Creep-Recovery of Wheat Flour Doughs and Relationship to Other Physical Dough Tests and Breadmaking Performance[1]

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ABSTRACT

Measurements of creep-recovery of flour-water doughs were made using a dynamic mechanical analyzer (DMA) in a compression mode with an applied probe force of 50 mN. A series of wheat flour and blend samples with various breadmaking potentials were tested at a fixed water absorption of 54% and farinograph optimum water absorption, respectively. The flour-water doughs exhibited a typical creep-recovery behavior of a noncross-linked viscoelastic material varying in some parameters with flour properties. The maximum recovery strain of doughs with a fixed water absorption of 54% was highly correlated ($r = 0.939$) to bread loaf volume. Wheat flours with a large bread volume exhibited greater dough recovery strain. However, there was no correlation ($r = 0.122$) between maximum creep strain and baking volume. The maximum recovery strain of flour-water doughs also was correlated to some of the parameters provided by mixograph, farinograph, and TA-XT2 extension.

The main ingredients of bread doughs are wheat flour and water. Flour dough belongs to a group of viscoelastic materials in which a high degree of plasticity or viscosity is combined with considerable elasticity (Schofield and Scott Blair 1932). Variations in baking quality among wheat cultivars exist and the reasons are not fully understood (Schofield 1985). Rheology has been a useful physical approach to study the relationships between wheat flour doughs and bread quality (Faubion and Hoseney 1990) because rheological properties of dough are important for breadmaking performance (Bloksma and Bushuk 1988). However, scientists often have difficulty relating basic rheological parameters of wheat flour dough to its baking behavior because of the use of empirical instruments (Szczesniak 1988).

The farinograph, mixograph, and extensigraph are the most common empirical instruments used for physical dough tests. They have provided much practical and useful information for the milling and baking industries and are still important in characterizing properties of wheat flour doughs. However, they do not provide enough information to interpret the fundamental behavior of dough rheology and its baking quality (Szczesniak 1988). The predictive correlation between physical dough test results, such as water absorption and mixing development time, and baking quality is not high (Oliver and Allen 1992), which means the usual physical dough tests do not appear to measure properties that are directly important for breadmaking performance (Bloksma 1990a,b). Therefore, dough technologists have become more interested in fundamental rheological measurements.

Dynamic oscillatory measurements in the synthetic polymer industry have been applied to dough systems (Faubion and Hoseney 1990). However, there is no consensus as to the practical advantages over established empirical methods (Amemiya and Menjivar 1992; Edwards et al 1999). Neither dynamic modulus nor tanδ value of wheat flour doughs shows a clear relationship with bread quality (Janssen et al 1996), which is probably due to the large deformations that occur in baking (Bloksma 1972). Consequently, the dynamic measurements are not considered suitable for predicting dough baking performance (Kokelaar et al 1996).

Stress relaxation technique was proposed to study viscoelastic properties of wheat flour doughs (Launay and Bure 1974; Fu et al 1997). It is evident that stress relaxation behavior is important in characterizing dough rheology and relates to bread volume (Bagley and Christianson 1986). A slow stress relaxation is associated with good baking quality (Launay and Bure 1974; Bloksma and Bushuk 1988).

Creep-recovery method should be preferred over stress relaxation because loading a sample by a constant stress is a simple approach (Bloksma and Bushuk 1988), and the interpretation should be simple (Bloksma 1962). Several studies, beginning in the 1930's, have researched the fundamental rheological properties of doughs by the creep-recovery technique (Schofield and Scott Blair 1932, 1933; Bloksma 1962; Smith and Tschoegl 1970; Hibberd and Parker 1979). The results reported, however, have produced inconsistent conclusions. The only common conclusion was that dough is a viscoelastic material and behaves as a typical noncross-linked polymer. There was no information available about the relationship between dough creep-recovery to the baking quality of wheat flours. We assume that the dough of wheat flour with higher protein content and better protein quality demonstrates larger elasticity and, consequently, may have a greater recovery. Recently, Edwards and coworkers (1999) used the creep-recovery technique to determine gluten strength of durum wheat doughs. They found that the maximum creep strain was important in assessing durum wheat dough strength, and this method was simple and required less sample. Therefore, creep-recovery might also be suitable in studying common wheat flour doughs to gain better insight into the factors determining breadmaking performance.

