GE, mammalian gelatin.

### *3.4. Low-Field $^1$H NMR*

$T_2$ and the corresponding peak areas in low-field $^1$H NMR relaxometry analyses indicate water molecules' distribution and movability, including hydrogen protons. Short $T_2$ is attributed to hydrogen atom nuclei in immovable structures, whereas long $T_2$ belongs to hydrogen nuclei in mobilizable structures [33]. As shown in Figure 2, three typical peaks were discerned in whole stages. The first and second peaks ($T_{21}$, $T_{22}$) lay at 0.2 to 0.5 ms and 8 to 20 ms, appointed to water protons of tightly bound and semi-bound water, respectively. They have little influence on gel strength and WHC. The third peak with maximal transverse relaxation time ($T_{23}$) at 400–820 ms was correlated with movable water. The addition of GP or GE had no remarkable impact on $T_{21}$ and $T_{22}$; compared to CG, $T_{23}$ value significantly decreased, which indicated that water in those had a smaller degree of freedom and was more closely bound to non-water components. However, $A_{23}$ displayed quantity of free hold water by protein gel structure; generally, the $A_{23}$ of GP and GE was not significantly different compared with CG. Therefore, GP or GE had a better capacity to retain water in matrix space and facilitate hydration of gel structure, which was according to firmness analysis of yogurts (Table 1). Results indicated that the firmness of yogurt was affected by free-water content, which agreed with previous studies [31,32].

### *3.5. Flow Behaviour Analysis*

Flow behavior is strongly linked to the intrinsic properties of yogurt, for example, mean particle size, and dynamic stability. As shown in Figure 3A,B, the yogurts showed typical pseudoplastic behavior; the apparent viscosity decreased steadily with increasing shear rate. This may be mainly attributed to breaking bonds between protein polymers [34]. The flow behavior of yogurts containing GP or GE agreed with previous research [23,35]. The apparent viscosities of yogurts with different concentrations of GE were higher than CG (Figure 3B). This is due to the GE interaction with the casein matrix, which connects casein micelle aggregates and chains of milk proteins, creating a firmer three-dimensional deformable system [36]. This agrees with the WHC and texture profile results indicated in Tables 1 and 2. In contrast, with increasing concentration of GPs, structure of yogurt were homogeneous, and apparent viscosity gradually enhanced as well (Figure 3A). With concentrations of polysaccharides increasing, casein aggregates may be trapped in increasingly viscous polysaccharide solution, making significant increases in apparent viscosity [16]. For the dynamic viscoelastic properties of yogurts, as shown in Figure 3C,D, storage modulus ($G'$) and loss modulus ($G''$) for yogurts were frequency-dependent. All yogurts exhibited

notable elasticity and stable gel structure, with G′ higher than G″ over the whole frequency range, which indicated that the elasticity of all yogurt samples was always stronger than the viscosity in the test frequency range [37]. In brief, the yogurt samples prepared with GP or GE showed higher viscosity than CG. Moreover, influence of frequency on tangent delta should be analyzed, which would help in more in-depth analysis of rheological properties of yogurt.

