Mechanical Dough Development—Dough Water Level and Flour Protein Quantity

P. K. SKEGGS[1]

ABSTRACT

Using a laboratory-scale version of a commercial bakery process commonly used in the United Kingdom, the interaction of dough consistency and the response of bread quality to changes in flour protein level was studied. Protein response was shown to depend on the dough consistency being used: there was little or no response with very slack doughs, but at higher consistencies the response to increased flour protein became apparent. These results highlight the importance of defining the system used to study the baking response of any variable being investigated, as the conclusion of the study may well be as dependent on the baking system chosen as it is on the variable itself.

Cereal Chem. 62(6):458–462

That loaf volume generally increases with flour protein level is a concept that has been accepted for many years. Aitken and Geddes (1934) showed that this protein response was a linear relationship for a series of Canadian wheats of the same class. The same workers went on (1938) to demonstrate that differences exist between different wheats in terms of protein "character" as well as protein level; they referred to gluten "quality." Finney (1943), using more refined techniques, demonstrated that loaf protein response was linear for flour protein levels of between 8 and 20%.

Since then, much work based on these concepts has been published. The baking methods used for these investigations have been based for the most part on bulk fermentation techniques; experience using the Chorleywood Bread Process (CBP) (Chamberlain et al 1962) has not always confirmed these observations. In a preceding paper (1981), I showed that loaf volume appeared to peak with a flour protein of about 11%, and suggested that this may be due to either the CBP being optimized for flours of this protein level or the peculiar mixing action of the Tweedy mixer. This apparent difference between the traditional bulk fermentation and the modern mechanical dough development technique required further investigation, as it had not been reported elsewhere.

One of the features of modern equipment is the opportunity it affords to work with slacker doughs, e.g., polytetrafluoroethylene (PTFE)-coated rollers and air blowing on molders, and there may be considerable variation in dough consistencies used at different bakeries. The work described here was designed to investigate the effect of decreasing dough consistency on the response of bread quality to changes in flour protein level ("protein response"). The baking formula and procedure were both based on typical commercial practice in the United Kingdom. Final loaf characteristics rather than intermediate rheological tests were used as the primary measure.

[1]RHM Research Ltd., Lincoln Road, High Wycombe, Bucks. HP12 3QR, England.

MATERIALS AND METHODS

Materials

For the first part of the work, two straight-grade flours with protein contents of approximately 9 and 13% were used. Both were commercial flours; the lower protein one was milled from all European wheat and the other from Canadian Western red spring wheat. A sample of commercial dried vital wheat gluten, derived from English wheat, was also used. Analyses of these materials are given in Table I.

The second part was carried out using 10 straight-grade flours with protein contents ranging from 10.8 to 13.9%. Again, they were all commercial flours; analyses are given in Table II.

TABLE I
Basic Analyses of the Flours and Gluten Used for the Initial Study

Property	Flour 1	Flour 2	Dried Gluten
Protein, %[a]	9.0	12.6	68.6
Starch damage, %	14	21	···
Alpha-amylase, Farrand units	4	2	···
Moisture, %	14.3	14.4	3.3
Farinograph absorption, %	56.0	62.6	···
Predicted Chorleywood Bread Process absorption, %	61.5	67.0	···
Grist, %			
Canadian Western red spring no. 1	···	100	···
French	90	···	···
English	10	···	100

[a]N × 5.7, as is (Kjeldahl).

TABLE II
Basic Analyses of the Flours Used for the Second Study

Property	Flour Number									
	3	4	5	6	7	8	9	10	11	12
Protein, %[a]	10.8	10.9	11.0	11.0	12.3	12.3	12.8	13.0	13.4	13.9
Starch damage, %	25	24	20	33	31	33	29	34	32	30
Alpha-amylase, Farrand units	2	8	3	4	8	2	9	4	2	2
Moisture, %	14.5	14.6	14.0	14.9	13.8	14.4	14.0	14.6	13.4	13.9
Predicted Chorleywood Bread Process absorption, %	65.5	63.4	63.0	65.9	67.7	66.7	67.0	67.7	69.8	67.4
Grist, %										
Canadian Western red spring	10	10	...	5	17.5	47.5	69.0	67.5	80	100
U.S. dark northern spring	5	5	...	5	7.5	...	...	...	...	...
U.S. hard winter	10	10	...	...	22.5	5	...	...	...	...
English	75	75	100	90	52.5	47.5	31.0	32.5	20	...

