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Research Article

Effects of Bamboo Shoot Dietary Fiber on Mechanical Properties, Moisture Distribution, and Microstructure of Frozen Dough

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In this paper, the effects of Bamboo shoot dietary fiber (BSDF) on the mechanical properties, moisture distribution, and microstructure of frozen dough were investigated. The state and distribution of water in frozen dough was determined by differential scanning calorimetry (DSC) and low-field nuclear magnetic resonance (LNMR) spectroscopy. The microstructure of frozen dough was studied. The structure of the gluten protein network found in wheat flour dough was studied by scanning electron microscopy (SEM). The result showed that the BSDF could significantly improve the viscoelasticity and extensibility of frozen dough after thawing in a dose-dependent manner. It was significantly improved with the increase in the addition amount of BSDF ($P < 0.05$). DSC analysis showed that the freezable water content and thermal stability of frozen dough were increased after the addition of BSDF. LNMR analysis showed that the appropriate (<0.1%) addition amount of BSDF could significantly ($P < 0.05$) decline the contents of bound water. Meanwhile, the loose bound water and free water were raised significantly ($P < 0.05$) after the addition of BSDF. Moreover, the addition of BSDF induces arrangement of starch granule and gluten network in frozen dough. BSDF can be used as a novel quality improver of frozen dough.

1. Introduction

Dietary fiber is the edible part of plants or analogous carbohydrates, which cannot be digested or absorbed in the human intestinal tract, and as such they proceed to the colon. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Many studies have demonstrated that the intake of dietary fiber can reduce the developing risk of cardiovascular diseases, hypertension, diabetes, obesity, cancer, and certain gastrointestinal disorders [1]. In addition to the various health benefits, dietary fiber also can improve the functional properties of many food products including water-holding capacity, oil-holding capacity, foaming capacity, emulsification and/or gel formation. When incorporated into foods (such as bakery and dairy products, jams, meats, and soups), dietary fibers can modify textural properties, avoid syneresis, stabilize high fat food and emulsions, and improve shelf life [2, 3]. Juvenile bamboo shoots have a long history of being used as nutritious food and medicine in many Asian countries like China, Korea, Japan, and Thailand. Bamboo shoots are a good source of edible fiber (6 to 8 g/100 g fresh weight). Bamboo shoot dietary fiber (BSDF) is available as a white tasteless powder containing little or no calories. Nowadays, BSDF has been widely used in various food products, such as bakery, meat, milk, sausage, beverages, spices, pasta, mustards, ketchups, and frozen dough [4].

Frozen dough technology began in the 1950s, which is widely used in food industry to facilitate the production of bread, Chinese steamed bread, dumplings, and several viennoiseries. Frozen dough technology can improve the work efficiency, reduce the labor intensity of workers, increase the shelf life of products, and facilitate long-distance distribution of foods [5]. Two kinds of frozen dough are available, differing in whether or not the fermentation has occurred prior to freezing. Nonfermented frozen dough is fermented after thawing, and dough fermented before freezing is referred to as prefermented frozen dough [6]. However, frozen dough requires a longer proof time and produces products with lower specific volume and a texture that differs from freshly produced. The freezing process result in denaturation of protein, fat, starch, and other major components in dough. In addition, ice crystals will form during the freezing process, which can destroy the structure of dough. Moreover, the viscoelastic property of dough is also decreased with the freezing and thawing processes of dough, resulting in quality changes of final food products [7, 8]. Thus, it is necessary to improve the quality of frozen dough by appropriate food process technology.

The use of bamboo fiber as an ingredient can be effective for preserving the softness of the internal paste for longer time and help control moisture loss in high- and intermediate-moisture foods. It has been demonstrated that BSDF can be added into cookies, wheat flour, and cakes [9] to improve the texture properties and color [10]. However, there are few reports on the research and application of BSDF in frozen dough.

In our previous work, the functions and physical chemical properties of rice dietary fiber (RDF), soybean dietary fiber (SDF), and BSDF were compared. The result showed that the water holding capacity, oil holding capacity, swelling property, adsorption capacity of nitrite, and cholesterol of BSDF were significantly better than that of RDF and SDF. The BSDF was much more suitable to be used in foods. Therefore, the aim of this study was to investigate the influence of BSDF addition on the mechanical properties of frozen dough after thawing and the state and distribution of water in frozen dough. Furthermore, the microstructure of frozen dough was also characterized by scanning electron microscopy (SEM) to clarify the possible reasons for BSDF-mediated processing property changes of frozen dough.

