Mechanical Dough Development—Pilot Scale Studies[1]

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ABSTRACT

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A laboratory scale version of a mixer commonly used for commercial baking in the United Kingdom was modified to give accurate control of the rate and amount of energy input. Using flours of four different protein contents, the effect of varying the mixer speed and work level on dough and bread characteristics was studied. In general, dough consistency after mixing increased with both mixer speed and work input. Flour containing 11% protein was found to give the best loaves and to have the greatest tolerance to mixing variations for this particular baking system; increasing and decreasing the protein by 1% were both detrimental. Increasing the mixer speed reduced the work input required to give the optimum loaf.

Mechanical dough development (MDD) in the form of the Chorleywood bread process (CBP) (Chamberlain et al 1962) accounts for about 80% of the bread production in the United Kingdom. In this process a brief, intense mix develops the dough so that the need for bulk fermentation is eliminated. The early Chorleywood work, based on a Morton Z-blade mixer, suggested that a work input of 5 Whr lb^{-1} (40 kJ kg^{-1}) imparted to the dough in less than 5 min would produce acceptable bread from a wide range of flours (Chamberlain et al 1965). These values have been adopted to such an extent by the industry that the ability to perform in this way has to some degree become a determinant of flour quality.

The original paper describing high speed mixing by Swanson (Swanson and Working 1926) indicated that different flours responded differently to a given amount of rapid mixing, but the differences were not quantified. More recent work done on a modified Morton Duplex mixer (Chamberlain et al 1967) and on the Canadian Grain Research Laboratory pin mixer (Kilborn and Tipples 1972) indicate that mixer speed and total work input are both important. The Grain Research Laboratory work also shows a minimum critical mixer speed below which MDD will not take place. The rheology of the bread-making process has been extensively studied, using doughs from a 300-g Brabender Farinograph bowl driven by a variable speed motor (Frazier et al 1975).

With the increased attention being given in the United Kingdom to bread grists and the increasing facility of instrumentation and control systems, the effect of total work input, rate of working, and flour protein level on dough and bread quality have been reexamined in some depth. Because mixers of different design exhibit a wide range of mechanical and mixing efficiency (Kilborn and Tipples 1973), a laboratory version of the mixer most commonly used commercially in the United Kingdom, the Tweedy, was modified to give accurate control of the rate and amount of energy input. To make the results commercially applicable, the baking method was based on typical commercial practice. Final loaf characteristics rather than intermediate rheological tests were used as the primary measure.

MATERIALS AND METHODS

The Mixer

The mixer incorporates a standard (commercial) Tweedy-10 mixer bowl and bread plate connected to a variable speed and energy system designed and constructed by the experimental engineering department of this research center. The final drive shaft to the mixing bowl incorporates a torque/speed transducer so that the mixer speed and the work being done on the dough can be measured. Figure 1 shows the mixing and monitoring systems schematically. The mixer impeller (impact plate) is connected to the drive motor via the final drive shaft through an electromagnetic variable speed coupling.

The coupling can be set electronically to give a constant speed, and the motor is powerful enough to allow speeds of up to 900 rpm to be used. During mixing the dough is thrown out from the impact plate against projections (stators) on the bowl wall, and then falls back onto the impact plate again. This method of mixing puts a lower limit on the mixer speed; at speeds below about 150 rpm the dough components will not mix.

Other facilities available on the mixer are also shown in Fig. 1. The mixer can be programmed to run at either constant speed or constant rate of power input and to stop after a fixed time, after a predetermined power consumption, or at a preset dough temperature.

Materials

Four flours were used. These were straight grade flours with protein contents of approximately 9, 10, 11, and 12% protein (on a 14.5% mb). They were all commercial flours, from grists consisting of all European wheat for the two lower protein flours and with increasing proportions of Canadian Western red spring wheat as protein increased. Flour analyses are given in Table I. The CBP absorption is determined by the Farinograph, using the peak consistency and degree of softening to predict the water addition necessary to give a chosen dough consistency after normal mixing in the Tweedy (ie, 4.5 Whr lb^{-1}, 430 rpm).

