Rheological Properties and Breadmaking Quality of Wheat Flour Doughs Made with Different Dough Mixers

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ABSTRACT

Four dough mixers—farinograph, mixograph, Krups, and Hobart—were used to make wheat flour doughs. Two sizes of farinograph mixers, with flour capacities of 10 g and 300 g, were tested. Dynamic rheological properties of the doughs were measured with a cone-and-plate system. The storage modulus (G') decreased with mixing time at different rates depending on the severity of mixing. Mixing was most severe with the mixograph and Krups mixers. As the dough rested, it became more elastic, and the phase angle decreased. Rheological properties were related to the empirical measurements (farinogram and mixogram) and to the results of test baking. A good correlation was observed between the farinogram and storage modulus values. With the mixograph, however, the empirical optimum was reached 1 min later than the optimum determined from the fundamental rheological measurements and baking tests. The storage modulus and phase angle values associated with the optimum quality of the finished product were fairly constant and did not depend on the mixing equipment. For the specific blend of flour used (approximately 70% winter wheat of the varieties Kosack and Folke and 30% spring wheat of the variety Kadett), the best quality bread (as indicated by loaf volume and porosity) was obtained when the average storage modulus was approximately 12 kPa.

Rheological properties are significant in determining the behavior of wheat flour doughs during mechanical handling in addition to their influence on the quality of the finished product. Knowledge of rheological behavior and dough properties is becoming more important as the baking industry becomes more automated.

Mixing significantly alters the rheological properties of dough. Mixing rapidly hydrates the flour particles, develops the gluten matrix, and incorporates air into the system. The high shear rate in a dough mixer aids hydration by removing the outer layer of flour particles as they become hydrated and exposing a new surface for hydration (Spies 1990). As protein is hydrated, it forms fibrils that are aligned in a matrix by the shearing action of the mixer, and the resistance of the system to extension increases. The full breadmaking potential of the dough is attained only at the optimum point of dough development (Faubion and Hoseney 1990). Amend and Belitz (1990) used scanning electron microscopy to study dough formation and reported that as dough is mixed, the protein strands are extended and torn apart into films, which form layers at optimum mixing. Hoseney (1986), on the other hand, reported that a freeze-dried, optimally mixed dough observed under the electron microscope showed no intact flour particles but rather a random mixture of protein fibrils with adhering starch granules. Beyond the point of optimum mixing, resistance to extension no longer increases, and the dough starts to break down. As dough breaks down, it becomes wet and sticky (Spies 1990).

Rheological properties of materials depend on their structure and on the arrangement of the constituents and the forces acting between them. The rheological properties of a dough system are analogous to the properties of gluten. Specific nonprotein components of flour interact with specific proteins of gluten and contribute significantly to the rheological properties of the gluten. Intermolecular interactions among gluten proteins and between protein and nonprotein components lead to the formation of various aggregates (films and fibrils). The rheological properties of dough depend on the structure of the aggregates and their tendency to interact with each other (Bushuk 1985).

Dough is a composite system in which a live biological ingredient, yeast, is constantly changing the rheological properties of the system. The difficulty of testing the basic rheological properties of a system as complex as wheat flour dough largely explains the delay in the application of rheological principles in the breadmaking industry. The lack of adequate information on the rheological properties of doughs has forced bakers to rely on empirical measurements in quality control and research situations. Several instruments are used to obtain empirical information on mixing. Two commonly used mixers, the farinograph and the mixograph, record the resistance of dough to the mixing blades during prolonged mixing (Spies 1990). Krups and Hobart dough mixers are larger and are used mostly for evaluating flours by test baking.

We used fundamental rheological measurements to compare doughs made with different mixers. In addition, we examined the relationship between the rheological data and the quality of the finished baked product.

MATERIALS AND METHODS

We used commercial-quality baking flour containing 73% carbohydrate, 10% protein (conversion factor 5.7), and 2% fat (Nord Mills, Malmö, Sweden). The flour was a mixture of approximately 70% winter wheat (varieties Kosack and Folke) and 30% spring wheat (variety Kadett). The basic recipe used 10 g of flour and 5.5 ml of water. The amounts were adjusted proportionally when larger doughs were needed. No yeast was used for the rheological tests; however, yeast, sugar, and salt were added for the baking experiments. Rheological tests were done on the doughs 2 and 20 min after the completion of mixing.

