NOTE

RHEOLOGY

Changes in Mixograms Resulting from Variations in Shear Caused by Different Bowl Pin Sizes[1]

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The mixograph is used widely in experimental baking and quality control laboratories as a method for measuring dough mixing properties. It produces a "pull, stretch, tear" action on small doughs, more closely approximating the action in the large horizontal bowl mixers commonly used in U.S. commercial breadbaking practice (Shogren 1990). This action usually is considered more effective in developing doughs made with strong U.S. wheat flours to the point of maximum resistance (minimum mobility) than is the more gentle kneading-type action traditionally used with the weaker European wheat flours. Mixographs are now commercially available in several sizes (35, 10, and 2 g).

When the original mixograph was developed, fixed bowl pins were used to facilitate adequate mixing (Swanson and Working 1933). Tests show that, within a trace of the revolving pin's path, clearance was sufficient to allow placement of the bowl pins, even if the bowl moved slightly. When the smaller 10-g mixograph was developed, it was necessary to reduce the diameter of the planetary and bowl pins from 1/8 in. (used with the 35-g mixograph) to 3/32 in. to allow for sufficient operating space between the pins (Finney and Shogren 1972). Note that the change from 1/8 in. to 3/32 in. is a ratio of 4:3 or 1.33, which is not the same as 1.52, the cube root of the ratio of 35 to 10 g as predicted by a simple volumetric downscaling (Table I). The theoretical linear ratio is the cube root of the weight (proportional to volume) ratio and represents the ratio of the side lengths of two cubes containing the relative volumes stated.

Likewise, with the development of the 2-g mixograph, another downsizing of the pin diameters was required. A mathematical model was used first in attempting to downsize to a 2-g mixograph (Buchholz 1990), extrapolating from the 35-g unit. Simply downscaling the dimensions of an existing mixer, especially pin size, caused many problems because continually reducing the pin diameter resulted in loss of strength.

Table I values were taken from the manufacturing specifications of the bowls and verified by measuring a number of bowls in regular use with a dial caliper. When comparing the bowl pin diameters for the 35, 10, and 2-g mixers, we noted that the ratios are quite close to the theoretical linear ratio, as are the pin length ratios. These differences in pin diameter ratios were a result of using standard diameter rod stock to maintain adequate pin strength. As a result, both the 10-g and 2-g versions have pin diameters that are proportionately larger than those of the 35-g unit when predicted from the theoretical linear ratio. Incidentally, the pin length and diameter ratios for the 100/200 pin mixer differ substantially for calculations of a 100-g mixer, but agree rather closely for a 200-g mixer.

Mixing is a complex process that converts flour and water into a viscoelastic dough. The mere addition of water to flour is not enough to make a dough. Mechanical energy (work input through mixing) must be applied. Mixing to an optimum consistency requires that a certain amount of work be done on the dough. Simplified, work input is equal to the mixing time × the efficiency of the mixing action × the speed at which the energy is put into the dough (Hoseney and Finney 1974). This was demonstrated by using a 2-g, variable speed, direct-drive mixograph. As the head speed increased from 76 to 100 rpm, the time to peak decreased from 3.81 to 3.03 min, and the peak height increased from 40.5 to 44.3% (Vidal-Quintanar and Walker 1994).

In theory, the more rapidly energy can be imparted into the developing dough, the more rapidly the mixing peak (optimum development) will occur. Therefore, the relative efficiency of mixing with respect to the shear force imparted by the revolving head pins and the resisting bowl pins upon the dough trapped between them can be important. The objective of this study was to observe the effects on mixogram parameters of using different sizes of bowl pins.

MATERIALS AND METHODS

A 35-g computerized mixograph (National Mfg. Div., TMCO, Lincoln, NE) was used. The mixograph was operated in a fixed-bowl configuration by attaching a bracket to the bearing housing so that the moving bowl arm could be immobilized at the 50% pen position by a load cell. The analog voltage output of the load cell was proportional to the torque imparted to the fixed bowl pins by the action of the planetary mixing head on the dough. A transducer power supply and signal amplifier with an integral 10-bit A/D converter conditioned the analog signal from the load cell and transmitted it to the parallel port of an MS-DOS computer, where the 0–1,023 digital values could be acquired and analyzed by Mixsmart software (AEW Consulting, Lincoln, NE), which is now commercially available (Walker and Walker 1990, 1992).

