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Influence of gliadin removal on strain hardening of hydrated wheat gluten during equibiaxial extensional deformation

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Abstract

The aim of the present work has been to study the equibiaxial extensional deformation of doughs of gluten- and glutenin-rich fractions containing 40 wt% water subjected to lubricated squeezing flow with four different crosshead speeds at room temperature. The gluten dough shows strain softening and hardening in succession whilst the dough where the gliadins have been removed by alcohol extraction does not show strain hardening behavior but breaks immediately after strain softening. The equibiaxial extensional viscosity decreases with increasing strain rate at given strains, appearing as strain rate thinning behavior, which is stronger in the glutenin dough than in the gluten dough. The large extensibility with strain hardening in the gluten dough is due to the presence of gliadins acting as both plasticizers and promoters for the more extensible networks.

Keywords: Wheat gluten; Glutenin; Equibiaxial extensional deformation; Softening; Hardening

1. Introduction

Among the cereal flours, only wheat flour can form viscoelastic dough upon hydration, which allows production of leavened bread. The viscoelasticity of doughs is closely related to the gluten proteins (He and Hoseney, 1991; Janssen et al., 1996a, b, c; Miller and Hoseney, 1999). Gliadins and glutenins, accounting for 80–90% of the total flour proteins, are the two primary classes of storage proteins in wheat. It is now widely accepted that gliadins confer viscous properties on gluten whilst glutenins impart strength and elasticity (Shewry et al., 1986).

Rheological testing in the linear viscoelastic region at small strains is widely used to characterize the structure and properties of wheat gluten and its subfractions and to indicate the breadmaking quality of wheat (Khatkar et al., 1995; Song and Zheng, 2007). During all stages of food making including mixing, proofing, molding and fermentation, however, flour dough undergoes large deformations primarily dominated by the gluten fraction (Kieffer et al., 1998; Kokelaar et al., 1996; Rinde et al., 1970; Uthayakumaran et al., 2002). Equibiaxial extension of wheat flour and gluten doughs is therefore of special interest because this deformation closely resembles practical condition experienced by the protein cell walls around the expanding gas cells within the dough during proof and oven rise. The nonlinear stress–strain relationship in biaxial extension of flour dough and hydrated gluten have been studied extensively (Dobraszczyk and Roberts, 1994; Kieffer et al., 1998; Kokelaar et al., 1996; Rinde et al., 1970; Uthayakumaran et al., 2002; van Vliet et al., 1992). Extensional deformation causes a nonlinear increase in viscosity with increasing strain, as shown by the increasing

Abbreviations: ε_B, equibiaxial strain; $\dot{\varepsilon}_B$, strain rate; η_B, apparent extensional viscosity; G_B, instantaneous shear modulus; HMW-GS, high molecular weight glutenin subunits; k, Boltzmann's constant; K, consistency; K_1, parameter characterizing the sensitivity of strain softening; L, Langevin function; L^{-1}, inverse Langevin function; λ_B, equibiaxial draw ratio; λ_i, principal draw ratio; LMW-GS, low molecular weight glutenin subunits; M, powder-law index; n, number of random links between effective crosslinks and chain entanglements; N, number of elastic chains per unit volume; σ_B, equibiaxial stress; T, absolute temperature; V, crosshead speed; W, strain energy potential

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upward slope of the stress–strain curve (Dobraszczyk and Morgenstern, 2003; Dobraszczyk and Roberts, 1994). The gluten fraction dominates the large deformation behavior of flour dough and hydrated gluten shows strain hardening higher than flour dough (Sliwinski et al., 2004). The strain hardening during extensional flow is thought to arise mainly from entanglement coupling of the large glutenin molecules which gives rise to the high viscosities at large strains (Dobraszczyk and Morgenstern, 2003; Singh and MacRitchie, 2001).

