Journal of Cereal Science 76 (2017) 28–34

Contents lists available at ScienceDirect

Journal of Cereal Science

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

Interrelation between mechanical and biological aeration in starch-based gluten-free dough systems

Dana Elgeti, Lu Yu, Andreas Stüttgen, Mario Jekle*, Thomas Becker

Technical University of Munich, Institute of Brewing and Beverage Technology, Research Group Cereal Process Engineering, 85354 Freising, Germany

A R T I C L E I N F O

Article history:
Received 13 January 2017
Received in revised form
18 April 2017
Accepted 10 May 2017
Available online 13 May 2017

Keywords:
Mixing
Quinoa
Bread
Batter

A B S T R A C T

Alternative aeration and gas stabilization strategies are required for the production of starch-based cellular food systems, such as gluten-free bread. In the present study, density and temperature were monitored in mixing experiments without yeast, aiming at maximum mechanical aeration. Additionally, the same trials were performed with subsequent biological aeration, including yeast fermentation and baking. As a result, the gas volume fraction was elevated to 21%, instead of 6% with conventional kneading. Reducing the water content from 120% to 90% (flour/starch weight base) raised dough viscosity and temperature without affecting the state of aeration. The bread volume was strongly influenced by the dough temperature after mixing ($R^2 = 0.98$), since it depended on yeast activity. The implemented process is suitable to aerate starch-based dough systems mechanically and enables the production of gluten-free bread with high volume and fine pores.

1. Introduction

Through the formation of a three-dimensional network, gluten is responsible for the stabilization of gas cells in wheat dough, resulting in a stable sponge-like crumb. Thus, it is challenging to produce gluten-free bread, with a similar volume and pore structure as conventional wheat bread. Yeast fermentation, in combination with evaporation and bubble expansion during baking, provide about 89–95% of the gas for wheat bread, while the amount of gas incorporated through kneading is minor, in comparison (values calculated from Campbell and Mougeot, 1999). In contrast, cake aeration is dominated by mechanical gas inclusion through beating, which produces 37–73% of the final gas volume (values calculated from Campbell and Mougeot, 1999). Since the consistency of gluten-free dough is often more fluid and sticky than wheat dough, aeration through beating presents a promising opportunity to improve current deficits. Moreover, the pore structure in the bread crumb is strongly related to the number and size distribution of initial air nuclei formed during kneading, which highlights the importance of the mixing stage for the overall aeration (Cauvain, 2015).

However, to date it is unknown how mechanical aeration through mixing influences gas amount and bubble distribution in gluten-free dough without yeast. While for wheat bread, the effect of single kneading parameters on dough and bread parameters has been studied extensively (e.g. Kilborn and Tipples, 1972; Martin et al., 2004; Oliver and Allen, 1992; Peighambardoust et al., 2010), this process is still a “black box” in the case of gluten-free bread. This lack of knowledge becomes obvious when comparing method sections of recent studies about gluten-free bread. There is a big variance concerning mixing parameters for dough production (Elgeti et al., 2015). While some mix gluten-free dough with a typical kneading program others refer to the dough as “batter” and use high-speed mixers (e.g. Mariotti et al., 2013). Because of major deviations between material properties of wheat-based and gluten-free dough, it is questionable, whether a conventional kneading stage is the best option for maximum gas entrapment and distribution.

For the formation of the gluten-network in wheat dough, an initial homogenization stage is followed by kneading, which can be described as a series of shearing, compressing and stretching operations. Further goals of the mixing process are the dissolution and hydration of proteins and starch as well as the incorporation and dispersion of air nuclei (Cauvain, 2003). During kneading, the resistance of the dough rises until reaching a maximum that represents the formation of the gluten network. High shear rates can impair this network and, in turn, the gas retention ability (Peighambardoust et al., 2010). By adapting mixing speed and

* Corresponding author.
E-mail address: mjekle@tum.de (M. Jekle).

http://dx.doi.org/10.1016/j.jcs.2017.05.008
0733-5210/

duration, the energy input can be adjusted to meet specific requirements of the dough recipe and to prevent an under- or over-developed structure (Skeggs, 1985). Because of the lacking network, different selection criteria must define an optimum energy input for gluten-free dough. Gómez et al. (2013) reported that different mixing parameters have a big influence on the gluten-free dough development in a Rheofermentometer and on the bread volume.

In the present study, a conventional kneading process was adapted iteratively, by changing only one parameter per trial, towards a high-speed mixing process, similar to beating cake batter. Investigated variables were duration, speed, mixing geometry and water content. Firstly, the influence of these settings on dough density was observed in a mixing trial without yeast, to evaluate the success of mechanical aeration. In parallel, the temperature and the energy input were monitored during mixing. Secondly, baking trials with yeast fermentation were performed to determine how mixing affects the biological aeration and the final bread density. Homegeneously distributed small pores and a target density of 0.20–0.35 g/ml, which is typical for wheat pan bread, was aspired (Campbell and Mougeot, 1999). Experiments were performed with a recipe based on quinoa white flour, because of its superior gas retention (Elgeti et al., 2014). In summary, this paper aims to develop a high-speed mixing procedure for maximum dough aeration.

