


Research Article

Evaluating the Effect of Electromagnetic Stir-Frying Barley Flour on Yoghurt Quality

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There is a great interest in the use of natural ingredients as functional components in food products. Barley is considered as a natural thickener substitute due to its high dietary fiber content. In this work, electromagnetic stir-frying barley flour (ESBF) was developed and applied in yoghurt. The yoghurt samples were prepared by adding 10, 20, 30, and 40 g L⁻¹ of ESBF, respectively; the control sample was made with 20 g L⁻¹ of whey protein concentrate (WPC), and the yoghurt without any thickener was regarded as blank. The rheological, microstructural, and sensory properties were investigated to evaluate the effect of ESBF on yoghurt quality. Compared to the blank and control samples, the yoghurt with ESBF had higher contents of total solids ranging from 232.5 ± 1.2 g·kg⁻¹ mix to 241.6 ± 1.4 g·kg⁻¹ mix, and crude fiber ranged from 1.6 ± 0.4 g·kg⁻¹ mix to 4.5 ± 0.6 g·kg⁻¹ mix according to the added amount of ESBF. Representing the rheological characteristics of yoghurt, the storage modulus (G'), loss modulus (G''), and apparent viscosity increased with the amount of ESBF. Scanning electron microscope images exhibited that both WPC and barley starch were distributed uniformly in a yoghurt sample, with starch strands between and attached to the protein aggregates reducing the free end. In addition, increased stability of viscosity, water-holding capacity, and bacteria were obtained with the addition of ESBF whether after postripening or during storage of yoghurt. The highest viscosity was up to 3305 MPa s in the yoghurt with 4% ESBF. Current results indicate that ESBF could be used as a suitable natural ingredient and thickener in food.

1. Introduction

Yoghurt, a popular fermented dairy product, has ability to improve intestinal flora and intestinal health. It has also been defined as one of the “super foods” which is benefit for antiaging, decreasing the incidence of diabetes, hypertension, Alzheimer's, and cancer diseases [1, 2]. In the preparation progress of yoghurt, a thickener is considered as a necessary ingredient to improve the viscosity and stability. Meanwhile, many more natural additives are developed and applied to lower the risk of synthetic food additives. In

addition, the use of natural additives also confirms to “clean label” which accords with the development trends of the food industry [3]. Especially, the application of natural ingredients is also meaningful to organic food production due to a number of synthetic food additives are limited and prohibited in organic food [4].

A variety of natural products were reported to have ability to increase viscosity and improve the texture of yoghurt [5, 6]. As a traditional cereal with large production in the world, barley has great potential as suitable food material because of its benefits to human health [7]. It is rich

in nutritional and bioactive substances including phenolic compounds, essential amino acids, and proteins. And it is also considered as a thickener substitute by reason of high dietary fiber content, mainly β -glucan [8].

It has been reported that barley products or barley flour showed obvious features to improve the texture, sensory characteristics, and shelf-life in food because of its water-binding capacity, gel-forming ability, and texturizing and thickening effects [9–11]. In a previous study, we also found that uncooked barley flour exhibited ability of improving the texture of yoghurt. Based on this, the cooked barley is potential to exhibit better features than the uncooked flour. Therefore, the electromagnetic heating treatment was used to prepare electromagnetic stir-frying barley flour (ESBF) in this study, since the process of electromagnetic treatment is easy to control and adjust so that more stable quality products could be obtained. Meanwhile, this method is also considered as one of friendly treatments for environment. Then, the yoghurt samples were prepared with addition of ESBF and whey protein concentrate, respectively, for comparison. The influences of ESBF on composition, rheology, microstructure, texture, and sensory acceptability of yoghurt were investigated. And the yoghurt qualities were evaluated to indicate the advantages of ESBF as a natural substitute of food thickeners.

2. Materials and Methods

2.1. Materials. The raw material is hulled barley (*Hordeum vulgare* L.), and the variety is *Yang si* no. 3 cultivated and harvested in Yancheng of China. Raw milk, sugar, and whey protein concentrate (WPC) were purchased from the local supermarket (Zhenjiang, China). The main components of WPC were determined, and it contained 816.0 g kg⁻¹ of protein, 72.0 g kg⁻¹ of lactose, 54.0 g kg⁻¹ of fat, 58.0 g kg⁻¹ of moisture, and minerals. The starter culture consisted of *Streptococcus thermophilus* Y4.10 and *Bulgaricus* Y6.15 was provided by Yiran Biological Science and Technology Company (Shijiazhuang, China) and kept at 4°C before use. The other reagents were purchased from Sinopharm Chemical Reagent Co. Ltd. (Shanghai, China).

2.2. Preparation of ESBF. The barley grains without mildew and impurity were picked and washed. A CZ-30 electromagnetic machine (Beijing Huoshi Machinery Manufacturing Co. Ltd., China) was used to prepare the electromagnetic stir-frying barley. And the optimized processing conditions were set as follows: the first stage was 30 r·min⁻¹ at 100°C for 30 min, the second stage was 30 r·min⁻¹ at 140°C for 20 min, and the last stage was 40 r·min⁻¹ at 180°C for 40 min. After cooling to room temperature, the grains were milled into powders and the ESBF was obtained through a pneumatic superfine mill. Then, it was packed with a sealed bag and kept at -20°C until use.