The objectives of this work were to obtain dough creep-recovery data from a wide range of wheat flours and to determine the relationship of creep-recovery parameters to other physical dough properties and bread baking volume.

MATERIALS AND METHODS

Eleven commercial wheat flours were used in this study. They were obtained from different flour mills; milled from different cultivars and types of wheats with a wide range of protein content, physical dough properties, and breadmaking potential; and all were untreated. Protein, moisture, and ash contents were determined using AACC Approved Methods 46-13, 44-15A, and 08-01, respectively. Protein content was 8.47–13.6% (14% mb). Two additional flour samples were obtained by blending flours No. 1 (a typical pastry flour) and No. 8 (a typical bread flour) at ratios of 20/80 and 40/60. Native wheat starch and vital wheat gluten were obtained from Midwest Grain Product Co., Atchinson, KS, and added to flour No. 8 to generate four more flour samples containing 7.59, 9.18, 13.3, and 15.6% protein, respectively. Flour No. 8 was also treated individually with sodium stearoyl-2-lactylate (SSL), potassium bromate ($KBrO_3$) and ascorbic acid (AA). SSL (Emplex, American Ingredients Co., Kansas City, MO), $KBrO_3$, and AA were all reagent-grade. SSL was added at 0.4 and 0.8%; $KBrO_3$ was added at 25 and 50 ppm; and AA was added at 50 and 100 ppm, all on a flour-weight basis.

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Physical Dough Tests

Mixing properties of the 23 flour samples (Table I) were determined using a 50-g farinograph (C.W. Brabender Instruments, South Hackensack, NJ) and a 10-g mixograph (National Manufacturing Co. Division, TMCO, Lincoln, NE) according to AACC Approved Methods 54-21 and 54-40A, respectively. Optimal water absorption, dough development peak time, and mixing stability were obtained using the farinograph. Mixogram was obtained by mixing 10 g of flour with two water absorption levels for 10 min at room temperature (≈25°C). One water absorption level was fixed at 54% (14% mb) and the other was the farinograph optimum water absorption. Mixograph pattern and parameters were analyzed and determined using Mixsmart computer software (v. 3.80, National Mfg.). Computer-analyzed parameters of the mixograph included time to peak, peak height, and width of envelope peak.

The resistance (*R*) to extension and extensibility (*E*) of each dough sample were measured using the Kieffer test (TA-XT2, Texture Technologies, Scarsdale, NY). This test involved a press mode to cut the dough, a spring-loaded rig with a sample plate to hold the dough, and a hook accessory to perform the tensile test. A 10-g sample of each wheat flour (14% mb) was mixed to its peak time, using the optimal water absorption according to the farinograph information. The dough then was transferred to an airtight plastic container and allowed to rest for 20 min. Dough then was cut compressively into strips with the grooved base of the mold. Another 20 min were allowed for the dough strips to rest in the mold. One dough strip at a time was removed carefully with a spatula for the tensile test. The pretest speed was 2.0 mm/sec, test speed was 3.3 mm/sec, distance was 75 mm, trigger force was 5 *g*-auto, and data acquisition rate was at 200 pps. The graph obtained from this test revealed the *R* (N) and the *E* (mm).

Creep-Recovery Measurement

Creep-recovery measurement of flour-water dough was made on a dynamic mechanical analyzer (DMA 7e, Perkin Elmer, Norwalk, CT), using a 10-mm parallel-plate probe. The test was performed in a controlled temperature environment (25°C). The flour-water dough samples were prepared in the 10-g mixograph at two different water absorptions (fixed water absorption of 54% and the farinograph optimum water absorption). Flour (10 g, 14% mb) and distilled water were mixed at room temperature (≈25°C) until the dough was optimally developed (mixogram peak). After mixing, the dough was removed from the equipment and rounded gently into a ball shape. The sample was placed in a small airtight plastic container to relax for 30 min at room temperature (≈25°C) before DMA creep-recovery measurement.