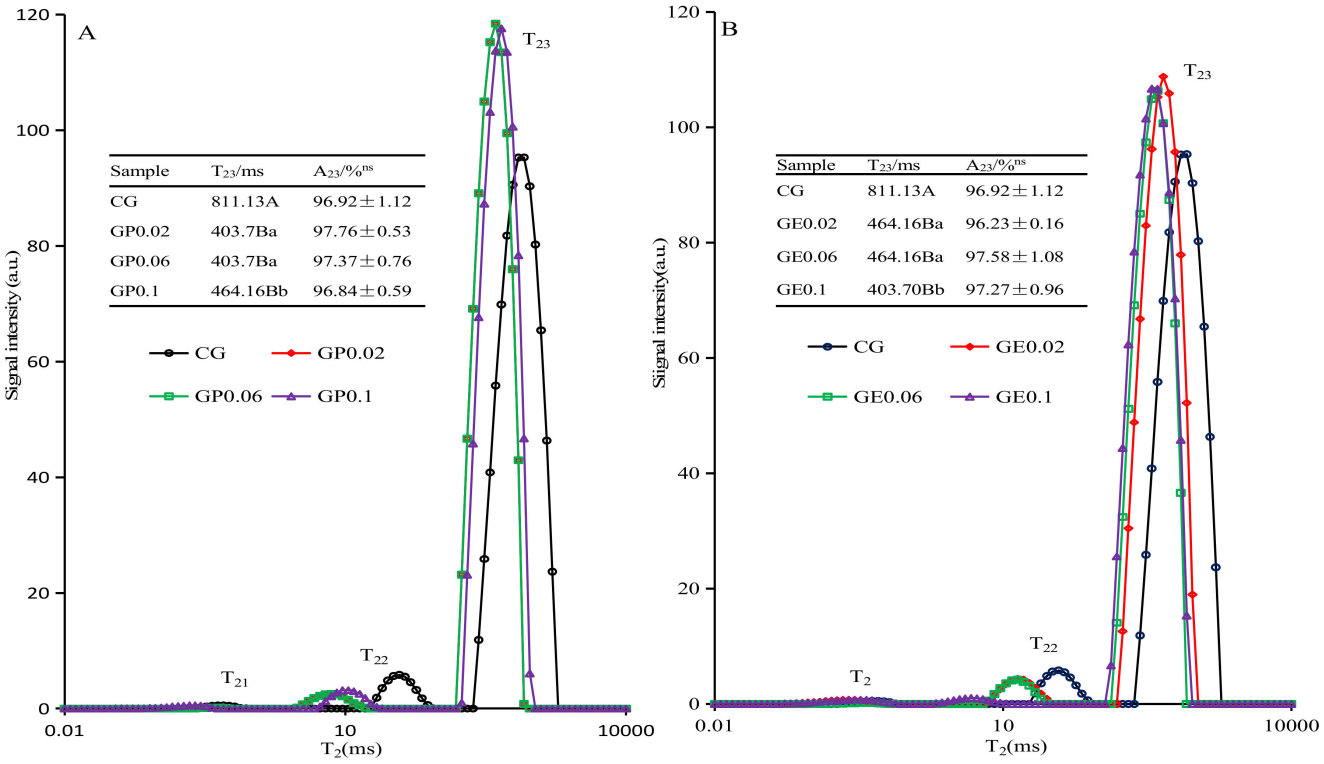


**Figure 2.** Distribution of T2 relaxation times estimated by distributed exponential fitting of LF-NMR on yoghurts with different GP (**A**) and GE (**B**) concentrations. $T_{21}$, transverse relaxation time of bound water; $T_{22}$, transverse relaxation time of semi-bound water; $T_{23}$, transverse relaxation time of mobile water; $A_{23}$, area mobile water. Different capital and small superscript letters in the same column indicate significant differences between and within groups respectively ($p \leq 0.05$). ns, not significantly different ($p > 0.05$).

### *3.6. Microstructure*

The microstructure of yogurt comprises a three-dimensional aggregate network of casein micelles, interspaced by the zones where whey is trapped or fixed. Microstructure of yogurt was observed using CLSM and the micrographs are shown in Figure 4, denser protein aggregates appeared in red color, and the black areas represented serum pores. After adding GPs, small voids among protein clusters reduced, and protein clusters presented a network structure, which became tighter with increasing concentration in yogurt samples, while CG showed fewer protein clusters with highly visible gaps. These indicated a more uniform structure in yogurt with GPs than in CG, which correlated with the consistency result of TPA. The similar results were observed when anionic polysaccharide was added to the yogurt samples [38,39]. These phenomena were due to polysaccharides, and oppositely charged casein micelles may form complexes with each other via electrostatic interaction. This complexation can enhance gel strength, depending on the structure and concentration of polysaccharides [23]. GE had a lower interaction with casein micelles, and no significant impact on protein network at different concentrations (Figure 4), and compared with yogurt made using GP, those made using GE had looser connections and lesser protein clusters.