2.3. Preparation of Yoghurt. The fresh cow milk was standardized to 32 g L⁻¹ of fat and 160 g L⁻¹ of total solids with skim milk powder and divided into six equal portions. Then, the milk is mixed with 10, 20, 30, and 40 g L⁻¹ of ESBF,

respectively. The control sample was prepared by adding with 20 g L⁻¹ of WPC, while the blank sample was prepared without any thickener. All the groups of mixture were preheated to 60°C, homogenized with 20 MPa at the first stage and 8 MPa at the second stage. Then, the mixtures were heated to 85°C lasting for 15 min and cooled to 42°C, inoculated with 30 g L⁻¹ of starter culture whose viable count was not lower than 1 × 10⁸ CFU·mL⁻¹ milk, and then the mixtures were transferred into 250 mL of cups and incubated continuously at 42°C until the pH value reached 4.6. After postripening at 4°C for 24 h, the yoghurt samples were kept at refrigerated condition for analysis.

2.4. Analysis of Chemical Components. The content of crude protein, crude fiber, fat, total solid, moisture, and ash in the milk and yoghurt samples were determined according to the Association of Official Analytical Chemists (AOAC) standard methods. And the yoghurt sample was analyzed immediately after postripening. The total carbohydrates (TCs) of ESBF and yoghurt were calculated by differences.

2.5. Analysis of Viscosity. The viscosity of yoghurt was determined using a digital Brookfield viscometer (DV-II + Pro, Brookfield Engineering Laboratories, Middleboro, MA) with no. 4 spindle rotating at 60 r·min⁻¹, according to the method of Farnsworth et al. [12] The readings were recorded as MPa·s at the 15th second of measurement [13].

2.6. Analysis of Water-Holding Capacity. The water-holding capacity was measured as described by Chau and Huang [14]. 50 mL of yoghurt was transferred into a centrifuge tube, and the total weight was measured. After centrifugation at 13,500 g for 30 min at 4°C, the supernatant was discarded and the total weight of the tube was measured again. The water-holding capacity was calculated as the percentage of centrifugal residues to the loss of the sample.

2.7. Microbiological Analysis. The viable count method, slightly modified according to Cruz et al. [15], was carried out at the end of fermentation, the 7th day, and 14th day of the storage period, respectively. Plates containing 30–300 colonies were enumerated and recorded as colony-forming units per milliliter of culture (CFU·mL⁻¹ milk).

2.8. Analysis of Rheological Characteristics. A rotational rheometer DHR-2 (Haake-RotoVisco, Karlsruhe, Germany) with a plate geometry (40 mm diameter) was used to detect the rheological parameters according to the method described by Lucey [16]. 1 mL of yoghurt was placed in the centre of the stationary plate, and the gap between plates was kept to 1000 μ m. The conditions of the dynamic model were set to 4°C, 0.5% of strain, and 0.1 to 10 Hz of frequency range, while the conditions of the static model were 4°C and 0.1 to 10 s⁻¹ of shear rate range. Then, the storage modulus (G') and loss modulus (G'') were described by the change of increasing frequency (Hz), respectively.

2.9. Observation of Microstructure. The microstructure of yoghurt samples was observed with a scanning electron microscope (SEM, S-3400N, Hitachi, Ltd., JPN) attached with a cryo-preparation chamber according to the method described by Damin et al. [17, 18]. The detection sample was taken out from nearly 1 cm below the centre and surface of yoghurt and transferred onto the aluminum sample holder. Then, it is frozen with liquid nitrogen at -210°C . The frozen sample was transferred into the cryo-preparation chamber and fractured using a cold scalpel blade at -140°C . Then, the fractured sample was etched at -90°C for 5 min and the sample was coated with a thin layer of platinum for 30 s and transferred onto the cold stage. Finally, the images were taken at 5.0 kV.

2.10. Sensory Evaluation. The sensory analysis was conducted with human ethics approval and carried on in a bright room with a temperature adjusted to 20°C . The panel was consisted of 5 male and 5 female assessors aged from 20 to 35 years old with food sensory evaluation experiences. The yoghurt samples after postripening were scored for color (10), flavor (10), taste (10), texture (10), and acceptability (10) as suggested by Guggisberg et al. [19].

2.11. Statistical Analyses. SPSS statistics software version 17.0 (SPSS, Chicago, IL, USA) was applied for the statistical analyses. All the experiments and analyses were carried out in triplicate. And the analysis of variance was used to test for differences between the means. The data are expressed as the arithmetic mean \pm standard deviation.

3. Results and Discussion

3.1. Chemical Compositions of Raw Materials. The chemical compositions of ESBF, WPC, and whole milk used in preparation of yoghurt formula are exhibited in Table 1, which indicated that WPC had a much higher content of crude protein ($745.21 \pm 27.45 \text{ g kg}^{-1}$) and fat ($84.82 \pm 3.63 \text{ g kg}^{-1}$) than the others, while ESBF and whole milk had a similar pH value higher than WPC. Besides, ESBF had a reasonable amount of crude fiber which was $37.65 \pm 3.16 \text{ g kg}^{-1}$ while neither WPC nor whole milk contained it.

