Journal of Food Engineering 201 (2017) 1–8

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Development of wheat dough by means of shearing

Stefan Tietze*, Mario Jekle, Thomas Becker

Technische Universität München, Institute of Brewing and Beverage Technology, Research Group Cereal Process Engineering, Weihenstephaner Steig 20, 85354 Freising, Germany

ARTICLE INFO

Article history:
Received 18 July 2016
Received in revised form
1 January 2017
Accepted 3 January 2017
Available online 6 January 2017

Keywords:
Dough development
Shear mixing
Rheology
CLSM
Relaxation spectrum

ABSTRACT

Wheat dough is transferred from the mixer to the rheometer in order to perform rheological measurements. During this step additional energy is inserted in the dough by stretching or squeezing, which causes an alteration of the gluten network. To avoid an unwanted additional energy input water and flour were mixed directly in a rheometer. The rheological data of reference dough and shearmixed dough were compared for correlations. The dough consistency during shear mixing was similar to the standard mixing method but the dough breakdown occurred faster. Relaxation spectra and the visualization of microstructure revealed that the gluten network development did not coincide with the indicated dough development of the consistency curve. A rheometer is capable of producing dough which is comparable to the standard procedure. The correlation of rheological properties between standard and shear mixed dough is of medium strength but the basics for a short dough characterization method were established.

1. Introduction

Fully developed wheat dough is characterized by a three-dimensional gluten network with evenly distributed gas nuclei and embedded starch granules. The gluten network is highly crosslinked and spread throughout the dough (Jekle and Becker, 2011; McCann and Day, 2013). This enables a high retention of gas which is produced during proofing. The gas containment results in a high baking volume and an appealing crumb texture (Dowell et al., 2008; Hrušková et al., 2006; Wikström and Bohlin, 1996). Changes in the gluten network constitution or microstructure directly affect the physical dough properties and thus the baking quality (Naeem et al., 2002; Wieser, 2007).

The network is formed from glutenin and gliadin protein fractions only by the input of mechanical energy (Jekle and Becker, 2015). Mixing is the essential step during dough formation where mechanical energy is transferred from the kneading elements to the forming dough. Peighambardoust et al. (2006a) showed that a mechanical energy input of app. 30 kJ/kg is required to form an optimum wheat dough. Depending on the mixer and flour type the energy input can be up to 100 kJ/kg (Rao et al., 2000; Zheng et al., 2000). The needed mechanical energy comprises tension, compression and/or shear.

Kneaders with spiral hooks incorporate mechanical energy mostly by tension and compression (Connelly and Kokini, 2006a; b; Connelly and Kokini, 2007). Whereas the rotating blades of high speed mixers provide predominantly shear for the production of dough. Schluentz et al. (2000) were the first who applied shear as the only source of mechanical energy to an undeveloped dough sample. Other authors experimented with shear and were successful in forming a gluten network (Peighambardoust et al., 2007, 2004; 2005, 2006b; van der Goot et al., 2008). Wheat flour and water were sheared and the material resulted in a texture comparable to wheat dough. However, the rheological characterization was conducted in a separate rheometer. It means in that particular case that the material was stressed additionally and that its structures were altered prior to the measurements. This could have led to falsified rheological data and therefore to a misjudgment of the possible baking performance.

The aim of this study was to establish a fast laboratory test where dough is produced only by shearing. Dough preparation and dough characterization was conducted in the same apparatus to avoid a transfer. The test setup was evaluated in terms of mixing speed and efficacy of different mixing geometries. All of the results were compared to dough prepared by the standard doughLAB method (AACCI 54–70.01). Another goal was to characterize the different wheat dough development states during shear mixing. This included visualization of the dough's microstructure by confocal laser scanning microscopy (CLSM) to get a deeper insight in the process of shear induced dough development.

---

* Corresponding author.
E-mail addresses: tietze@wzw.tum.de (S. Tietze), mjekle@tum.de (M. Jekle).

http://dx.doi.org/10.1016/j.jfoodeng.2017.01.001
0260-8774/

2. Materials and methods

All experiments were conducted at constant 30 °C and were done in triplicate.

2.1. Z-blade mixer settings

The standard dough was produced on a lab-scale recording z-blade mixer (doughLAB, Perten, Germany). 50 g of wheat flour type 550 (Rosenmühle, Ergolding, Germany) and 30.4 ml distilled water were mixed according to AACCI method 54–70.01. The dough consistency reached a maximum torque of 1 Nm during mixing. At this point the dough was optimally mixed and the gluten network was fully developed.

2.2. Shear mixing settings

Shear mixed wheat dough was produced in an AR-G2 rheometer equipped with a non-serrated cone (1°) or plate geometry each with a diameter of 40 mm (TA Instruments, New Castle, USA). The mixing vessel was a cylinder with an inner diameter of 40.1 mm 199 mg flour were distributed flat and evenly on the cylinder bottom. 121 μl of distilled water were pipetted droplet-wise on seven different positions onto the flour; one droplet in the middle and six droplets circular around the center. The gap between rheometer geometry and cylinder bottom was set to 500 μm. The resulting dough was examined every 60 s after mixing for a total of 360 s.

