ELSEVIER

Journal of Cereal Science 43 (2006) 183–197

Journal of CEREAL SCIENCE

www.elsevier.com/locate/jnlabr/yjcrs

Microstructure formation and rheological behaviour of dough under simple shear flow

S.H. Peighambardoust [a,b], A.J. van der Goot [b,*], T. van Vliet [c], R.J. Hamer [c,d], R.M. Boom [b]

[a] *Food Science and Technology Group, Faculty of Agriculture, University of Tabriz, Tabriz 51664, Islamic Republic of Iran*
[b] *Food and Bioprocess Engineering Group, Wageningen University, P.O. Box 8129, 6700 EV Wageningen, The Netherlands*
[c] *Wageningen Center for Food Sciences, WCFS, Diedenweg 20, 6703 GW Wageningen, The Netherlands*
[d] *Centre for Protein Technology-TNO, WUR, P.O. Box 8129, 6700 EV Wageningen, The Netherlands*

Received 29 April 2005; received in revised form 1 September 2005; accepted 3 October 2005

Abstract

In a z-blade mixer, both shear and extensional deformations contribute to the development of dough structure. I effect of simple shearing versus z-blade mixing at similar levels of work input, on the microstructure and uniaxial extensional properties of two doughs prepared from flours of different strengths. With respect to microstructure, mixing initially increased the formation of coarse protein patches, leading to a heterogeneous dough structure with a high fracture stress (σ_{max}) and significant strain hardening. These parameters decreased with prolonged mixing. This was accompanied by loss of glutenin macro polymer (GMP) wet weight and formation of a more homogenous microstructure. Prolonged mixing typically led to an over-mixed state. In contrast, prolonged simple shearing did not affect GMP content or strain hardening and gave enhanced shear banding. Confocal scanning laser microscopy revealed that short-term simple shearing induced structure formation in the direction of the shear flow for both flour types, followed by formation of shear-banded gluten structures both parallel and perpendicular to the direction of shear flow. Uniaxial extension of dough oriented parallel or perpendicular to the shear field did not reveal anisotropy. Apparently, the observed heterogeneity on a scale of 'mm' was not relevant for this type of rheology. Nevertheless, a relative weakening of dough strength (reduced fracture stress) was observed as a function of long-term shearing. This seems to be related to a local segregation effect caused by differences in visco-elasticity between the gluten phase and the starch granules. The results of this study reveal important features of the dough processing and underline the importance of not only work input, but also the type of deformation applied.

Keywords: Dough; Gluten; Mixing; Simple shearing; Microstructure; Confocal scanning laser microscopy; Uniaxial extension; Rheology

1. Introduction

Mixing flour with water results in an even distribution of the ingredients and the development of a continuous gluten network (Indrani et al., 2003; Sandstedt et al., 1954). According to Bloksma and Bushuk (1988), mixing has three distinct functions in the development of the dough: distribution of materials, hydration, and energy input to develop a protein structure. Therefore, understanding the role of mixing energy is an essential step towards optimising wheat dough development (Schluentz et al., 2000). During the mixing process, dough is formed by a combination of shear and elongational deformations at high strain rates (MacRitchie, 1986). According to Jongen et al. (2003), a z-blade mixer provides a combination of rotational, shear and elongational deformations on the dough, which makes it difficult to understand dough mixing on a mechanistic level. It is therefore interesting to compare the effect of well-defined shear deformation with z-blade mixing on dough properties.

Several researchers (Campos et al., 1997; Lee et al., 2001; Schluentz et al., 2000) have studied the effects of either well-defined shear or elongational deformations and their combination (using a farinograph mixer) on dough properties. Lee et al. (2001) showed different effects of shear or extensional deformation versus their combination on dough properties. They concluded that pure shear or extensional deformation alone cannot produce a high quality dough (defined as a high fraction of protein matrix), comparable to that obtained by

Abbreviations: CSLM, confocal scanning laser microscopy; FFT, fast Fourier transform; FITC, fluorescein isothiocyanate; MC, moisture content; PMV, protein matrix value; RGB, red–blue–green; RH, relative humidity; SME, specific mechanical energy; TA, texture analyser; ZD, zero developed.

* Corresponding author. Tel.: +31 317 4 84372; fax: +31 317 482237.
E-mail address: atzejan.vandergoot@wur.nl (A.J. van der Goot).

0733-5210/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcs.2005.10.004

a farinograph mixer. However, they did not use comparable energy inputs for their different treatments.