A 0.5-g dough sample (≈8 mm diameter) was loaded between the parallel plate-cup and held for 3 min equilibrium with a static force of 5 mN applied. There were two reasons to use the 5 mN initial force: 1) to avoid the extra dough deformation caused by the probe moving down before creep test, although the probe was tarred; 2) to flatten the dough sample, assuring as much uniform stress as possible within the dough during creep test. To reduce moisture loss, a thin plastic film at the sample-plate interface was used to cover the dough sample, and the whole geometry was covered in the holding chamber. This film also served to minimize variations caused by stickiness between probe and dough surface during recovery. Oil lubrication was first considered, but was not used because oil might diffuse into the dough or interact with the dough, causing property change. The same film was used for all dough samples to minimize variations. Pyris Software for Windows (Perkin Elmer) was used to program the creep-recovery experiment. A static force of 50 mN was suddenly applied to compress the dough and maintained for 4 min; thus, the dough was allowed to creep for 4 min. The creep stress generated within the dough under 50 mN force was ≈636 N/m^2. The static force then was suddenly reduced to 5 mN, and the dough was allowed to recover for 4 min. Changes in probe position (dough height) were recorded as a function of time, and the creep-recovery curve (strain vs. time) was plotted.

Baking Test

A 100-g optimized straight-dough breadmaking procedure (AACC Approved Method 10-10B) was used for baking experiments. The formula consisted of 100 g of flour (14% mb), 4 g of nonfat dry milk, 3 g of shortening, 1.5 g of salt, 6 g of sugar (sucrose), 2 g of yeast (instant dry), various amounts of the additives (SSL, $KBrO_3$, and AA), and the optimal amount of water according to the farinograph optimum water absorption.

A 100-g mixer (Swanson-Working pin-type, National Mfg.) was used to mix the bread dough, which was mixed to optimum accord-

TABLE I
Flour Protein Content (14% mb) and Physical Dough Properties[a]

Sample	No.	Protein (%)	FWA (%)	MPT (min)	*R* (N)	*E* (mm)
Pastry flour	1	8.47	51.4m[b]	3.00l	0.119l	51a
Pastry	2	8.49	52.5l	3.75i	0.186j	43e
All purpose	3	9.58	55.3j	4.00h	0.294gh	44de
Bread	4	10.6	59.8g	5.50c	0.460cd	28m–o
Bread	5	10.6	59.3h	5.00e	0.350f	38g–i
Bread	6	10.7	59.5gh	4.00h	0.270h	50b
Steamed bread	7	10.8	59.6gh	3.15k	0.150k	44de
Bread	8	10.9	61.6e	5.50c	0.359f	32kl
Bread	9	12.0	62.5bc	3.50j	0.315g	38g–i
Noodle	10	12.3	60.5f	3.60j	0.231i	46cd
Bagel	11	13.6	62.3cd	3.50j	0.287gh	45d
20/80 blend of 8 and 1	12	8.96	53.4k	3.50j	0.187j	47c
40/60 blend of 8 and 1	13	9.45	55.5j	4.00h	0.223i	40fg
Additives to bread flour No. 8[c]						
32% starch	14	7.59	57.4i	4.25g	0.278h	31k–m
16% starch	15	9.18	59.5gh	4.50f	0.271h	35ij
4% gluten	16	13.3	62.8b	5.25d	0.488bc	34j
8% gluten	17	15.6	64.2a	5.25d	0.511ab	39gh
0.4% SSL	18	10.9	61.8e	6.00b	0.441d	36h–j
0.8% SSL	19	10.9	62.0de	6.25a	0.446d	40fg
25 ppm $KBrO_3$	20	10.9	61.6e	5.00e	0.400e	30l–n
50 ppm $KBrO_3$	21	10.9	61.6e	5.25d	0.401e	31k–m
50 ppm AA	22	10.9	61.6e	5.00e	0.468cd	29mn
100 ppm AA	23	10.9	61.6e	5.25d	0.538a	27o

[a] FWA = farinograph optimum water absorption, MPT = mixograph mixing peak time, *R* = resistance to extension, E = extensibility.