2. Materials and Method

2.1. Materials. Bamboo shoot dietary fiber (BSDF) was obtained from Zhejiang Geng Sheng Tang Ecological Agriculture Co., Ltd. (Zhejiang, China). Wheat flour was purchased from China National Cereals, Oils, and Foodstuffs Corporation (Zhengzhou, China) with a protein content of 9.0%, moisture content 12.8%, and fat content 1.5%.

2.2. Preparation and Freezing of Dough. Wheat flour (1.0 kg), BSDF (0%, 1.0%, 1.5%, and 2.0% of the wheat flour weight), and salt (10 g) were mixed evenly. Then the mixed powder was hydrated by adding water (420 g) for 6.5 min and molded into dough. The doughs were put in the constant temperature box about 30 min (about 30°C, humidity 85%). Doughs were rounded and moulded into 400 g sausage shaped pieces. After mixing, dough pieces were frozen for 10 min in a mechanical blast freezer for 120 min at −35°C to a core temperature of −18°C. Immediately after freezing, dough pieces were placed in double high-density polyethylene (HDPE) bags and transferred to storage freezers at −20 ± 0.5°C.

2.3. Determination of Mechanical Properties of Frozen Dough

2.3.1. Determination of Tensile Properties. The frozen doughs were defrosted at 30°C in an incubator for 1 h and then subjected to the tension test with a tensile analyzer (TMS-Pro, Food Technology Co., Virginia, USA). The measurement was conducted with a Kieffer dough and gluten extensibility rig at a crosshead speed of 3.3 mm/s. The plots of force versus distance were recorded to obtain R_{max} and E values. R_{max} is the maximum peak force, which is a measure of the resistance of dough to stretching. E indicates the distance to rupture, which is the extensibility of dough [11].

2.3.2. Determination of Rheological Properties. The rheological properties were measured according to the methods of Wang et al. [12]. Briefly, the rheological behavior of dough was analyzed by a controlled stress rheometer (DSR200, Rheometric Scientific, USA) for small amplitude oscillation test. The measurement system was equipped with a parallel plate geometry (40 mm diameter) with a smart swap peltier plate temperature system to maintain the temperature at 25°C. Then, dough was loaded between the parallel plates and compressed to obtain a gap of 1 mm. Subsequently, dough was rested between the plates (5 min) before measurement. Stress sweep at 1 Hz frequency was carried out to determine the linear viscoelastic zone. Frequency sweeps test was carried out from 0.1 to 10 Hz to determine the elastic modulus (G'), viscous modulus (G''), and loss tangent ($\tan\delta$) as a function of frequency.

2.4. Analysis of Water State and Distribution in Frozen Dough

2.4.1. Differential Scanning Calorimetry (DSC). A differential scanning calorimeter (model DSC-Q200, TA Instruments, USA) was used to measure the freezable water in the heat treated samples. A slice subsample of 5–10 mg from each sample was encapsulated into an aluminum pan and cooled from 30°C to −40°C at 5°C/min using liquid nitrogen and then heated to 40 K at 5°C/min. According to the method of Yoshida et al. [13], the total amount of freezable water (W_f) in extrudate was calculated from the ratio of melting enthalpy at 0°C for per gram of sample and pure water. The amount of nonfreezable water (W_{nf}) in the extradite was defined as $W_{nf} = W_c - W_f$, where W_c was the total water content of samples, obtained by weight loss method. Two duplicate measurements were made for each sample.

2.4.2. Nuclear Magnetic Resonance (NMR). A low field pulsed NMI 20-Analyst (Shanghai Niumag Corporation, China) with 22.6 MHz was used in the experiment. Approximately 2 g of strip sample was placed in a 15 mm glass tube and inserted in the NMR probe. Carr-Purcell-Meiboom-Gill (CPMG) sequences were employed to measure spin-spin relaxation time, T_2. Typical pulse parameters were as follows: dwell time was 4 μs, echo time was 420.00 μs, recycle time

Table 1: Effects of BSDF addition on extensive ability of frozen dough*.

Addition amount of BSDF (%)	Tensile resistance (BU)	Extensibility (mm)	Ratio values
Control	493 ± 7^{c}	158 ± 2^{a}	2.9 ± 0.4^{b}
1.0	540 ± 5^{b}	139 ± 4^{b}	5.0 ± 0.4^{a}
1.5	611 ± 8^{a}	142 ± 5^{b}	4.8 ± 0.2^{a}
2.0	537 ± 4^{b}	132 ± 3^{b}	4.6 ± 0.3^{a}

*Means ± SD ($n = 3$). Within a column means with different superscript letters are significantly different ($P < 0.05$).

was 600 ms, echo count was 350, and scan repetitions were 16. Each measurement was performed in duplicate.