We previously compared the effect of simple shearing with z-blade mixing on physical properties of a highly aggregated fraction of gluten, glutenin macro polymer (GMP), at a relevant work input level (Peighambardoust et al., 2005). We found that, compared with mixing, both GMP wet weight and the size of the glutenin particles were stable upon simple shearing. The importance of the amount as well as composition of GMP in assessing wheat quality and predicting dough properties has been emphasised in many recent studies (Aussenac et al., 2001; Don et al., 2003; Moonen et al., 1986; Sapirstein and Suchy, 1999). Thus, the stability of GMP under simple shear conditions might lead to the formation of different structures in the dough compared to those normally seen in mixed doughs. At the structural level, we expect the formation of a gluten network that is relatively stable upon simple shearing. Moreover, the visco-elastic properties of gluten may not be drastically changed under simple shear conditions. This prompted us to further investigate the effect of simple shearing on the microstructure of dough using confocal scanning laser microscopy (CSLM). This technique allowed observation of dough microstructure to a depth of about 20–30 μm.

Changes in dough microstructure and its visco-elastic properties will influence the rheological behaviour of the dough. According to Bloksma (1990), the macroscopic behaviour of given dough, like that of any material, depends on its composition and microstructure (spatial arrangement of its constituents). It has also been reported (Letang et al., 1999) that the molecular structure of dough (i.e. type of bonds) directly affects its rheological properties. Dobraszczyk and Morgenstern (2003) showed a correlation between the molecular structure of dough (presence or absence of long-chain branching in glutenin subunits) and large-deformation rheology. Numerous studies have confirmed that the rheological behaviour of wheat flour dough at large deformations is dominated by the gluten fraction (Dobraszczyk and Morgenstern, 2003; Kieffer et al., 1998; Sliwinski et al., 2004a,b; Tronsmo et al., 2003). Moreover, according to Tronsmo et al. (2003), large-deformation rheological methods are better suited for characterising flour doughs with respect to protein quality than small deformation methods (dynamic oscillatory testing and creep recovery). Thus, large-deformation rheology provides a basis to study structural changes in the protein phase of the dough microstructure, which has been shown to account for its visco-elastic behaviour and end-use quality (Bloksma, 1972; Faubion and Hoseney, 1990; Janssen et al., 1996).

In the current study, the effect of well-defined shear processing was compared with a z-blade mixing process using CSLM and large-deformation rheology. Specific objectives were:

1. to elucidate dough microstructure and gluten network formation as affected by simple shear and z-blade mixing, and
2. to study the large-deformation fracture properties of dough using the uniaxial extension test.

2. Experimental

2.1. Wheat flour samples and physicochemical characteristics

Flours milled from Spring, a strong and hard Canadian, and Soissons, a weak French wheat cultivar were used. Both flours were from single (unblended) wheat cultivars. The physico-chemical characteristics of these flours are shown in Table 1.

2.2. Preparation of zero-developed (ZD) dough for shear experiments

A zero developed (ZD) dough was prepared according to the method of Campos et al. (1996) with the following modifications. Powdered ice was prepared in the presence of solid carbon dioxide (dry ice) inside a walk-in-freezer (−25 °C). The resulting mixture was sieved to a particle size of approximately 700 μm and was held undisturbed at −25 °C overnight, allowing sublimation of the dry ice. Wheat flour was blended with powdered ice and NaCl (2%, w/w) inside the walk-in-freezer. The materials were carefully weighed, placed in a Waring blender (with a modified mixing propeller) and distributed uniformly by mixing at a reduced speed for a desired time. The resulting mixture (ZD dough) was kept frozen until simple shear processing.

Moisture contents of 43 and 45% (based on 14% moisture in flour) were used in preparation of Soissons and Spring ZD doughs, respectively. These values allowed successful shear processing (no slippage) and good handling (no stickiness) properties. The latter was important for rheological measurements. The ZD dough was used as the starting material for the shearing experiments.

2.3. Simple shearing experiments

Simple shearing (further abbreviated to shearing) was performed using a cone and plate shearing device (shear cell) as described by Peighambardoust et al. (2004). Frozen ZD dough (240 g) was put in the bottom cone of the shear cell, inside the walk-in-freezer. The cone was then covered with a moisture tight plastic film and kept at 35 °C for at least 60 min before each shear treatment. This holding period allowed the ice particles to melt, resulting in hydrated ZD dough.

Table 1
Physicochemical analysis of the materials used

	Soissons flour	Spring flour
Moisture (%)	12.70	13.30
Ash (% db)	0.48	0.57
Protein (% db)	11.30	16.10
Farinograph		
Water absorption[a] (%)	53.2	57.9
Arrival time (min)	10.5	7.9
Time-to-peak (TTP; min)	15.0	16.0
Stability (min)	21.0	25.1
Time to breakdown (min)	31.5	33.0

[a] 14% moisture basis.