[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

[c] Sodium stearoyl-2-lactylate (SSL), potassium bromate ($KBrO_3$), and ascorbic acid (AA).

ing to the mixograph. Fermentation time was 90 min, proof time was 33 min at 30°C and 85% rh, and baking time was 24 min at 215°C. All loaves were weighed and measured for volume by rapeseed displacement 1 hr after they were removed from the oven.

Statistical Analysis

Physical dough, creep-recovery, and baking tests all were conducted in a randomized complete block design with three replicates for all wheat flour samples tested. The experimental batch (or day) was used as a blocking factor. The Statistical Analysis System (SAS Institute Inc., Cary, NC) was used for analysis of variance and correlation of data at $P < 0.05$. Results reported are the average of the three replicates, where each replicate represents a newly mixed dough for each flour sample.

RESULTS AND DISCUSSION

The physical dough characteristics and baking loaf volumes of the 23 flour samples are presented in Tables I and II, respectively. Significant differences in physical dough characteristics and baking volume existed among these wheat flours. Farinograph optimum water absorption (FWA) was 51.4–64.2%; mixograph peak time (MPT) was 3.00–6.25 min; resistance (*R*) to extension was 0.119–0.538 N; extensibility (*E*) was 27–51 mm; and bread loaf volume was 674–872 cm^3.

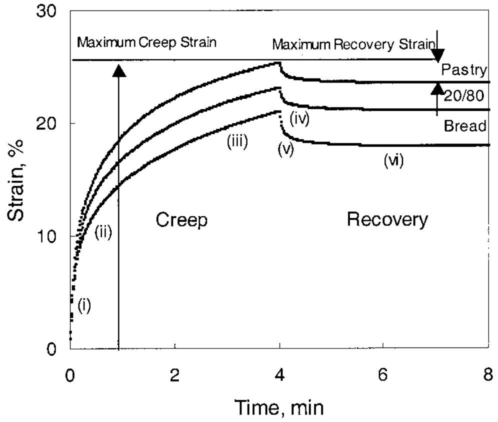

Fig. 1. Creep-recovery curves for doughs of bread flour (No. 8), pastry flour (No. 1), and blend (20/80) with a fixed water absorption of 54%. Applied static force was 50 mN using a 10-mm plate. Six deformation regions: (i) instantaneous elastic deformation, (ii) retarded elastic deformation, (iii) equilibrium deformation, (iv) instantaneous recovery, (v) delayed elastic recovery, and (vi) steady recovery.

Creep-Recovery Measurement

Mechanical analogs composed of springs and dashpots can be useful in conceptualizing the viscoelastic behavior of flour-water dough (Carson and Sun 2001). The spring is considered an ideal solid element obeying Hooke's law, and the dashpot is considered an ideal fluid element obeying Newton's law. Connected in various ways, they can portray the behavior of viscoelastic materials (Steffe 1996). Elastic and viscous components are generally expressed by spring and dashpot components in most of the models. However, the wheat flour dough system was more complicated, which was beyond the simplified Burger's model, a combination of the Maxwell and Kevin models, recommended for describing viscoelastic material (Steffe 1996).

Typical creep-recovery curves of doughs prepared from bread flour (No. 8), pastry flour (No. 1), and the blend (20/80) are shown in Fig. 1. The strain increased with time and approached a steady state where the strain rate was kept constant in the creep step, in

TABLE III
Correlations Between Bread Volume and Creep-Recovery Strains[a]

Creep-Recovery	Water Absorption	Equation[b]	*r*
Max. creep strain			
	Farinograph optimum	$Y = 2.93X + 718$	0.103
	Fixed 54%	$Y = -3.00X + 850$	0.122
Max. recovery strain			
	Farinograph optimum	$Y = 123X + 438$	0.906
	Fixed 54%	$Y = 103X + 490$	0.939

[a] Based on linear regression at $P < 0.05$.