[a]N × 5.7, as is (Kjeldahl).

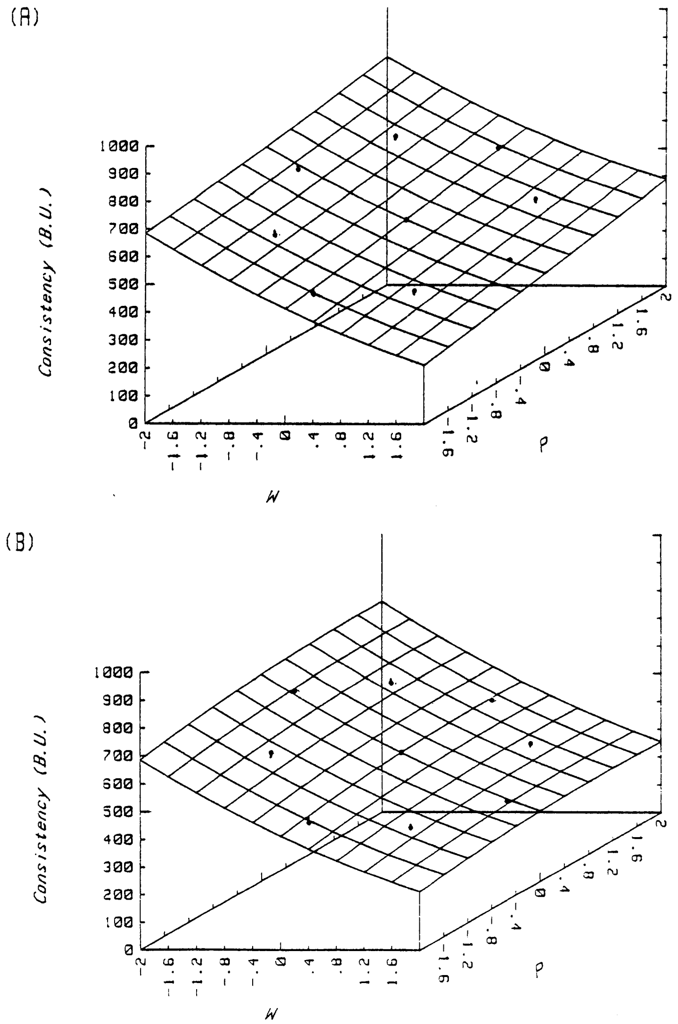

Fig. 1. Effect of dough water level and flour protein content on ex-mixer dough consistency (**A**) for flour 1 with flour 2, (**B**) for flour 1 with dried gluten. The net represents the surface described by equation 1: the actual results used to derive this equation are represented by dots, joined to the surface by vertical lines. (Multiple $R^2 = 0.966$, significant at 0.01%.)

Analyses

Protein was determined as N × 5.7 by a Kjeldahl method. The starch damage and α-amylase were measured as described by Farrand (1964). The Farinograph absorption determination was made by AACC method 54-21 (1976). The CBP absorption was 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 Tweedy mixing (i.e., 10 Whr/kg, 430 rpm).

TABLE III
Design of the Initial Experiment

Test	P[a]	W[b]
1	−1	−1
2	−1	1
3	1	−1
4	1	1
5	−1.5	0
6	1.5	0
7	0	−1.5
8	0	1.5
Control	0	0

[a]Flour Protein, % = P + 11.
[b]Water Addition, % = 4W + 60.

Loaf volume was measured using a seed displacement method, and texture score was judged by an expert panel: the scores run from one (very poor) to seven (excellent), with scores of four or above considered acceptable.

