Corn Flour Addition to Wheat Flour Doughs—Effect on Rheological Properties

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ABSTRACT

Doughs were prepared from blends of a hard red spring wheat flour and dry-milled corn products. The shear modulus, *G*, of these doughs increased with replacement of the wheat flour solids by corn products. Stress relaxation behavior at constant deformation was determined, from which a time for 50% relaxation was interpolated from probability plots of percent stress decay against log time. This relaxation time, t_{50}, increased as more corn product was incorporated. Loaf volumes decreased as the relaxation time increased. A loaf volume of 93% of the control (hard red spring wheat flour) could be achieved by the addition of wheat gluten. Mixogram patterns for these doughs mixed at a constant water content are reported.

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Wheat flour is commonly diluted with flours from other cereal grains for the production of specialty breads. Also, in many countries where wheat is not a major domestic crop, it is extended for economic reasons by incorporation of other flours. Such substitutions can be expected to alter both the rheological properties of the dough and the quality of the baked product. Dough properties are commonly evaluated by measuring the "consistency" with instruments of the mixing type, such as the farinograph or mixograph. Such measurements are widely used for evaluating the effect of dough additives, for quality control of flours, and for characterizing grain varieties. The mixing curve characteristics depend on a changing combination of plastic, elastic, and viscous components of the mixing dough (Johnson et al 1943, Kunerth and D'Appolonia 1985). In addition to characterizing the viscoelastic behavior of doughs by mixing curves, more fundamental rheological properties can be determined by applying well-defined stresses or strains and measuring time-dependent responses. Pioneering investigations to separate and measure the elastic and viscous components of aqueous wheat flour doughs were made in the 1930s by Schofield and Scott-Blair (1932). They assumed that dough could be modeled by a Maxwell element, and they computed the ratio of viscosity to modulus of elasticity as the Maxwell relaxation time. Halton and Scott-Blair (1936, 1937) subsequently showed that this relaxation time is of primary importance when evaluating wheat flours for baking quality. Later workers showed that the relaxation of stress in wheat flour doughs, at constant extension, can better be described by a distribution of relaxation times rather than by a single Maxwell element (Cunningham et al 1953, Cunningham and Hlynka 1954). A graphic method for treating dough relaxation data was subsequently introduced (Grogg and Melms 1958, Shelef and Bousso 1964).

The purpose of this paper is to show how two basic rheological properties change as wheat flour solids are partially replaced with either of two dry-milled corn products, corn flour or pregelled corn flour. The dough moisture was held constant. The first parameter measured after extended mixing was an instantaneous modulus of rigidity in simple shear, *G*, here defined as the ratio of shear stress to a rapidly applied (small) shear strain. The sample geometry used for simple shear between parallel plates meets the requirements of homogeneous strain (Hibbard and Parker 1975). The other parameter was a geometric mean relaxation time, t_{50}, determined by following the relaxation of internal stresses while the material was held at constant deformation. Stress relaxation methods have often been used as a principle means of quantitating the viscoelastic responses of foods, including doughs (Mohsenin 1970). It is understood that the small deformations and rapid strain rates used in these measurements do not duplicate those in mixing type instruments nor in commercial baking operations. Mixograms obtained during the preparation of the doughs are also discussed.

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MATERIALS AND METHODS

Materials

Corn products used were dry milled commercially (Ill. Cereal Mills, Paris, IL) and analyzed as follows: regular corn flour (RCF) = 7.0% (db) protein, 11.8% moisture; pregelled corn flour (PCF) = 6.6% (db) protein, 5.7% moisture. Wheat flour (HRS) is a North Dakota hard spring having 17.3% (db) protein and 15.1% moisture. Commercial vital wheat gluten (Midwest Grain Co., Pekin, IL) had 72.9% total protein (db) and 6.53% moisture.

Methods

The flours were blended dry so that 10, 30, and 50% by weight (db) of the wheat flour solids were replaced by the corn products, then mixed with water to form doughs of 42.0% moisture content. Mixing was done with a 10 g mixograph (National Mfg. Co., Lincoln, NE). Three to five doughs of each flour blend were prepared for replication. The peak heights of the mixograms were determined by the method outlined by Johnson et al (1943) and were averaged. Test baking was accomplished by AACC method 10-10A (1983) without dough improvers, ascorbic acid, or malt, and the loaf volumes were averaged.