The yoghurt texture is generally attributed to the macromolecules including milk fat, protein, and complex carbohydrates. The chemical compositions of yoghurt samples are shown in Table 2, which exhibited a significant difference in total solid content among the blank, WPC, and ESBF yoghurt samples. And the total solids increased significantly with the addition of ESBF, which may be reflected by the increase of total carbohydrates. The total solids are directly related to the formation and distribution of casein network structure which could affect the quality of food, especially yoghurt products. A few percent variations of total solid content would influence the development of casein network structure greatly [20, 21]. The curded texture would arise if the total solid content was excess, while a low content would result in casein network structure formulation and coarse

TABLE 1: The chemical analyses of ESBF, WPC, and whole milk.

Composition	ESBF*	WPC	Whole milk
Crude protein (g kg^{-1})	$114.74 \pm 7.33^{\text{b}}$	$745.21 \pm 27.45^{\text{a}}$	$32.52 \pm 4.24^{\text{c}}$
Fat (g kg^{-1})	$33.51 \pm 1.14^{\text{b}}$	$84.82 \pm 3.63^{\text{a}}$	$28.15 \pm 3.25^{\text{c}}$
Crude fiber (g kg^{-1})	37.65 ± 3.16	—	—
Ash (g kg^{-1})	$31.35 \pm 3.53^{\text{b}}$	$35.75 \pm 2.55^{\text{a}}$	$5.34 \pm 0.48^{\text{c}}$
Moisture (g kg^{-1})	$95.12 \pm 4.12^{\text{b}}$	$52.35 \pm 6.34^{\text{c}}$	$877.45 \pm 12.36^{\text{a}}$
pH value	$6.97 \pm 0.08^{\text{a}}$	$6.25 \pm 0.07^{\text{ab}}$	$6.74 \pm 0.05^{\text{a}}$

*ESBF: electromagnetic stir-frying barley flour; WPC: whey protein concentrate; pH was determined in 20% aqueous solution (w/v). Data were analyzed by one-way ANOVA using SPSS. Values represent the means of triplicate trials \pm standard deviation. Different letters in each row indicate a significant difference ($P < 0.05$).

texture. Thus, the ESBF is conducive to improving yoghurt quality, and this rising trend also performed on the carbohydrate content in the samples.

Protein also has ability of affecting the yoghurt quality for providing a slight flavor, better water-holding capacity, and the formation of air cells. Hogan et al. reported that protein could interact with fat at the oil-water interface to stabilize the fat emulsion during homogenization and freezing [22]. The application of protein is to encapsulate the air cells and control the destabilization of fat. Table 2 shows a significant increase of protein content in yoghurt samples with the addition of WPC which was consisted of higher protein than ESBF.

The major challenges for manufacturing yoghurt, demonstrated by Pandya and Ghodke [23], are related to providing creaminess, minimizing the separation of whey, and developing better flavoring formulas. The increase of fat content has been shown to reduce the separation effect of whey and affect the sensory evaluation through a lubricating sensation in the mouth. Table 2 exhibits a significant increase of fat content with the increasing amount of ESBF compared to the blank and WPC samples.

In addition, there is no crude fiber in blank and WPC samples, while ESBF can supply more crude fiber to yoghurt. The similar results were obtained by Mahdian et al. [24] who investigated the effect of substituting skim milk protein with soy flour on yoghurt quality, and the results showed that the increasing soy flour caused a remarkable augment in crude fibers.

3.2. Influence of ESBF on Rheological Characteristics of Yoghurt. Rheological properties are one of the most important properties of yoghurt and are closely related to the whole production of yoghurt [25]. There are varieties of non-Newtonian effects during the measurement of rheological features of yoghurt, such as viscoelasticity, time dependence, yield stress, and shear thinning. The storage modulus (G') value represents the elastic behavior of the sample, which is used as a measure of the deformation energy stored in the sample during the shear process [18]. And the loss modulus (G'') represents the energy dissipation of viscous properties. The higher the ratio of G' and G'' , the stronger the liquidity [26].

TABLE 2: The contents of main compositions of yoghurt ($\text{g}\cdot\text{kg}^{-1}$ mix).

