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# Foam stabilization during processing of starch-based dough systems

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ABSTRACT

The goal of the study was to identify material properties that (1) facilitate the incorporation of gas into starch-based dough and (2) favor bubble stabilization during all processing stages. A novel rheometer program simulated processing conditions in four consecutive stages with varying shear and temperature profiles. A broad range of viscosities was obtained by various recipe compositions. In consequence, the energy consumption varied during mixing and directly dictated the dough temperature ($R^2 = 0.98$). Rheological data were correlated with the gas volume fraction of doughs (5–25%) and with the bread densities (0.21–0.42 g/ml). Pronounced shear-thinning was more relevant for mechanical aeration ($R^2 = 0.74$) than the absolute dough viscosity. In contrast, during fermentation and baking, high viscosities increased the bread volume ($R^2 = 0.72$) and reduced the mean pore size ($R^2 = 0.68$). In conclusion, valuable new insights were obtained into relevant structures of sensitive cellular food systems, such as gluten-free bread.

*Industrial relevance:* An extensive variety of novel gluten-free flours and additives is available for the production of bakery products. This makes it difficult to assess and compare the functionality of ingredients. The present paper offers a new method to predict the baking performance of different recipe compositions. This lays the groundwork for an improved understanding of key factors for the production of high quality aerated food structures without a dominating gluten network. Notably, the highest bread volume resulted from a combination of high-speed mechanical aeration with a recipe based on quinoa white flour or refined rice and 2% hydroxypropyl methylcellulose.



## 1. Introduction

For the production of starch-based food foams without egg or gluten, aeration and gas stabilization are central challenges. In the process of mechanical aeration by mixing, air bubbles are incorporated into the dough or batter. Subsequently, further mixing can lead to coalescence or kinetic disentrainment, which decreases the number of bubbles and increases their size (Jang, Nikolov, Wasan, Chen, & Campbell, 2005). The opposite effect of smaller, more numerous bubbles results from bubble breakage through shearing (Chesterton, de Abreu, Moggridge, Sadd, & Wilson, 2013; Massey, Khare, & Niranjan, 2001). The balance between entrainment, disentrainment and disruption depends on numerous internal and external factors and determines the success of the aeration process (Mills, Wilde, Salt, & Skeggs, 2003). Moreover, the created bubbles provide atmospheric oxygen for the yeast metabolism and serve as nuclei, into which carbon dioxide can diffuse during fermentation (Khatkar, 2011). The mixing process strongly influences the distribution of pores in bread and cake, since - despite the action of other leavening mechanisms - no new gas cells are generated afterwards (Baker & Mazi, 1941; Scanlon & Zghal, 2001). To produce bread with small and homogeneous pores as well as high volume, it is important to prevent gas-loss throughout processing. Therefore, the present study evaluates key properties and mechanisms that are important for aeration and gas stabilization.

For wheat bread, several fundamental and empirical rheological methods estimate the baking performance of recipe compositions. As an example, it is generally accepted that the target torque of 4.9 N•m (or 500 BU) in a 300 g Farinograph mixer or 1.1 N•m in a Mixolab is associated with preferable dough consistency and bread volume under standard conditions. In contrast to the slight variations in water content or flour composition for wheat bread, gluten-free recipes include an extensive range of flours, starches and functional additives. With few exceptions, starch-based dough does not provide enough stability or elasticity for examinations in wheat dough analysis systems. The viscoelastic properties of wheat dough are defined by the ability of gluten proteins to network in a specific manner. Gluten-free formulations are required to be absent (<20 ppm) of these proteins, so that both, the micro- and macrostructure, depend on other ingredients and their interactions. Currently, a wide variety of strategies is available to either mimic or compensate the gluten network (Masure, Fierens, & Delcour, 2016). Starch, as the main component of cereals and pseudocereals, provides the basis of most gluten-free recipes and is typically supplemented by hydrocolloids, such as hydroxypropyl methylcellulose (e.g.

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Bàrcenasa & Rosell, 2005; Mariotti, Pagani, & Lucisano, 2013; Sivaramakrishnan, Senge, & Chattopadhyay, 2004). In these systems, the water concentration is important for the rheological behavior, as has previously been discussed by Kobylañski, Pérez, and Pilosof (2004). Because of the heterogeneity of raw materials, not only dough and bread properties, but also analytical methods differ considerably. In consequence, it is often impossible to compare the baking performance of single ingredients.

This study addresses two main questions: which rheological properties are required for maximum gas input during mixing and how does dough rheology affect the gas stabilization during processing? A fundamental rheological method was developed to characterize different gluten-free formulations and to predict their baking performance. The resulting rheological data were correlated with the level of gas entrapment during mixing without yeast. This allowed for an identification of the most important dough properties for mechanical aeration. Moreover, the energy input during mixing was evaluated to estimate dough heating through viscous dissipation (Shehzad, Chiron, Della Valle, Lamrini, & Lourdin, 2012).

Subsequently, the same dough recipes were fermented with yeast and baked before measuring bread density and pore size. As a prerequisite, it had to be avoided that the bread density is influenced by the dough temperature after mixing (through yeast activity). An effect on yeast activity would also derive from the variations in substrate in different flours. Since even the use of double-wall jackets has failed to control the dough temperature in literature studies (Edoura-Gaena, Allais, Trystram, & Gros, 2007), the biological aeration was standardized, so that bread density was only related to medium properties and mechanical gas input. Finally, bread volume and pore structure were correlated with rheological dough properties, to examine which material properties are favorable for aeration and bubble stabilization.