[b] Y = bread loaf volume (cm^3), X = maximum creep-recovery strains (%) of doughs.

TABLE II
Bread Volume and Creep-Recovery Parameters of Flour-Water Doughs

		54% Water Absorption		Optimum Water Absorption	
Sample No.[a]	Bread Volume (cm^3)	Creep Strain (%)	Recovery Strain (%)	Creep Strain (%)	Recovery Strain (%)
1	674o[b]	22.7c–e	1.94n	22.2g–i	2.15m
10	684no	22.0d–f	2.00mn	22.0h–j	2.31kl
7	693n	22.0d–f	2.20kl	22.0h–j	2.35j–l
14	710m	16.4j	2.60h	16.9o	2.51hi
12	720lm	24.8b	2.10lm	22.9e–g	2.23lm
2	728kl	22.6c–e	2.29jk	23.4d–f	2.39i–k
6	740jk	22.8c–e	2.57h	22.2g–i	2.47h–j
13	748ij	25.1b	2.39ij	24.8b	2.57h
15	760i	24.7b	2.84fg	19.1n	2.74g
3	776h	23.9bc	2.48hi	23.6c–e	2.54h
9	790gh	25.1b	2.81g	24.2b–d	2.49hi
11	800g	28.1a	2.47hi	27.4a	2.39i–k
5	803fg	21.2e–g	2.97ef	21.1kl	2.86g
8	818ef	20.8f–h	3.17cd	22.1f–h	3.15e
20	825de	21.4d–f	3.10de	21.6i–k	3.12ef
4	826de	20.9f–h	3.26c	19.7mn	3.15e
18	828de	20.9f–h	3.22cd	20.3lm	3.10ef
22	833de	19.3hi	3.20cd	21.2jkl	3.03f
21	835cd	22.4c–e	3.50b	23.1ef	3.44b
19	840b–d	19.0i	3.45b	21.4i–k	3.30cd
16	850bc	22.8c–e	3.58b	21.9h–j	3.36bc
23	853b	20.6g–i	3.50b	22.6f–h	3.31cd
17	872a	23.0cd	3.72a	24.3bc	3.60a

[a] Samples as listed in Table I.

[b] Values (means of three replicates) followed by the same letter are not significantly different ($P > 0.05$) in the same column.

which the dough sample was subjected to a constant stress. In the recovery stage, the dough strain partially recovered with time after removal of the force from maximum creep strain to a constant value. The creep-recovery curves exhibit a typical viscoelastic behavior combining both viscous fluid and elastic components (Hibberd and Parker 1975; Carson and Sun 2001). All the creep-recovery curves are qualitatively similar to the characteristics of a noncross-linked polymer because the deformation strain did not approach a constant value and the nonrecoverable viscous proportion is larger than the recoverable elastic proportion (Hibberd and Parker 1978).

The curves have six principal regions. i) Instantaneous elastic deformation, where at the beginning of applying a sudden constant force, the dough was rapidly deformed. In this region, the bonds between the structural units in dough were deformed elastically due to the elastic component (Rao et al 1987). If the force was removed, the structure of the dough would recover completely. ii) Retarded elastic deformation, occurring just after the rapid elastic deformation where the deformation continued to increase more slowly. This region corresponds to a time-dependent retarded elastic state. The bonds broke and reformed with various rates, accounted for by the combination of viscous and elastic components (Davis 1973). iii) Equilibrium deformation after a sufficient time, when the dough crept at a constant strain rate, reaching an equilibrium between elastic and viscous components in a linear portion. iv) Instantaneous recovery as the force suddenly became small, when the dough sample showed a rapid or instantaneous recovery because of the elastic components, resulting in a steep slope. v) Delayed elastic recovery, when the dough continued to recover more slowly due to an elastic retardation contributed to by the elastic and viscous components. vi) Steady recovery after a certain time, when the dough recovery reached equilibrium and stopped.