Methods

The dough formula, based on flour weight, was: flour, 100%; compressed yeast, 2.1%; salt, 2.1%; fat, 0.7%; and water (adjusted for each flour), 57.3–67.0%. Ascorbic acid (30 ppm) and potassium

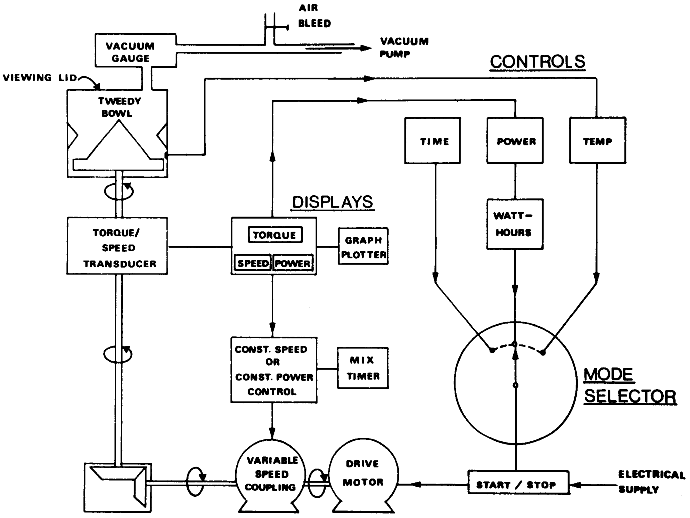

Fig. 1. Schematic diagram of the modified Tweedy-10 mixer control system.

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bromate (45 ppm) were added to the mix in aqueous solution.

All doughs were mixed in the Tweedy-10 at a pressure of 15 in. of Hg below atmospheric pressure (50.5 kPa). The mixer speed and total work were varied; all combinations of 200, 400, 600, and 800 rpm and 2.6, 5.2, 7.8, and 10.4 *W*hr lb^{-1} (20.6, 41.3, 61.9, and 82.5 kJ kg^{-1}) were used. The target dough temperature was 30 ± 1°C, although this was not achieved for some of the high work input doughs. Seven 900-g doughpieces were obtained from each mix, plus one 480-g doughpiece for a dough consistency determination on the Brabender Farinograph. After scaling, the doughpieces were mechanically molded, rested at ambient temperature for 10 min, remolded, placed in tins, and proved in humidified cabinets for 1 hr at 38°C. They were baked at 225°C for 21 min in a rotary oven fitted with a forced convection fan. Each mix was done in duplicate, and all the values given are averages. Mixing order was randomized.

In addition, the dough gassing ability of the 11% protein flour was examined over the complete mixing matrix. Dough (10 g) was taken from the mixer and kept in a closed vessel immersed in a water bath at 30°C. These vessels were each connected via a three-way stopcock to a manometer. The volume of gas produced during 90 min was recorded.

Analysis

Protein was determined as N × 5.7 by a Kjeldahl method. Starch damage and α-amylase analysis were those of Farrand (1964). The Farinograph absorption determination was made by an AACC method.

RESULTS AND DISCUSSION

Dough Gassing Activity

The gas produced during 90 min was similar over the whole mixing matrix, with the exception of the mix at 10.4 *W*hr lb^{-1} and 800 rpm, which gave 1.55 ml of gas per gram of dough. The other 15 mixes produced an average of 2.51 ml/g (standard deviation 0.158 ml/g). This implies that the yeast was damaged by the sustained high shear rates; possibly localized high temperatures were responsible. Therefore, the baking results at this point on the mixing matrix clearly will not be entirely due to the flour properties.

Dough Consistency After Mixing

Water absorptions for each flour were determined with the Farinograph so that the dough consistency after mixing, averaged over all the mixing combinations studied for each flour, is a function of the water absorption determination rather than of the flour properties. However, the effect of moving over the mixing matrix can be studied.

The effect of after-mixing dough temperature on dough consistency was examined first. The dough consistencies could be corrected to a dough temperature of 30°C using a factor of 15 BU °C^{-1} (ie, within ± 3°C, the Farinograph-indicated consistency is inversely proportional to the dough temperature).

