Journal of Cereal Science 65 (2015) 167–174

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

Rheological properties of wheat flour dough and French bread enriched with wheat bran

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ARTICLE INFO

Article history:
Received 12 November 2014
Received in revised form
3 June 2015
Accepted 27 June 2015
Available online 16 July 2015

Keywords:
Density
Extensional viscosity
Gluten
Particle size
Texture

ABSTRACT

Wheat flour doughs were elaborated with wheat-bran in various contents, up to 20%, and particle sizes of fractions, in order to study the specific role of rheological properties in processing high fibre breads. The addition of wheat bran, especially more than 10%, decreased the specific mechanical energy developed by the mixer, which was attributed to a deficient formation of the gluten network. It increased the elongational viscosity of the dough, measured by biaxial extension tests, likely through a solid particles effect. These changes explained the lower increase of porosity during proofing, assessed by digital camera and 2D image analysis. The loss of dough stability was rather attributed to the destabilizing effect of bran particles on the films separating gas bubbles. The resulting changes of bread texture, determined by image analysis and mechanical testing of breads, including crust and crumb, were governed by bread density, which was established at the end of proofing. These results help to understand the impact of wheat bran on dough rheological properties in order to design French breads with increased fibre content.

1. Introduction

High dietary fibre diets and whole grain consumption have been associated with a lower risk of various diet related diseases such as cardiovascular disease, diabetes, hypertension, obesity, and gastrointestinal disorders (Anderson et al., 2009). For a healthy diet the recommended daily dose of dietary fibre (DF) is at least 25 g/day that is far higher than the consumption observed in most western countries. Cereals products and especially bread are staple food that provides opportunities to deliver health benefits to large populations and therefore bread is a priority target for enrichment in dietary fibre. Among the numerous sources of DF, the most prevalent insoluble DF source is the wheat bran of the cereal kernel (Galliard and Gallagher, 1988). However, the addition of wheat bran causes severe problems on dough rheology, texture and sensory quality of bread (Pomeranz et al., 1977). Addition of bran in bread production has been widely studied, but its effect on dough rheological behaviour, proofing and baking has not been fully explored. The breadmaking process is based on three main operations: (1) mixing, in which ingredients are transformed into a macroscopic homogeneous medium with viscoelastic properties, mainly due to gluten network formation; (2) proofing step over which dough expands due to gas production by yeast activity, until porosity reaches about 70%; gas retention capacity of the dough depends on the rheological properties of the gluten matrix built during mixing (van Vliet, 2008); (3) baking does not increase much the porosity but sets the cellular structure by dough/crumb transition and crust formation (Bloksma, 1990). Density, or inversely, specific volume, is a common technological target.

Numerous negative effects of bran addition on dough processing and breads properties have been reported such as: dough stickiness and loaf weight increase, mixing and fermentation tolerances decrease, specific volume reduction, coarser crumb texture, darker crumb colour and reduced crumb softness (Poutanen et al., 2014). Loss of crust crispiness is also inferred in the case of French bread (Chaunier et al., 2014). But the main problems are the major increase of density and crumb elasticity (Pomeranz et al., 1977), which seem to explain the lower consumer's acceptability of dietary fibre-enriched breads (Zhang and Moore, 1999). Different mechanisms have been inferred to explain the effects of bran addition: bran particles would weaken gluten network (Pomeranz et al., 1977) rather than dilute it (Galliard and Gallagher, 1988), by preventing protein aggregation during mixing (Noort et al., 2010). This could possibly be due to ferulic acid release, size depletion

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http://dx.doi.org/10.1016/j.jcs.2015.06.014
0733-5210/

Nomenclature

a, b, c, d	Parameters of the Gompertz model for porosity
a′, b′, c′	Parameters of the exponential decay for stability
E_{bread}	Apparent modulus of bread (Pa)
E_s	Specific mechanical energy (kJ/kg)
K	Consistency index (Pa.s^n)
M	Total dough mass during mixing (kg)
n	Flow index (−)
P(t)	Dough porosity (−)
$P_m(t)$	Value of mechanical power during mixing (kW)
S(t)	Dough shape ratio or stability (−)
T_f, T_t	Dough temperature after pre-mixing and texturing steps, respectively (°C)
ΔT	Temperature rise during mixing = (T_t−T_f) (°C)
ε_b	Elongational strain (biaxial) (−)
$\dot{\varepsilon}_b$	Elongational strain rate (biaxial) (s^{-1})
η_E	Elongational viscosity (Pa s)
ρ_s	Density of gas-free dough
ρ^*	Density (g cm^{-3})
σ_m, $\sigma_{2/3}$, σ_r	Apparent stress at the end of relaxation (Pa)
$\dot{\gamma}$	Shear rate in the mixer (s^{-1})

effects, and competition with gluten for water due to their high water binding capacities (Wang et al., 2002, 2003); in addition, during proofing, bran particles could also restrict gas cells expansion (Gan et al., 1995), destabilize the interface between gas bubbles in the fermented dough, thus limiting dough expansion (Cavella et al., 2008), while larger particles may also pierce gas cells (Courtin and Delcour, 2002). As solid particles act like a charge in a suspension, bran addition also increases the extensional and shear viscosities (Cavella et al., 2008; Bonnand-Ducasse et al., 2010), which is unfavourable to the growth of the gas cells. Campbell et al. (2008) also suggested that bran acted during baking rather than during proofing by releasing extra water available for starch gelatinisation, and thereby lowering the final bread volume.