Farinograph

The farinograph (Brabender OHG, Duisburg, Germany) is one of the most widely used dough-mixing devices. The mixing action is provided by two sigma-shaped blades that rotate toward each other at differential speeds of 3:2. The temperature is controlled during mixing by water circulating in a jacket surrounding the bowl (Kunerth and D'Appolonia 1985).

We used farinographs with two bowl sizes. With the small-bowl farinograph, we mixed 10 g of flour and 5.5 ml of water and used a rotation speed of 60 rpm on the slower blade for 3, 5, 7, and 9 min. To test the breadmaking quality of the doughs, we mixed doughs under the same conditions but added yeast, salt, and sugar in the proportions described below (see Baking Test). For each mixing time, 12 g of dough was used to bake a microloaf of bread. With the large-bowl farinograph, doughs made with 300 g of flour were mixed for 4, 5, 6, and 7 min. The temperature was set at 25°C during mixing. For each mixing time, three 100-g dough samples were used for baking.

Mixograph

The mixograph (National Mfg. Co., Lincoln, NE) is another widely used dough mixer. Dough is mixed by four vertical pins revolving about three stationary pins in the bottom of the bowl.

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This type of mixing works as a pull, fold, and repull action, which is much more severe than the mixing in a farinograph (Kunerth and D'Appolonia 1985). As a result, dough is developed faster.

In our mixograph experiments, we used 25 g of flour for each dough and mixing times of 2, 3, 4, and 5 min. Three 12-g doughs were baked for each mixing time.

Krups

The Krups mixer (Robert Krups Stiftung & Co. KG., Solingen, Germany) is an example of a dough mixer used in the home. Two spiral-type blades revolving at the same speed provide the mixing action. Three mixing speeds are available. Because the Krups and Hobart mixers have larger bowls, we increased the amount of flour for each dough to 500 g. Mixing started on the lowest speed, was increased stepwise to the medium and high speeds at intervals of 15 sec, and was then kept at the high speed for the rest of the mixing time. After 3, 7, 11, and 15 min of mixing, 1-g samples were taken out for rheological testing. For each mixing time, five pieces of dough, each weighing 100 g, were used for baking.

Hobart

The Hobart mixer (Hobart Corporation, Troy, OH) is a small version of dough mixers used by the industry. Mixing is accomplished by a hook-shaped blade that rotates around itself as well as in a circle. We used the same recipe and procedure as with the Krups mixer.

Rheological Measurements

The doughs used for rheological tests were made only of flour and water in the previously mentioned proportions. Oscillation measurements were done with the cone-and-plate system on a Bohlin rheometer (Bohlin Rheology, Science Park Ideon, Lund, Sweden). The cone and plate had a radius of 1.5 cm and an angle of 5.4°. A measurement was completed within 3 min at a temperature of 25°C. Shear amplitude was set at 0.06° (strain value of 8×10^{-3}), and a frequency range of 0.02–5.0 Hz was used. One gram of dough was placed on the plate, the cone was lowered, and the measurements were started. The procedure was repeated on a new sample from the same initial dough after 20 min. During the 20 min of resting, the dough was kept inside a plastic film to avoid drying. Coating the dough surface with Vaseline or silicon oil is possible in the rheometer but introduces undesirable delays in preparation when a time-dependent function is studied (Lindahl and Svensson 1988). Mixing and rheological measurements were done for five replications.

The rheometer results are given as graphs of storage modulus (G', Pa), loss modulus (G'', Pa), complex modulus (G^*, Pa), phase angle (δ, °), and viscosity (η, Pa) versus frequency (Hz). In an oscillation test as the frequency increases, the moduli also increase at the same velocity because the phase angle, tan δ, is almost constant. Similar results have been obtained in earlier studies (Hibberd and Wallace 1966, Smith et al 1970, Dreese 1987).

Because the rheometer provides an overabundance of data, we chose the storage modulus and the phase angle at 0.2 Hz as representative of all the data obtained. The phase angle is the degree by which the stress is ahead of the shear strain. It varies between 0° for an elastic solid and 90° for a Newtonian liquid. The storage modulus represents elastic properties and increases as the dough becomes stiffer.