Composition	Blank*	WPC	T1	T2	T3	T4
Crude protein	$31.42 \pm 1.71^{\text{de}}$	$38.45 \pm 2.74^{\text{a}}$	$31.65 \pm 2.53^{\text{de}}$	$31.81 \pm 1.54^{\text{d}}$	$32.47 \pm 2.16^{\text{c}}$	$33.62 \pm 3.43^{\text{b}}$
Fat	$29.62 \pm 2.21^{\text{de}}$	$31.74 \pm 2.56^{\text{c}}$	$30.17 \pm 1.56^{\text{d}}$	$31.64 \pm 3.17^{\text{c}}$	$33.25 \pm 3.74^{\text{b}}$	$34.36 \pm 1.36^{\text{a}}$
Crude fiber	—	—	$1.64 \pm 0.43^{\text{c}}$	$1.75 \pm 0.26^{\text{c}}$	$2.65 \pm 0.48^{\text{b}}$	$4.53 \pm 0.56^{\text{a}}$
Total solids	$223.47 \pm 1.15^{\text{e}}$	$231.54 \pm 0.83^{\text{d}}$	$232.45 \pm 1.24^{\text{c}}$	$232.63 \pm 0.67^{\text{c}}$	$237.45 \pm 1.27^{\text{b}}$	$241.63 \pm 1.44^{\text{a}}$
Ash	$5.74 \pm 0.68^{\text{e}}$	$7.43 \pm 1.27^{\text{a}}$	$6.18 \pm 0.55^{\text{d}}$	$6.24 \pm 0.34^{\text{d}}$	$6.36 \pm 0.47^{\text{bc}}$	$6.53 \pm 0.56^{\text{b}}$
Total carbohydrates	$175.73 \pm 1.75^{\text{e}}$	$183.2 \pm 2.12^{\text{b}}$	$176.34 \pm 0.87^{\text{d}}$	$176.74 \pm 1.26^{\text{d}}$	$178.45 \pm 1.42^{\text{c}}$	$185.18 \pm 1.67^{\text{a}}$

*Blank: yoghurt without additives; WPC (whey protein concentrate): yoghurt added with 20 g L^{-1} of WPC; T1: yoghurt added with 10 g L^{-1} of electromagnetic stir-frying barley flour (ESBF); T2: yoghurt added with 20 g L^{-1} of ESBF; T3: yoghurt added with 30 g L^{-1} of ESBF; T4: yoghurt added with 40 g L^{-1} of ESBF. Data were analyzed by one-way ANOVA using SPSS. Values represent the means of triplicate trials \pm standard deviation. Different letters in each row indicate a significant difference ($P < 0.05$).

The G' and G'' values of blank, WPC, and ESBF yoghurt were obtained used by a frequency sweep from 0.1 to 10 Hz. In Figure 1, the G'' of the yoghurt sample exhibited a similar profile to G' , while the values were lower than that of G' at all frequencies investigated. This indicated that all of the yoghurt samples had elastic or solid-like character. And G' increased similarly to the increasing total solids with the addition of ESBF. As shown in Figure 2, the apparent viscosity of yoghurt as a function of shear rate increased with the addition amount of ESBF. The higher viscosity of yoghurt added with ESBF indicated the interactions between the starch or protein in ESBF and the protein network of the yoghurt gel compared to the blank sample. This was probably due to the rearrangement of proteins during storage leading to higher protein-protein or protein-starch interactions [18]. These interactions could strengthen the gel structure leading to higher elastic characteristics of the yoghurt gels with higher G'' values and lower G' values representing the weaker liquidity [27]. Moreover, barley starch was clearly observed throughout the ESBF yoghurt gel with the high-resolution SEM (Figure 3), which further confirmed the interactions between barley starch and milk proteins and formed a solid-like structure in yoghurt.

3.3. Influence of ESBF on Microstructure of Yoghurt. The microstructure of food, providing qualitative information about their physical state, is significant to realize the spatial arrangement of identifiable elements in the food matrix and their interactions below the level of $100 \mu\text{m}$ [28]. For yoghurt products, it is considered as a key tool to observe the microstructure for understanding the suitable textural and sensory properties [26].

Figure 3 exhibits SEM images of yoghurt added with different ingredients. The blank sample showed a compact homogenous structure consisted of a three-dimensional network which was composed of chains and aggregates of fused casein micelles, whose globular shape was still discernible (Figures 3(a) and 3(b)). The yoghurt added with WPC and ESBF exhibited larger pore sizes with a well-defined porous web-like structure. The whey protein and barley starch were distributed well in yoghurt, where starch strands were observed between and attached to the protein aggregates reducing the free end. The white arrows point to whey protein and starch strands in Figures 3(d) and 3(f). In general terms, the protein network of 20 g L^{-1} of ESBF

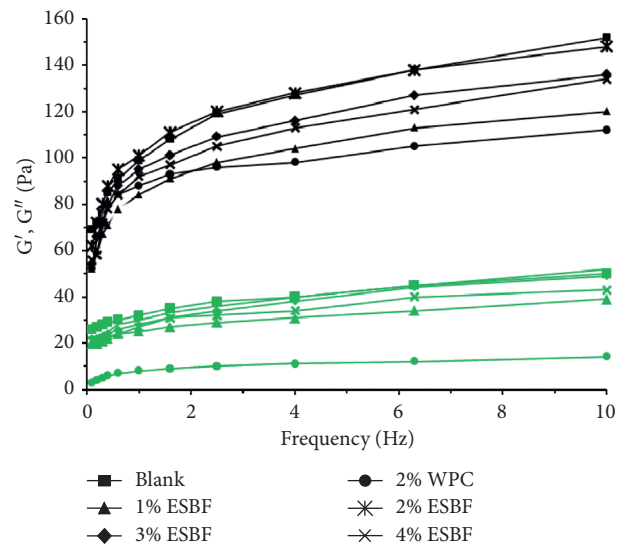


FIGURE 1: Storage modulus (G' , black line) and loss modulus (G'' , green line) of yoghurt as a function of oscillatory frequency at 4°C . Blank: yoghurt without additives; 2% WPC: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of WPC; 1% ESBF: yoghurt added with $10 \text{ g}\cdot\text{L}^{-1}$ of ESBF; 2% ESBF: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of ESBF; 3% ESBF: yoghurt added with $30 \text{ g}\cdot\text{L}^{-1}$ of ESBF; 4% ESBF: yoghurt added with $40 \text{ g}\cdot\text{L}^{-1}$ of ESBF.

