Comparison of Small and Large Deformation Measurements of Whole Meal Rye Doughs

K. Autio,[1,2] L. Flander,[1] R. Heinonen,[1] and A. Kinnunen[1]

ABSTRACT

Cereal Chem. 76(6):912–914

The rheological properties of rye flour-water-salt doughs prepared from different flour types (different falling number and coarseness) at different water levels were studied after mixing and after 90 min of incubation (30°C and 80% rh). Both the effect of water and the coarseness of the flour had significant effects on storage modulus (G') measured by oscillatory test in the linear viscoelastic region and on compressional force measured at large deformation. The results of the two rheological methods correlated very well with each other (correlation coefficients varied in the different doughs at $r = 0.975–0.999$). Dough rheological measurements suggested that falling number did not have a statistically significant effect on dough rheology after mixing or incubation. Although the two rheological methods correlated well, the responses for incubation were different. In the small deformation method, the storage modulus of all doughs, independent of the falling number, decreased during incubation, whereas in the large deformation method, only the hardness of doughs made from flours with lower falling number decreased during incubation. The rheological measurements of doughs after mixing and the viscosity measurements of flour-water suspension at 30 and 40°C did not correlate with each other. Total pentosans have great effect on viscosity measurements of flour-water suspensions, whereas flour particle size and soluble pentosans correlated more with rheological properties of doughs ($r = 0.851$ between G' and soluble pentosans).

Good baking performance is dependent on several rheological properties of wheat doughs: viscosity must be above a certain value throughout the whole breadmaking process, and the dough must have an optimal resistance to extension, high extensibility, and high strain hardening properties during fermentation and baking (Kokelaar 1994). Studies made with wheat doughs have shown that not all rheological measurements predict the baking quality of different flours (Amemiya and Menjivar 1992, Safari-Ardi and Phan-Thien 1998). The rheological measurements can differ in terms of magnitude and type of deformation or deformation rate. In the case of wheat doughs, oscillatory measurements in the linear viscoelastic region have not been able to predict the baking quality of different flours. The rheological method with potential for predicting baking quality is very much dependent on the structure of the dough system. Wheat and rye dough have marked differences in microstructure (Autio et al 1997). Wheat dough has a stronger continuous phase. In glutenin, the polypeptide chains are linked together covalently by intermolecular disulfide bridges (Kasarda 1989). The hydrophobic interactions and hydrogen bonds are important for the stabilization of the glutenin structure (Schofield and Booth 1983, Eliasson 1990). The ratio of glutenin to gliadin is important (Janssen et al 1992) because gliadin contributes to extensibility and softness, whereas glutenin contributes to firmness, elasticity, and resistance. In rye dough, very rigid particles are dispersed in a weak continuous phase composed of protein, starch, and cell wall polysaccharides (Autio et al 1997). The increase of volume in rye dough during fermentation and baking is much less than that of wheat dough.

The results of large deformation measurements correlate well with the properties of the overall network structure (Stadig 1993). Amemiya and Menjivar (1992) showed that at strains >300% the rheological difference of wheat bread and cookie (biscuit) dough could be demonstrated; bread flour dough had larger shear and normal stresses than cookie doughs. In addition, the strain hardening of wheat bread doughs was observed. The effect of water content and different flour types (weak, medium, and strong) could also be demonstrated by stress relaxation test at a strain level of 20% (Safari-Ardi and Phan-Thien 1998). Viscosity measurements of wheat doughs show increased strain hardening behavior for doughs made of stronger flours (Lindborg 1995). In small oscillatory measurements, the strain is usually <0.1%. At these strains, the weak van der Waals and hydrogen bond interactions, starch-starch, and starch-protein bonds dominate and do not have any major role in the expansion of the dough.

Susceptibility of rye to preharvest sprouting is one reason for the variation in baking quality (Seibel et al 1983). The most important method for determining the preharvest sprouting of rye flour is falling number. The aim of the present study was to compare the response of the small deformation oscillation test and the large deformation compression test of rye doughs prepared from rye flours with different falling numbers and water contents. The results were related to chemical analyses of flours and viscosity measurements of flour-water suspensions.