The smoothed midline from the mixogram was used to determine time to peak (min), peak height (% scale), and envelope band width (% of full scale), along with other parameters. The peak integral (%torque × min) represents the area under the midline from start to peak time, or average work input required to bring the flour-water dough to peak development; it is a function

TABLE I
Mixograph Bowl Dimensions Size Comparison

	Bowl Size				Ratio	
	Pin Mixer	35 gram	10 gram	2 gram	35/10	35/2
Sample weight, g	100–200	35	10	2	3.5:1	17.5:1
Theoretical linear ratio	...	...	...	...	1.518	2.596
Bowl diameter, in.	4.970	2.968	1.875	1.306	1.583	2.272
Pin length, in.	4.250	1.575	1.375	0.600	1.145	2.625
Pin diameter, in.	0.312	0.125	0.094	0.072	1.330	1.736
Pin clearance[a]	0.500	0.281	0.172	0.135	0.633	2.081

[a] Free space between a bowl pin and a moving head pin pair at the time they straddle the bowl pin.

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of mixing time and applied torque. Time, height, and integral for a point, determined by 55%-of-peak-time (MP × 0.55), were assessed as an indication of absorption. The slope and integral of the envelope area (curve swept by the envelope lines from peak to peak + 2 min) and right-of-peak (ROP, by 2 min) height and width also were measured as indicators of flour strength.

The mixograms were run at 25 ±1° C following standard method 54-40 (AACC 1983), modified only to accommodate the computerized format. The mixing head speed was 87.0 rpm. Data were collected at 10 Hz for 10 min. Three custom-made 35-g bowls were provided by National Mfg. Pin sizes were: regular or small (1/8 in.); medium (3/16 in.); and large (1/4 in.). The free space

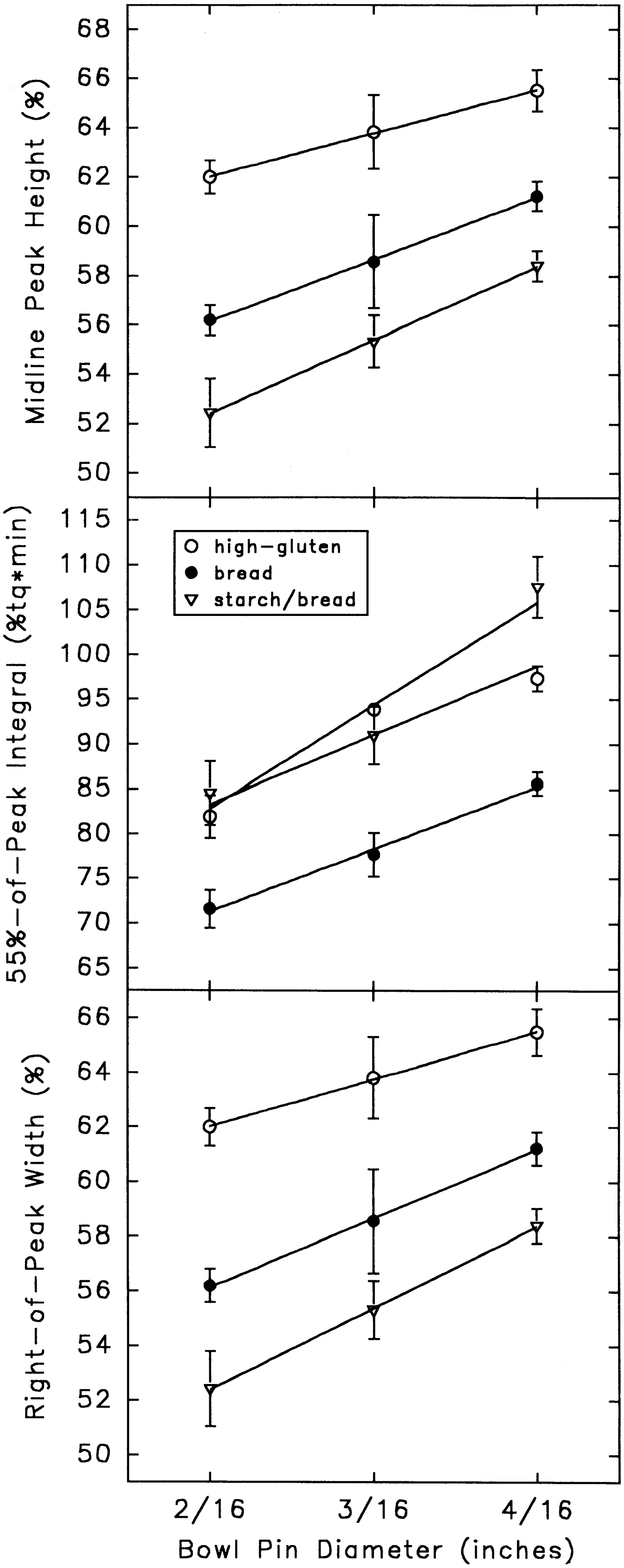

Fig. 1. Effect of bowl pin diameter on midline peak height, 55%-of-peak integral, and right-of-peak width for three flours. Correlation coefficients for high-gluten, bread, and starch-diluted bread flours are 0.85, 0.90, 0.94; 0.94, 0.96, 0.93; and 0.99, 0.96, 0.98, respectively.