The description and operation of the rheometer (Rheometrics KMS-71) have been described elsewhere (Navickis et al 1982). The relevant dimensions and sample geometry are depicted in Figure 1. Dough was placed on the lower platen, and the upper platen was lowered to the desired sample height of 4.0 to 5.0 ± 0.001 mm. The sticky nature of these doughs and the use of roughened platens eliminated the need for adhesive bonding. Next, surplus dough beyond the disk radius was coated with paraffin oil, and the assembly (A, Fig. 1) was slowly rotated with a razor blade held against the platens to trim the dough to the radius of the platens. In addition, the blade smeared oil along the cut edge to minimize subsequent drying. A chamber lined with moist filter paper surrounded the assembly during measurements so that the relative humidity was held at more than 90%. Shear modulus measurements of the samples indicated that no measurable drying of the dough occurred, even after standing overnight.

Before measurements were started, the stresses introduced during loading and trimming were allowed to relax to constant force values, first in the Z direction, then in the X and Y directions. This required from 5 to 20 min, depending on the dough properties and, to a lesser extent, on the force imposed during loading of the sample. To measure the instantaneous modulus in simple shear, the lower platen was displaced rapidly (about 0.8 sec) in the Y direction to a strain ($a/h \times 100$) of 0.05 to 0.65%. The maximum force resisting this displacement, Fy, is used to calculate the modulus as:

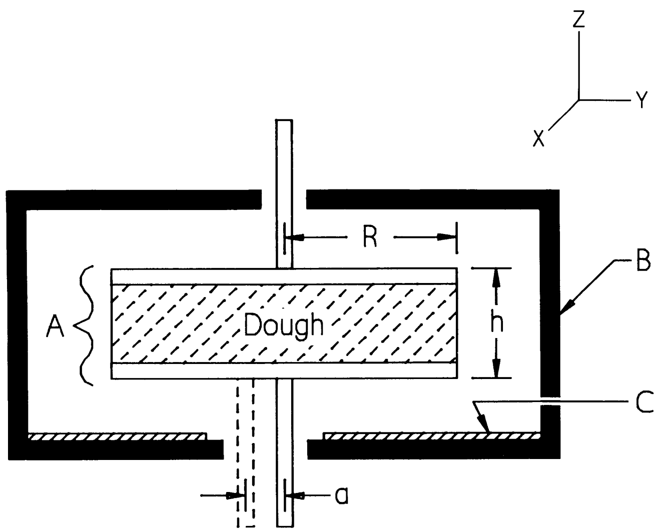

Fig. 1. Critical dimensions for the simple shear geometry. **A** = Assembly of dough between disks, **B** = Plexiglas enclosure, **C** = wetted filter paper, **R** = radius, **h** = height of dough disk, and **a** = displacement in Y direction.

$$G = \frac{Fy \cdot g \cdot h}{\pi \cdot R^2 \cdot a} \cdot \frac{\text{dynes}}{cm^2}$$

where Fy = grams force in Y-direction, g = 980.9 dynes per gram force, h = dough thickness (cm), R = dough radius (cm), and a = relative displacement (cm) of the upper and lower platens in the Y direction. The lower disk was then brought back to coincidence, and the sample was allowed to relax to a constant level before repeating the displacement several times for averaging. The modulus was corrected for instrument compliance (Macosko and Davis 1974). Stress relaxation measurements were next made on the same dough retained between the platens. The lower platen was displaced to a strain of 0.25–0.50% (0.8–1.3 sec) and held in place while the magnitude of the decaying force, Fy, was continuously monitored by computer (Modcomp Classic), which calculated the ratio P/Po, where Po is the maximum stress (force/area) at the maximum strain and P the stress at a later time, t (sec). Plotting the ratio $P/Po \times 100$ against log time on log-probability paper gave a straight line over a reasonable (or lengthy) interval of time, from which the time for the force to decay to 50% of its initial value could be read. Measurements of the properties were made in an air-conditioned room at 22.0–23.8°C and completed within 1 hr.