MATERIALS AND METHODS

The rye samples were obtained from Vaasanmylly Oy and were harvested in 1997. All analyses were done in duplicate and were reported on a dry matter basis. The dry matter content was determined by oven drying at 105°C for 16 hr. Crude protein and ash were analyzed according to standard methods (AOAC 1984). Total and soluble arabinoxylans were determined by the method of Douglas (1981). Chemical composition of the flours is shown in Table I. Falling number (7.0 g flour on a 14% moisture basis) was measured by standard method 107/1 (ICC 1995). The water absorbance of the dough was determined in a Brabender Farinograph to achieve a consistency of 240 ± 10 BU with 200 g of rye flour (Table I). In the swelling curve test (Table II), the viscosity of a rye flour suspension (120 g/420 mL of buffer, pH 5.0) was determined in a viscograph by a method proposed by Drews (1971). Detected parameters in BU were initial viscosity at 30°C (A), viscosity at 42°C (B), and viscosity after 30 min at 42°C (C). The change in viscosity at 42°C was calculated as (logB – logC) ×

TABLE I
Chemical Composition and Properties of Rye Flour

Flour Type	Crude Protein[a] (%)	Ash (%)	Falling Number (sec)	Total Pentosans (%)	Soluble Pentosans (%)	Farinogram Absorption (%)
Coarse	9.2	1.4	200	3.1	1.3	77
Normal	10.2	1.7	200	3.6	1.5	77
Normal	9.5	1.4	145	3.0	1.4	77
Normal	10.6	1.7	95	3.3	1.6	80

[a] N × 6.25.

---

[1] VTT Biotechnology and Food Research, P.O. Box 1500, FIN-02044 VTT, Finland.

[2] Corresponding author. Phone: +358-9-4565215. Fax: +358-9-4552103. E-mail: karin.autio@vtt.fi

Publication no. C-1999-1006-03R.

1,000. The initial viscosity reflects the amount of water-binding material present in the flour (Drews 1971). The decrease in the viscosity during the holding time is influenced by the amount, solubility, and properties of cell-wall polysaccharides and by the activity of cell-wall-degrading enzymes (Nilsson et al 1997).

Full-factorial design was used to study the effects of falling number and water content on storage modulus (G') and compressional force. Modde 3 for Windows (Umetri Ab, Umeå, Sweden) software was used for evaluation of the experimental data. The standard errors of means of six measurements are indicated as error bars. The correlation coefficient between swelling curve data, A and B, storage modulus (G') after mixing, $G'_{\mathrm{mix}} - G'_{\mathrm{inc}}$, falling number, crude protein, soluble, and total pentosans was calculated.

Doughs consisted of milled rye (250 g), water, and salt (3.75 g). The amount of water was varied to give three different dough yields depending on the farinogram absorption. When farinogram absorption was 77%, the water contents were 193 g (optimum), 187 g (–3% from optimum), and 200 g (+3% from optimum). The rye dough was mixed for 3 min in a household mixer (Kenwood Chef Excel, New Lake, Great Britain) fitted with a K-beater. Dough pieces were incubated at 30°C for 90 min and 80% rh.

The viscoelastic measurements were made with a rheometer (StressTech, Reologica, Lund, Sweden) with parallel-plate geometry. Two replicate doughs were prepared and three pieces of each dough were measured. The dough sample (1.07 g) was slowly compressed by the upper plate until the gap between the plates was 3.0 mm. Silicon oil was applied around the plate edges to prevent the sample from drying. The sample was allowed to rest to reach a normal force <0.4 N. The measurements were made at 25°C after dough mixing and after incubation. The stress was 10 Pa (within the linear region) and the frequency 1 Hz. The standard deviation after mixing 1.5–4.8 and after incubation was 0.6–2.2. The compression measurements were performed with a texture analyzer (TA-XTA, Stable Micro Systems, Surrey, Great Britain). A round plastic box (68 mm i.d., 20 mm height) was filled with dough and excess dough was carefully trimmed off with a knife to achieve an even surface. The doughs were compressed with a cylinder (sample area 314 mm^2). The compression range and rate were 50% and 2 mm/sec, respectively. The standard deviation after mixing and after incubation was 0.003–0.012 and 0.003–0.020, respectively.

