RESULTS OF BALL-MILLING BUHLER EXPERIMENTALLY MILLED HARD WINTER WHEAT FLOUR[1]

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ABSTRACT

Ball-mill action on Buhler experimentally milled flour resulted in smaller average particle size, higher maltose value, increased farinograph absorption, longer farinograph curve, lower loaf volume, and poorer baking score. Moisture, sedimentation, and protein values were essentially unchanged. Ash increased slightly because of jar abrasion. Starch damage and the increased water thus required, rather than gluten damage, was shown to be the cause of poor baking results. Although improvement in bread quality was obtained by lowering absorption and by increasing the mixing time of the ball-milled flour, as indicated by the longer farinograph curve, the strenuous ball-mill action, which damaged starch granules, impaired the breadmaking ability of normal flour. The more significant correlation coefficients are maltose *vs.* particle size, −0.725; maltose *vs.* absorption, +0.937; maltose *vs.* bake score, −0.812; maltose *vs.* loaf volume, −0.712; maltose *vs.* farinograph peak, +0.704; bake score *vs.* loaf volume, +0.951; farinograph peak *vs.* farinograph tolerance, +0.937; farinograph absorption *vs.* bake score, −0.84.

Although the effect of mechanical action on flour has been studied previously (1–11), investigation of the effect of ball-milling of Buhler experimentally milled hard winter wheat flour appears justified.

Materials and Methods

Seven wheats, three pure varieties (Kaw, Triumph, and N551146) and four commercial blends, were milled on a pneumatic Buhler experimental flour mill (12) in sufficient quantity to provide flour for analysis and baking, as milled, and to provide flour for ball-milling for various periods. The ball-milled flour was analyzed and baked by the regular Union Equity straight dough method. It was subsequently baked with variable absorption and mixing times.

Ball-milling was performed in a 9-qt. stoneware jar, with 10 lb. each of 13/16- and 1¼-in. ceramic cylinders as the grinding agent. The mill was electrically driven with a jar speed of 60 r.p.m. One thousand grams of flour milled for 1 hr. was considered to be one "unit" of ball-milling. This was equivalent to 2,000 g. of flour milled in the same apparatus for 2 hr.

Two flours were each given one and then two units of ball-milling; another flour received a single unit, and four flours received two units.

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The flours were analyzed before and after ball-milling for Fisher average particle size, moisture, protein, ash, sedimentation, maltose, farinograph absorption, peak, and tolerance, and for baking ability. Loaf volume, external appearance, grain, and texture were the factors used to determine the total bake score.

Particle size was determined by the Fisher average particle size equipment and method; moisture by the 15-min. aluminum-plate air-oven method at 135°C. (12); protein by the Kjeldahl boric acid method (12); ash by burning 3 g. for 3 hr. at 1,100°F.; sedimentation by the Zeleny method for flour (12); maltose by the Blish-Sandstedt method (12); farinograph absorption, peak, and tolerance by the Brabender uniform flour weight method (12); and baking by the Union Equity straight-dough, lean-formula, constant mix time method.[3]

Discussion

Table I gives data for the Buhler-milled flours and the corresponding ball-milled flours, showing the direction and the average amount of change per unit of ball-milling for each test. The average change per unit of ball-milling is insignificant for moisture, protein, and sedimentation. Ash increased 0.013% because of jar abrasion. Significant changes occurred in the average particle size, which decreased 3.4 μ, or 21%. For each unit of ball-milling maltose significantly increased 52.4 mg., while loaf volume decreased 144 cc. and bake score declined 8.4 units. The farinograph absorption increased 3.4%, farinograph peak increased 2.1 min., and farinograph tolerance increased 3 min. These relatively large changes in normally stable indices indicate that ball-milling (or similar mechanical attrition) causes significant alterations in the flour.