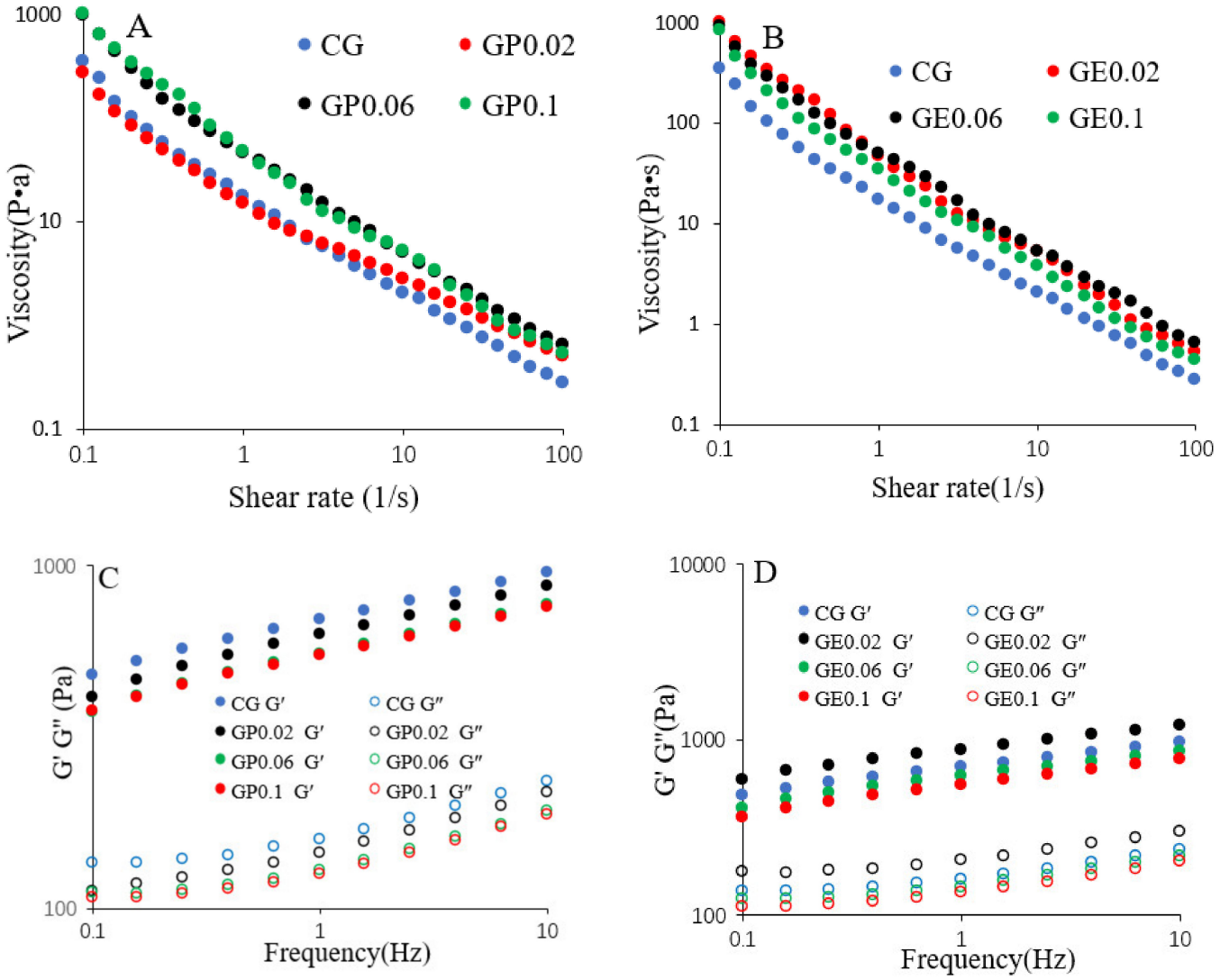


**Figure 3.** Rheological characterization of the yogurts. (**A**,**B**) Flow behavior and (**C**,**D**) storage modulus (G′) and loss modulus (G″).

### *3.7. Sensory Evaluation*

The sensory properties of yogurts obtained after 48 h of storage at 4 °C are presented as a spider diagram Figure 5. Appearance is an important attribute of the quality and product acceptance, and the first impression of food is generally visual. The appearance scores of GP0.1 were higher than those of the others. The yogurt samples with GE or GP added showed similar flavor scores to CG regardless of concentration. Moreover, the texture of yogurts with GP or GE added was largely dependent on concentrations, and those samples showed the higher texture scores than CG, which were in accordance with texture analysis (Table 2). The yogurt sample of GP0.1 showed the highest total acceptance scores (8.53). This result indicated that the inclusion of appropriate GPs was sufficient to positively influence the sensory properties of yogurt. Certain plant-based food ingredients have been known for sensory quality improvements in dairy products. This could be mainly due to improvements in texture/mouth feel and flavors in the final products fortified with plant-based ingredients [40,41].

