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Extensional dough rheology – Impact of flour composition and extension speed

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ABSTRACT

The rheological properties of dough have an essential role in processing handling and quality of baked products. Understanding how measurement parameters impact dough strain hardening behaviour and how dough microstructure changes during the extensional deformation measurements is important for the evaluation of dough rheological properties. Four wheat flour samples were used in this study. They had either a low (9%) or high (13%) protein content and a glutenin-to-gliadin ratio of 0.35:1 or 0.7:1. The uniaxial extensional measurements were performed at three different extension speeds of 60, 120 or 600 mm/min, respectively. A typical characteristic of viscoelastic materials was obtained, showing that the maximum extension (E_{max}) and maximum resistance (R_{max}) were dependent on the measurement speed, whereas the strain hardening indices were found to be independent on the speed. The differences in glutenin-to-gliadin ratios did not show a significant influence on E_{max} and strain hardening behaviour of dough but they affected the strength and extensibility of rehydrated gluten. The confocal microscopic in situ tensile experiments show that starch granules became aligned within the gluten network in the direction of extensional force. This indicates that both the re-arrangement of gluten network and starch granules contribute to the extensional rheological properties of dough.

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1. Introduction

Rheological properties of dough play an important role in processing handling during the manufacture of dough-based products and end-product quality of baked food such as bread. At different stages of dough processing such as mixing, sheeting, proofing and baking, dough undergoes different mechanical deformations including extension or compression. The extensional deformations dominantly occur during the proofing and baking process, therefore the extensional properties of dough have been seen as an important factor to evaluate the baking performance of flour. The extensional behaviours of wheat flour dough and gluten, are primarily governed by the polymeric network of gluten proteins, which is influenced by the protein content and protein composition such as the molecular size and the ratio of polymeric glutenin to monomeric gliadins (Glu:Gli) (MacRitchie, 1992; Sliwinski et al., 2004a) as well as the interactions between the entanglement of polymeric chains (Singh and MacRitchie, 2001). Upon extensional deformation, wheat flour dough exhibits strain hardening behaviour, which is demonstrated by increasing in stress values with increasing strain (MacRitchie, 1992; Sliwinski et al., 2004a). Gluten shows stronger strain hardening and smaller strain rate dependency compared with flour dough (Sliwinski et al., 2004c). Elongational tests on the dough with modified protein content and Glu:Gli ratios revealed that glutenins contribute to the strength and elastic properties of dough whereas the flow properties are driven by the gliadin fractions (Uthayakumaran et al., 2000). The addition of starch to gluten-starch mixtures also decreased elongational viscosity and changed the strain hardening of gluten-starch mixture (Uthayakumaran et al., 2002).

Large deformation measurements of dough extensibility have been used to assess the baking quality of flour (Dobraszczyk and Salmanowicz, 2008) or for the discrimination of wheat varieties (Anderssen et al., 2004). The selection of appropriate methods to measure the rheological properties of dough which are relevant to bread-making processing continues to be a scientific challenge. Practically, dough extension is measured using the Brabender Extensograph. Such tests provide limited fundamental understanding of dough material behaviour, in particular, the strain–-stress behaviour because the geometry of the samples is not be well

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defined. The Kieffer method with extensibility rig has been developed for the assessment of the flour quality in which the sample size was controlled (Kieffer et al., 1998). However, Ktenioudaki et al. (2011) found that the Extensograph method provided a better correlation of extensibility at rupture with loaf volume compared with the Kieffer rig method. The correlations of fracture stress and fracture strain determined from Kieffer extensibility rig method with loaf volume were found to be rate-dependent (Sliwinski et al., 2004a). The loaf volume was well correlated with fracture strain at the low displacement speed (12 mm/min) while the better correlation between loaf volume and fracture stress was found at the high displacement speed (120 mm/min). Increased speed of extension (from 24 to 200 mm/min) in the Kieffer rig method improved the correlation between the extensibility at rupture of the dough and the loaf volume of bread (Ktenioudaki et al., 2011). Differences in protein content and protein composition could attribute to the different viscoelastic behaviour measured by the Extensograph method compared to the Kieffer rig method (Ktenioudaki et al., 2011; Sliwinski et al., 2004b, 2004c).

Recently, uniaxial extensional measurements with a defined dough sample dimension have been used to study dough rheological properties (Charalambides et al., 2006; McCann and Day, 2013; Uthayakumaran et al., 2000). When changes in the sample shape during the extensional measurement were accounted for the true stress, it was found that dough exhibited a strain rate dependent, non-linear viscoelastic behaviour (Charalambides et al., 2006). Using a similar extensional measurement set-up and data analysis, our recent study showed that differences in the rheological properties of wheat flours with different protein levels can be distinguished by their strain hardening behaviour (McCann and Day, 2013; McCann et al., 2013).