RESULTS AND DISCUSSION

The mixograms in Figure 2 are typical of those obtained during mixing of the control (100% HRS) and blended flours for rheological measurement. As more of the corn products were incorporated, the wheat protein content decreased. With addition of the regular corn flour (R-10, 30, 50), peak heights decrease from the control, but they increase with pregelled flour (P-10, 30, 50) (Table I). The bandwidth, at the point of sampling in particular, is a measure of resistance to extension (between mixer pins) and increased with both corn materials. Because the amount of water in these doughs was held constant at 42.0% and was not optimized for each flour blend, comparisons, other than in general, between curves or between a curve and a bake test are questionable and can be misleading. As an example, mixograms HRS-R50-G and P50 were similar as to arrival time and peak heights, but the loaf volumes were 93 and 36% of the control, respectively. The effect of adding wheat gluten to the 50% RCF blend on mixing characteristics is shown by comparing R-50 with the HRS-R50-G trace. The gluten protein level for the latter was raised from 7.3 to 14.7% (db) with a commercial wheat gluten.

Sampling the doughs for rheological measurement at peak development gave moduli that were poorly reproducible between replicate mixes. However, the arbitrarily chosen 15 min of mixing time gave satisfactory replication.

Table I shows the values of the rheological properties. With RCF replacement the shear modulus increased by a factor of 1.2, 2.3, and 5.9 as more of the wheat flour solids were replaced,

TABLE I
Physical Properties of Wheat Flour Doughs at Various Levels of Corn Product Replacement[a]

Flour Blend[b]	G_t dynes/cm^2	SD	t_{50} (sec)	SD	Peak (mm)	SD	% Gluten[c] in Solids	Relative Loaf Volume[d]
100% HRS	1.02×10^5	0.08	4.8	0.23	81	2.9	14.7	1.0
10% RCF	1.24	0.13	5.6	0.40	78	2.6	13.2	···
30% RCF	2.33	0.16	6.1	0.23	61	2.6	10.3	···
50% RCF	6.06	0.34	12.9	0.12	49	2.4	7.3	0.58
10% PCF	1.29	0.14	7.4	1.0	88	4.3	13.2	···
30% PCF	2.30	0.30	30.0	1.4	94	3.9	10.3	···
50% PCF	3.46	0.36	216.0	15.3	108	5.4	7.3	0.36
50% RCF + Gluten	2.63	···	6.1	···	86	···	14.7	0.93

[a] All doughs at 42.0% moisture.
[b] RCF = Regular corn flour; PCF = Pregelled corn flour.
[c] Total protein × 0.85.
[d] Average of three loaves.