yoghurt (Figures 3(g) and 3(h)) was denser and less open and presented more fused casein micelle aggregates than that of the blank yoghurt sample as consequence of a lower number of fat globules acting as linking protein agents. Compared with the micrographs of the blank sample, slightly more cohesive, less coarse network and smaller pores were evident as the increasing amount of ESBF, which enhanced the yoghurt network by acting as a water-structuring agent, producing a denser casein network (Figures 3(g) and 3(h)). It is possible that a second hydrophilic network based on β -glucan was built up, which was not visible by SEM, partly increasing the water-holding capacity of yoghurt. It is also thought that these two networks together might lead to an increase in the consistency as measured by the rheological methods (Figures 1 and 2). In addition, the porous structure could increase the viscosity and water-holding capacity of the gel structure observed in WPC and T1, T2, T3, and T4 compared to the blank sample (Figures 4(a) and 4(b)). This result suggested that starch and

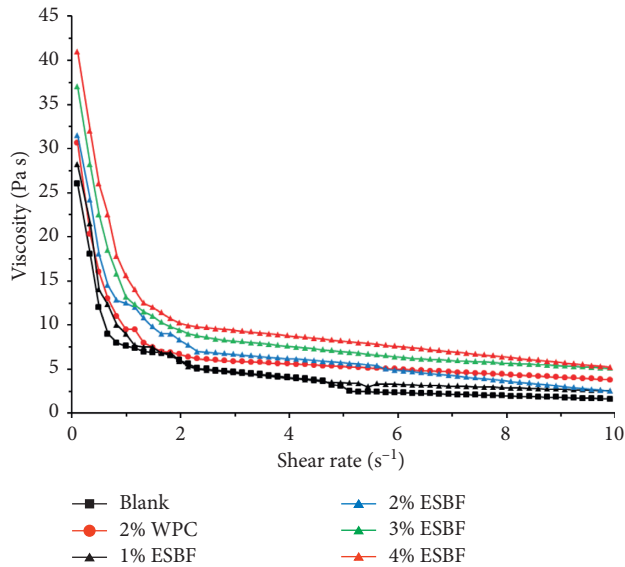


FIGURE 2: Apparent viscosity of yoghurt as a function of shear rate. Blank: yoghurt without additives; 2%WPC: yoghurt added with 20 g·L⁻¹ of WPC; 1% ESBF: yoghurt added with 10 g·L⁻¹ of ESBF; 2% ESBF: yoghurt added with 20 g·L⁻¹ of ESBF; 3% ESBF: yoghurt added with 30 g·L⁻¹ of ESBF; 4% ESBF: yoghurt added with 40 g L⁻¹ of ESBF.

β -glucan of ESBF interacted with the milk proteins, in which the case β -glucan was not clearly observed in the yoghurt with ESBF (Figures 3(e)–3(h)). Similarly, modified starch or β -glucan was reported to create porous structures which would be helpful to enhance the water-holding capacity in yoghurt. Besides, the porous structure was considered to be useful to resist mechanical treatments without disturbing the structure, which was very significant for yoghurt products during mechanical handling, especially the transporting and handling process [29].

3.4. Influence of ESBF on Quality of Yoghurt after Postripening.

A certain level of viscosity is essential for proper whipping and retention of air cells in the yoghurt system [30]. Generally, the viscosity of yoghurt is related to several factors such as total solids and the amount and type of stabilizers. Figure 4(a) represents the effect of different quantities of ESBF on viscosity of yoghurt. The results indicated that there was a significant difference between the viscosities of yoghurt samples after postripening at 4°C for 24 hours. The viscosity of yoghurt had significantly increased with the increasing addition amount of ESBF, and the highest viscosity was up to 3305 MPa s when yoghurt was added with 4% of ESBF.

Figure 4(b) depicts water-holding capacity of yoghurt samples. It could be noticed that water-holding capacity increased with the addition amount of ESBF. This could be attributed to the differences in composition of WPC and ESBF, in which the higher contents of dietary fiber may act as a stabilizing ingredient and reduce the free water [28]. The differences of viscosity and water-holding capacity between the blank sample and yoghurt added with ESBF could be due

to the significant increase in total solids, which decrease the fluidity and then supply a higher viscosity for the food system. Another reason was that ESBF contained a higher amount of dietary fibers, which has gelatinized capacity, and may absorb and bind more free water in food. As a result, more dietary fibers lead to a higher viscosity compared to substituted WPC under the processing conditions of yoghurt [31]. Meanwhile, a higher content of β -glucan can be used as the growth substrate of lactic acid bacteria to produce more exopolysaccharides (EPSs), as the EPS has ability to contribute to the textural and sensory properties of yoghurt [32]. The results were consistent with the study of Prasanna et al. [18] who reported an increase of viscosity in the low-fat samples added with inulin. It could be explained by the interactions between dietary fiber and liquid components in yoghurt mixture.