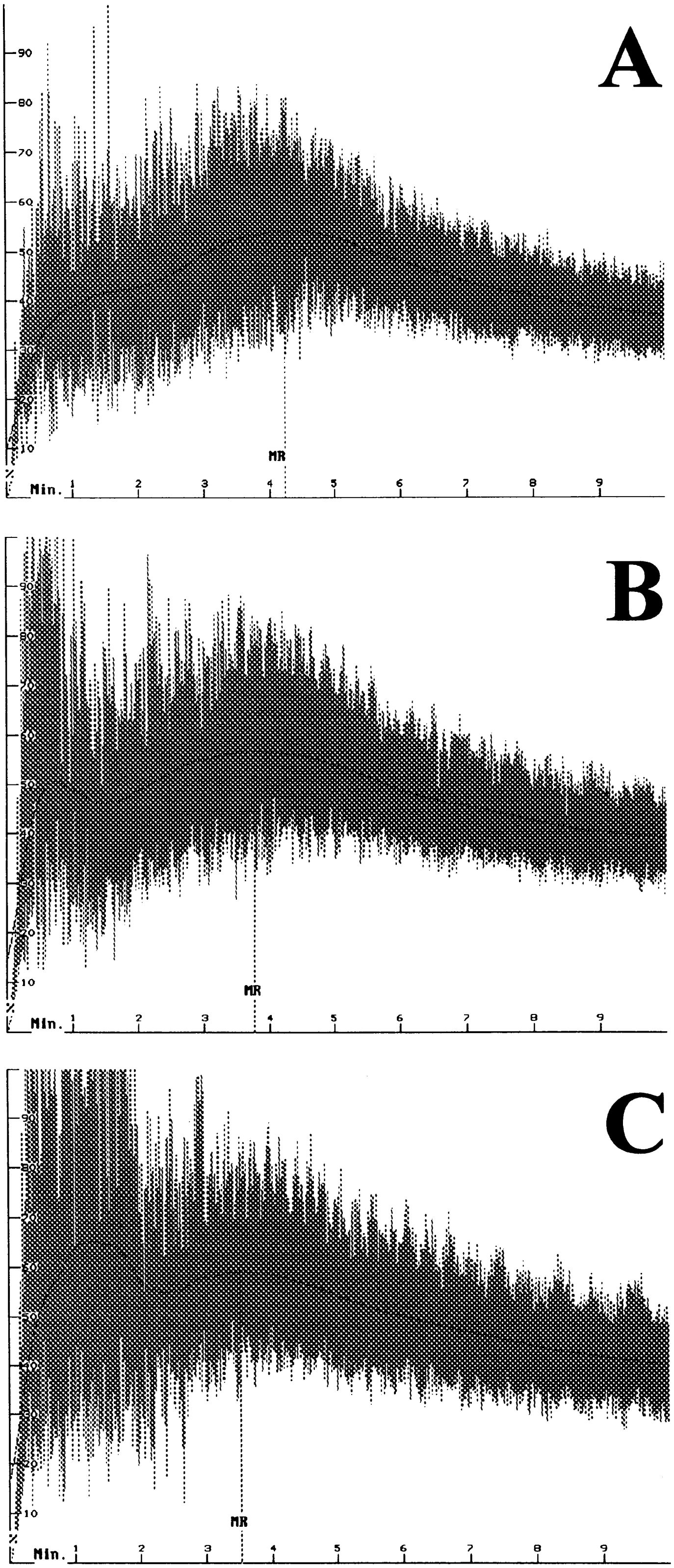

Fig. 2. Sample mixograms for blended starch-bread flour using small (A), medium (B), and large (C) size bowl pins.

between a bowl pin and a moving head pin pair at the time they straddle the bowl pin were 0.281, 0.250, and 0.219 in. for the small, medium, and large bowl pins, respectively.

Three flours were used: 1) high-gluten (HG) flour (14% mb: absorption 63%, protein 13%, ash 0.45%) donated by General Mills (Minneapolis, MN); 2) bread (B) flour (14% mb: absorption 60%, protein 11%, ash 0.43%) provided by Cargill (Wichita, KS); 3) a starch-bread (S-B) flour blend (14% mb: absorption 58%, protein 9.7%, ash 0.43%) consisting of the bread flour diluted by 20% with Midsol-75 wheat starch obtained from Midwest Grain Products, Inc., (Atchison, KS). The mixograph absorption was approximated according to Finney (1945): % absorption = (% protein × 1.5) + 43.5, where the percent protein is on a 14% basis. It was subsequently adjusted, based on trial runs using a bowl with regular size pins. Absorption was not altered for the different bowl pin sizes.