Various means can help to reduce these drawbacks. Reducing particle size has been claimed to increase bread volume (Lai et al., 1989), but opposite effects have been observed by Noort et al. (2010) and Zhang and Moore (1999). Noort et al. (2010) explained this negative impact by an increase of surface interaction and water absorption rate, and also liberation of reactive compounds diminishing aggregation of gluten proteins. Pre-treatments of bran, such as pre-fermentation or heat treatments (Zhang and Moore, 1999; Salmenkallio-Marttila et al., 2001), and addition of vital gluten, or the use of surfactants and enzymes (Shogren et al., 1980), can also minimize the negative effect of bran addition on dough rheology and bread volume. Finally, literature survey reveals that the effects of the incorporation of dietary fibres on dough and bread properties depend on the type of bran, the addition level and the breadmaking process. Meanwhile, very few studies addressed the effect of bran addition on the dough properties relevant at different steps of the breadmaking process.

In this context, the aim of the study was to determine the influence of wheat bran addition on wheat flour dough rheological properties, in order to ascertain its consequence on bread texture. In this purpose, wheat bran fractions having different particle size were added at various levels to wheat flour. Gluten addition was also tested, as a possible mean to balance the effect of bran addition. The effects on the rheological properties of the dough were, investigated at the mixing and proofing steps. Subsequently, the effects on bread texture were assessed by studying the cellular structure and the mechanical properties of the crumb.

2. Materials and methods

2.1. Raw materials

Commercial wheat bran, a coarse fraction (CB) and a fine fraction (FB), was supplied by Moulins Soufflet (F91-Corbeil-Essonnes). FB fraction was obtained by grinding CB. Median particle size was 1.8 mm (CB) and 18 µm (FB). DF content, according to AOAC 985-2 method, was 47% (CB) and 40% (FB); protein content was 18% for both fractions. Water-binding capacity was 6.1 g/g for CB, 4.0 g/g for FB and both fractions were mainly constituted of insoluble fibres (>90%). Standard commercial bread flour was supplied by Moulins Soufflet (F44-Pornic). Its protein content was 10.5% and initial moisture content 15% (total wet basis). Dry vital gluten (Moulins Soufflet, F91-Corbeil-Essonnes), fresh yeast (Lesaffre, F94-Maisons Alfort), salt (K + S, Hanovre) and tap water were used in the breadmaking experiments.

2.2. Breadmaking procedure

Control dough was obtained by mixing 2000 g wheat flour, 1240 g tap water, 28 g fresh yeast, 28 g salt and 0.04 g acid ascorbic. Bran samples were substituted for flour at levels of 5%, 10%, 15% or 20% on flour weight basis (Table 1). In case of recipe containing dry vital gluten, 4% of the flour was replaced. To take into account water absorption increase due to bran addition, our expert baker adjusted the amount of water added, at the end of pre-mixing stage in view of dough behaviour and mechanical power measurements, in agreement with the French breadmaking procedure (AFNOR standard V03-716). This led to add an amount of water of about half the level of bran to the control water amount (Campbell et al., 2008).

The water temperature was adjusted to give a final dough temperature of 25 ± 2 °C. Mixing involved two stages: pre-mixing at 80 rpm for 4 min, and texturing at 160 rpm during 7 min, in a spiral mixer (Diosna SP12, Osnabrück, Germany) and the mechanical power supplied to the dough and of the temperature of the dough were recorded. As detailed by Shehzad et al. (2012), mixing conditions were assessed by computing the final temperature increase from the initial value during texturing (ΔT, °C), and the specific mechanical energy (E_s, kJ/kg) from the mechanical power P_m:

$$E_s = \sum P_m(t).\Delta t \Big/ M \quad (1)$$

where $P_m(t)$ is the average value of the mechanical power at time t, during interval Δt, with ΣΔt = t, total texturing time, and M the total dough mass. Three replicates were carried out for all 18 formulas (Table 1). After a first bulk fermentation of 20 min at 27 °C and the relative humidity (rh) of 75% in proofing cabinet (Panem, F79-La Crèche), the dough was divided into 350 g pieces. These pieces were hand-rounded and mechanically moulded (Tregor, F35-Noyal sur Vilaine) and finally proofed for 100 min at 27 °C and 75% (rh). After scarification, the dough pieces were baked in a traditional Bongard deck oven for 25 min at 245 °C (hearth and vault temperatures), with 300 mL of steam just before and after loading. Breads were cooled at room temperature for 2 h before characterization.

2.3. Dough rheological properties

Rheological measurements were performed at large bi-extensional deformations by Lubricated Squeezing Flow test. At