Figure 4(c) depicts that the number of lactic acid bacteria in yoghurt extremely increased with a higher proportion of ESBF, with the addition of 3%, achieving the highest level which was 2.33×10^9 CFU·mL⁻¹. This might be due to the potential of β -glucan in ESBF acting as a good growth substrate for lactic acid bacteria, while WPC lacked this ability [10]. It has been reported that barley flour was conducive to promote the production of glucosidase of lactic acid bacteria which could hydrolyze β -glucan into glucose to produce large amounts of lactic acid, inhibiting the secretion and activity of glucosidase and limiting the use of barley β -glucan so that lactic acid bacteria would not continue to rise [33].

3.5. Influence of ESBF on Sensory Evaluation of Yoghurt.

The sensory quality of yoghurt is presented in Figure 5. The improved body and texture of the yoghurt substituted with 20 g L⁻¹ and 30 g L⁻¹ of ESBF might be associated with the reasonable increase of crude fiber and total solids as shown in Tables 1 and 2. This is in line with the study of Sharma [34] which stated that total solids affect the texture of yoghurt directly and effectively resulting in firm texture and improved mouthfeel. The substitution with 40 g L⁻¹ of ESBF had significant improvement on structure attribute of yoghurt. Nevertheless, the increasing ratio of ESBF may deteriorate the flavor of products. Therefore, it is necessary to conduct more comprehensive studies to obtain a better formula for yoghurt product [35–37].

3.6. Influence of ESBF on Quality of Yoghurt during Storage.

Viscosity, water-holding capacity, and lactic acid bacteria count of yoghurt were detected during storage at 4°C lasting for 20 days, and the relevant results are shown in Figure 6. Viscosity is an important indicator of yoghurt quality during storage, which directly affects texture, hardness, and flavor of products. In Figure 6(a), 30 and 40 g L⁻¹ of ESBF maintained a higher level of viscosity in yoghurt during the 20 days of storage period than 20 g L⁻¹ of WPC. In Figure 6(b), 20 g L⁻¹ of WPC and 30 and 40 g L⁻¹ of ESBF could maintain a high water-holding capacity of yoghurt, especially in the later storage, and this may be due to the suitable ratio of solids in yoghurt improving the structure of gel. The total number of