Coefficients of correlation between maltose, particle size, loaf volume, bake score, farinograph absorption, peak, and tolerance are given in Table II. The highly significant correlations are between loaf volume and bake score, 0.951; between maltose (starch damage) and farinograph absorption, 0.937; and between farinograph peak and tolerance, 0.937. Other significant correlations are: farinograph absorption and bake score, −0.84; maltose (starch damage) and bake score, −0.812; maltose and loaf volume, −0.728; maltose and average particle size, −0.725; and average particle size and bake score, 0.722.

Table III shows the average analytical and baking values, for those tests showing significant change, for the three flours with one unit of ball-milling and for the six flours with two units. In the instances involving two units, Fisher average particle size is reduced over 41%,

[3]Details on request.

TABLE I

BALL-MILLING EXPERIMENTS

Flours and Units	Fisher Average Particle Size	Moisture	Protein [a]	Ash [a]	Sedimentation [a]	Maltose [a]	Farinograph Peak	Farinograph Tolerance	Farinograph Absorption	Loaf Volume	Bake Score	Mixing Time	Bake Absorption
	μ	*%*	*%*	*%*	*units*	*mg.*	*min.*	*min.*	*%*	*cc.*	*units*	*min.*	
Experiment 1: N-1551146 wheat													
Buhler	12.2	14.85	11.10	0.340	45.7	117	5.5	11.0	53.8	2,630	77	5	59.8
BM[b], 1	9.8	14.40	11.00	0.357	43.2	150	7.0	12.0	57.0	2,480	72	5	62.7
Experiment 2: Commercial blend													
Buhler	16.6	14.10	11.71	0.403	50.0	138	6.75	8.5	57.8	2,685	83	5	63.8
BM, 1	11.6	14.15	11.52	0.404	48.5	172	6.75	14.0	60.2	2,510	78	5	66.1
BM, 2	9.4	13.85	11.38	0.419	55.5	233	8.0	16.5	64.2	2,330	63	5	69.2
Experiment 3: Triumph													
Buhler	15.6	14.15	13.22	0.371	68.0	143	6.75	12.0	60.0	2,755	82	5	64.9
BM, 2	8.8	14.10	13.22	0.403	65.0	288	8.0	14.0	67.6	2,410	68	5	72.6
Experiment 4: Kaw													
Buhler	18.8	14.60	13.14	0.365	68.2	154	10.0	15.5	57.7	2,510	82	5	62.7
BM, 1	12.2	14.45	13.12	0.385	69.6	214	13.5	26.0	61.4	2,360	68	5	66.4
BM, 2	10.2	14.60	13.09	0.403	71.0	286	18.0	29.0	65.0	2,080	48	5	70.0
Experiment 5: Blend 81-B													
Buhler	16.0	14.35	11.95	0.418	66.0	136	7.5	15.5	57.7	2,655	84	5	63.5
BM, 2	9.4	14.20	12.03	0.444	70.0	268	14.5	22.0	66.6				
BM, 2										2,580	76	5	63.5 [c]
Experiment 6: Blend 77-B													
Buhler	16.4	13.85	11.88	0.416	63.0	138	6.5	13.5	58.5	2,550	84	5	64.6
BM, 2	10.0	13.90	11.84	0.439	57.0	207	9.5	14.5	64.4	2,400	73	5	70.4
BM, 2										2,570	81	5	64.6 [c]
BM, 2										2,560	82	7 [d]	70.4
Experiment 7: Blend 81-B													
Buhler	16.2	14.50	12.07	0.405	67.0	131	8.0	16.0	57.9	2,600	85	5	64.0
BM, 2	10.2	14.45	11.91	0.419	60.0	204	13.0	23.0	63.2	2,445	77	5	69.2
BM, 2										2,545	80	7 [d]	69.2
BM, 2										2,645	80	7 [d]	64.0 [c]
Average (change/unit grind)	−3.4	−0.08	−0.05	+0.013	−0.5	+52.4	+2.1	+3.0	+3.4	−144	−8.4		

[a] 14% moisture basis. [b] BM = ball-milled. [c] Buhler absorption used on ball-milled flour. [d] Long mix.