Methods

The dough formula and processing method were as described in a previous paper (Skeggs and Kingswood 1981). The dough formula, based on flour weight, was: flour 100%, compressed yeast 2.1%, salt 2.1%, fat 0.7%, and water (adjusted as required) 54.0–71.8%. Ascorbic acid (30 ppm) and potassium bromate (to give 45 ppm total) were added to the mix in aqueous solution; no α-amylase supplements were used.

All doughs were mixed in a Tweedy-10 at a pressure of 15 in. of mercury below atmospheric (50.5 kPa) and a speed of 430 rpm, to a work level of 10 Whr/kg (35.7 kJ/kg). The target dough temperature was 30 ± 1°C. Seven 900-g doughpieces were obtained from each mix, plus one 480-g doughpiece for a dough consistency determination on the Brabender Farinograph. The curve obtained peaks immediately and slackens back within one minute to a steady reading: curve width remains constant. The consistency is read in the center of the trace at 1½ min, in the steady region. After scaling (by hand), the doughpieces were mechanically molded, rested at ambient temperature (controlled at 20°C) for 10 min, remolded, placed in pans, and proofed 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.

For the initial study, a central, composite, rotatable, second-order experimental design was used. This type of design is an efficient method of examining a response surface; the statistical theory and justifications have been discussed at length by Cochran and Cox (1957) and by Davies (1978). Two series of tests were carried out to examine the interaction of flour protein level with dough water. For the first series, flours 1 and 2 were blended to give the required protein; for the second series, dried gluten was added to flour 1 to give these protein levels. The water levels used were adjusted for flour moisture content, so that the work was carried out using various water additions with flours at 14.4% moisture. Using the combinations described in Table III, protein was varied