2.3. Rheological characterization

DoughLAB samples were examined with the AR-G2 rheometer equipped with a steel plate geometry with a diameter of 40 mm. The gap between the probe and the bottom plate was set to 2 mm. Excess dough was trimmed and the edge was covered with liquid paraffin to avoid drying. For shear mixing the gap and geometry remained unchanged and no oil was used. Frequency sweep tests were performed in the linear viscoelastic region at a deformation of 0.1%. The lower and upper frequency limits were 0.1 and 100 Hz. A dough rest of 60 s was allowed before measuring. Frequency, storage modulus (G') and loss modulus (G'') were used to compute the relaxation spectra for further interpretation. This was performed by using the Matlab routine contspec from the freely available ReSpect package (Shanbhag, 2013).

2.4. Confocal laser scanning microscopy

A confocal laser scanning microscope e-C1plus (Nikon, Düsseldorf; Germany) with a 60× oil immersion objective was used for the visualization of the dough structure. The examination method was in compliance with the method of Beck et al. (2011). The dough samples were transferred into a specimen shape. 10 μl Rhodamin B (diluted 1:100.000) were pipetted onto the dough surface to mark the proteins. The dough was covered with a glass plate and the proteins were observed as fluorescence micrographs ($\lambda_{ext} = 543$ nm, $\lambda_{em} = 590$ nm) in a constant z-position.

2.5. Image analysis

For the image analysis the open source software ImageJ was used following the dough microstructure quantification method (DoMiQ) of Jekle and Becker (2011). Micrographs were converted into binary black and white pictures, threshold pixels smaller than 2 × 2 were removed and a filter was applied according to Huang and Wang (1995). 10 micrographs were taken from each dough sample and analyzed in terms of protein particle size and particle aspect ratio. The aspect ratio is defined as the quotient of width by length of the protein particle.

2.6. Statistical evaluation

GraphPad Prism 5 software (GraphPad Software, Inc., La Jolla, CA, USA) was used for the analysis of variance, fitting regression equations and the determination of significant variations in the resulting values.

3. Results and discussion

3.1. Evaluation of shear mixing settings

First of all, the settings for the rheometer and the geometries had to be identified in order to produce dough in a rheometer. The gap size was determined regarding to the density of dough (~1100 kg/m^3) (Ktenioudaki et al., 2009; Soleimani Pour-Damanab et al., 2011), bulk flour (~500 kg/m^3) and the used amount of flour and water. The result was 230 μm, which was enlarged to 500 μm. This precaution was intended to avoid that material was squeezed out of the gap. Another reason is that it prevented falsified measurements caused by crushed starch granules (Schirmer et al., 2013; Wilson et al., 2006).

Secondly, the shear rate or the shear mixing speed had to be determined. Experiments with different shear rates between 10 and 100 s^{-1} were performed in the rheometer. The results were evaluated with respect to the dough development time (DDT). In a standard mixing process the maximum peak in the torque-time graph is interpreted as the DDT. At this point the dough is in the optimum state for further processing and will yield the highest baking quality (Dobraszczyk and Salmanowicz, 2008; Kahraman et al., 2008). The shear tests ran for a total of 360 s. As shown in Fig. 1a the optimum DDT decreased by increasing the shear rate. Even the lowest shear rates did not exceed development times over 93 ± 43 s. In comparison to that, the doughLAB dough was optimally mixed after 149 ± 29 s.

Dismounting the shearing geometry revealed that for shear rates between 10 and 40 s^{-1}, no dough production had occurred. A flour-water slurry was present where flour particles were wetted and agglomerated on the bottom. The drag flow in the gap must have been too weak and the energy input too low to provide for a sufficient dough development. Peighambardoust et al. (2006b) produced developed dough at this speed with the difference that the author had sheared up to 45 min. At a rate of 50 s^{-1} the material formed an intermediate between slurry and dough. For rates of 60 and 70 s^{-1} the material in the rheometer gap exhibited the typical dough-like texture. Shear rates above 70 s^{-1} did not lead to dough formation. Instead, the material was dragged out of the rheometer gap due to an imbalance of centripetal and centrifugal force. Flour and wetted flour flakes accumulated at the edges and were pushed upwards the cylinder wall. These results and the evaluation of the peak in the plotted torque graph during shear mixing showed that: (1) a minimum shear rate is necessary to form dough in an acceptable time; (2) a critical shear rate should not be exceeded to avoid discharging the material out of the rheometer gap; and (3) in contrast to standard mixing, a maximum peak in the torque-time graph had no informative value about the actual state of dough development (compare Fig. 2). Therefore, the specific mechanical energy (SME) input was evaluated for the determination of the dough development and the optimum shear rate. Equation (1) allowed the computation of the needed shear rate for the shear mixing process