TABLE II
COEFFICIENTS OF CORRELATION

	MALTOSE [a]	AVERAGE PARTICLE SIZE	FARINOGRAPH Absorption	FARINOGRAPH Peak	FARINOGRAPH Tolerance	LOAF VOLUME	BAKE SCORE
Maltose [a]	......	−0.725	+0.937	+0.704	+0.325	−0.728	−0.812
Average particle size	−0.725	......	−0.662	−0.362	−0.367	+0.578	+0.722
Farinograph							
Absorption	+0.937	−0.662	......	+0.594	+0.538	−0.568	−0.840
Peak	+0.704	−0.362	+0.594	......	+0.937	−0.667	−0.655
Tolerance	+0.325	−0.367	+0.538	+0.937	......	−0.695	−0.652
Loaf volume	−0.728	+0.578	−0.568	−0.667	−0.695	......	+0.951
Bake score	−0.812	+0.722	−0.840	−0.655	−0.652	+0.951	......

[a] Starch damage.

TABLE III
AVERAGE ANALYTICAL VALUES

	FISHER AVERAGE PARTICLE SIZE	MALTOSE	FARINOGRAPH Peak	FARINOGRAPH Tolerance	FARINOGRAPH Absorption	LOAF VOLUME	BAKE SCORE
	μ	mg.	min.	min.	%	cc.	units
Three flours [a]							
Buhler	15.7	136	7.4	11.7	56.4	2,608	80.7
BM	11.2	179	9.1	17.3	59.5	2,450	72.7
Percent of change	−28.7	+ 31.6	+23.0	+47.9	+ 5.5	− 6.1	− 9.9
Six flours [b]							
Buhler	16.6	140	7.6	13.5	58.3	2,626	83.3
BM	9.7	248	11.8	19.8	65.1	2,333	66
Percent of change	−41.6	+ 77.1	+55.3	+46.7	+11.7	−11.2	−20.1

[a] Ball-milled, 1 unit.
[b] Ball-milled, 2 units.

maltose increased 77%, farinograph peak increased 55%, tolerance increased almost 47%, absorption increased about 12%; loaf volume and bake score declined 11 and 20% respectively.

Figure 1 depicts the relationship between particle size, maltose (starch damage), loaf volume, and bake score for zero, one, and two units of ball-milling, emphasizing the decline in baking value with an increase in mechanical action, as evidenced by the smaller average particle size and the increased maltose value.

Flour from ungerminated wheat, with no added malted wheat flour, normally has very low alpha-amylase activity and high beta-amylase activity (9,13,14). Since beta-amylase does not attack undamaged starch granules to any significant degree but does vigorously attack damaged granules (10), the Blish-Sandstedt maltose test may be used as an indicator of relative starch damage. If the original reducing sugars (about 37 mg.) are subtracted, a more realistic value will be obtained.

The effect of ball-milling of Buhler flour on farinograph values in relation to average particle size and maltose is shown in Fig. 2. The