Baking Test

The following basic formula was used for baking dough mixed in the small farinograph (10 g): flour, 10 g; water, 5.5 ml; yeast, 0.5 g; salt, 0.17 g; and sugar, 0.17 g. The amounts were increased proportionally for the equipment with larger mixing bowls.

After mixing, the dough was fermented at 27–32°C and 60% humidity for 30 min. Pieces of dough weighing either 12 g or 100 g were used, depending on the mixing equipment. A good correlation has been reported between standard baking and microbaking (Meppelink 1981). After fermentation, the dough pieces were rounded, placed in greased pans, and proofed at 38°C and 85% relative humidity for 40 min. The small and large breads were baked in a 210°C oven for 12 and 20 min, respectively (Hammam et al 1988). Steam was sprayed into the oven during the first minute of baking. The breads were cooled out of the pans for 15 min. Volume was then measured by rapeseed displacement. The breads were cut in half, and porosity was judged on an 8-point scale, where 1 indicated large and uneven pores (low crumb quality) and 8 indicated small and even pores (high crumb quality).

RESULTS AND DISCUSSION

The rheological data showed that the storage modulus decreases with mixing (Fig. 1). Elasticity also decreases, as shown by an increase in the phase angle. The rate at which doughs became softer varied with the mixer according to the severity of mixing. Mixing was most severe with the mixograph and Krups equipment (Fig. 1). The phase angle decreased when the dough rested for 20 min (Fig. 1), indicating that the dough became more elastic with resting.

The relationship between storage modulus and the volume of the finished bread is not readily seen in the graphs. A small change in storage modulus may correspond to a substantial change in bread volume (Fig. 1B and D). Considering both measures of bread quality, volume and porosity, these changes can be related to the air mixed in the dough. The inferior quality of overmixed doughs can be explained in two ways. With the Krups mixer (Fig. 1D), the rapid drop in bread volume when the dough was mixed more than 11 min could have been caused by the rupture of the gluten membranes separating the air cells. With the mixograph (Fig. 1B), however, mixing for more than 4 min appears to have caused the air bubbles to merge, keeping the volume still high but reducing the porosity. The changes in temperature (Fig. 2) suggest that the breakdown of the membranes with the Krups mixer may be related to the very high rise in dough temperature during mixing.

We defined the optimum baking result as the bread with the highest volume and the best porosity. When several good results were obtained, we chose the middle one as the optimum (Fig. 1C and E). Table I shows the average storage modulus and phase angle values for optimum mixing with each type of equipment. The G' values are fairly close together, indicating a good relationship between storage modulus and optimum quality of the finished product independent of the mixer used. The δ values are also close together except for the 10-g farinograph. Although these values are specific to the flour blend used in this experiment, the general conclusion can be drawn that the fundamental rheological properties of optimally mixed doughs do not depend on the mixing equipment.

The storage modulus of the doughs mixed for 4–7 min in the 300-g farinograph decreased slightly over the 1-min intervals. The quality of the breads baked from doughs with these mixing times also agreed with the close G' values (Fig. 1C). We chose such short intervals because Kunerth and D'Appolonia (1985) suggested that farinograms obtained with the 300-g bowl are somewhat stronger than those obtained for corresponding flours with the 50-g bowl, and the same relation may hold between 50-g and 10-g bowls.

When we compared the storage modulus values with the farinogram, we noted a slight decrease for both with mixing. The optimal mixing times obtained with the farinograph correlated well with the optimum storage modulus and the baking test optimum. As the dough was mixed, the torque on the rotating axle decreased; this was reflected in the decrease in the storage modulus, showing that the dough became softer. The phase angle increased, indicating a more viscous response. With the mixograph, on the other hand, the peak of the mixogram occurred later than the optimal mixing according to the fundamental rheological tests and the baking tests.

