Effect of Dough Water Content and Mixing Conditions on Energy Imparted to Dough and Bread Quality

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ABSTRACT

This study explores the influence of water content, mixing speed, and mixing time on energy imparted to dough and on specific volumes and bake scores of the resulting pan breads made with flours of different qualities. Responses measured were dough work input (Y_1), specific volume of bread (Y_2), and bake score (Y_3) while the variables chosen were water added (X_1), mixing speed (X_2), and mixing time (X_3). Water added ranged between 59.7 and 62.7 %, mixing speed between 20 and 100 rpm, and mixing time between 2 and 12 min. Dough work input was strongly correlated with all variables chosen for this study, while specific volume and bake score had only a high statistical significance with respect to mixing speed (X_2) and mixing time (X_3). The maximum value for Y_2 (5.2 cm^3/g) resulted when X_2 = 90 rpm and X_3 = 8 min. This indicates that better products are obtained with 720 mixer blade revolutions; this is a critical factor for optimal dough development and then for obtaining a good crumb grain. Finally, bread quality can be improved by increasing mixer blade revolutions up to values in the range of 700–800, corresponding to a dough work input of ~40 kJ/kg.

As an indicator of freshness and acceptability to consumers, physical texture greatly affects the value of baked goods such as bread. During bread formulation, in addition to flour origin, particle size, protein or gluten content, and extent of starch damage, water absorption plays a key role in producing high-quality bread (17).

During baking, viscoelastic dough becomes an elastic solid, and gluten is responsible for dough formation and its ability to retain gas. Mixing, fermentation, yeast concentration, and handling (such as punching and molding) affect gluten development, influencing the dough's rheological properties (14,17). Bread quality is controlled by wheat flour composition and also by mixing variables such as mixer design, mixing time and speed, and water content (5,6). Mixing intensity (impeller speed) must be above a minimum critical level that varies with both flour and mixer; and the work imparted to the dough must be greater than a minimum critical amount that is dependent on the flour used (2). During processing, every breadmaking step significantly affects product quality (11).

Several measurements have been used to measure rheological properties of wheat dough; such measurements must be sensitive to dough water content, since optimal mechanical properties result from an optimum flour-to-water ratio (3). Small-scale laboratory mixers are widely used to predict dough-mixing behavior on an industrial scale. Two traditional instruments for testing wheat dough are the farinograph and the mixograph, which mix flour and water by shear and extensional deformation and form developed dough (10). If laboratory-scale mixers are to be used to predict industrial-scale mixing behavior, their mixing mechanism must be similar to that of industrial-scale mixers (18). In Argentina, industrial-scale pan bread is produced mainly by mechanical dough development, which uses high-speed mixing and an oxidizing agent.

Response surface methodology (RSM) is a statistical technique used to optimize processes or formulations, using minimal experimental trials, when many factors and interactions may be involved (12). RSM uses a central composite design to fit a model using least-squares analysis. The adequacy of a proposed model is revealed by diagnostic checking provided by analysis of variance (ANOVA) and residual plots. Contour plots are useful to study RSM data and determine optimal conditions (16).

This study explores the influence of water content, mixing speed, and mixing time on energy imparted to dough and on specific volumes and bake scores of the resulting pan breads made with flours of different qualities.

Table I. Gluten content, damaged starch, and rheological characteristics of samples

	Samples					
	A	B	C	D	E	F
Wet gluten (%)	25.3	29.0	27.5	25.5	25.6	23.5
Damaged starch (% db)	5.20	5.60	5.40	5.15	5.20	5.25
Farinographdata						
Water absorption (%, as is)	61.2	59.6	59.8	59.6	61.5	60.5
Water absorption (%, 14% mb)	60.2	59.1	59.5	57.8	59.6	59.8
Development time (min)	2.0	1.5	2.0	2.0	2.0	2.0
Stability (min)	4.5	2.5	5	5.0	18	3.0
Drop off (BU)	30	50	40	40	0	40
Alveograph data						
W (J × 10^{-4})	280	345	320	240	240	210
P (mm)	100	100	105	106	114	101.5
G (mL)	24	21.8	21.7	17.1	16	16
P/L ratio	1.16	1.03	1.10	1.80	2.19	1.91