The variation of dough consistency with mixing conditions for the four flours is shown in Fig. 2. This is a three-dimensional diagram with work input and mixer speed as the horizontal axes and corrected dough consistency as the vertical axis. Mixer speed rather than work input has the greater effect on dough consistency. Figure 3 shows that, in general, dough consistency rises with both work input and mixer speed. Thus, for a given energy input, the final dough consistency is dependent on work rate, as indicated by mixer speed; this has implications for the commercial definition of the water absorption of a flour.

Mixing Efficiency and Work Rate

The mixing efficiency is the amount of work done on the dough by each revolution of the impact plate. The work rate is the amount of work done on the dough in unit time. The mixing time required to put in a particular amount of work at a particular speed varied very little between the flours because the CBP water absorption is designed to give constant consistency after mixing. These mixing times were therefore averaged to study the mixer characteristics. Figure 4a shows that the work rate increases, although not linearly, with mixer speed, and Fig. 4b shows that the mixing efficiency rises with work rate. Efficiency appears in Fig. 4c to be a linear function of mixer speed (correlation coefficient 0.995, significant at the 0.1% level), but Fig. 4d shows that it also varies slightly with work input.

TABLE I
Basic Analyses of the Flours

	Flour Number			
Property	**1**	**2**	**3**	**4**
Protein[a] (%)	8.7	10.2	10.9	12.1
Starch damage (%)	22	18	26	28
Alpha amylase (Farrand units)	7	7	5	5
Moisture (%)	14.7	13.2	12.7	12.5
Farinograph absorption (%)	53.4	56.4	60.6	63.0
Predicted Chorleywood Bread Process absorption (%)	57.3	60.2	60.2	67.0
Grist (%)				
European	100	100	90	60
Canadian Western red spring (No. 1)	···	···	10	40

[a] N × 5.7, on 14.5% mb (Kjeldahl).

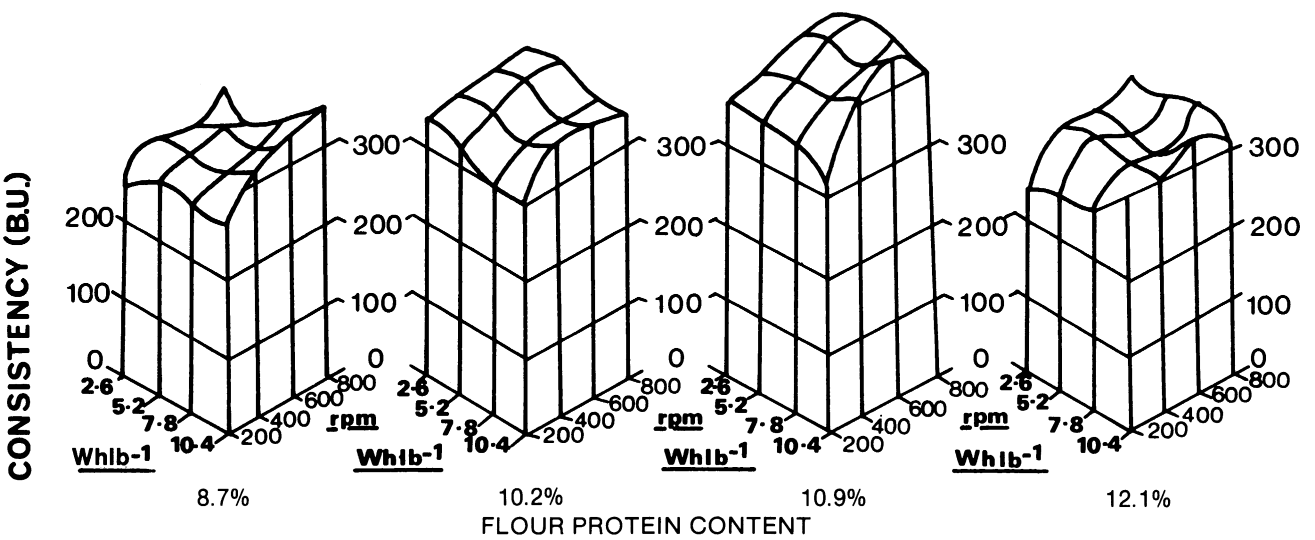

Fig. 2. Three-dimensional diagram showing the effect of mixer speed (rpm) and work input (*W*hr lb^{-1}) on the after-mixing dough consistency (BU). The consistency values have been corrected to a dough temperature of 30°C.

