Extensional rheology of cereal protein systems

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ABSTRACT

Dough systems from wheat have been compared to doughs from sorghum in order to predict the foam stability necessary for good baking performance. The extensional rheological properties were found to correlate well with baking performance and system relaxation times correlated with prolamin molecular weight.

INTRODUCTION

The wheat protein gluten is the origin of the excellent elastic properties of wheat dough responsible for its good baking properties. Gluten forms a network which has high extensional viscosity and is strain hardening thus stabilizing and trapping air bubbles to give the desired highly porous structure typical of white bread. There are prolamins corresponding to wheat gluten in all cereals, however, few of them have the required properties for baking, i.e. they especially lack the extensional rheological properties necessary for foam stabilization.

Products based on e.g. oat and African cereals such as sorghum and millets are naturally gluten-free. Their prolamins have in previous research projects[1] been shown to have excellent elastic melt properties which could be utilized in gluten-free bread products to form a porous texture similar to wheat based breads. Gluten-free products are necessary for those suffering from coeliac disease caused by wheat gluten. Coeliac disease is a well recognised problem in Sweden affecting several hundred thousands of Swedes. There is a good assortment of frozen gluten-free bread on the retail market, but the bread quality is still far from that of wheat based bread, especially regarding porosity.

The foam formation during baking involves high extension at low extension rates. The relevant rheological methods for predicting foam stability of dough should involve extension as reviewed by Dobraszczyk and Morgenstern[2]. Measurements in shear have only been found to yield information on high Mw protein components which are proposed to be responsible for foam stabilization.

The aim of the present study was to evaluate rheological methods relevant for predicting foam stability of dough systems. Wheat dough was compared to the gluten free sorghum dough.

MATERIALS AND METHODS

Wheat flour of the Kosak variety was kindly supplied by Svalöf Weibull AB in the three different protein contents 9.5, 10.7 and 12.0 %. White sorghum flour was kindly supplied by John Taylor at the University of Pretoria.

The flour was mixed with water for four minutes in a Rheomixer pin mixer (Reologen i Lund, Öved Sweden) according to AACC 54-40A. 10g of wheat flour was mixed with 6 g distilled water and 10 g sorghum flour with 11 g water.

A Stresstech HR Rheometer (Reologica Instruments, Lund, Sweden) equipped with a 30 mm parallel plate system was used and the dough was mounted in a 2 mm gap, the periphery covered with paraffin oil to avoid drying. Mechanical spectra was obtained at frequencies 0.0001-10 Hz at a strain of 10^{-3} which was in the linear region. The data was evaluated using the IRIS platform version 9.0 (IRIS Development, Amherst, USA).

Contraction flow[3] was used to determine extensional rheology of the dough systems at a maximum Hencky strain of 4.5. The shear contribution was small (<2% of the total stress) and was compensated for assuming Power Law behavior of the dough, extracting K and n parameters from the mechanical spectra using Cox-Merz relation.

RESULTS AND DISCUSSION

The wheat doughs were tension thinning with the highest protein content giving the highest extensional viscosity as shown in Fig. 1. The sorghum dough was also tension thinning but showed a substantially lower extensional viscosity. The sorghum dough was furthermore concluded to unsuitable for the contraction flow method because the compression of the sorghum dough caused water loss. Results could therefore only be obtained at lower extension rate for which the stresses are lower.

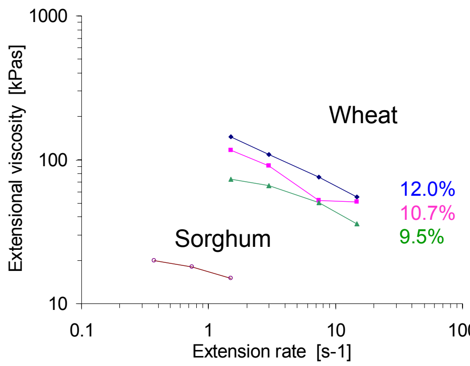

Figure 1. Extensional flow curves for wheat and sorghum doughs. The protein content of the wheat flour is given in the figure.

Extensional stress growth experiments (data not presented) showed substantial strain hardening for the wheat doughs which was absent for the sorghum dough. Strain hardening i.e. that the stress-strain curve is J-shaped so that any incipient defect in a bubble membrane experiences an increased stress thus stabilizing the bubble[2, 4], as well as absolute extensional viscosity has been concluded to be beneficial for foam stability and baking performance of wheat dough[4]. By using contraction flow rheometry and multivariate statistics, 95% of the variation in bread volume was previously predicted[5].

Mechanical spectra of the wheat doughs were obtained at 40°C to emphasize the influence of the long relaxation times, yet staying below the temperature of noticeable influence of starch on the viscoelastic properties. Fig. 2 shows the mechanical spectra where the extrapolated G'-G" crossover occurs at lower frequency for the high protein content flour.

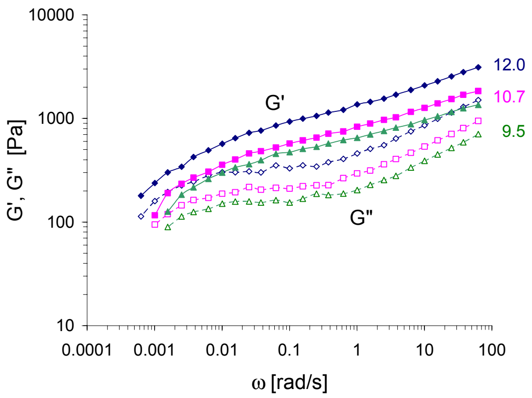

Figure 2. Mechanical spectra for wheat dough. The lines are fits obtained from the relaxation time spectrum. The protein content of the wheat flour is given in the figure.

The IRIS software was used to extract the relaxation time spectrum from the mechanical spectra. A characteristic relaxation time[6] calculated for each spectrum is presented in Table 1.

Table 1. Characteristic relaxation times for the doughs obtained by mechanical spectroscopy[6].

Dough sample	Characteristic relaxation time [s]
Sorghum	1 090
Wheat 9.5 % protein	4 774
Wheat 10.7 % protein	18 160
Wheat 12.0 % protein	24 630

The characteristic relaxation time correlated well with the protein content and was much longer than that for the sorghum dough. The long relaxation times in wheat dough have been proposed to be caused by the insoluble fractions of the high molecular weight glutenin polymer which form an elastic, strain hardening entanglement network[2, 7]. The absence of such a structure in the sorghum dough explains its short characteristic relaxation time and poor baking performance.

CONCLUSIONS

The differences in baking performance of wheat flours of different protein content and sorghum flour is well explained by extensional rheological properties of the corresponding dough. The high protein wheat flour produces dough with high extensional viscosity and strain hardening. Sorghum dough, which lacks baking properties, have low extensional viscosity as well as no strain hardening. The mechanical spectra of the doughs give information on the high molecular weight fraction of the proteins present and therefore correlate well with baking performance.

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