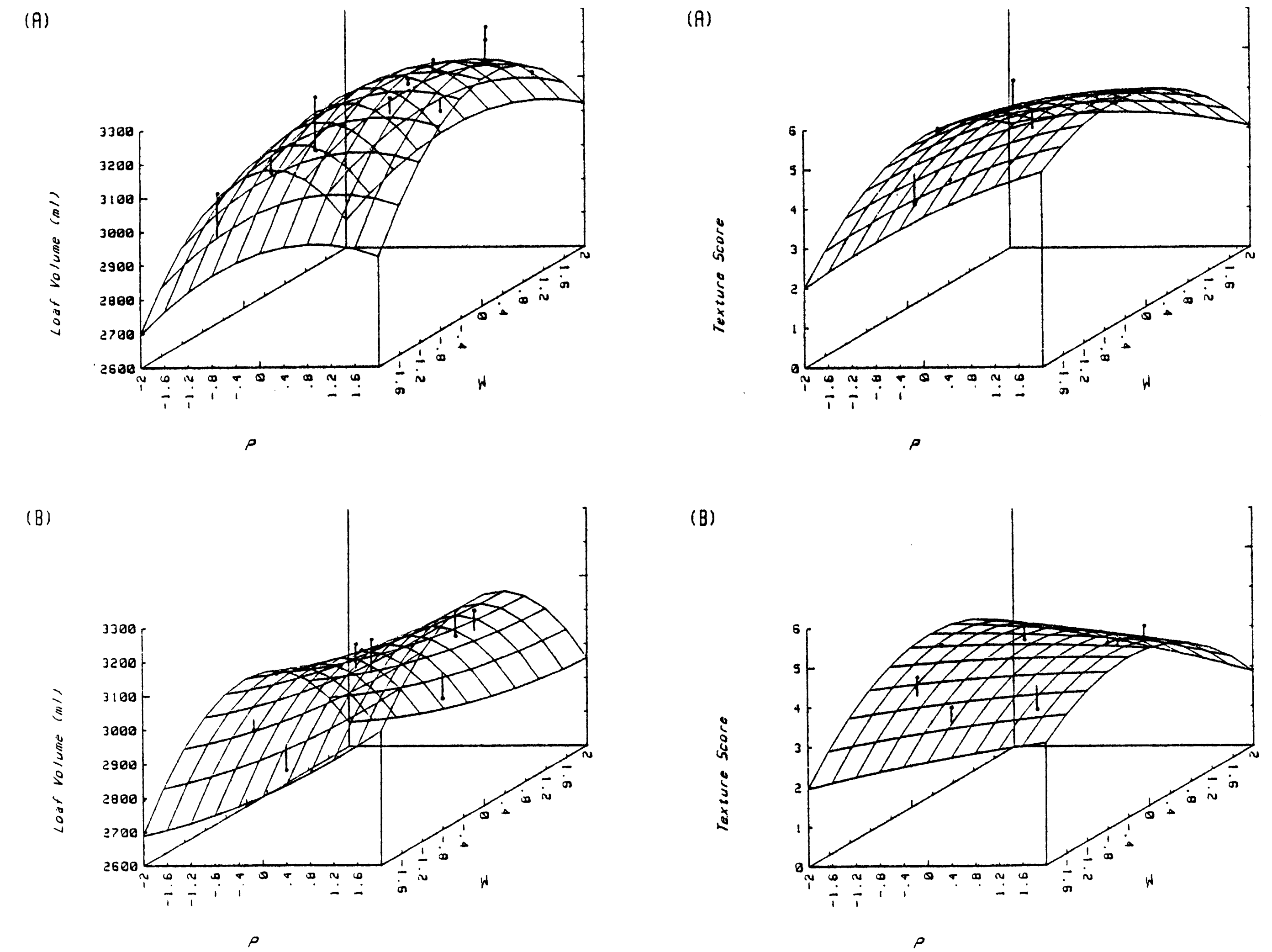

Fig. 2. Effect of dough water level and flour protein content on loaf volume and crumb texture score (**A**) for flour 1 with flour 2, (**B**) for flour 1 with dried gluten. The results are represented as in Figure 1. (Loaf volume multiple $R^2 = 0.815$, significant at 0.01%; texture score multiple $R^2 = 0.746$, significant at 0.05%.)

TABLE IV
Experimental Accuracy

Property	Control Bakes			Error of Check Baking Compared to Prediction[a]		
	Number	Average	Standard Deviation	Number	Average	Standard Deviation
Ex-mixer dough consistency, BU	11	470	22	10	−6	14
Loaf volume, ml	11	3175	53	9	22	60
Crumb texture score	11	4.6	0.3	9	0.0	0.5

[a] Actual result − predicted result.

TABLE V
Protein Response of Ten Straight-Grade Commercial Flours at Three Ex-Mixer Consistency Ranges

Dough Consistency (BU)		Loaf Volume (ml)				Crumb Texture Score			
Average	Standard Deviation	m[a]	c[a]	r[b]	Significance (%)	m[a]	c[a]	r[b]	Significance (%)
372	9	23.0	2834	0.296	N.S.	0.16	2.2	0.378	N.S.
444	18	54.6	2504	0.579	10	0.14	2.6	0.475	25
513[c]	9	102.1	1979	0.583	25	0.22	1.9	0.464	N.S.

[a] $y = mx + c$: Least squares fit; x = flour protein, %.
[b] r = Correlation coefficient.
[c] 7 Results, others 10 results each.

from 9.5 to 12.5% and water addition from 54 to 66%; the mixing order was randomized. The baking results were analyzed by computer using multiple linear regression to derive equations describing the variations observed in terms of flour properties; then extra bakes were carried out using these flours to test the equations.

The 10 commercial flours were each baked four (in some cases five) times, adding different amounts of water, to give a series of ex-mixer dough consistencies for each. By analyzing each of these series, the bread quality that would have been obtained at any required consistency (within the range used) could be calculated. Thus, the hypotheses derived from the initial study could be examined in practice.