RESULTS AND DISCUSSION

Table III shows the correlation between different measurements. Falling number and swelling curve are the most commonly used methods for rye quality control. Water-soluble pentosans have a high positive correlation with rye baking quality (Weipert 1995). Table III shows that soluble pentosans have correlation with falling number but not with swelling curve data. Soluble pentosans, on the other hand, have great correlation with the storage modulus of doughs.

The results of the rheological measurements of doughs are shown in Figs. 1–4. Both the effect of water and the coarseness of the flour had statistically significant effects on G' value at low deformation and on compressional force at large deformation. Both rheological methods correlated with each other. The correlation coefficients varied between the two methods at 0.975–0.999. The results clearly indicated that flour coarseness and water content of the doughs have a much greater impact on the rheology of the doughs than does falling number.

Although the two rheological methods correlated well, there were also differences. The responses for incubation were different. In the small deformation method, all doughs independent of the falling number became softer during incubation. Softening during incubation has also been observed in earlier studies (Autio et al 1998). The decrease of G' during incubation is due to changes in both the continuous and dispersed phases of the dough (Fabritius et al 1997). These changes are related to enzymatic hydrolysis, physical changes (swelling, solubilization) and to redistribution of water in the dough. In the large deformation method, only doughs made from flours with lower falling numbers became softer during incubation (Fig. 3 vs. Fig. 4.) The results of large deformation measurements correlate well with the properties of the overall network structure (Stadig 1993), suggesting that after mixing, when the falling number is lower, the continuous phase is stronger, but that during incubation, the continuous phase of doughs with low falling numbers weakens. In rye dough, very rigid particles are dispersed in a weak continuous phase composed of protein, starch, and cell-wall polysaccharides (Autio et al 1997). During baking, cell wall components become a

TABLE II
Swelling Curve Data for Rye Flours[a]

Sample	Initial Viscosity A (BU)	Final Viscosity C (BU)	Difference (logB – logC)
FN200C	270	198	110
FN200	320	338	37
FN145	265	230	73
FN95	232	185	104

[a] A = initial viscosity at 30°C, B = viscosity of sample at 42°C, C = viscosity after holding at 42°C for 30 min.

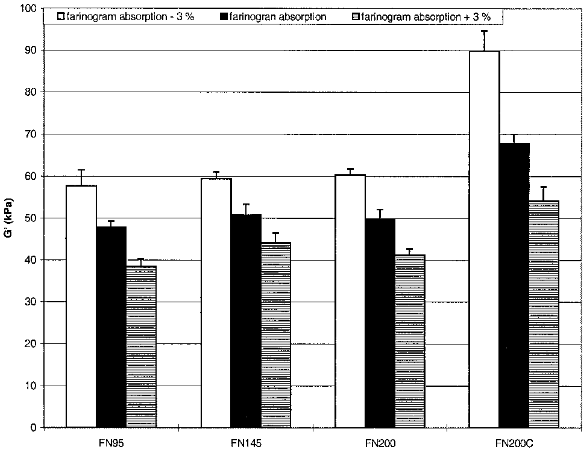

Fig. 1. Effect of water content and flour type (FN = falling number, C = coarse) on storage modulus (G') of doughs after mixing. Farinograph absorption at –3% (white), optimum (black), and 3% (grey).