The dynamic rheological behavior of glutenin-rich fractions and the influence of gluteinin enrichment on the rheological and processing properties of gluten and flour doughs have been investigated. Glutenin viscoelasticity is highly dependent on molecular weight (Tsiami et al., 1997) and the dominant factor is the interaction of large concatenations formed by high molecular weight glutenin subunits (HMW-GS) and low molecular weight glutenin subunits (LMW-GS) (Cornec et al., 1994). Except for the gliadin/glutenin ratio, glutenins influence the gluten viscoelasticity by modifying the size distribution and the protein aggregation through crosslinking. The glutenin aggregation leads to a significant rise in elastic plateau modulus of the gluten network (Cornec et al., 1994; Popineau et al., 1994). Glutenin addition in wheat flour results in a more elastic dough in comparison with gluten and gliadin additions (Edwards et al., 2001). It has been speculated that the structural and rheological properties of the insoluble glutenin fraction are mainly responsible for variations in baking performance (Dobraszczyk, 2004). This speculation should be further examined by using equibiaxial extension technique.

To reveal the contribution of glutenins to the large deformation behavior of gluten, it is necessary to remove gliadins and to study the stress–strain relationship during equibiaxial extensional deformation. The present study investigates equibiaxial extensional flow of hydrated gluten and glutenin-rich fractions with a water content of 40 wt% using lubricated squeezing flow technique (Chatraei et al., 1981) at different crosshead speeds.

2. Materials and methods

2.1. Materials

Wheat gluten with a protein content $\geqslant$75% and an ash content $\leqslant$0.95% was supplied by Shanghai Wangwei Food Co. Ltd., China. The moisture content was 7.8 wt% on dry basis.

Glutenin-rich fraction was extracted from wheat gluten according to the method described by Larre et al. (1997) with slight modification. Gluten (100 g) was extracted in an aqueous solution (200 ml) of 70% (v/v) ethanol/water mixture at 40 °C for 4 h under continuous stirring. The suspension was centrifuged for 15 min at 4000g at room temperature. The supernatant, containing the gliadin-rich fraction, was discarded. The precipitate, consisting mostly of glutenins and starch, was treated again according the procedure described. The precipitate after the second centrifugation was dried at 40 °C and was ground to pass through a 100 mesh sieve. The protein content in the glutenin-rich fraction was ~58%. Although the use of ethanol as an extractant could alter the properties of the proteins and prolong the mixing time to develop the dough (Hoseney et al., 1969; MacRitchie and Gras, 1973), ethanol extraction was still the most used method to separate gliadin- and glutenin-rich fractions from gluten in a large scale. Janssen et al. (1996c) used 70% (v/v) ethanol to separate gliadins and glutenins from gluten pre-extracted using 0.5 M NaCl. They called the residue after ethanol extraction as "glutenin", whose composition should be similar to the glutenin-rich fraction in this study.

2.2. Sample preparation

Powders of the gluten- or the glutenin-rich fractions were mixed with deionized water to form an apparently homogeneous paste with 40 wt% water content. The paste was molded in a cylindrical mould of polytetrafluorethylene with a size of 20 mm in diameter and 20 mm in height. A strip of polyester film was used to line the inside of the cylindrical mould. The sample surface exposed to air was coated with a thin layer of paraffin oil to avoid moisture exchange between the sample and the surroundings. The samples were rested for 1 h at room temperature. The polyester film was then peeled off and the lateral surface of the sample was coated with paraffin oil.

2.3. Lubricated squeezing flow

The sample was transferred between two parallel disks coated with a thin layer of paraffin oil as lubricant (Charalambides et al., 2005). A universal testing machine (CMT-4204, Shenzhen SANS Test Machine Co. Ltd., China) was used to compress the sample by moving the lower disk at a constant crosshead speed v at room temperature. The displacement, δ, of the lower disk and the load, F, were recorded simultaneously. The diameter of the disk was much larger than that of the sample during the testing so that the method used was referred to the changing area lubricated squeezing flow (Soskey and Winter, 1985; Takahashi et al., 1993).

Assuming that the deformation was uniform and the material was incompressible, equibiaxial strain ε_B and equibiaxial stress σ_B could be calculated according to (Soskey and Winter, 1985; Takahashi et al., 1993)

$$\varepsilon_B = -\frac{1}{2}\ln\left(\frac{H_0-\delta}{H_0}\right) \tag{1}$$

and

$$\sigma_B = \frac{F}{\pi R^2} = \left(\frac{F}{\pi R_0^2}\right)\left(1-\frac{\delta}{H_0}\right), \tag{2}$$