Shear Rates

Analysis of all the results shows that

$$\text{Mix time (sec)} \simeq 10^7 \cdot (\mathit{W}\text{hr lb}^{-1}) \cdot (\text{rpm})^{-2} \qquad (1)$$

Analysis of dimensions shows that 10^7 has the dimensions $L^{-2}T$. The time required by a mixer to impart work into a dough is inversely proportional to dough consistency, which is a measure of the dough's resistance to mixing—a combination of viscosity (flow) and density (mass being moved): the higher the viscosity, the higher the consistency. For a fixed mass of dough, a larger volume will be more efficiently mixed than a smaller volume; therefore mixing time (to impart a fixed work level) will be inversely proportional to dough volume, ie, proportional to dough density. Thus,

$$\text{Mix time} \propto \frac{\text{dough density}}{\text{viscosity}} \times \text{work input} \times (\text{mixer speed})^{-2} \quad (2)$$

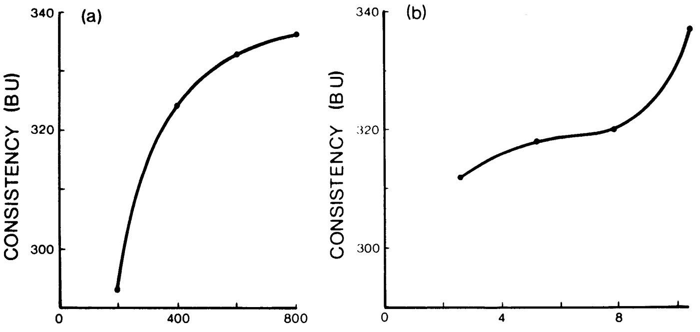

Fig. 3. Effect of mixer speed (**a**) and work input (**b**) on after-mixing dough consistency (corrected to 30° C). The consistency values have been averaged over all the work inputs used (in a) and over all the mixer speeds used (in b). Results are averaged from all four flours.

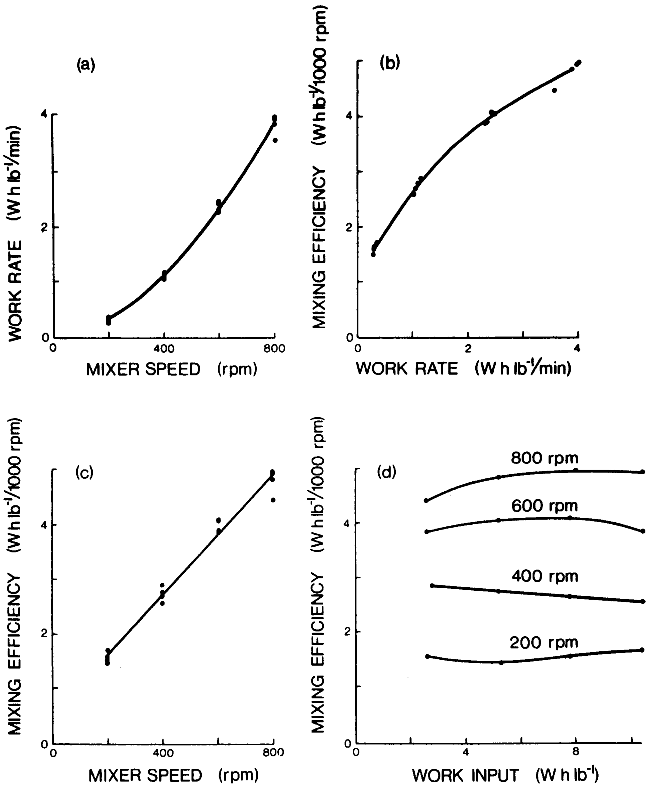

Fig. 4. Effects of: **a**, mixer speed on work rate; **b**, work rate on mixing efficiency; **c**, mixer speed on mixing efficiency; **d**, work input on mixing efficiency. The results are averaged from all four flours.