2.5. Microstructure Analysis of Frozen Dough. Microstructure analysis of frozen dough was referenced by Zhang et al. (2015) and Zounis et al. [14, 15]. The frozen dough was dried by a freeze dryer (ALPHA 1-2, Martin Christ Inc., Osterode, Germany). Then, a thin layer of the sample powder was mounted on the copper sample-holder with a double sided carbon tape and coated with gold of 10 nm thicknesses to make the samples conductive. The microstructure of frozen dough was observed using a scanning electron microscope (JSM-7001F, JEOL, Tokyo, Japan) at acceleration voltage of 15 kV.

2.6. Statistical Analysis. The results were analysed by one-way ANOVA under the significance level of $P < 0.05$ using SPSS 16.0 software (IBM Corporation, NY, USA). The graphs were drawn by OriginPro8 (OriginLab Corporation, MA, USA).

3. Results and Discussion

3.1. The Effects of BSDF on the Mechanical Properties of Frozen Dough

3.1.1. Tensile Properties. The tensile resistance and extensibility are the two important indicators of processing characteristics of dough [16, 17]. The resistance, extensibility, and draw ratio values of dough with different amount BSDF after thawing are shown in Table 1.

As seen from Table 1, the addition of BSDF significantly ($P < 0.05$) increased the resistance value and decreased extensibility of the dough. The addition of BSDF strengthen the gluten network structure of dough. Enhanced gluten network provides more flexibility for dough. The high extensibility indicates a high extend ability of dough, which collapses during the proofing stage. As shown in Table 1, the addition of BSDF significantly ($P < 0.05$) reduced the extensibility, which was indicating that the BSDF weakened the ductility of dough after thawing. BSDF has good water swelling properties; the swollen granules of BSDF were broken easily and impact the ductility of dough [18]. Compared with the control group, the ratio of tensile resistance and extensibility of dough with BSDF was significantly increased. The addition of BSDF improved the viscoelasticity, extensibility, and plasticity of frozen dough.

3.1.2. Rheological Properties. The G values were used to indicate the stiffness of viscoelastic properties and present the rheological properties of dough. The effects of BSDF on the rheological behavior of dough were shown in Figure 1.

According to Figures 1(a) and 1(b), the values of G' and G'' of dough were increased with the increasing levels of BSDF. These results suggested that the addition of BSDF strengthened the elasticity and viscosity abilities of dough, which could be beneficial to the products quality of dough [19]. The $\tan\delta$ value is another important indicator of dough quality. Compared with the control group (addition amount of 0%), the $\tan\delta$ was an obvious decrease regardless of containing different BSDF. The lowest value was obtained at the addition amount of 1.5% (Figure 1(c)). The lower $\tan\delta$ implied more elastic and lesser viscous behavior and the formation of a stable network structure [12].

3.2. Effects of BSDF on the Water State and Distribution in Frozen Dough. The influences of BSDF on the rheological property of frozen dough may be attributed to the changes in the moisture distribution, microstructure, and aggregates formation [20]. Therefore, the effects of BSDF addition on moisture distribution and microstructure of frozen dough were studied.

3.2.1. DSC Analyses. The effects of BSDF addition on changes of ice crystals melting enthalpy and freezable and nonfreezable water contents of frozen dough were shown in Table 2. The enthalpy (ΔH) presents the ice crystals melting enthalpy [21].

As shown in Table 2 the enthalpy of frozen dough was increased with the increasing of BSDF addition amount. The higher enthalpy values represent a higher thermal stability of frozen dough. With the BSDF addition amount increased, the relative percentage content of freezable water was increasing. By contrast, the relative percentage content of nonfreezable water declined with the increase of BSDF addition amount. The differences and changes of water state in food could reflect the different interactions between molecular water and food components [22]. Hayashi et al. [23] found that the water molecules in polysaccharide hydrogels (namely, sodium salts of xanthan and hyaluronic acid) could be classified into nonfreezable, freezable bound, and free water by using DSC technique based on the difference in phase transition behavior of different water states and found that, below the critical quantity, all the water molecules were bound to protein or