TABLE III
Correlation Coefficients Between Different Analyses

Method	Falling Number	Crude Protein	Ash	Viscosity A	Viscosity B	$G'_{\mathrm{mix}} - G'_{\mathrm{inc}}$	G'_{mix}	Soluble Pentosan
Falling number	1							
Crude protein	–0.573	1						
Ash	–0.286	0.948	1					
Viscosity A	0.826	–0.135	0.135	1				
Viscosity B	0.567	0.181	0.395	0.932	1			
$G'_{\mathrm{mix}} - G'_{\mathrm{inc}}$	–0.389	–0.221	–0.362	–0.831	–0.962	1		
G'_{mix}	0.600	0.787	–0.653	0.046	–0.316	0.499	1	
Soluble pentosan	–0.665	0.989	0.894	–0.210	0.128	–0.208	–0.851	1
Total pentosan	0.212	0.680	0.873	0.585	0.732	–0.624	–0.411	0.586

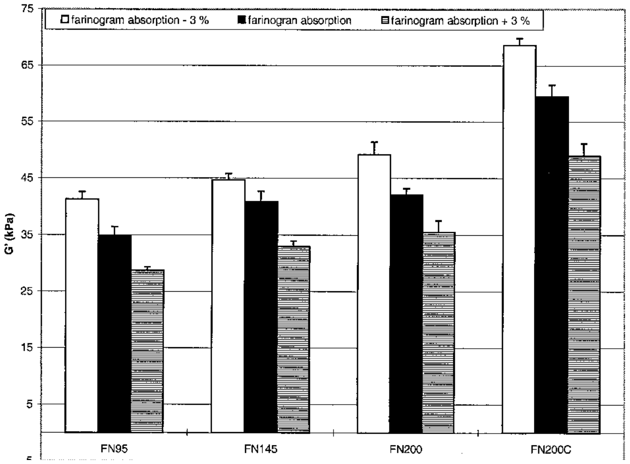

Fig. 2. Effect of water content and flour type on storage modulus (*G*′) of doughs incubated at 30°C and 80% rh for 90 min after mixing. Farinograph absorption at –3% (white), optimum (black), and 3% (grey).

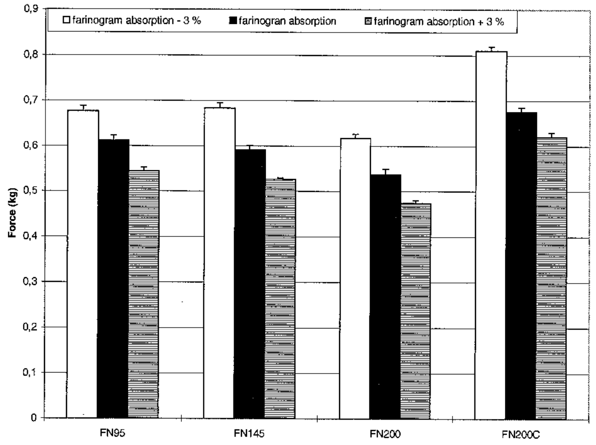

Fig. 3. Effect of water content and flour type on compressional force after mixing. Farinograph absorption at –3% (white), optimum (black), and 3% (grey).

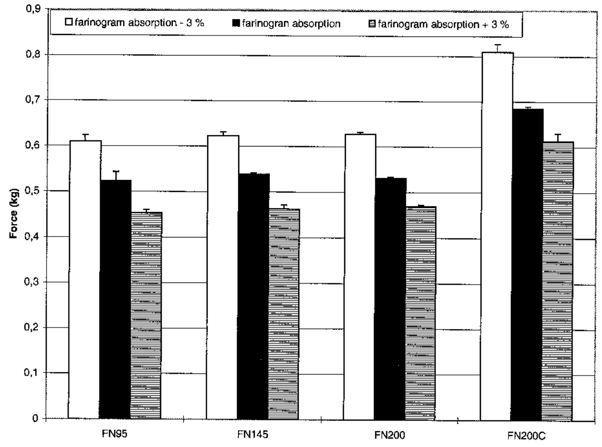

Fig. 4. Effect of water content and flour type on compressional force of doughs incubated at 30°C and 80% rh for 90 min after mixing. Farinograph absorption at –3% (white), optimum (black), and 3% (grey).

more important part of the continuous phase (Parkkonen et al 1994). The low falling number of rye flour is related not only to higher α-amylase activity, but also to higher activity of xylanase (Autio et al 1998), and the softening of doughs made from low falling number flour may be due to both enzymatic hydrolysis and physical changes in the cell walls of the continuous phase.