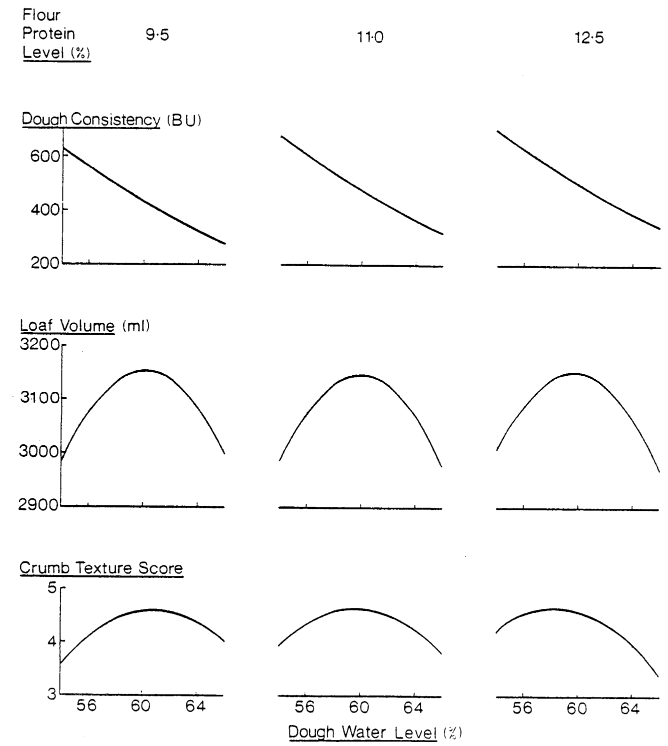

Fig. 3. Predicted effect of changing dough water level, obtained by solving equations 1, 2, and 3, setting D = 0 (i.e., at 16% damaged starch).

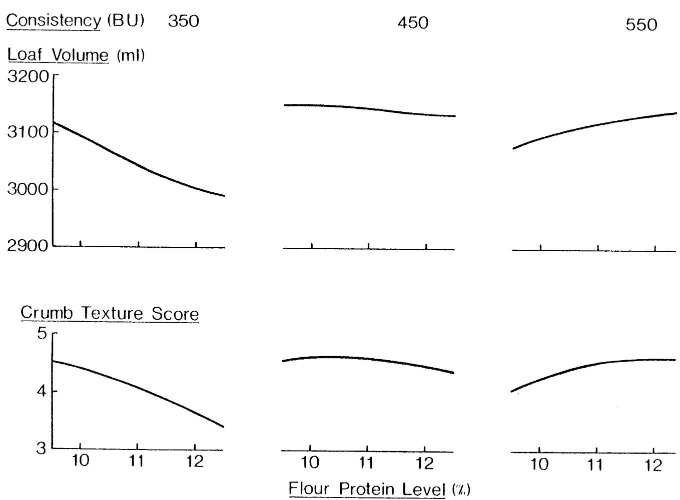

Fig. 4. Predicted effect of changing flour protein while controlling ex-mixer dough consistency, obtained by solving equation 1 to give the required water level for the selected dough consistency at the selected flour protein, and using this water level when solving equations 2 and 3: D = 0 (16% damaged starch) was used throughout.

RESULTS AND DISCUSSION

Initial Study

The ex-mixer dough consistency, loaf volume, and crumb texture results were analyzed in terms of percent flour protein and added water (P, W, P^2, W^2, and PW, see Table III). Unfortunately, the two sets of equations, one for flour 1 with flour 2 and the other for flour 1 with dried gluten, were unreconcilable, indicating that variables other than protein and water level were important. A factor for damaged starch was included and the results reanalyzed; these equations explained the results with very high significance, indicating that the protein supplied by the dried gluten was as functional as that from the Canada Western red spring wheat flour for this application.

Ex-Mixer Dough Consistency

The ex-mixer dough temperatures were all between 29.4 and 31.1°C: to overcome the effect of this variation, the dough consistency results were adjusted to a temperature of 30.0°C (Skeggs and Kingswood 1981). The equation derived for the adjusted dough consistency was:

$$\text{Dough consistency (BU)} = 477 + 23.9\,P + 5.1\,D - 117.4\,W - 4.7\,P^2 + 3.0\,PD - 1.4\,PW + 1.9\,DW + 8.9\,W^2 \quad (1)$$

where P = protein % − 11, D = damaged starch %, and W = (water addition % − 60)/4.

