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Protein polymerization and water mobility in whole-wheat dough influenced by bran particle size distribution

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The influences of bran particle size distribution on the protein polymerization and water mobility in whole-wheat dough (WWD) were investigated. Four bran particle size distributions were obtained by fine-grinding treatments and the mean particle sizes of reconstituted whole-wheat flour (WWF) were 242, 160, 114, and 45 μm, respectively. Mixolab parameters showed that WWF water absorption was increased with reduced bran particle size, and the 160 μm group exhibited a higher stability than any other WWF group. A more continuous gluten matrix and a more compact structure were observed in the 160 μm group due to its moderate bran particle size. Protein secondary structure analyses indicated the increased β-sheet conformation and reduced β-turns structure in the 160 μm group, demonstrating a more polymerized and stable gluten network formed. Additionally, ^{1}H NMR measurements showed larger populations of tightly bound water in WWD due to the presence of arabinoxylan, and confirmed the strengthened gluten strength in the 160 μm group by indicating increased water availability to gluten proteins. The results suggest that modifying bran particle size is a potential method for protein polymerization enhancement and gluten formation improvement in WWD, but appropriate bran particle size is needed to strengthen gluten network.

1. Introduction

To meet the growing demand for low-calorie and healthy food, the development of cereal products with high contents of dietary fiber has become an effective way to change the dietary pattern of consumers. Whole-wheat product, as a rich source of dietary fiber and phytochemicals, has received increasing attention in recent years (Liu, 2007). Long-term intake of whole-wheat products can provide beneficial effects on the prevention of chronic diseases such as hypertension, diabetes, and colon cancer (Giacco, Della Pepa, Luongo, & Riccardi, 2011). However, the addition of wheat bran not only interrupts the formation of gluten network but also exerts adverse effects on the sensory and textural properties of bran-contained products. Many efforts are being made to enhance the quality characteristics of whole-wheat products (Koocheki, Mortazavi, Mahalati, & Karimi, 2009; Vijayakumar & Boopathy, 2014).

Among the existing techniques, milling process is considered one of the effective ways to reduce the destructive effects of bran and germ on end-use products. The particle size distribution of wheat bran or whole-wheat flour (WWF) has been proven an important factor that influences dough mixing properties and product qualities (Talbert et al., 2013). A number of milling techniques such as stone mill, hammer mill, and roller mill are used to produce WWF (Posner, 2009; Prabhasankar & Rao, 2001). Alternatively, superfine and ultrafine grinding techniques, which can produce fine powders on micro- and submicron-scales, have been applied for grinding wheat bran or wheat kernels to produce bran-contained flour or WWF (Korolchuk, 2005; Liu et al., 2015). Several literatures have reported the influences of milling processes and

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Abbreviations: AACC, American Association of Cereal Chemists; CPMG, Carr-Purcell- Meiboom-Gill; EDTA, Ethylene Diamine Tetraacetic Acid; FT-IR, Fourier Transform Infrared spectroscopy; SEM, Scanning Electron Microscopy; SDS-PAGE, Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis; SGF, Straight Grade Flour; NMR, Nuclear Magnetic Resonance; WWD, Whole-Wheat Dough; WWF, Whole-Wheat Flour.

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particle size on the properties of bran, WWF, and their products. Hemery et al. (2011) noted that milling process caused the dissociation of different layers in wheat bran and increased the release of bioactive compounds. Chen et al. (2011) obtained three particle size distributions (1.5–2 mm, 0.43–1 mm, and 0.16–0.43 mm) of wheat bran by further grinding, and found that the textural properties and sensory qualities of dried white Chinese noodles were enhanced with decreased particle size. Liu et al. (2015) reported that bran grinding processes by a hammer mill or an ultrafine mill provided a larger height/diameter ratio and specific volume of Chinese steamed bread than entire grain grinding processes by a stone mill or an ultrafine mill. In our previous studies, the impacts of bran particle size on the properties of WWF and its noodle qualities were investigated (Niu, Hou, Lee, & Chen, 2014a; Niu, Hou, Wang, & Chen, 2014b). The reduced wheat bran or WWF particle sizes provided beneficial effects on the quality improvement of whole-wheat noodle.