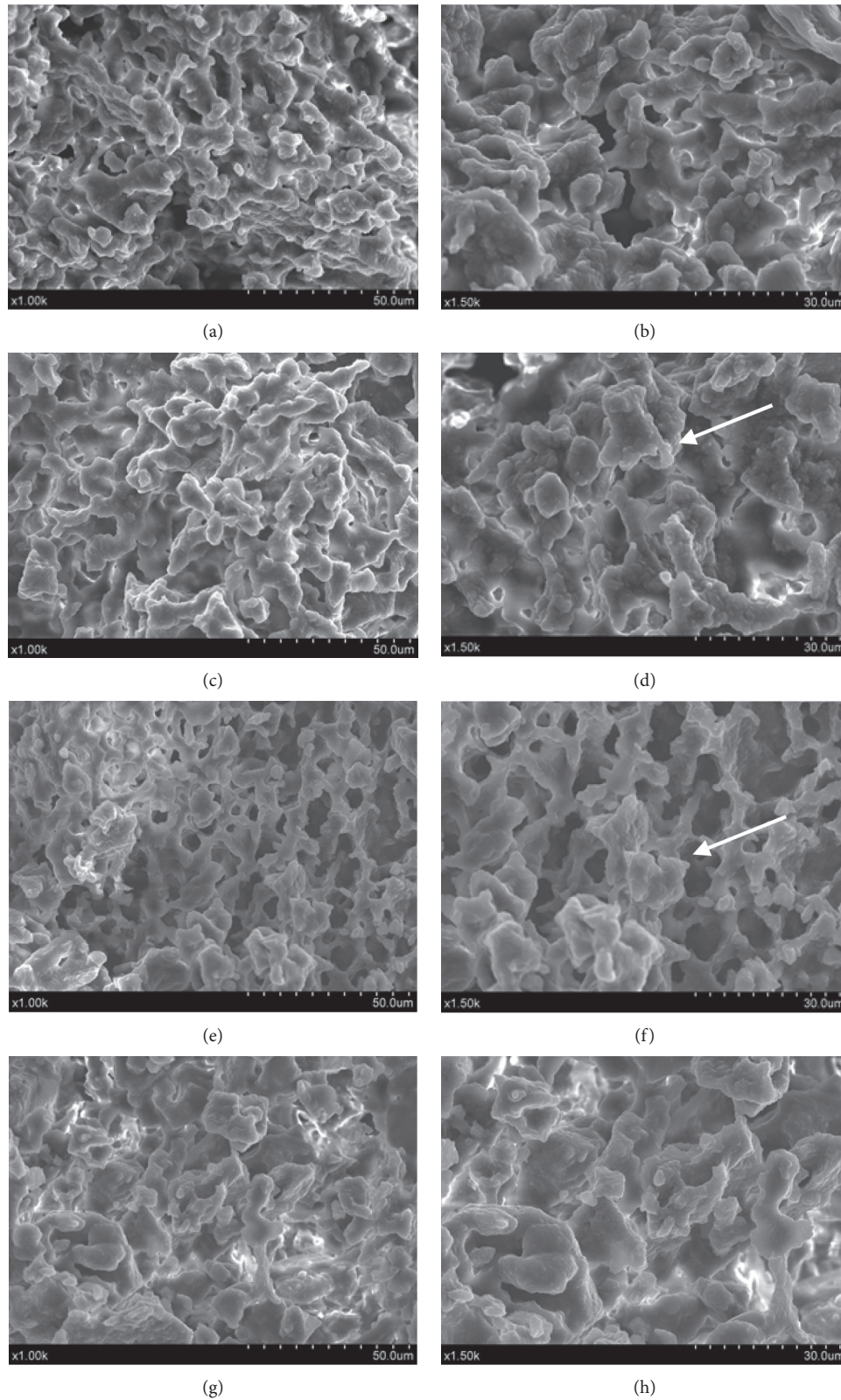


FIGURE 3: Scanning electron micrographs giving single optical sections of yoghurt. Blank yoghurt ((a) 1,000 \times ; (b) 1,500 \times), yoghurt with 2% WPC ((c) 1,000 \times ; (d) 1,500 \times), yoghurt with 1% ESBF ((e) 1,000 \times ; (f) 1,500 \times), and yoghurt with 2% ESBF ((g) 1,000 \times ; (h) 1,500 \times).

lactic acid bacteria is the main indicator of nutritional value of yoghurt, especially during storage for sale. As shown in Figure 6(c), the viable count of bacteria in yoghurt added

with ESBF was higher than the blank and WPC yoghurt, and the value in 20 g L⁻¹ of the sample reached 2.84×10^9 CFU·mL⁻¹ at the 10th day.

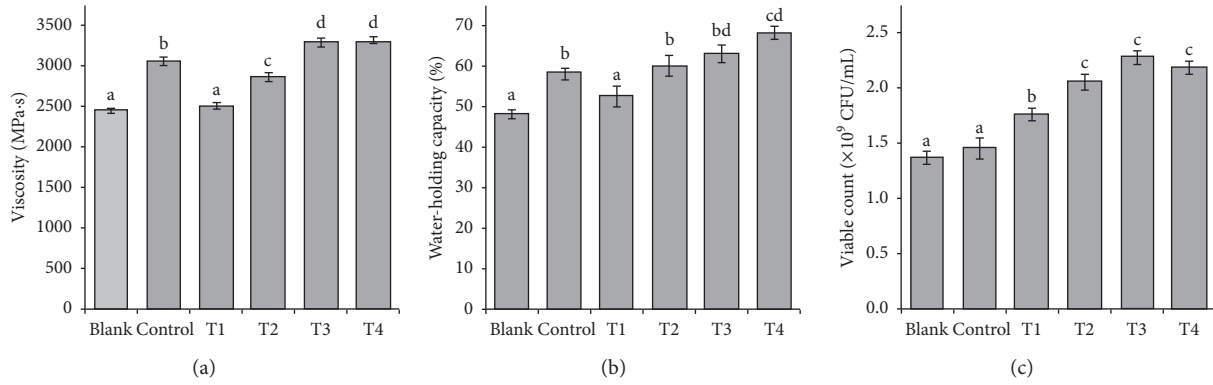


FIGURE 4: Effect on viscosity, water-holding capacity, and the total number of lactic acid bacteria of yoghurt by ESBF after 24 hours. Blank: yoghurt without additives; control: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of WPC; T1: yoghurt added with $10 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T2: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T3: yoghurt added with $30 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T4: yoghurt added with $40 \text{ g}\cdot\text{L}^{-1}$ of ESBF. Data represent the means of triplicate trials \pm standard deviation.

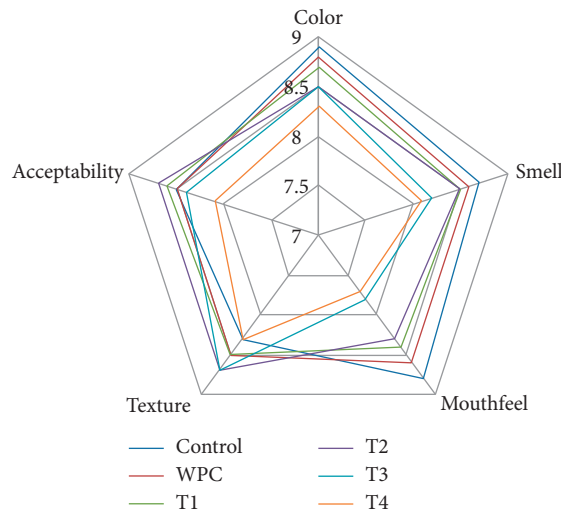


FIGURE 5: Effect of ESBF on sensory quality of yoghurt. Blank: yoghurt without additives; WPC: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of WPC; T1: yoghurt added with $10 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T2: yoghurt added with $20 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T3: yoghurt added with $30 \text{ g}\cdot\text{L}^{-1}$ of ESBF; T4: yoghurt added with $40 \text{ g}\cdot\text{L}^{-1}$ of ESBF. Data represent the means of triplicate trials \pm standard deviation.