2. Experimental

2.1. Ingredients for dough and bread preparation

Corn starch produced by Davert (Senden, Germany) originated from ground, washed, and dried corn. Quinoa white flour was produced by removing the bran of Organic Royal Quinoa grains (Bolivian *Chenopodium quinoa*, freed of saponins) purchased from Ziegler & Co. GmbH (Wunsiedel, Germany). Milling fractionation was performed in a Quadrumat Junior mill (Brabender, Duisburg, Germany) with a 200 μm mesh, as previously described by Föste et al. (2015). The resulting flour fraction consisted of 87.0% starch, 3.9% proteins (N × 5.45), 2.0% lipids, 0.7% ash (all on dry base), and 14.7% water. This composition was determined by the following AACC approved methods: 76-13, 46-10, 30-25, 08-12, and 44-01 (AACC, 2002).

The recipe was based on a mixture of quinoa white flour and corn starch in a ratio of 3:1. Further components were 3.0% shortening (baking margarine, CSM Deutschland GmbH, Bingen am Rhein, Germany), 2.0% hydroxypropyl methylcellulose (HPMC, K4M, The Dow Chemical Company Midland, USA), 2.0% NaCl (esco, Hannover, Germany), and for baking trials 1.5% dry yeast of the species *S. cerevisiae* (Casteggio Liveti, Casteggio, Italy). Percentages are related to the flour-starch weight basis (fwb). Starting with 80% (demineralized) water, which is a common amount for wheat bread but resulted in comparably stiff dough, recipes with more water (either 90, 105 or 120%) were prepared to widen the viscosity range and to enable whisking. In order to compensate for deviations in the moisture content of starch and flours from the standard value of 14%, the actual water addition was adapted. Therefore, the moisture content of starch and flours was regularly analyzed.

2.2. Mechanical aeration through mixing

For mixing trials, no yeast was added to the dough recipes. To produced 3.00 kg dough, all dry ingredients, including shortening, were distributively blended for 1 min at the lowest speed (110 rpm) in a planetary mixer (Bear-Varimixer RN10 VL-2, A/S Wodschow & Co., Brøndby, Denmark). The temperature of this mixture was measured with a thermometer (TLC 730, Ebro Electronic GmbH, Ingolstadt, Germany) and water was tempered to obtain 20 °C initial dough temperature with the following formula: $T_{water} = 2\ T_{dough} - T_{flour}$ (adapted from Cauvain, 2015). The mixing process was started directly after water addition with a scraper and either a kneading or a whipping geometry. The speed of the mixing geometry rotating around its own axis was either 200 rpm (level 5) or 420 rpm (level 15, maximum speed). After 1, 2, 4, 6 and 8 min the mixer was stopped and a small dough sample was collected to monitor temperature and density. The temperature was detected by immediately inserting the thermometer probe, before taking small samples for density determination (see Section 2.3) and directly restarting the mixer. The duration of the interruptions was kept as short as possible (approximately 20 s). Thus, the final dough temperature with interruptions varied by less than 1 °C from the one with continuous mixing. For baking trials, density and temperature measurements were performed only after 8 min of continuous mixing to prevent affecting the extent of fermentation. Mixing trials were performed in triplicates.

2.3. Determination of aerated and gas-free dough densities

The aerated dough density ρ_{bulk} was analyzed by filling dough into two shallow glass dishes with a filling volume of 25 ml. The density was calculated as mass of the sample divided by its volume. In order to determine the gas-free density, dough samples were degassed by centrifugation. Dough was transferred into three 50 ml graduated tubes with a 1 ml scale and centrifuged for 20 min at 4500*g at 20 °C in a swing-out rotor (Rotina 420R, Andreas Hettich GmbH & Co. KG, Tuttlingen, Germany). The gas-free density $\rho_{gas\text{-}free}$ resulted from dividing the mass of a dough sample by its volume after centrifugation. The gas volume fraction ϕ was calculated by Equation (1). Two samples were analyzed per dough batch. Each trial was performed in triplicates.

$$\varphi = \left(1 - \frac{\rho_{bulk}}{\rho_{gas-free}}\right) \times 100 \tag{1}$$

2.4. Determination of the complex shear modulus of dough

For rheological measurements, 100 g dough was produced in a z-kneader similar to the 50-g-bowl of a DoughLAB (Perten Instruments, Germany). Dry ingredients including shortening were mixed for 1 min prior to water addition and further 3 min mixing. Mixing was performed at low speed (63 rpm) to guarantee homogenization while entrapping a minimum amount of gas (~6–9%). Water amount and temperature were adapted as mentioned in Section 2.2. The fundamental rheological behavior of dough was analyzed by a time-sweep oscillatory test with controlled shear deformation. The according AR-G2 rheometer (TA instruments, New Castle, USA) was equipped with a 40 mm parallel plate and a constant gap of 2 mm and connected to a smart-swap peltier plate system to maintain a temperature of 20 °C. To protect the outer dough surface against dehydration, paraffin oil was applied after trimming the edges carefully with a spatula. Preliminary amplitude sweep tests identified 0.1% deformation as highest value in the linear viscoelastic range. After 1 min for equilibration, the rheological measurement started with a frequency of 0.5–15 Hz. The complex shear modulus G^* was evaluated to assess the stiffness of samples. Measurements were performed in triplicates.