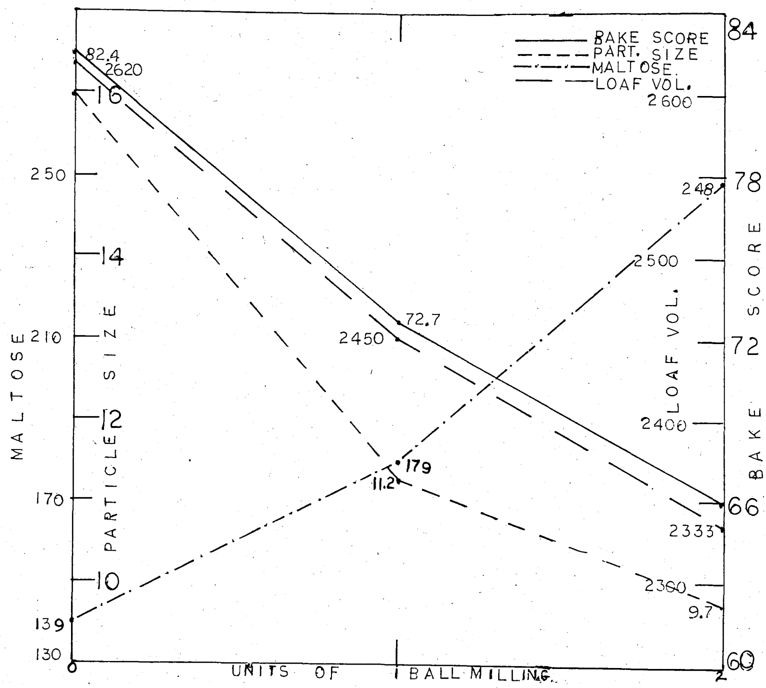

Fig. 1. Composite of values for loaf volume, bake score, particle size, and maltose for Buhler and ball-milled flours.

TABLE IV

Analytical Results for Regular and Ball-Milled Vital Gluten with Buhler Flour

Test	Base Flour	RVG [a]	BMVG [b]	+2% RVG	+4% RVG	+2% BMVG	+4% BMVG
Average particle size	16.6	7.8	5.8	16.44 [c]	16.27 [c]	16.4 [c]	16.2 [c]
Moisture [d]	14.25	4.47	5.55	14.05 [c]	13.86 [c]	14.08 [c]	13.90 [c]
Protein [d]	11.73	65.90	66.47	12.81 [c]	13.90 [c]	12.82 [c]	13.92 [c]
Ash [d]	0.404	1.087	1.09	0.418 [c]	0.431 [c]	0.418 [c]	0.431 [c]
Sedimentation [d]	50	. . .	. . .	. . .	. . .	. . .	. . .
Fat [d]	. . .	0.42	. . .	. . .	. . .	. . .	. . .
Maltose [d]	144	61	69	142	141	143	141
Farinograph							
Peak	6.25	. . .	. . .	7.0	7.75 [c]	6.50	6.75 [c]
Tolerance	8.5	. . .	. . .	9.5	10.5 [c]	10.0	11.5 [c]
Absorption	58.2	. . .	. . .	60.2	62.2 [c]	60.2	62.2 [c]
Loaf volume	2,620	. . .	. . .	2,560	2,610	2,625	2,675
Bake score	83	. . .	. . .	83	83	83	83

[a] Regular vital gluten.
[b] Ball-milled vital gluten.
[c] Calculated values.
[d] 14% moisture basis.

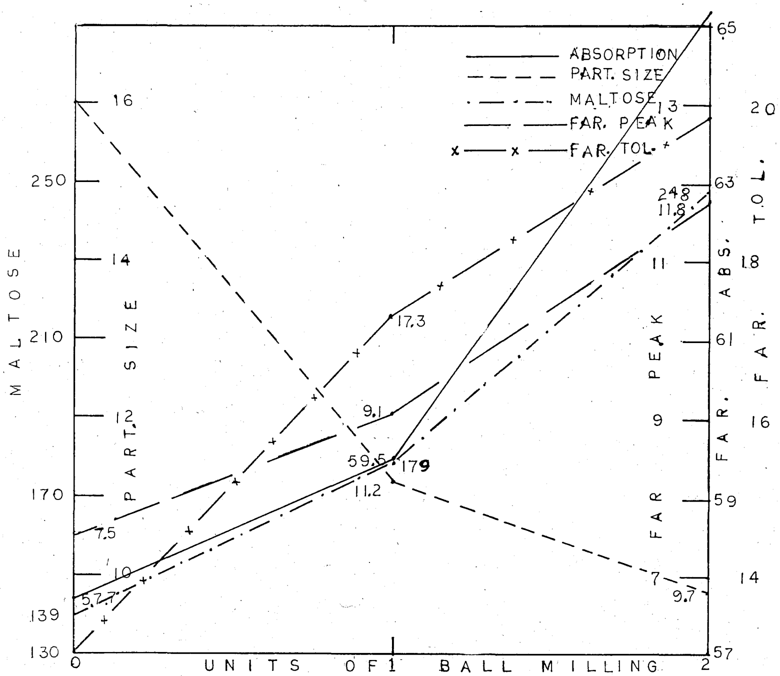

Fig. 2. Composite of values for farinograph absorption, peak, and tolerance, average particle size, and maltose for Buhler and ball-milled flours.

effects of ball-milling are graphically illustrated by the increase in farinograph absorption, peak, and tolerance and by the increase in maltose in conjunction with the decline in particle size. The figures show the effects of either starch damage or gluten damage, if gluten damage occurs, or both.