Doughs and flour-water suspensions represent different types of microstructures due to different water contents. Earlier studies (Autio et al 1996) and results here suggest that cell-wall hydrolyzing enzymes and total pentosans have great effect on viscosity measurements of flour-water suspensions, whereas flour particle size and soluble pentosans correlate more with rheological properties of doughs.

ACKNOWLEDGMENTS

We wish to thank Technology Development Centre of Finland (TEKES), Baco Oy, Vaasan & Vaasan Oy, Leivon Leipomo Oy and HK Ruokatalo Oy for financial support.

LITERATURE CITED

Amemiya, J. I., and Menjivar, J. A. 1992. Comparison of small and large deformation measurements to characterize the rheology of wheat flour doughs. J. Food Eng. 16:91-108.

AOAC. 1990. Association of Official Analytical Chemists Official Methods of Analysis, 15th ed. The Association: Washington, DC.

Autio, K., Parkkonen, T., and Fabritius, M. 1997. Observing structural differences in wheat and rye breads. Cereal Foods World 42:702-705.

Autio, K., Fabritius, M., and Kinnunen, A. 1998. Effect of germination and water content on the microstructure and rheological properties of two rye doughs. Cereal Chem. 75:10-14.

Douglas, S. G. 1981. A rapid method for the determination of pentosans in wheat flour. Food Chem. 7:139-145.

Drews, E. 1971. Quellenkurven von Roggenmahlprodukten. Mühle und Mischfuttertechnik 49:723-724.

Eliasson, A.-C. 1990. Rheological properties of cereal proteins. Pages 67-110 in: Dough Rheology and Baked Product Texture. H. Faridi and J. M. Faubion, eds. Van Nostrand Reinhold: New York.

Fabritius, M., Gates, F., Salovaara, H., and Autio, K. 1997. Structural changes in insoluble cell walls in wholemeal rye doughs. Lebensm. Wiss. Technol. 30:367-372.

ICC. 1995. Standard Methods of the International Association for Cereal Science and Technology. ICC: Vienna, Austria.

Janssen, A. M. 1992. Obelisk and Katepwa wheat gluten. A study of factors determining bread making performance, PhD thesis. State University of Groningen: Groningen, The Netherlands.

Kasarda, D. D. 1989. Glutenin structure in relation to wheat quality. Pages 277-302 in: Wheat is Unique. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Kokelaar, J. J. 1994. Physics in breadmaking. PhD thesis. University of Wageningen: Wageningen, The Netherlands.

Lindborg, K. M. 1995. Rheological studies of wheat flour doughs, the development of structure during mixing. PhD thesis. University of Lund: Lund, Sweden.

Nilsson, M., Åman, P., Härkönen, H., Hallmans, G., Knudsen, K., Mazur, W., and Adlercreutz, H. 1997. Nutrient and lignan content, dough properties and baking performance of rye samples used in Scandinavia. Acta Agric. Sect. B. Soil Plant Sci. 47:26-34.

Parkkonen, T., Härkönen, H., and Autio, K. 1994. The effect of baking on microstructure of rye cell walls and proteins. Cereal Chem. 71:58-63

Safari-Ardi, M., and Phan-Thien, N. 1998. Stress relaxation and oscillatory tests to distinguish between doughs prepared from wheat flours of different varietal origin. Cereal Chem. 75:80-84.

Schofield, J. D., and Booth, M. R. 1983. Wheat proteins and their technological significance. Dev. Food Proteins 2:1-65.

Seibel, W., Brummer, J.-M., and Stephan, H. 1983. Influence of flour from sprout-damaged rye on the quality of rye and rye-mixed bread. Cereal Foods World 28:503-505.

Stadig, M. 1993. Rheological behaviour of biopolymer gels in relation to structure. PhD thesis. Chalmers Univ. of Technology: Gothenburg, Sweden.

Weipert, D. 1995. Processing performance of rye as influenced by sprouting resistance and pentosan contents. Pages 39-48 in: International Rye Symposium: Technology and Products. K. Poutanen, and K. Autio, eds. VTT: Espoo, Finland.

[Received January 19, 1999. Accepted August 3, 1999.]