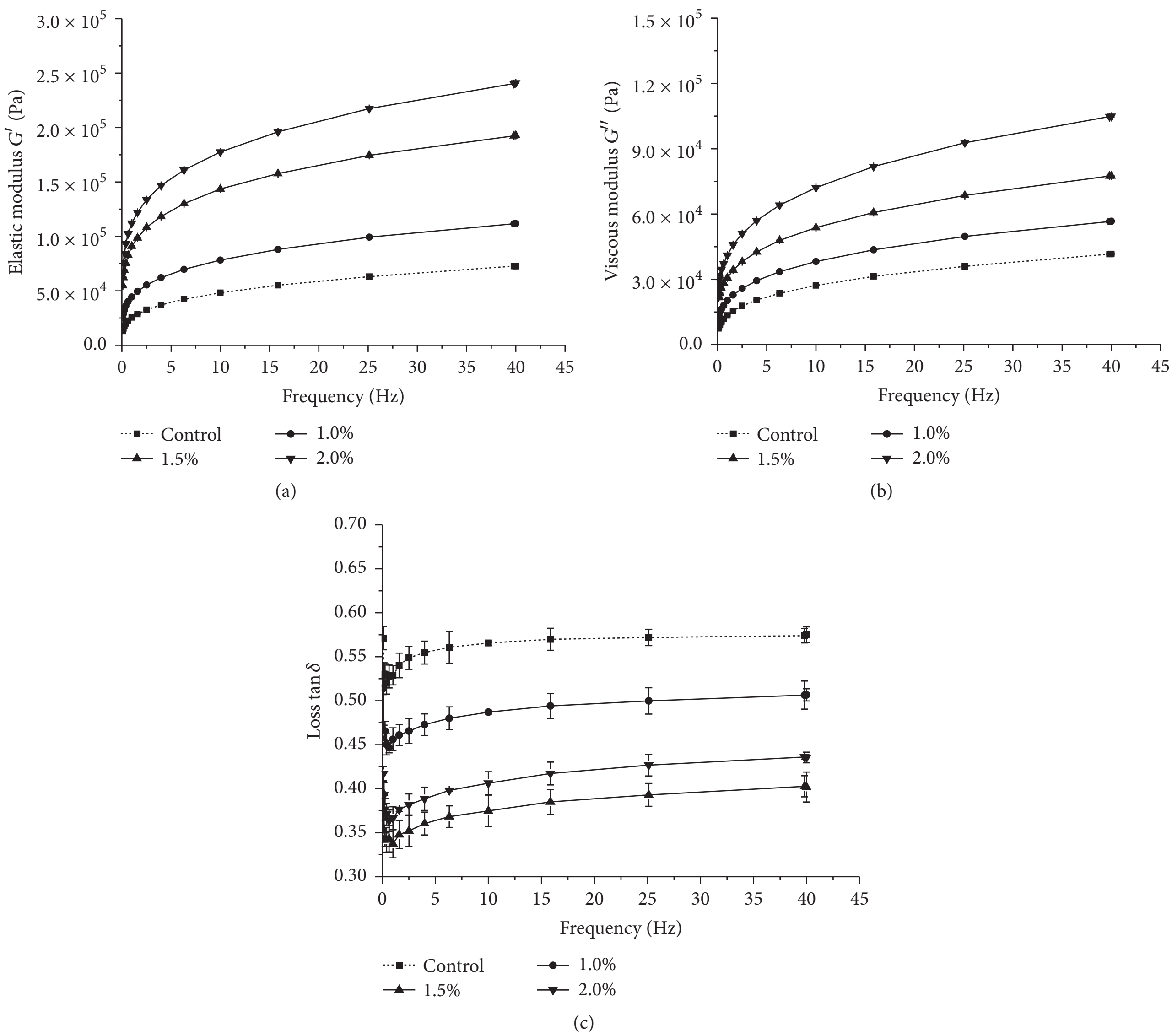

Figure 1: The effects of BSDF addition on the rheological property of frozen dough ((a) elastic modulus, (b) viscous modulus, and (c) loss tan δ.).

other macromolecules. Previous literature also found that when adding water into raw materials, nonfreezable water was necessary for protein plasticization [24], and freezable water worked as a lubricant to affect the flow and viscosity of protein dough [23].

Generally, the addition of BSDF increased the freezable water content of frozen dough and the thermal stability of frozen dough. This change maybe caused the decrease of extensibility of frozen dough.