To ascertain if ball-milling injured the gluten of wheat flour, a sample of vital gluten was given two units of ball-milling. Two and 4% regular and 2 and 4% ball-milled vital gluten were added to an average flour. A summary of the results is given in Table IV. These results show no loss of baking quality for the ball-milled vital gluten. That this was true was also shown by adding 10% regular and 10% ball-milled vital gluten to two portions of a low (7%) protein flour (Table V).

The regular vital gluten blend gave loaves with greater loaf volumes and better exteriors, whereas the ball-milled vital gluten blend had the best grain and texture, balancing the total bake score at 77 for each.

It was suggested that, if ball-milling did affect the gluten, the soluble

TABLE V
BAKING VALUES OF 10% REGULAR AND 10% BALL-MILLED VITAL GLUTEN ADDED TO LOW-PROTEIN (7%) FLOUR

Test	7% Low-Protein Flour + 10% Regular Vital Gluten	7% Low-Protein Flour + 10% Ball-Milled Vital Gluten
Loaf volume, cc.	2,710	2,505
Loaf volume score	30	28
External	7	5
Grain	20	22
Texture	20	22
Total bake score	77	77

protein content might show an increase if the mechanical action was sufficient to alter the protein structure. The values for soluble protein for the regular vital gluten were 3.6% and for the ball-milled vital gluten, 4.0%, indicating no appreciable change in soluble protein due to mechanical action.

From the increase in maltose from 61 for regular to 69 for ball-milled vital gluten (Table IV) and from the total (79%) of the other constituents (protein, 73%; moisture, 4.47%; ash, 1.32%; and fat, 0.46%, as-received basis), it is assumed that some carbohydrate, undoubtedly partly starch, is still in the vital gluten and could be damaged by ball-milling. Any possible minor loss in baking quality of the ball-milled vital gluten might be attributed to the starch still in the vital gluten.

It is reasonable to assume that the increased maltose value of the ball-milled flour is due to the increased susceptibility of the starch to attack by beta-amylase, because of the mechanical action damaging the starch granules (9,15). Decreased particle size is caused by the physical action. Since it was demonstrated that gluten was not injured by two units of ball-milling, the loss of loaf volume and bake score and the increase in absorption are due to starch damage. The higher ash content is due to abrasion of the jar. Farinograph peaks and tolerances increased markedly, suggesting that starch condition may be a factor in determining rheological values. Why the farinograph curve lengthens under the influence of ball-milling is not understood. It may be conjectured that the longer curve may result from the freeing of protein particles from the conglomerate flour particles by the mechanical action, so that they may form a stronger gluten in the farinograph bowl. Nevertheless, the stronger farinograph curve is not reflected by the regular baking test.

In an effort to determine whether it is actually damaged starch that is hurting baking quality, or the additional water that ball-milled flour requires to form a dough of proper consistency, samples of Buhler-milled flour, portions of which were given two units of ball-milling, were baked. The same absorption was used for both, in spite of the apparent need for additional water in the ball-milled flour doughs. Results are given in Table VI. Also in Table VI are the results of a 50% increase in mixing time of the ball-milled flour with the "proper" dough consistency and with stiff doughs containing the amount of water required by the original Buhler flours.