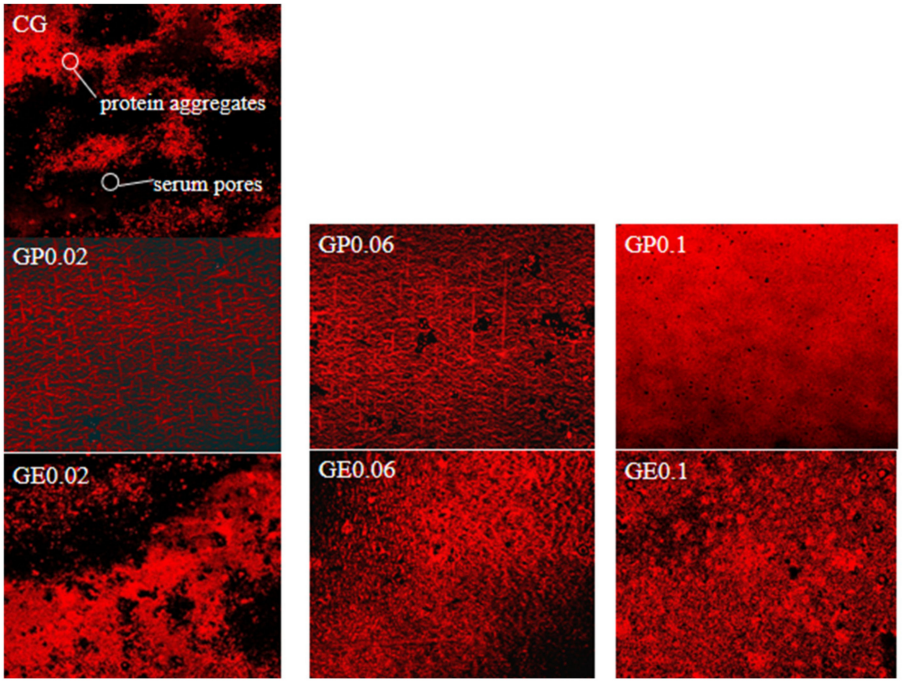


**Figure 4.** Microstructure of yogurt samples.

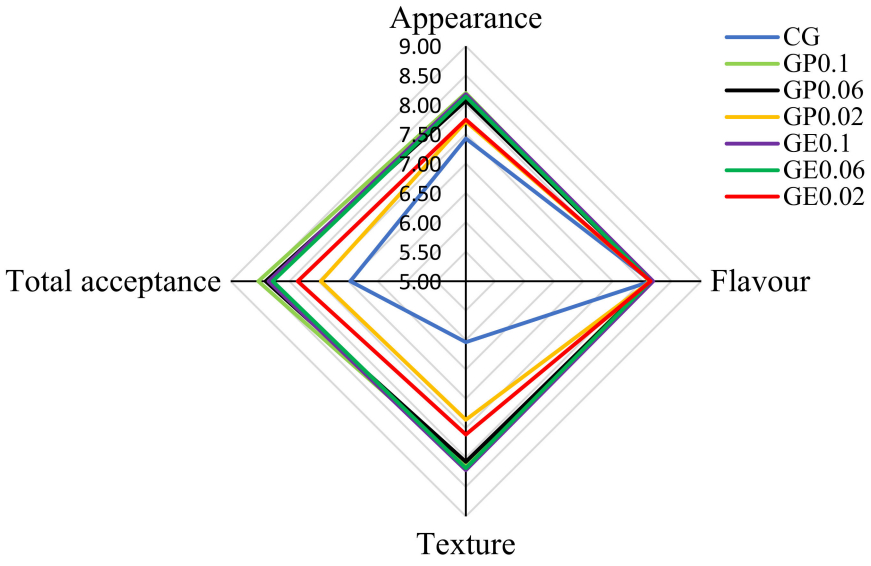


**Figure 5.** Sensory properties of yogurt samples.

## 4. Conclusions

Results obtained in this research showed that the addition of GP was suitable for enhancing WHC, firmness, and adhesiveness of yogurt and encouraged the growth of lactic acid bacteria. The results of low-field $^{1}$H NMR revealed that GP had a better ability to decrease water flow in the matrix space and facilitate the hydration of the gel structures. The effects on consistency, pseudoplasticity, and apparent viscosity of GP were similar to those of GE. GP can decrease the porous structure of gels and facilitate the formation of more protein clusters, which ultimately contribute to a tighter protein network. Overall, GP demonstrated a prominent ability to enhance the yogurt products' structural and textural properties. The yogurt prepared with 0.1% GP showed the best sensory acceptance. The results indicated that small amounts of GP can replace GE as a yogurt thickener and provide useful guidance for the development of functional yogurt without significantly changing the properties of yogurt.

**Author Contributions:** Investigation, Methodology, Validation, Data curation, Writing-original draft, D.G.; Investigation, Validation, X.Y. (Xiuxiu Yin) and H.C.; Supervision, Conceptualization, Writing-review & editing, Project administration, Funding acquisition, X.Y. (Xingqian Ye) and J.C. All authors have read and agreed to the published version of the manuscript.

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