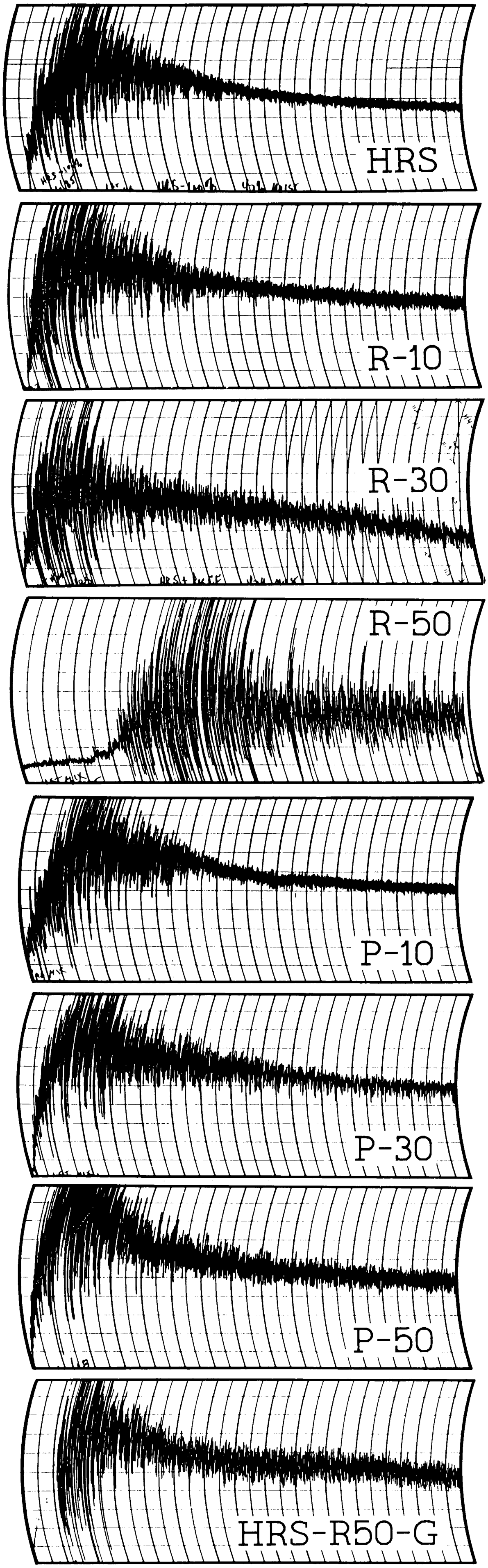

Fig. 2. Representative mixograms during 15 min of mixing. 42.0% Total moisture. **HRS** = 100% Hard red spring wheat flour solids. **R-10, 30, 50** = 10, 30, 50% Wheat flour solids replaced by regular corn flour solids. **P-10, 30, 50** = 10, 30, 50% Wheat flour solids replaced by pregelled corn flour solids. **HRS-R50-G** = 50% Regular corn flour replacement plus vital wheat gluten.

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indicating a stiffening of the dough even though the wheat protein content is decreased. It has been shown (Smith et al 1970) by dynamic stressing of wheat flour doughs at 42% moisture that the elastic modulus *G* decreases when the protein content is decreased. Possible explanations for the modulus increase for these blended flour doughs are that the corn products are behaving as strengthening fillers, or that there is a greater interaction between the particles in a matrix that is less abundant in gluten (Bloksma 1972). The moduli with presumably softer PCF increased by a factor of 1.2, 2.2, and 3.4, having less effect at 50% than RCF. The torque traces (mixographs) cannot generally be compared to basic rheological measurements, because the torque results from a combination of physical properties; however, these increases in the moduli are paralleled in the increased bandwidth (Fig. 2). At the small strains used (<1%), the moduli were found to be independent of strain. The standard deviations include all the individual measurements for the three to five dough preparations at each substitution level.

Figure 3 illustrates a typical plot of $P(t)/Po \times 100$ on a probability scale against log *t*, the time of observation (being measured from the time the deformation is completed). The total force *Fy* on the platens could have been plotted instead of the stress *P* (= Force/Area), because the area of the shear plane is constant in this geometry. *Po* is the stress at the maximum strain, *P*(*t*) the stress at a later time, *t*. The data points are closely linear in the range from 5 to 100 sec, which indicates a log-normal distribution of relaxation times for these wheat/corn flour doughs. For all doughs, the data at observation times of less than about 5 sec curved upward. This implies that the short relaxation times have been effectively removed and do not contribute to the relaxation process. In Figure 3, for example, relaxation times of less than 0.1 sec do not show up. This point has been discussed by Irani and Callis (1963) with reference to particle size distribution effects during screening. The effects of these short relaxation times are better studied by dynamic methods. Another factor that may contribute to the deviation from the log-normal fit at short times is that vibrations set up in the material due to the sudden stopping of the displacement and the inertia of the material cause stresses in the material to vary with time, affecting the shorter relaxation times predominantly. At long times of observation (>100 sec), the asymptotic leveling of the straight line indicates that the internal