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MATERIALS AND METHODS

Samples

Six samples of wheat flours, suitable for industrial breadmaking, were provided by different millers from Santa Fe (Argentina); their characteristics are shown in Table I. The following physical and chemical analyses were performed according to AACC Approved Methods (1). A Brabender Farinograph with a 300-g flour sample was used to determine water absorption, dough development time, degree of dough stability, and degree of dough softening (drop off). A Chopin Alveograph with a 250-g flour sample was used according to Faridi and Rasper (7). *W* (energy), *P* (resistance), *G* (swelling index), and *L* (extensibility) were measured, and the *P*/*L* ratio was calculated. Amylograms were obtained on the Brabender Viscoamylograph using 80-g samples (14% moisture basis) in 450 mL of distilled water, stirring at 75 rpm, and heating at 1.5°C/min to 95°C.

Table II. Central composite design-variables and levels

Variable	Coded Variable Levels		
	–1	0	1
Water added (%)	59.7	61.2	62.7
Mixing speed (rpm)	20	60	100
Mixing time (min)	2	7	12

Breadmaking

All ingredients (300 g of flour [as is], 15 g of yeast, 6 g of NaCl, 18 g of sucrose, 9 g of shortening, and 6 g of nonfat dry milk) were mixed in a Brabender Do-Corder Farinograph (300-g mixing bowl). Similar types of mixers, at industrial scale, are used in some industries like Bimbo-Argentina. Technological parameters such as water added, mixing speed, and mixing time were varied.

Water was warmed to a certain temperature so as to obtain, at the end of kneading, a dough temperature between 24 and 26°C. Fermentation was carried out in a thermostatic fermentation chamber at 27°C and 80% rh, controlling the rising with a push meter to measure the proofing. This apparatus consists of a glass cylinder (75 mm height, 45 mm i.d.) with a tight-fitting plastic piston that rises during proofing. The first fermentation ended when the dough doubled its volume (measured by a push meter displacement from 1.25 to 2.5, approximately 40 min). Then 250-g dough portions were laminated, rolled up, and put in molds for a second fermentation. The proofing time ended when the dough volume was four times the initial volume (push meter displacement from 1.50 to 6.0, approximately 75 min). Baking molds were 5.5 cm high, with 7- × 17.5-cm bottom sides and 9- × 18-cm top sides. Dough was baked at 210°C for 30 min in an electric oven with steam (Ojalvo S.A., Santa Fe, Argentina). Breads were evaluated 1 hr after baking. Loaf volume was determined by rapeseed displacement. Crumb grain (texture) was scored, by three experts, on a 0–10 scale. Bake score was calculated as the sum of specific volume × 3 and crumb grain score.

Work input, a measure of the energy imparted to dough during kneading, can be calculated from average mixer rotor torque and number of revolutions (8,18). In our study, however, work input was calculated by considering that the area under the farinograph curve was proportional to energy consumed in a certain time interval, so 1 cm^2 of area was equivalent to 454 J/kg (4).

Table III. Experimental mixing variables and values of work input, specific volume, and bake score

Water Added (%)	Mixing Speed (rpm)	Mixing Time (min)	Mixer Blade Revolutions	Work input (kJ/kg of dough)	Specific Volume (cm^3/g)	Bake Score[a]
X_1	X_2	X_3	$X_2 \cdot X_3$	Y_1	Y_2	Y_3
61.2	60	7	420	23.0	5.05	24.1
61.2	60	7	420	23.6	4.93	23.8
61.2	60	7	420	22.8	5.10	24.3
59.7	20	7	140	12.8	4.13	16.4
61.2	100	2	200	7.72	4.71	20.1
59.7	60	2	120	6.50	4.51	18.5
62.7	60	12	720	38.6	5.17	24.5
62.7	100	7	700	26.6	5.50	25.5
62.7	20	7	140	12.3	4.54	19.6
61.2	20	2	40	3.94	3.94	15.8
61.2	100	12	1,200	57.6	4.89	22.9
62.7	60	2	120	3.94	4.14	16.4
59.7	60	12	720	44.7	5.14	24.4
61.2	20	12	240	23.7	4.49	18.5
59.7	100	7	700	32.2	5.25	25.7

[a] Calculated as the sum of specific volume × 3 and crumb grain score.