Uniaxial extension studies to understand the impact of inherent gluten protein composition and concentration on the rheological properties of wheat flour varieties have been mostly carried out with the Kieffer rig method at low extension speeds (maximum at 200 mm/min). Such work has not been extensively carried out at high deformation speeds (e.g. 600 mm/min) with the consideration of changes in dough geometry to provide better understanding of true stress and true strain relationship. In addition, the fracture stress and fracture strain have not yet been fully considered in the defined geometry method for comparison of flours with different protein levels and quality (i.e. Glu:Gli ratio).

Therefore, this study aims to investigate how the various measurement speeds, in particular at the high deformation speed i.e. 600 mm/min which is more closely corresponds to the strain/stress experienced by the dough during proofing and oven rise in bread dough, affecting the strain hardening behaviour of dough obtained from flour samples at different levels of protein content and composition. The true stress and true strain values calculated with the actual sample dimensions captured during the deformation have been used to evaluate the strain hardening behaviour of dough. Furthermore, the pre-orientated arrangement of starch granules has been observed in dough sample prepared for extensional measurement (Dai and Tanner, 2012). However, the re-arrangement of starch granules within the gluten network polymeric systems during the extensional deformations has not been fully investigated. Therefore, in this study confocal laser scanning microscopy coupled with a tensile stage was used to visualise the changes in the microstructure of dough at different stages of extensional deformation. Such information could provide additional insights to understand the unique viscoelastic properties of the composite food materials such as the dough system.

2. Materials and methods

2.1. Materials

Four commercial flour samples, with different protein contents and ratios of glutenin-to-gliadins were obtained. Flours 1, 2 and 4 (S2012-03011 APW2 ALH ZFCS; S2012-04009 ASWI WAL ZFCS; S2012-04763 respectively) containing 9.4, 9.6 and 12.6% protein (w/w flour) respectively, were kindly provided by Cargill (Melbourne, Australia). Flour 3 (13% protein, w/w flour) was from Allied Mills (Kensington, Australia). The moisture and protein contents of the flour samples were determined using AACC Methods 44-15A and 46-30.01, respectively. All flour samples were stored at −20 °C and equilibrated to room temperature prior to analysis.

2.2. Gluten preparation

Gluten was prepared from wheat flour using a starch washing procedure. Briefly, flour samples (150 g) at 2% NaCl addition (w/w flour base) were mixed with water (82.5–86.2 mL) using a mixer (Mixmaster MX001, Sunbeam, Australia) at setting 1 for 2 min to form a dough. The dough was hand kneaded for 2 min and then rested for 30 min in water. Starch components were manually removed from the dough matrix in 3 × 5 L water or until the washing water was clear. The wet gluten was collected and freeze-dried (Dynavac Freeze drier, Model FD5, Melbourne, Australia). The freeze-dried gluten was ground to powder using a coffee grinder (Home maker, Model HMCGK, Melbourne, Australia) and sieved through a 250 μm sieve. Dried gluten was stored at 4 °C until further analysis. The protein and moisture content were then determined.

2.3. SE-HPLC of flour protein

The ratio of Glu:Gli was determined using the extraction method and SE-HPLC method described previously (McCann et al., 2013). Flour samples (10 mg) were dispersed in 1 mL 0.5% SDS of 0.05 M phosphate buffer (pH 6.9), mixed for 10 min in a shaker (Multi Reax, Heidolph, Schwabach, Germany) at ambient temperature, and then sonicated for 30 s at amplitude level 6 (Soniprep 150, MSE Scientific Instruments, Sussex, England) using the sonicator equipped with a 3 mm probe tip. The samples were centrifuged at 16,000*g* for 15 min and the supernatant collected and filtered using a 0.45 μm acetate filter (Bonnet, Sydney, Australia). Each filtered supernatant (20 μL) was injected into the Biosep-SEC S4000 column (Phenomenex, Sydney, Australia) and connected to a Shimadzu HPLC system (Shimadzu, Kyoto, Japan) equipped with a LC-10A model pump, a SIL-20A automatic sampler and a SPD-20A UV–Visible detector. The sample was eluted under isocratic conditions using a 50% acetonitrile solvent containing 0.1% trifluoroacetic acid at a flow rate of 0.5 mL/min. The solute was monitored using UV detection at 214 nm. The Glu:Gli ratio was calculated as the ratio of the first peak area to the second peak area.

2.4. Dough preparation for uniaxial tensile test

Optimal mixed dough was prepared by mixing the flour sample (4 g at 14% moisture) at 2% NaCl addition (w/w flour base) with the amount of deionised water (30 °C) determined from the optimum water absorption (AACCI approval method 54–70), using a 4 g-dough mixer (Micro-dough LAB mixer, Perten Instruments, Sydney, Australia), using the method previously described (McCann and Day, 2013). Dough was collected for the uniaxial tensile test at 4 min mixing for the low protein flours (Flour 1 and Flour 2) and 5 min mixing for the high protein flours (Flour 3 and Flour 4), which

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