This is dimensionally correct. Using a typical after-mixing dough density value of 1.25 g/ml, and assuming a proportionality constant of one, equations 1 and 2 give an effective dough viscosity of the order of 3×10^6 cP. Most of the published values for dough viscosity are of the order of 10^7–10^9 cP (Bloksma 1972), although values as low as 10^4 cP have been reported (Muller et al 1962). These values depend on the experimental conditons, eg, water content, strain, stress, and time. Dough viscosity falls with increasing shear rates (Zangger 1979). As mixing proceeds in the Tweedy, once a homogenous mass of the ingredients has been formed, the dough is thrown off the impact plate against the stators on the bowl walls, and then falls back onto the impact plate. This action is interspersed with periods when the dough rolls round the bowl between the impeller and the wall. Thus, the Tweedy will not react to a single valued viscosity of the dough (depending on the water content, temperature, etc.) but to an apparent viscosity that depends on the varying shear rates applied by the mixer as the contact between the mixer and the dough changes.

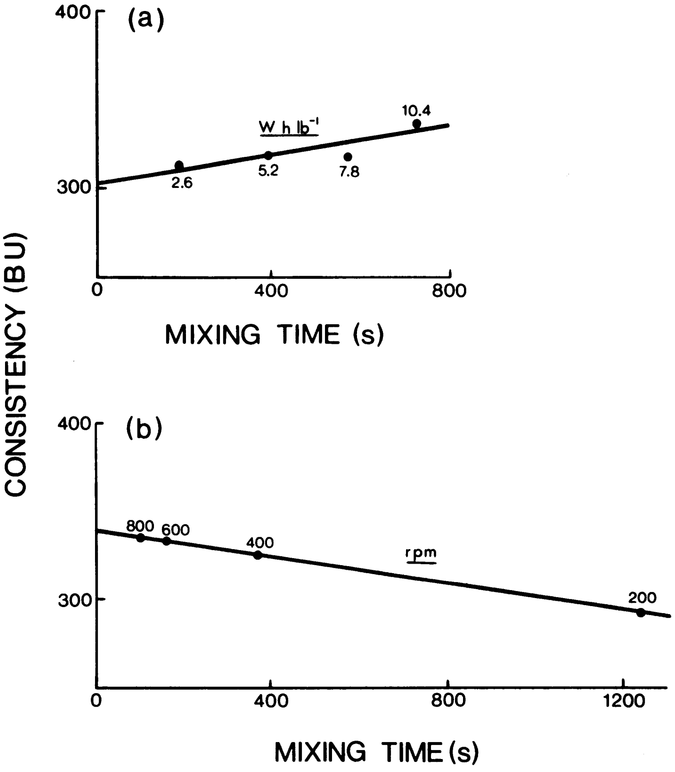

Fig. 5. Effect of mixing time on after-mixing dough consistency averaged over (**a**) all the mixer speeds used (correlation coefficient 0.909, significant at 10%) and (**b**) all the work levels used (correlation coefficient 0.999, significant at 0.1%). Both are averaged from all four flours.

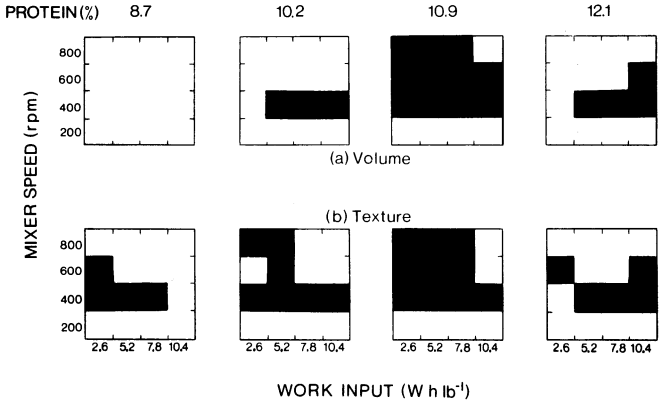

Fig. 6. Areas (shaded) in the mixing matrix that produced acceptable loaf volumes (**a**) and acceptable crumb textures (**b**) from each flour.