Table IV. Results of analysis of variance[a]

Variable[b]	Degrees of Freedom	*F* Value		
		Work Input	Specific Volume	Bake Score
X_1	1	157.11*	1.68	12.5
X_2	1	3674.35*	1,72.97*	1,471.53*
X_3	1	1,4643.93*	93.54*	1,046.05*
X_1^2	1	20.53*	0.45	1.17
$X_1 \cdot X_2$	1	37.51*	0.84	72.25*
$X_1 \cdot X_3$	1	18.07	5.24	64.00*
X_2^2	1	29.49*	19.75*	493.63*
$X_2 \cdot X_3$	1	1,308.48*	24.48*	27.56*
X_3^2	1	35.08*	48.63*	783.01*
Lack-of-fit	3	7.88	14.70	238.1*
Coefficient R^2 (%)		99.9	88.2	84.5

[a] Statistical significance: * = $P < 0.05$.

[b] X_1 = Water added (%), X_2 = mixing speed (rpm), X_3 = mixing time (min).

Experimental Design

Sample A was tested at the first stage in the experimental design, and then results were compared with the performances of samples B–F.

Three responses were measured: work input (Y_1), specific volume (Y_2), and bake score (Y_3). Variables chosen were water added (X_1), mixing speed (X_2), and mixing time (X_3). Water added ranged between 59.7 and 62.7% (central point 61.2%); mixing speed ranged between 20 and 100 rpm (central point 60 rpm); and mixing time ranged between 2 and 12 min (central point 7 min.). Table II summarizes variables and levels. Selection of extremes was based on our previous studies. A central composite design, shown in Table II, was arranged to allow for fitting of a second-order model. Star points were added to the factorial design to provide for estimation of curvature of the model (13). Three replicates at the center of the design were used to estimate pure error at the sum of the square.

Statistical Analysis

A software package (STATGRAPHICS) was used to fit second-order models and generate response surface plots. The model proposed for each response is given by the following expression:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_{11} X_1^2 + b_{22} X_2^2 + b_{12} X_1 X_2.$$

RESULTS AND DISCUSSION

Table III shows work input values (measured in kJ/kg of dough), specific volume (cm^3/g), and bake score for sample A. Table IV summarizes *F* values for the variables water added (X_1), mixing speed (X_2), mixing time (X_3), and their combinations.

Work Input

Work input is strongly correlated with water added, mixing time, and mixing speed (Table IV). Figure 1 shows the relationship between number of mixer blade revolutions and work input for sample A at different water levels (r^2 = 0.947, 0.938, and 0.914 for 59.7; 61.2, and 62.7% water added, respectively). In agreement with Wilson and coworkers (18), work input increases from 3.94 to 57.6 kJ/kg of dough as mixer blade revolutions increase from 40 to 1,200. The potential energy is stored as elasticity in the gluten matrix formed during the mixing. Consequently, the changing elasticity of the dough is an indirect measure of the elastic energy that the dough has accumulated during mixing. Also during mixing, dough develops a protein network in which air bubbles are incorporated and it becomes a soft and viscoelastic material. Mixer blade revolutions and work input are thus critical factors for optimal dough development. This is in agreement with Lee and coworkers (10), who found that energy input and type of deformation are both significant with respect to development of protein matrix and further enhancement of dough strength.

Bread Quality: Specific Volume and Bake Score

For sample A, specific volume and bake score have a high statistical significance, especially with mixing speed (X_2) and mixing time (X_3) but not with water added (Table IV). Zghal and coworkers (19) indicated that bread-crumb grain score was unaffected by baking absorption at levels between 60 and 66%. Figure 2 shows response surface and contour plots for specific volume (Y_2). They show that the maximum value for Y_2 (5.2 cm^3/g) resulted when X_2 = 90 rpm and X_3 = 8 min. This indicates that the best product can be obtained (for sample A) when 720 mixer blade revolutions (90 rpm × 8 min) are used.

We verified these optimal conditions (90 rpm × 8 min) in six replicate experiments with sample A; the result was Y_2 = 5.10. By the hypothesis-testing technique of Montgomery (13), differences between responses from models and the verification experiment were not significant at the 5% level.