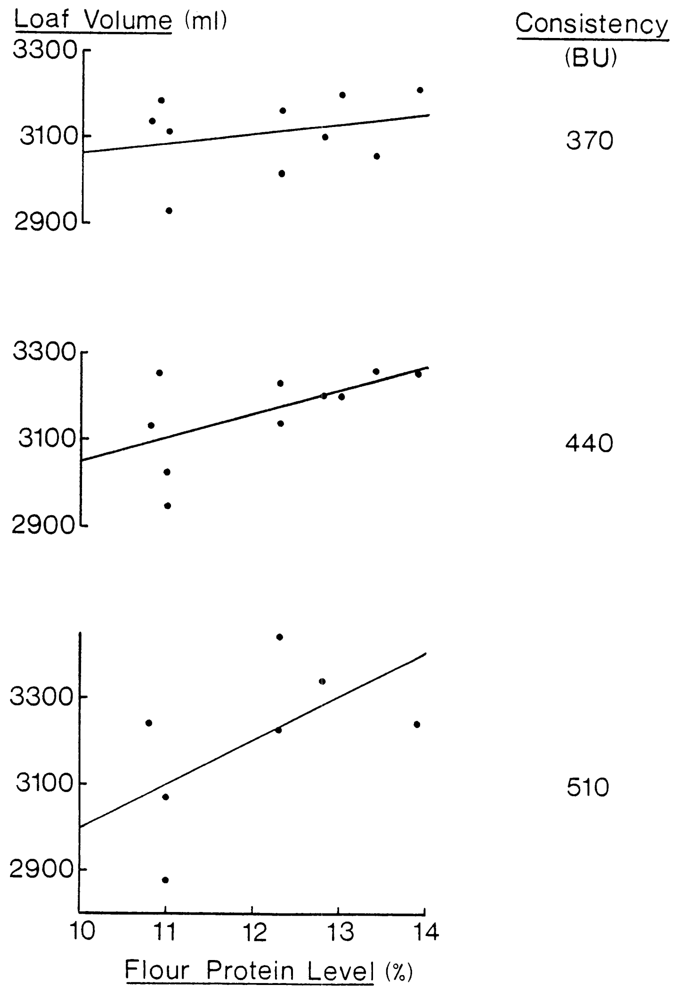

Fig. 5. Effect of flour protein level on loaf volume for 10 straight-grade commercial flours. (Flour analyses are presented in Table II; statistical analysis is given in Table V.) The wide scatter is thought to be due to both variation in the flour parameters other than protein and in part to dough consistency variation within the ranges selected.

The surface represented by this equation is shown in Figure 1. The success of the equation is indicated by the closeness of the actual results to the surfaces, i.e., the shortness of the vertical lines. The ability of the one equation to fit both series of results indicates that the two proteins have the same water absorbing properties and that any apparent differences are due to the differing levels of damaged starch.

The coefficients of P and D in the consistency equation (1) are 23.9 and 5.1, respectively. The results of other (unpublished) work carried out within this laboratory indicate that an increase of 1% water addition causes an ex-mixer dough consistency fall of about 20–25 BU. Dividing the above coefficients by 22.5 BU indicates that: changing the flour protein by + 1% changes the CBP water absorption by + 1.1%; and changing the flour damaged starch by + 1% changes the CBP water absorption by + 0.2%. These values are similar to the effects predicted by Farrand's equation (Farrand 1964) for Farinograph water absorption, i.e., about + 1.1% per 1% protein and about + 0.3% per 1% damaged starch.

Loaf Volume and Crumb Texture

The equations derived for loaf volume and crumb texture were:

$$\text{Loaf volume (ml)} = 3{,}148 + 45.6\ D - 2.1\ W + 2.1\ P^2 - 25.9\ PD - 5.7\ PW + 4.5\ D^2 + 6.6\ DW - 73.7\ W^2. \quad (2)$$

$$\text{Crumb texture score} = 4.7 + 0.22\ D - 0.06\ W - 0.03\ P^2 - 0.02\ PD - 0.15\ PW - 0.02\ DW - 0.37\ W^2. \quad (3)$$

The surfaces represented by these equations are shown in Figure 2. The equations can be used to predict the effect of varying the water or protein level. Figure 3 shows the effect of increasing dough water; the graphs indicate that there is an optimum dough consistency for the baking system used of between 400 and 500 BU. Figure 4 shows the effect of changing flour protein while working to various target dough consistencies. At 350 BU both volume and texture fall with increasing protein, whereas at 550 BU they both rise with protein; 450 BU gives an intermediate result. Thus, protein response does appear to depend on the dough consistency level at which the work is carried out. With slacker doughs, the beneficial effects of increasing protein are outweighed by the extra water necessary to keep to the required consistency. Therefore, the earlier conclusions (Skeggs and Kingswood 1981) were heavily influenced by the slack doughs used.