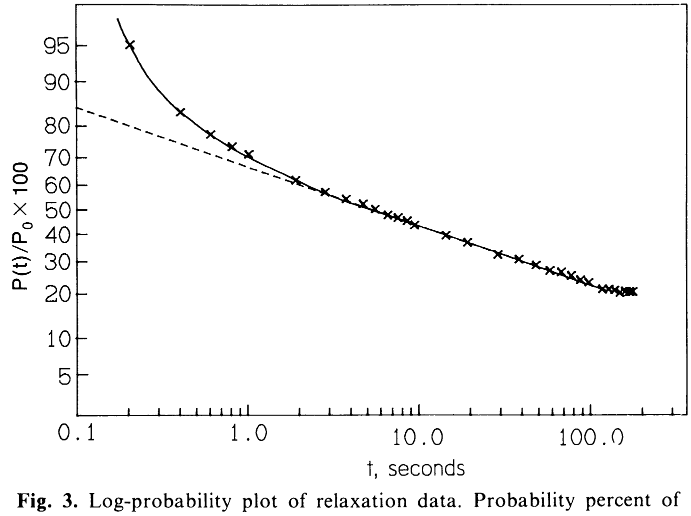

Fig. 3. Log-probability plot of relaxation data. Probability percent of initial shearing stress against log time. **Po** = Initial stress in Y direction, and **P(t)** = stress at later time, t sec.

stress has decayed to a constant value, as far as can be measured, and also indicates that the relaxation was incomplete as expected for a material possessing some solid properties. This asymptotic value, sometimes considered a "yield stress," was constant over several hundred seconds and was dependent on the magnitude of the stress at the start of the decay, i.e., when the maximum strain was reached. Shelef and Busso (1964) determined a geometric mean relaxation time from such straight line plots over observation times of 0.25–10 min for unyeasted wheat doughs by using essentially the apparatus of Schofield and Scott-Blair. Over this time scale range no deviation at either end was shown. For the RCF blends, the mean relaxation time t_{50} increases as more of the wheat flour is replaced by factors of 1.2, 1.3, and 2.7, respectively, whereas with pregelled flour the increases are by factors of 1.5, 6.3, and 45.0. It is of interest to note that the increase in t_{50} or the product $G \times t_{50}$ (= viscosity in the Maxwell model) is reflected in the mixogram bandwidth with RCF, but not significantly with PCF. Both G and t_{50} increased with replacement of wheat flour in these mixed flour doughs. Udy (1953), fitting his data to a single Maxwell element, where $t_{relax} = \mu / G$, also found that both modulus and relaxation time increased when he investigated resting time effects on purified gluten. These results suggest that the viscosity (μ) increases relatively more than the modulus.

The volume of bread loaves baked with 50% of the wheat flour replaced with RCF at optimum water absorption was 58% of the control volume (100% wheat flour). With PCF, the volume was 36% of the control. When wheat gluten was added to the 50% RCF blend to the level in all-wheat flour, the loaf volume was 93% of the control.

It appears that in these mixed flour doughs, t_{50}, even though measured on unyeasted doughs, is an index of loaf volume. Shelef and Busso (1964) showed a higher geometric mean relaxation time, measured on unyeasted all-wheat flour doughs, to be deleterious to loaf volume. Work now in progress will include measurements of relaxation time and modulus on yeasted doughs from these flour blends after pan fermentation to confirm the results of this preliminary study.

SUMMARY

The modulus measured in simple shear increased as more of the wheat flour solids were replaced by regular or pregelled corn flour, suggesting that these corn products act as a strengthening filler in the developed gluten. The geometric mean relaxation time increased as more wheat flour was replaced, more so with pregelled corn flour than with regular corn flour at the same level. The distribution of relaxation times followed a log-normal distribution closely over a large time range in these corn-wheat flour blends, as reported by others for straight wheat flour doughs. The relaxation time measured on simple aqueous flour doughs was an index of loaf volume.

Mixograms at a constant water content of 42% showed a decreasing peak height as more regular corn flour was incorporated, but an increasing height as more pregelled corn flour was substituted. Loaves baked at optimum water absorption with 50% regular corn flour and 50% pregelled corn flour were 58 and 36% of a control volume (100% wheat flour), respectively. When wheat gluten was added to the level in wheat flour in the 50% regular corn flour blend, the loaf volume increased to 93% of the control.

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