The storage modulus values varied widely among the five replications for the 10-g farinograph and the Hobart mixer, mak-

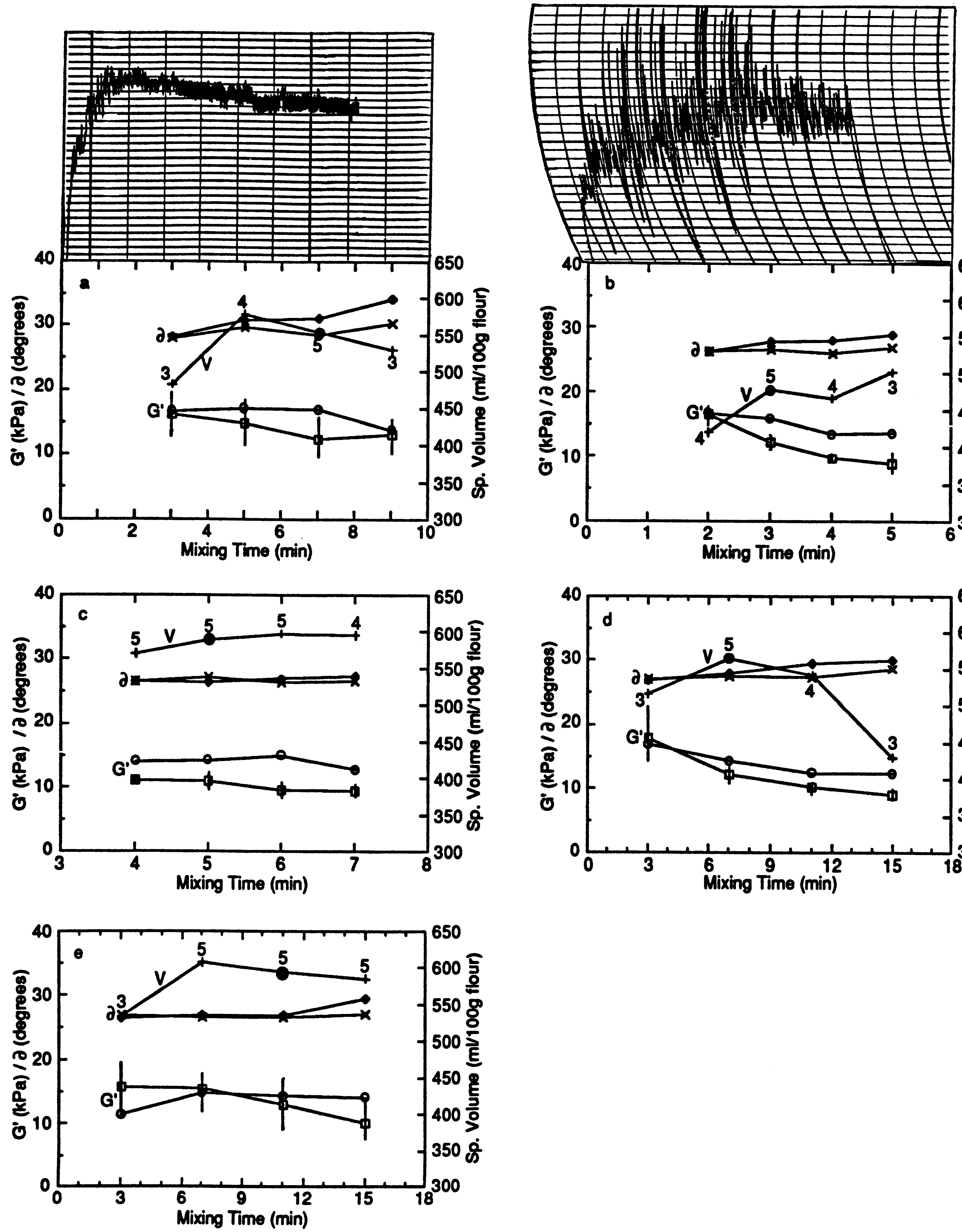

Fig. 1. Rheological properties and baking results for doughs mixed in the 10-g farinograph (**A**, shown with the corresponding farinogram), the mixograph (**B**, shown with the corresponding mixogram), the 300-g farinograph (**C**), the Krups mixer (**D**), and the Hobart mixer (**E**). The storage modulus, *G′*, was measured 2 min (□) and 20 min (○) after completion of mixing; ◫ indicates the 95% confidence interval for the five replications. The phase angle (∂) was measured 2 min (◆) and 20 min (x) after completion of mixing. *V* = specific volume; numbers indicate porosity (higher numbers indicate better quality); ● indicates optimum quality.