Although the creep stage qualitatively includes three kinds of deformations, they are not easily separated quantitatively (Smith and Tschoegl 1970). The maximum creep strain, as defined in Fig. 1, could be used to describe dough rigidity. The stronger dough, such as bread flour dough with greater resistance to deformation, had smaller creep strain than the softer dough, such as pastry flour dough. A partial recovery was observed in the dough recovery stage. The dough recovered only partially from the total deformation because of the viscous components that caused a permanent deformation. It also is not easy to quantitatively divide the recovery into instantaneous and delayed elastic components (Bloksma 1962). The resultant total strain, however, can be clearly separated into two parts: unrecoverable (viscous or plastic flow) and recoverable (elastic deformation, the sum of the instantaneous and delayed elastic deformation). The maximum recoverable strain can be determined by subtracting the unrecoverable strain caused by viscous components from the total deformation (the maximum creep strain). The recovery strain forms a basis for determining the dough springiness or resilience and can be used to describe the elastic property of doughs. The pastry flour had little elasticity and, consequently, had little substantial recovery when force was removed. The bread flour dough showed a much greater recovery than the pastry flour.

TABLE IV
Maximum Recovery Strain (%) of Dough at 54% Water Absorption vs. Other Flour and Dough Parameters[a]

Parameter	Equation[b]	r
Flour protein content (%)	$Y = 2.20X + 4.83$	0.555
Farinograph water absorption (%)	$Y = 4.75X + 45.9$	0.736
Mixograph mixing peak time (min)	$Y = 1.53X + 0.17$	0.889
Resistance to extension (N)	$Y = 0.21X - 0.27$	0.947
Extensibility (mm)	$Y = -9.70X + 65.7$	0.737
Resistance/Extensibility (N/mm)	$Y = 0.01X - 0.01$	0.892

[a] Based on linear regression at $P < 0.05$.
[b] Y = maximum recovery strain of dough at 54% water absorption, X = other flour and dough parameters.

Table II summarizes the creep-recovery parameters measured for the flour-water doughs under the conditions of constant water absorption at 54% and constant dough consistency at farinograph optimum water absorption, respectively. Significant differences in maximum creep strain and maximum recovery strain existed among the 23 different flour samples. The maximum creep strain range was 16.9–27.4% for the farinograph optimum water absorption and 16.4–28.1% for 54% water absorption. The maximum recovery strain range was 2.15–3.60% for the farinograph optimum water absorption and 1.94–3.72% for the fixed water absorption of 54%.

The relationships of bread loaf volume with maximum creep strain and maximum recovery strain of the 23 wheat flour samples are summarized in Table III, with farinograph optimum water absorption and 54% water absorption, respectively. There was no trend apparent between the maximum creep strain and loaf volume. However, the maximum recovery strains were highly positively correlated to bread loaf volumes for both optimum and 54% water absorptions (r = 0.906 and 0.939, respectively). In other words, wheat flour dough has to exhibit greater recovery strain to obtain a high loaf volume. Also, the correlation of loaf volume and maximum recovery strain for the fixed 54% water absorption was higher than that for the farinograph optimum water absorption, which means that constant water absorption would be more desirable for the creep-recovery test of evaluating flour quality because the testing procedure is simpler and fewer measurements are needed.

The results show that a large dough recovery strain is associated with large bread volume. This probably indicates that the recovery strain represents elastic properties of doughs by estimating springiness or resilience. It has been reported that the proper bread dough must not only be viscous or plastic, but also elastic or recoverable for good baking performance (Schofield and Scott Blair 1932; Bloksma 1990a,b). As a general experience, bakers have described doughs as being lively and springy to indicate their elastic properties, and the property of being lively and springy is associated with good baking quality (Hlynka 1970). The creep-recovery test, as an objective approach, provides the measurement of dough elasticity simply by recovery strain, which can be used to classify and predict flour quality for breadmaking.

Creep-recovery experiments may give some insight into the macrostructure of dough. For example, a small recovery may indicate the presence of small structures in dough, whereas a large recovery may indicate the presence of larger structures (Weegels et al 1995). The recovery also is an important factor for dough film stability. The higher the recovery strain, the better the stability against rupture of dough films between gas cells. The elasticity or springiness should be sufficiently high to prevent the ascent and spreading of gas cells under the influence of gravity (Bloksma and Bushuk 1988).