A model fitted by bake score, however, does not represent the data as well (Table IV). Nevertheless, we can see in Figure 3A that maximum bake score was obtained with 700–800 mixer blade revolutions, corresponding to a work input of ~40 kJ/kg of dough (Fig. 1).

When work input is higher than 40 kJ/kg of dough (more than 800 mixer blade revolutions), the bake score diminishes (Figure 3B) because of gluten rupture by overmixing. Also, bake score diminishes when work input is below 30 kJ/kg of dough because of inadequate gluten development. Kilborn and Tipples (9) found a sharp decrease in bread volume below a critical mixing speed, which for their special experimental mixer was ~100 rpm. In addition, Wilson and coworkers (18), using Australian commercial flour with an MDD125 mixer, obtained an increase in bubble number, a decrease in bubble size, and a decrease in density of doughs mixed at 300–500 rpm as compared with those mixed at 75–150 rpm.

CONCLUSIONS

Conclusion for Sample A

Dough work input is strongly correlated with water added, mixing speed, mixing time, and the mixer blade revolutions (mixing speed × mixing time). The relationship between mixer blade revolutions and work input may be considered a linear function. The specific volume of bread and the bake score are highly affected by mixing speed, mixing time, and their combination. These variables are thus critical factors for optimal dough development. So when mixer blade revolutions increase, specific volume and bake score also increase—but like a polynomial function, with a maximum value at a level of 700–800 mixer blade revolutions, corresponding to a work input of 40 kJ/kg of dough. On the one hand, the increasing elasticity is reflected in an initial increase in the resistance of the dough to mixing as the gluten matrix forms. On the other hand, if the dough is overmixed, the matrix is partially destroyed, resulting in a loss of elastic energy.

Conclusions for Samples B–F

Figure 4 shows the specific volume of breads (three replicates) made with flours with different alveographic data, as a function of mixer blade revolutions (4A) and work input (4B). We can see that two families of curves were obtained, one of them (D–F) having the alveographic value *W* lower than 250 (weak flours) and the other (A–C) having *W* above 250 (strong flours). In all cases, specific volume is affected by mixing blade revolutions and consequently by work input. In the case of weak flours, best results were obtained when low energy was imparted; it happened as a consequence of the weakness of the gluten network. Strong flours have

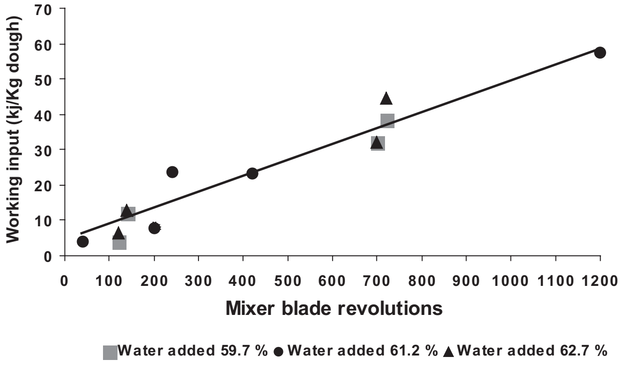

Fig. 1. Relationship between number of mixer blade revolutions and work input for sample A.

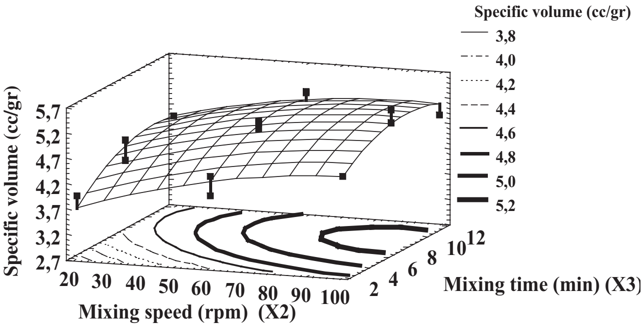

Fig. 2. Response surface for specific volume as a function of mixing speed and mixing time for sample A. Contour plots for X_2 vs. X_3.

maximum specific volumes between 700 and 800 mixer blade revolutions, similar to the results obtained with sample A. These flours had a high tolerance to the energy imparted during kneading because of the high gluten resistance shown in Table I.

Finally, the model studied for sample A is applicable only to strong flours, with alveographic value *W* above 250, and the data presented above confirm the hypothesis only for mixing on a farinograph. One is, however, tempted to conclude that the hypothesis extends naturally to mixing on other devices.