Experimental Accuracy

In order to check the ability of the equations to predict the performance of these test flours, 10 more composite flours were made from the test materials and their baking performance measured. The results were compared with the equation predictions. The differences between the actual results and the predictions are presented in Table IV. As can be seen, the average error is close to zero in each case, and the standard deviations of the errors are similar to the standard deviations of the control bakes. Thus, the equations appear to describe the performance of these flours accurately, within the limits of the baking test itself, which demonstrates the power and efficiency of this type of experimental design.

Second Study

The baking results for the 10 straight-grade flours were separated into three groups according to dough consistency, and their protein response analyzed. The loaf volume results are presented in Figure 5, and the statistical data for both the volume and the crumb texture score responses are given in Table V.

It is clear that there is considerable scatter about the regression lines. This is thought to be due to variations in flour parameters other than protein, in particular starch damage and α-amylase, and to some extent to variation in dough consistency within the ranges used. However, it is apparent that the slope of the response increased as tighter doughs were used, as the initial work indicated. Further, working at tighter consistencies (up to 530 BU) improved the bread quality. Thus, the results for these varied samples of flour confirm the general conclusions drawn from the initial study.

CONCLUSIONS

This article describes work designed to investigate the response of bread quality to changes in flour protein level for a CBP procedure, and the effect on this response of changing the target ex-mixer dough consistency. An initial, statistically designed, controlled experiment was followed by a second study in which a series of unrelated flours were baked to check the applicability of the initial results.

The results indicate that for certain applications the protein supplied by a good dried gluten can be as functional as that from a good quality wheat. Protein response has been shown to depend on the ex-mixer dough consistency being used. There is little or no response with very slack doughs, presumably because the excess water necessary with high protein flours negates the improved flour quality, whereas as the dough consistency increases, so does the response to higher protein levels. For the baking test used, the best overall bread quality was obtained using ex-mixer consistencies in the range 400–500 BU. These results highlight the importance of defining the system used when studying the factors affecting bread quality, and of ensuring that the system is relevant when applying the results of such studies in practice.

ACKNOWLEDGMENTS

I thank M. R. Booth for conducting the work reported here as the second study and J. Gregory and D. Armitage for carrying out the experimental work.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 54-21, approved April 1961. The Association: St. Paul, MN.

AITKEN, T. R., and GEDDES, W. F. 1934. The behavior of strong flours of widely ranging protein content when subjected to normal and severe baking procedures. Cereal Chem. 11:487.

AITKEN, T. R., and GEDDES, W. F. 1938. The effect of flour strength on increasing the protein content by addition of dried gluten. Cereal Chem. 15:181.

CHAMBERLAIN, N., COLLINS, T. H., and ELTON, G. A. H. 1962. The Chorleywood Bread Process. Bakers Dig. 36:52.

COCHRAN, W. G., and COX, G. M. 1957. Experimental Designs, 2nd ed. Wiley: New York.

DAVIES, O. L., ed. 1978. The Design and Analysis of Industrial Experiments. Longman: London.

FINNEY, K. F. 1943. Fractionating and reconstituting techniques as tools in wheat flour research. Cereal Chem. 20:381.

FARRAND, E. A. 1964. Flour properties in relation to the modern bread processes with special reference to alpha-amylase and starch damage. Cereal Chem. 41:98.

SKEGGS, P. K., and KINGSWOOD, K. 1981. Mechanical dough development—pilot scale studies. Cereal Chem. 58(4):256.

[Received October 29, 1984. Revision received April 25, 1985. Accepted April 25, 1985.]