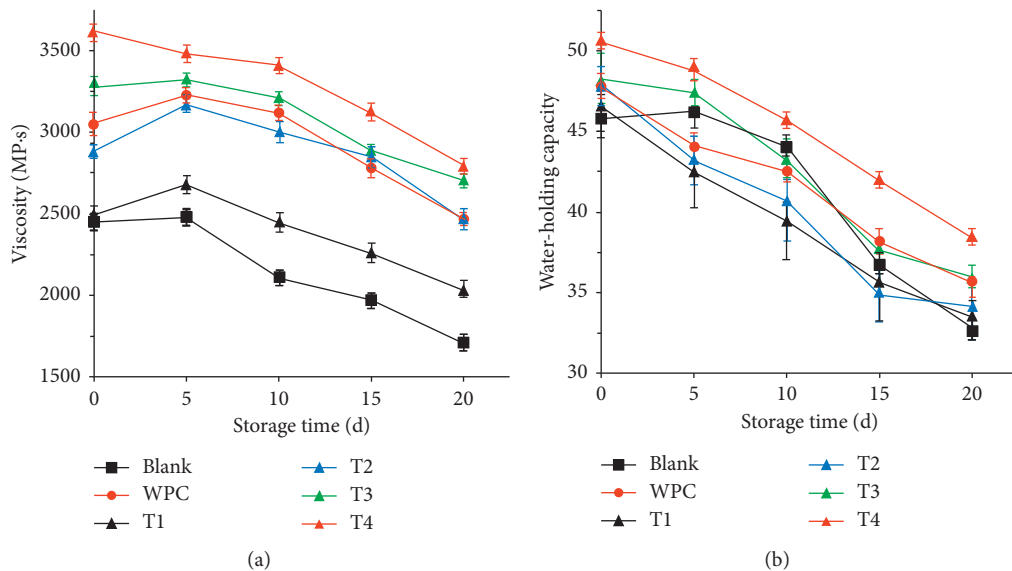


FIGURE 6: Continued.

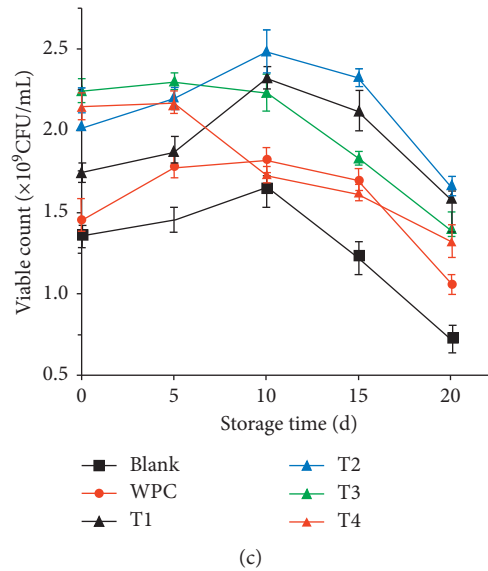


FIGURE 6: Effect on viscosity (a), water-holding capacity (b), and the total number of lactic acid bacteria (c) of yoghurt by ESBF during storage. Blank: yoghurt without additives; WPC: yoghurt added with 20 g·L⁻¹ of WPC; T1: yoghurt added with 10 g·L⁻¹ of ESBF; T2: yoghurt added with 20 g·L⁻¹ of ESBF; T3: yoghurt added with 30 g·L⁻¹ of ESBF; T4: yoghurt added with 40 g·L⁻¹ of ESBF. Data represent the means of triplicate trials ± standard deviation.

4. Conclusions

This study evaluated the applicability of ESBF as natural additives with thickening properties and the potential to increase water-holding capacity and lactic acid bacteria amount of yoghurt. The ESBF was shown to increase G' , lower G'' , and improve the texture of yoghurt. The thickening effect of ESBF in yoghurt could be attributed to dietary fibers and proteins, which has gelatinization property to absorb and bind more amount of free water. Besides, β -glucan in ESBF could be utilized as a growth substrate by lactic acid bacteria to produce more EPS which is also beneficial to the improvement of yoghurt texture. The barley starch grain and protein tend to deposit themselves on the surface of the casein micelles for reducing the free end, while β -glucan in barley may form secondary gelled structures between casein micelle aggregates, which is not visible by SEM. Based on the above, the ESBF has great potential as a natural ingredient with a role in improving textural and nutritional properties of yoghurt products. In particular, barley is a more economical food ingredient than some other proteins.

Data Availability

All data generated or analyzed during this study are included in this article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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