Triplicate flour-water mixograms of each flour were run in random order on each of the three bowl designs. One-way analyses of variance (ANOVA) were run on each parameter to compare any differences in bowl pin sizes.

RESULTS AND DISCUSSION

One-way ANOVA analyses show significant differences between pin size and mixogram values ($P > 0.05$, or better). Effects are illustrated in Figure 1. Sample mixograms of the three different pin sizes are shown in Figure 2.

Midline peak time decreased significantly, whereas height (Fig. 1), width, and integral (area under the curve) increased significantly as pin size increased ($P > 0.05$). Because the peak integral is a function of the mixing time and height value, this suggests that larger pins result in a more efficient use of the input energy (increased shear rate) when compared to the smaller pins. However, differences in peak integrals were significant only between the HG and B flours, not for the lower protein blend (S-B).

Similar to the peak results, MP × 0.55 time decreased ($P > 0.05$), while height and integral (Fig. 1) increased ($P > 0.01$) with increased pin size. These values may have reflected the increased hydration rate of the particles due to increase in the surface area. Starch hydrates much more quickly, without any added energy, than does protein, although its water-holding capacity is lower. Also, unlike protein, it does not continue to change its hydration as the dough mixes.

Envelope area integral ($P > 0.01$) and ROP height and width ($P > 0.05$ and $P > 0.01$, respectively) also increased significantly as the pin size increased (Fig. 1). Although the differences in envelope area slope were significant for the HG and B flours, no regular patterns of increase or decrease were noted ($P > 0.05$). The increase in values, particularly for the envelope area integrals, can be explained. Although the dough is breaking down (past peak), a minimum amount of energy still is required to stretch the viscous dough around the pins. Hence, dough moving around a larger obstacle (pin) needs a larger work input. Furthermore, the clearance between pins (moving vs. stationary) decreases as bowl pin size increases, which results in an increased energy requirement to push and pull the dough through the clearances during the mixing action (Table I). As demonstrated, the bowl pin diameter does have a significant effect on most of the mixogram parameters discussed in this article, as well as to the other 30 parameters derived by the software. Therefore, great care needs to be used in developing pin type mixers of various sizes, recognizing that the results from one size may not be extrapolated to another size. This also provides a possible explanation for the fact that the three commercially available mixographs give similar, but not identical, results, and that they require adjustments in the torque-sensing mechanisms.

Each flour type exhibited similar trends. However, the protein-to-starch ratios affected the degree of the differences observed in relation to bowl pin size. This was very evident in the pronounced hydration peak at the beginning of mixing (Fig. 2). Although a slight hydration peak (~1 min) is not considered abnormal, its tendency to appear was enhanced as pin size increased, especially when using the large pin bowls and the lowest protein flour (S-B). This phenomenon probably was due to the increased surface area available for rapidly hydrating the flour particles and was amplified by the fact that the lowest protein flour also had the lowest peak height. In addition, the reduced mixing times probably resulted from the intense and rapid hydration.

CONCLUSIONS

Increasing shear during mixing results in reduced dough development time. Even without increasing mixing speed, the relative efficiency of the mixing action was affected by the size of the bowl pins. Shear rate is increased as the clearance between the resisting bowl pins and the moving head pins decreases, thus virtually trapping the dough between them. In this case, the decreased clearance was accomplished by increasing the size of the bowl pins. As a result, mixing time was reduced and peak heights, band widths, and area integrals (work input) were increased.

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LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 54-40A, approved April 1961, revised October 1988. The Association: St. Paul, MN.

BUCHHOLZ, R. H. 1990. An epitrochoidal mixer. Math. Sci. 15:7-14.

FINNEY, K. F. 1945. Methods of estimating and effects of variety and protein content level on the baking quality of flour. Cereal Chem. 22:149-160.

FINNEY, K. F., and SHOGREN, M. D. 1972. A ten-gram mixograph for determining and predicting functional properties of wheat flours. Baker's Dig. 46(2):32-42, 77.

HOSENEY, R. C., and FINNEY, P. L. 1974. Mixing—A contrary view. Baker's Dig. 48(1):22-28.

SHOGREN, M. D. 1990. A short history of the mixograph. Cereal Foods World 35:480-482.

SWANSON, C. O., and WORKING, E. B. 1933. Testing the quality of flour by the recording dough mixer. Cereal Chem. 10:1-29.

WALKER, C. E., and WALKER, A. E. 1990. Mixograph data acquisition and analysis by personal computer. (Abstr) Cereal Foods World 35:823.

WALKER, C. E., and WALKER, A. E. 1992. Documentation and users instructions for Mixsmart. National Mfg. Div. TMCO: Lincoln, NE.

VIDAL-QUINTANAR, R. L., and WALKER, C. E. 1994. Absorption and rpm effects on mixing parameters as determined by a prototype 2-gram direct-drive recording dough mixer. National Notes 1(2):2-5.

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