3.2.2. NMR Analyses. Low-field nuclear magnetic resonance (LNMR) technique is widely used to investigate the phase and distribution characteristics of moisture in foods and food materials [25, 26]. T_{21} (peak 1 in Figure 2), T_{22} (peak 2 in Figure 2), and T_{23} (peak 3 in Figure 2) were the relaxation components, and PT_{21}, PT_{22}, and PT_{23} were the corresponding area fractions. It has been suggested that T_{21} component reflects water closely associated with micromolecules (bound water) [27] and T_{22} component reflects water trapped within the frozen dough microstructure (weak binding water), while T_{23} component corresponds to free water [28].

The peak 2 was the main peak (Figure 2), indicating that the water distribution of frozen dough was mainly based on loose binding water. The addition of the BSDF changed the water status and distribution in frozen dough. After the addition amount of BSDF, the area fractions of bound water declined significantly ($P < 0.05$), and decline by 57.26% at the addition amount of BSDF was 1% compared to the control (Table 3). After the addition of BSDF at 1.5% and 1.0%, the area fractions of loose bound water and free water

Table 2: Effects of content of BSDF on water content of frozen dough determined by DSC*.

Addition amount of BSDF (%)	ΔH (J/g)	Freezable water (%)	Nonfreezable water (%)
Control	73.00 ± 0.51^{d}	21.89 ± 0.38^{d}	18.20 ± 0.22^{d}
1.0	76.81 ± 0.63^{c}	23.00 ± 0.36^{c}	17.02 ± 0.32^{c}
1.5	80.78 ± 0.70^{b}	24.17 ± 0.23^{b}	15.77 ± 0.40^{b}
2.0	83.79 ± 0.51^{a}	25.14 ± 0.30^{a}	14.89 ± 0.31^{a}

*Means ± SD ($n = 3$). Within a column means with different superscript letters are significantly different ($P < 0.05$).

Table 3: Effects of content of BSDF on 3 kinds of state water content of frozen dough*.

Addition amount of BSDF (%)	T_{21} (%)	T_{22} (%)	T_{23} (%)
Control	7.51 ± 0.19^{a}	92.20 ± 1.11^{b}	0.24 ± 0.14^{c}
1.0	7.42 ± 0.09^{a}	92.10 ± 0.90^{b}	0.46 ± 0.21^{a}
1.5	3.21 ± 0.23^{b}	96.49 ± 0.77^{a}	0.29 ± 0.18^{b}
2.0	3.58 ± 0.25^{b}	96.11 ± 0.89^{a}	0.28 ± 0.19^{b}

*Means ± SD ($n = 3$). Within a column means with different superscript letters are significantly different ($P < 0.05$).

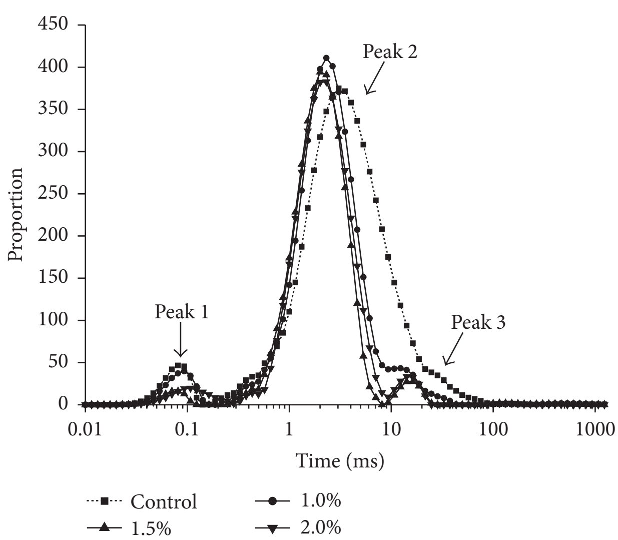

Figure 2: The effects of BSDF on the low-field nuclear magnetic resonance water distribution of frozen dough.

were increased by 4.65% and 91.67% ($P < 0.05$), respectively. When the addition amount of BSDF was more than 1.5%, the effects of BSDF on water distribution were not enhanced.

BSDF with a strong water holding ability could change the water distribution of frozen dough by competing with gluten protein and starch in dough. The change of water distribution in frozen dough has a direct impact on the characteristics of elasticity, viscosity, and rheological properties of frozen dough after thawing.

3.3. Effects of BSDF on Microstructure of Frozen Dough. In order to investigate the influence of BSDF on the microstructure of frozen dough, the SEM characterization was examined and the results were shown in Figure 3.