Gluten protein is a main determinant for the qualities of flour-based products by influencing dough water absorption and viscoelasticity. The formation of gluten network plays a vital role in affecting the mechanical properties of wheat dough. Both hydration and mixing are the critical processes for protein polymerization and dough formation. During hydration, water acts as a solvent that solubilizes water-soluble low molecular weight (Mw, 30–60 KDa) proteins and increases dough mobility. It also can induce the conformational changes for hydrophobic interactions (Wang, Jin, & Xu, 2015). The mixing process results in tightly polymerized gluten proteins and the formation of a three-dimensional viscoelastic network. Gluten network is formed and stabilized by covalent disulfide bonds and non-covalent interactions such as hydrogen bonds, ionic bonds and hydrophobic bonds (Domenek, Morel, Redl, & Guilbert, 2003). Hence, flour components or dough additives that impact hydration and mixing processes have certain effects on gluten formation and end product qualities. Wheat bran accounts for 250–300 g/kg of WWF; bran particle size influences its interaction with proteins and the cross-linking between gluten proteins, thus demonstrating an impact on protein polymerization and dough making process. Nevertheless, there have been very few literatures available on the effects of varying bran or WWF particle size on protein polymerization and gluten formation in whole-wheat systems.

Water mobility and distribution in wheat dough have prominent effects on dough rheological behaviors and technological properties. Generally, water, either bound to flour components or free, is not evenly distributed among the constituents in dough (Lu & Seetharaman, 2013; Ruan et al., 1999). Bound water facilitates the formation of gluten network and contributes to the supramolecular organization of dough structure. Unbound water is related to dough flow properties (Roman-Gutierrez, 2002). Overall, the dynamic properties of water and its distribution are strongly associated with the elasticity and extensibility of dough and textural properties of end products. However, to the best of our knowledge, the impacts of bran particle size on the water mobility and distribution in whole-wheat dough (WWD) have been rarely reported.

The objective of this study was to investigate the influences of bran particle size distribution on the protein polymerization and water mobility in WWD. The dough mixing properties, microstructure, protein electrophoresis patterns, protein secondary structure, and water mobility were evaluated. The study was expected to interpret the interactions between bran and other flour components in WWD, and provide valuable guidance for further quality improvement of whole-wheat products.

2. Materials and methods

2.1. Materials

Wheat bran (millfeeds) and straight grade flour (SGF) were provided by Dacheng Group (Zhumadian, Henan). Wheat bran was obtained by collecting the coarse bran, shorts, and red dog fractions after wheat kernels were milled and blending them according to their respective yields. SGF was from the same batch of wheat samples (hard white spring) as wheat bran and the extraction rate was around 700 g/kg. The protein, starch, ash, and moisture contents of the wheat samples were 137 g/kg, 566 g/kg, 17 g/kg, and 125 g/kg, respectively.

2.2. Preparation of fine-ground bran and whole-wheat flour (WWF)

Wheat bran was further ground using a ZM 200 ultra-centrifugal mill (Retsch, Haan, Germany) with a 0.25 mm mesh at 8000, 10 000, 14 000, and 18 000 r/min, respectively, to achieve varying particle size. WWF samples were prepared by combining fine-ground bran with SGF in accordance with their respective yields. The particle size distributions of fine-ground bran and reconstituted WWF were determined using a Mastersizer 2000 laser particle analyzer (Malvern Instruments Ltd., Malvern, United Kingdom) equipped with a wet sample delivery and measurement system. The resulting bran and WWF groups were labeled with each mean particle size. Damaged starch in WWF was determined according to the AACC International Approved Method 76-30A (AACC, 2010).

2.3. Mixolab parameters

The dough mixing properties of WWF and starch pasting properties of WWD were determined by a Mixolab (Chopin Technologies, Villeneuve-la-Garenne, France), according to the method of Niu, Hou, Kindelspire, Krishnan, and Zhao (2017). A constant dough weight (75 g) method was used under standard “Chopin+” protocol. An exact amount of each WWF sample was weighed and placed into the mixer as specified by the Mixolab software. The settings of the heating and cooling circles were first maintained at 30 °C for 8 min, increasing at 4 °C/min until the mixer temperature reached 90 °C, decreasing at the same speed until the temperature reached 50 °C after an 8-min holding period at 90 °C, and finally holding at 50 °C for 6 min. The parameters obtained from the recorded curve were water absorption, dough development time, stability, peak torque, setback, and hot-gel stability.

2.4. Preparation of whole-wheat dough (WWD)

WWF sample (300 g, 140 g/kg moisture basis), water (the same amount as the water absorption indicated by Mixolab), and yeast (3.6 g) were weighted and placed in a laboratory dough mixer. The blend was mixed for 10 min at 60 r/min and the resulting WWD was fermented at 37 °C with 85% relative humidity for 60 min. The dough made from SGF was set as the control group. The fresh fermented dough was lyophilized before the analyses of free sulfhydryl group, protein electrophoresis patterns, and protein secondary structure.

2.5. Scanning electron microscopy (SEM)

The SEM study of WWD microstructure was carried out as described by Niu et al. (2017), using a Quanta 3D scanning electron microscope (FEI Co, Tokyo, Japan). The fresh fermented WWD was soaked in glutaraldehyde solution (25 mL/L) for 2 h and rinsed with phosphate buffer (0.1 mol/L), followed by a secondary fixation in