The correlations of maximum recovery strain of dough at 54% water absorption with flour protein content and some physical dough parameters obtained from farinograph, mixograph, and extension for the 23 wheat flour samples are summarized in Table IV.

Maximum recovery strain is positively correlated with protein content but the correlation coefficient is low (r = 0.555). The protein content is generally associated with the strength of a flour for breadmaking purposes within a given wheat cultivar. As known from previous research (Bloksma and Bushuk 1988), water absorption, mixing requirement, and extension characteristics are related to protein content and generally increase with protein content. In this creep-recovery study, however, the wheat flours used were of different cultivars, classes, and types. Therefore, the large recovery strain could not be accounted for by high protein content because breadmaking potential is attributed to both the quantity and quality of flour protein. For example, in two flours (Nos. 4 and 7) with similar protein content (Table I) but different baking volume (Table II) flour No. 4, which had better protein quality than flour No. 7, also had a superior recovery strain value, illustrating that protein quality, not just quantity, plays a role in recovery strain.

Maximum recovery strain was positively correlated with farinograph optimum water absorption ($r = 0.736$), and mixograph mixing peak time ($r = 0.889$), which comprise strength ratings obtained with the two mixing devices, respectively. Higher farinograph absorptions of wheat flours are generally considered a sign of better baking quality (Bloksma 1990b). Similarly, longer dough development time of flour results in better breadmaking performance.

Resistance to extension and extensibility are important quality criteria for doughs used for breadmaking. The dough films must be sufficiently extensible to prevent premature rupture, and the extensibility must be maintained long enough during oven rise to obtain satisfactory bread volume (Bloksma 1990a,b). For extensibility and maximum recovery strain, $r = 0.737$; for maximum recovery strain and resistance to extension, $r = 0.947$. As Halton (1949) stated, the tensile strength of the dough was the basis of flour strength and determined the breadmaking potential of the flour. The elastic recovery strain of the dough, on the other hand, is a measure of the springiness or elasticity of the dough, which helps to determine the dough's resistance to deformation (Petrofsky and Hoseney 1995), and, thus, largely determines the volume of bread. Correlation ($r = 0.892$) between maximum recovery strain and extension ratio is also strong. A combination of good resistance to extension and good extensibility results in desirable dough properties for bread making.

The addition of chemical improving agents, such as ascorbic acid (AA), potassium bromate ($KBrO_3$), and surfactant SSL improved dough strength and resulted in larger volume bread (Table II). Flour improvement should refer to changes in the rheological properties of the dough (Bloksma and Bushuk 1988). However, these changes were not consistently detected by the empirical instruments. AA, $KBrO_3$, and SSL all had positive effects on resistance to extension but no effect on the farinograph water absorption (Table I). The oxidants and surfactant did not show a general pattern in how they affected dough mixing properties. Mixing time of doughs containing SSL tended to increase, but some decrease was noticed in mixing time with addition of AA and $KBrO_3$. However, these changes were observed from the creep-recovery test, i.e., maximum recovery strain significantly increased with addition of AA, $KBrO_3$, and SSL (Table II). Therefore, correlations of maximum recovery strain with empirical measurements were not very high, except with the resistance to extension, because both the parameters provide information about flour strength related to loaf volume.

CONCLUSIONS

Creep-recovery test was successful at ranking wheat flours for breadmaking based on loaf volume. A high correlation ($r = 0.939$) was found between the maximum recovery strains and baking volumes of the tested flours. Higher recovery strain favors larger loaf volume. Therefore, the relationship between loaf volume and recovery strain probably reflects a more fundamental relationship between dough rheological behavior and baking performance. The dough springiness or elasticity may be an important factor in determination of bread volume. The maximum recovery strain was also significantly positively correlated with resistance to extension ($r = 0.947$), mixograph mixing time ($r = 0.889$), and farinograph water absorption ($r = 0.736$). The creep-recovery test is simple and practical because one could obtain useful information easily from looking at the recovery strain of the curve of 0.5-g dough at a constant water absorption (54%).

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