## 2. Experimental

### 2.1. Ingredients for dough and bread preparation

Fine ground whole grain rice flour from brown rice of *Oryza sativa* L., henceforth referred to as rice (flour), fine ground corn flour of *Zea mays* L. without sperm and corn starch produced of ground, washed, and dried corn were obtained from Davert (Senden, Germany). Dry cleaned, ground and polished white rice was milled and fractionated by Müller's Mühle GmbH (Gelsenkirchen, Germany), in the following referred to as refined rice. Organic Royal Quinoa grains (*Chenopodium quinoa*, freed of saponins) originating from Bolivia were purchased from Ziegler & Co. GmbH (Wunsiedel, Germany). Quinoa white flour was produced by removing bran components in a Quadrumat Junior mill (Brabender, Duisburg, Germany) with a 200 μm mesh, as previously described (Föste, Elgeti, Brunner, Jekle, & Becker, 2015). The resulting flour fraction contained 87.0% starch, 3.9% proteins (N × 5.45), 2.0% lipids, 0.7% ash on dry base, and 14.7% water as determined by the following AACC approved methods: 76-13, 46-10, 30-25, 08-12, and 44-01, respectively (AACC, 2002). In the following sections, rice/corn refers to a 2:1 mixture/corn refers to a 2:1 mixture of the above mentioned whole grain rice flour with corn flour, quinoa refers to fractionated quinoa white flour and rice indicates whole grain rice flour.

Further ingredients for dough production were shortening (baking margarine, CSM Deutschland GmbH, Bingen am Rhein, Germany), hydroxypropyl methylcellulose (HPMC, K4M, The Dow Chemical Company Midland, USA) NaCl (esco, Hannover, Germany) and demineralized water. For baking trials dry yeast of the species *S. cerevisiae* (Casteggio Liveti, Casteggio, Italy) and anhydrous D(+)-glucose (AppliChem GmbH, Darmstadt, Germany) were added. The gluten-free recipes used for this study are listed in Table 1, in which quantities are related to the respective flour-starch weight basis (fwb). For each formulation, the respective water amount was adapted to compensate for deviations in the moister content of starch and flours from a standard value of 14%. Both, rheometer trials and high-speed mixing with a wire whip, require relatively high water content.

### 2.2. Density and temperature monitoring in mixing trials without yeast

For each mixing trial, 3.00 kg dough was produced without yeast in a planetary mixer (Bear-Varimixer RN10 VL-2, A/S Wodschow & Co., Brøndby, Denmark). Prior to temperature measurements, all dry ingredients, including shortening, were distributively blended for 1 min at the lowest speed (110 rpm). In order to compensate raw material and climate variations, water was tempered to produce dough of 20 °C with the formula $T_{water} = 2T_{dough} - T_{flour}$ (adapted from Cauvain, 2007). Directly after water addition, the mixing process was started with a scraper at 420 rpm with a wire whip for 8 min. For comparison of high speed beating with traditional processing, one dough (quinoa, 105% water) was mixed at 200 rpm with a spiral kneader for 8 min. Dough temperature after mixing was detected with a thermometer (TLC 730, Ebro Electronic GmbH, Ingolstadt, Germany). The dough density $\rho_{dough}$ was determined by carefully filling two dough samples into shallow glass containers with a specified filling volume and by dividing their weight by their volume. Mixing trials were performed in triplicates.

### 2.3. Monitoring energy consumption during mixing

The motor-power $P_{dough}$ was recorded during mixing with an external kilowatt-hour meter with a resolution of 0.1 W (Energy Logger 4000, Voltcraft, Wollerau, Switzerland). To be able to subtract the no-load power $P_0$, the mixer was run empty. Because the power was recorded in 1-min-intervals, the first and last values during mixing could correspond to the warm-up or cool-down phase. Since these phases lasted approximately 15 s, the values for $t = 0.25$ min and $t = 8$ min were extrapolated. Integrating the power curves over 8 min of mixing ($t_0$ to $t_{end}$) gives the consumed energy. The subtraction of the integrated no-load curve from the integrated curve with dough reveals the energy required to mix a particular dough formulation and reflects the torque of the mixing arm (Shehzad et al., 2012). The energy required for mixing $E_{mix.}$ was calculated according to Eq. (1).

$$E_{mix.} = \int_{t_0}^{t_{end}} P_{dough} - \int_{t_0}^{t_{end}} P_0 \quad (1)$$

### 2.4. Determination of the glucose concentration for standardized yeast activity

Preliminary trials determined the minimum glucose concentration to maximize the gas production rate during yeast fermentation. For this purpose, the corn starch recipe (No. 10, Table 1) was supplemented with 0–4% glucose (fwb), which is a preferred monosaccharide for *Saccharomyces cerevisiae*. Corn starch was chosen as a control with negligible mono- and disaccharide content. After homogenizing dry ingredients with the lowest speed for 1 min, dough was produced by kneading at 200 rpm for 8 min in a KitchenAid (5KSM150, St. Joseph, USA). To monitor the biological aeration during fermentation, two dough samples were filled into the bottom of previously cut glass cylinders with an inner diameter of 35.6 mm and were weighed to obtain the initial density. The cylinder bottoms had a filling volume of 27 ml. Subsequently, after the cylinder top was reapplied and fixed with parafilm, the cylinders were placed for 45 min into proofing chambers (30 °C, 80% relative humidity). Dough density development was monitored through measuring the dough height every 5 min with a precision caliper. Due to interactions with the cylinder wall, in most cases the dough surface became spherical during fermentation, which was factored into density calculations. The preliminary trial was performed once with two samples per glucose concentration.