Mixer speed (rpm)	2·6	5·2 7·8	10·4
800	OPEN SOLID SHORT, WEAK	FINE SOLID SHORT	IRREGULAR SOLID VERY FIRM
600	OPEN WEAK SHORT	FINE SOFT	OPEN FIRM FAIRLY RESILIENT
400	OPEN WEAK FAIRLY RESILIENT	RESILIENT	SOFT SOLID FAIRLY RESILIENT
200	COARSE & OPEN SOLID 'RUBBERY'	COARSE&OPEN WEAK	VERY COARSE & OPEN SOLID FIRM & RUBBERY

Work input (Wh lb^{-1})

Fig. 7. General effects of varying the mixing on the resultant crumb texture, taken from the comments of the assessment panel.

Dough Consistency and Mixing Time

The effect of mixing time on dough consistency can be examined, averaging the after-mixing dough consistency of all the flours. Figure 5a shows that as the dough is developed, the consistency rises, although the temperature correction may not be sufficiently accurate for some of the deviations encountered at 10.4 *W*hr lb^{-1}. At 200 rpm no MDD takes place and the dough consistency does not change significantly over the work levels used. As the mixer speed increases, the dough is more developed and, again, consistency can be seen to rise (Fig. 5b).

Loaf Volume and Crumb Texture

For the baking method used, the standard deviation for loaf volume is 50 ml for a 3,000-ml loaf; acceptability is defined as larger than 2,800 ml. The texture score, as judged by a panel, runs from 1 (very poor) to 7 (excellent); a score of 4 or above is considered acceptable.

Areas of acceptability for loaf volume are represented in Fig. 6a. The 9% protein flour gave no loaves with acceptable volumes; the largest loaves were obtained for 2.6 and 5.2 *W*hr lb^{-1} at 400 rpm. The 11% protein flour was very tolerant to mixing variation, whereas at 12% protein, tolerance decreased.

The areas of acceptable texture follow the same pattern as the volume results, although Fig. 6b shows a few more acceptable samples than were shown for volume, especially at lower protein levels.

The overall effect on texture of varying the mixing characteristics is shown in Fig. 7. The exact texture pattern varied for each flour, but the best bread was always in the central region of the matrix.

In general, as the mixer speed goes up, the work input required to produce the best loaf goes down. This is best illustrated by Fig. 8, a three-dimensional diagram with loaf volume as the vertical axis. As mixing speed increased, the volume increased to a maximum and then deteriorated. Kilborn and Tipples (1972) have suggested that every type of high energy mixer has a minimum critical speed below which MDD is not possible; for the Tweedy-10 this appears to lie in the range of 200–400 rpm.