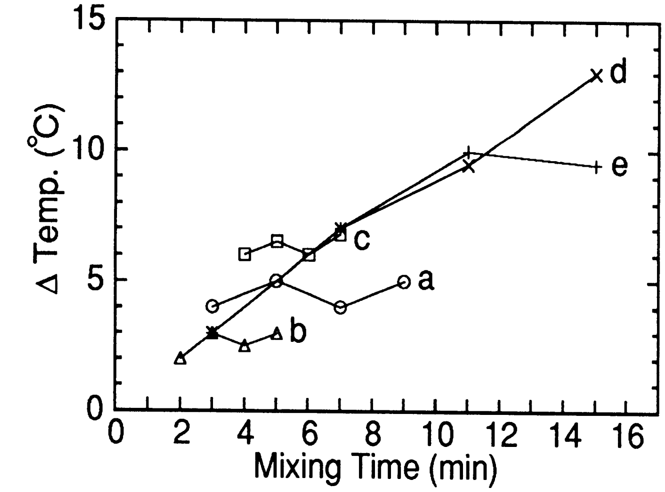

Fig. 2. Difference in temperature between the flour and water mixture and the dough mixed in the 10-g farinograph (a), the mixograph (b), the 300-g farinograph (c), the Krups mixer (d), and the Hobart mixer (e).

ing the interpretation of the results for these mixers difficult. The variation might be an indication of the nonhomogeneity of the dough. The storage modulus values for different mixing times overlapped, and the optimum could not be distinguished by considering the storage modulus alone. With the other mixers, however, the storage modulus values for optimal mixing could be distinguished from the values for undermixed and overmixed doughs.

Mechanical mixing of the dough puts energy into the system. Some of the energy is changed into heat and raises the temperature of the dough as it is mixed. The amount of energy put into the system differs for each mixer. The complex geometry of the equipment and the unknown rotation speeds of the mixograph, Krups, and Hobart mixers make calculation of the energy input almost impossible.

Temperature control during the mixing process was obtained only in the farinograph. Although temperature was not controlled in the mixograph, the dough temperature was relatively stable during mixing (Fig. 2), perhaps because the small amount of dough had a relatively large surface area in contact with the bowl and surrounding air. Heat energy is given off to the surroundings, which keeps the temperature relatively constant. In the Hobart and Krups mixers, which have no temperature control device, the temperature of the dough rose substantially during mixing. The intensive mixing of the Krups equipment produced a sticky dough with a relatively high temperature after 15 min of mixing.

CONCLUSION

The elasticity of the dough is one of the most important factors determining the quality of bread. Elasticity affects the gas-holding capacity of the dough. Dough must be extensible to prevent rupture of the membranes between gas cells (Bloksma 1990). Other important determinants of bread quality include the amount of air incorporated in the dough and the size of the air bubbles. These variables affect the volume and the porosity of bread.

What is usually referred to as dough development means the optimization of the viscoelastic properties. One of the oldest methods bakers have used to detect the point of optimal dough development is to feel or stretch the dough piece between their fingers, which is a subjective test of viscoelasticity. In this experiment we used the same principle but based it on objective measurements of dough rheology rather than subjective tests.

TABLE I
Average Storage Modulus (G') and Phase Angle (δ) for Optimal Mixing

Mixer	G' (kPa)	δ (°)
Farinograph (10 g)	12.5	31.2
Farinograph (300 g)	11.1	26.5
Mixograph	12.3	27.8
Krups	12.3	28.1
Hobart	13.1	27.0

The optimum mixing time is specific to each flour, mixer, and type of bread. The results of this experiment suggest a potential relationship between rheology and optimum mixing independent of the mixing equipment used. This information can be used to establish the optimum quality of the finished baked product. The fundamental rheological studies must be complemented by test baking to determine the optimum mixing time. This type of testing could be applied to industry-scale dough mixers, and the results could be compared to those of this experiment. It would be interesting to observe how close the storage modulus values for optimum mixing would be to the ones obtained in this experiment.

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