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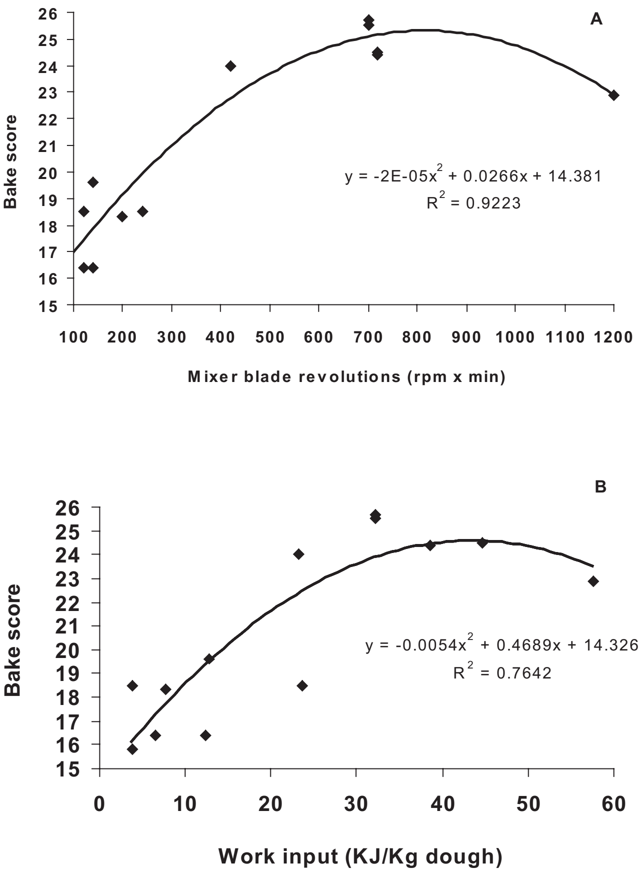

Fig. 3. Bake score for sample A, as a function of mixer blade revolutions (A) and work input (B).

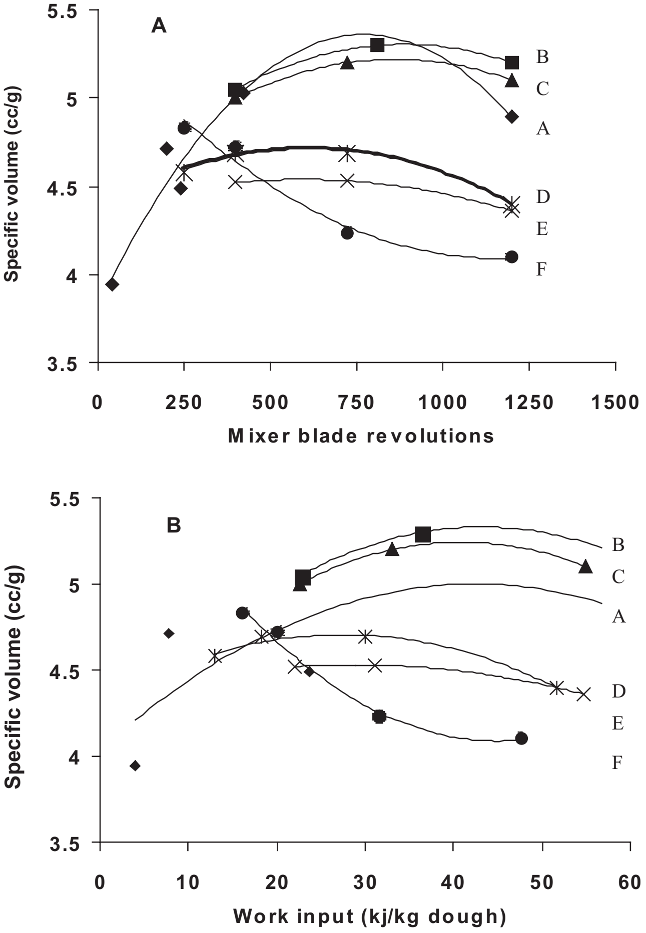

Fig. 4. Specific volume for samples A–C and D–F, as a function of mixer blade revolutions (A) and work input (B).