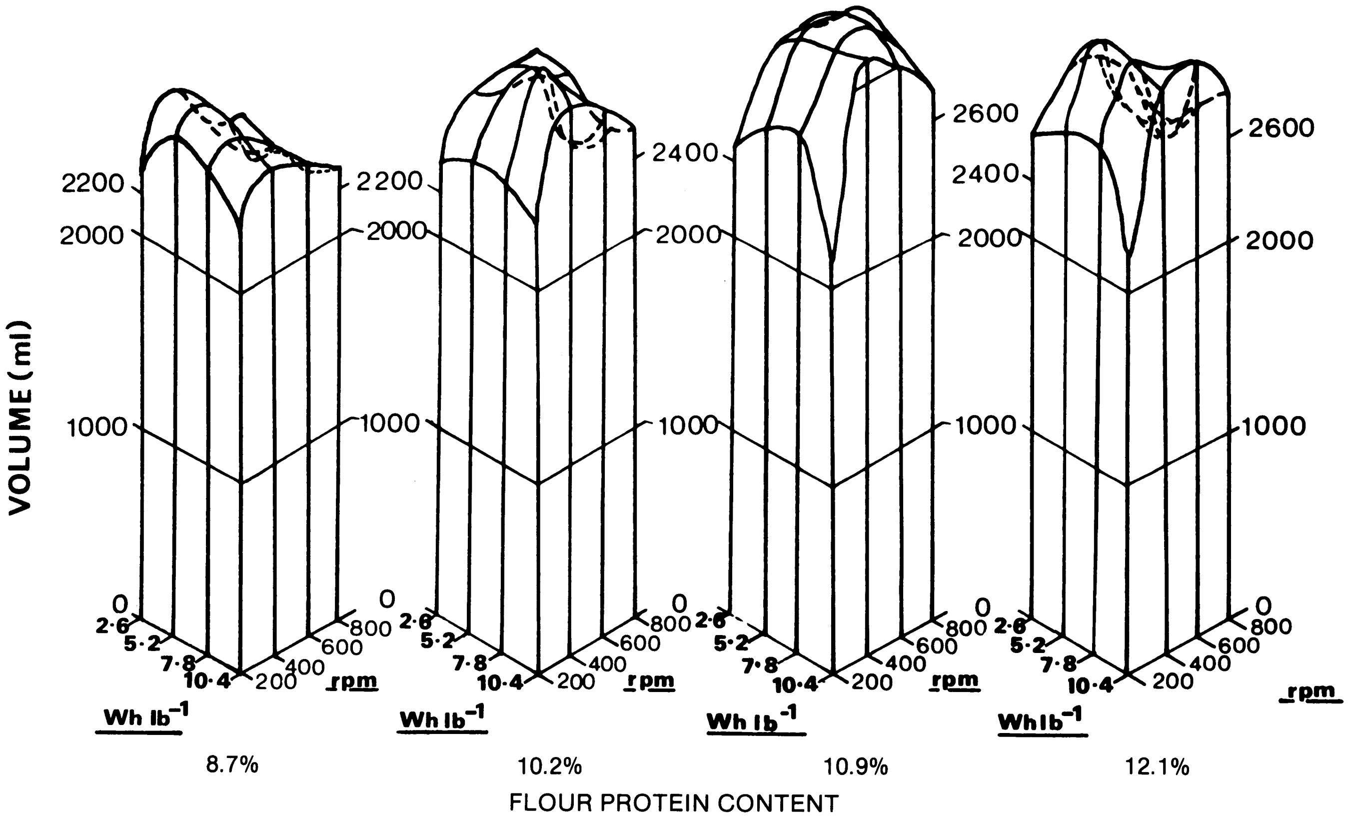

Fig. 8. Three-dimensional diagram showing the effect of mixer speed (rpm) and work input (*W*hr lb^{-1}) on loaf volume (ml).

The loaf volume and crumb texture both rose with flour protein, to peak at about 11%, and then fell with the highest protein level examined. This response to protein appears to be peculiar to the Tweedy machine, which has a unique mixing action. It may be due to the particular combination of high and low shear rates experienced in a Tweedy, or else because the whole CBP (ingredients, mixer and process) has been optimized for 11% protein and changing this in either direction is detrimental. However, the flour protein is the only flour characteristic that systematically changes, except for the associated Farinograph water absorption, and the work reported here examines the effect of this; the results are therefore valid within their context.

CONCLUSIONS

This article has described a technique for investigating the tolerance of a flour to mixing variation; in order to isolate this area, subsequent stages in the baking process have been standardized. The marked degree of tolerance of the 11% protein flour to changes in the mixing regime of the Chorleywood Bread Process and the small area of acceptability associated with a change in protein of one percentage point have been demonstrated.

This concept of tolerance is useful for examining the role and effect of other variables in bread production, eg, mixer vacuum level, bread improvers, additives, fat, etc., and other materials claimed to have a gluten-extending function. If the claims are real in a practical sense, either an increased area of acceptability within the mixing matrix, in terms defined here, or a shift in the optimum point should be seen.

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