As shown in Figure 3(a), the starch granules in the dough with different sizes were wrapped in the network structure of gluten. Starch granules were featured as clear circular particles and the gap of starch granules were larger. Figures 3(b)–3(d) showed that the addition of BSDF changed the microstructure of frozen dough in a BSDF dose-dependent manner. Compared to control group (Figure 3(a)), the gap between starch granules of the BSDF added samples decreased, starch granules and dough matrix network structure began to appear adhesive state.

Summarily, the addition of BSDF changed the microstructure of frozen dough, causing a more delicate arrangement of starch granules and gluten network. The BSDF-induced changes in microstructure of frozen dough are the important reason for the changed of mechanical properties of frozen dough.

4. Conclusion

In this work, the effects of BSDF (1.0%, 1.5%, and 2.0%) on the processing properties, water distribution, and microstructure of frozen dough were investigated. The result showed that the viscoelasticity and extensibility of frozen dough after thawing were significantly ($P < 0.05$) improved with the addition of BSDF. The addition of BSDF also changed the water state and distribution in frozen dough. After adding the BSDF, the freezable water contents and thermal stability were significantly increased ($P < 0.05$). The bound water of frozen dough was significantly decreased ($P < 0.05$) at the

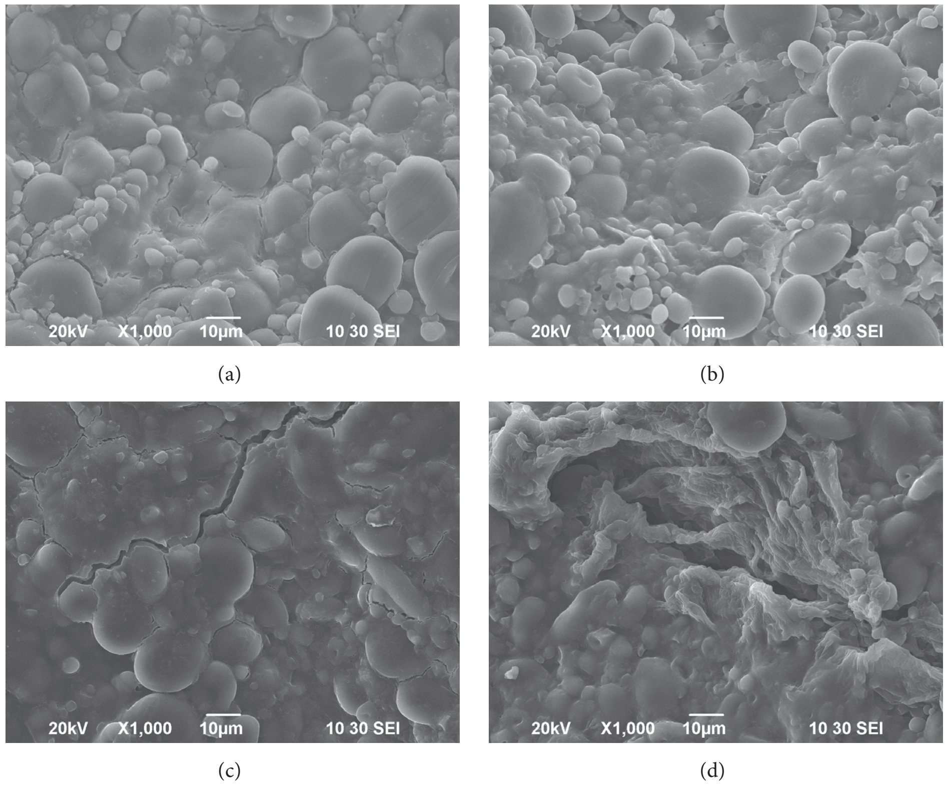

Figure 3: The effects of BSDF on the microstructure of frozen dough ((a) control, (b) BSDF addition amount of 1.0%, (c) BSDF addition amount of 1.5%, and (d) BSDF addition amount of 2.0%).

appropriate adding amount (<0.1%) of BSDF. Meanwhile, the loose bound water and free water were raised significantly ($P < 0.05$) by the addition of BSDF. SEM analysis found that the addition of BSDF induced obvious changes in the microstructure of frozen dough, such as the arrangement of starch granule and gluten network.

This work demonstrated that the addition of BSDF can increase the viscoelasticity, extensibility and plasticity of frozen dough, and improve the processing properties of frozen dough. The quality improvement effects of BSDF may be related with the increases in freezable water content, loose binding water content, and free water content the decrease in the binding water content and changes in the microstructure of frozen dough.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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