TABLE VI
RESULTS OF ABSORPTION AND MIXING TIME VARIATIONS

FLOUR	MIXING TIME	BAKE ABSORPTION	LOAF VOLUME		EXTERNAL CHARACTERISTICS	GRAIN	TEXTURE	TOTAL BAKE SCORE
			cc.	units [a]				
Experiment 5								
Buhler	5	63.5 [b]	2,655	30	7	24	23	84
BM [c]	5	63.5	2,580	30	5	21	20	76
Experiment 6								
Buhler	5	64.6 [b]	2,550	30	7	24	23−	84
BM-A	5	70.4 [b]	2,400	23	6	22	22	73
BM-B	5	64.6	2,570	30	6	23	22	81
BM-C	7	70.4 [b]	2,560	30	7	23	22	82
Experiment 7								
Buhler	5	64.0 [b]	2,600	30	8	24	23	85
BM-D	5	69.2 [b]	2,445	25	7	23	22	77
BM-E	7	69.2 [b]	2,545	30	6	22	22	80
BM-F	7	64.0	2,645	30	6	22	22	80

[a] Loaf volumes of 2,540 or higher rated 30.
[b] Correct absorption.
[c] Ball-milled.

In Table VI, experiment 5, the ball-milled flour baked from a dough containing the absorption required by the original Buhler flour *vs.* the original Buhler flour baked with the same absorption demonstrates a material loss in baking quality for the ball-milled flour, though the decline in loaf volume was less than average. Again, in experiment 6, ball-milled flour BM-B, with the absorption required by the Buhler flour *vs.* the Buhler flour with its correct absorption, suffered a loss of internal quality for the ball-milled flour, though loaf volume was normal. When the ball-milled flour BM-A was baked with the dough at its proper consistency, the loaf volume declined, indicating that the additional water, *per se,* hurt the over-all bread quality. Experiment 7, ball-milled flour BM-D *vs.* the original Buhler flour (both at the "proper" consistency for each), again demonstrated the loss of loaf volume and bake score due to damaged starch and the added water that it absorbs.

The farinograph data indicate that longer mixing times are required for ball-milled flours. To check this point, flour BM-C (experiment 6) was baked using a 50% increased mixing time and the *correct* consistency. The volume of the loaf was equal to that of the Buhler flour, but the internal character was slightly poorer. By mixing both flours BM-E and BM-F (experiment 7) 50% longer than the regular mix and by using the absorption required for the Buhler flour for BM-F and the "proper" consistency for BM-E, the drier and longer-mixed flour, BM-F, gave the better loaf volume and had an equal bake score.

None of the ball-milled flour – regardless of the percentage of absorption and/or mixing time – had as good a total bake score as the original Buhler flour. It was shown, however, that stiffer doughs and longer mixing times for ball-milled flours tend to improve bread quality over the correct absorption and standard mixing times.

The evidence points to the fact that damaged starch, indicated by increased maltose and higher water absorption values, lowers flour quality, as determined by the regular lean-formula, straight-dough baking test. This agrees with current thought that bread flour quality is a function not only of protein quantity and quality but also of starch condition (16).

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Literature Cited

1. ALSBERG, C. L., and GRIFFING, E. P. Effect of fine grinding upon flour. Cereal Chem. **2:** 325–344 (1925).
2. KARACSONYI, L. P., and BAILEY, C. H. Relation of the overgrinding of flour to dough fermentation. Cereal Chem. **7:** 571–587 (1930).
3. PULKKI, L. H. Particle size in relation to flour characteristics and starch cells of wheat. Cereal Chem. **15:** 749–765 (1938).
4. SANDSTEDT, R. M., JOLITZ, C. E., and BLISH, M. J. Starch in relation to some baking properties of flour. Cereal Chem. **16:** 780–792 (1939).
5. JONES, C. R. The production of mechanically damaged starch in milling as a governing factor in the diastatic activity of flour. Cereal Chem. **17:** 133–169 (1940).
6. DADSWELL, INEZ W., and GARDNER, JOAN F. The relation of alpha-amylase and susceptible starch to diastatic activity. Cereal Chem. **24:** 79–99 (1947).
7. SANDSTEDT, R. M., and MATTERN, P. J. Damaged starch. Quantitative determination in flour. Cereal Chem. **37:** 379–390 (1960).
8. SULLIVAN, BETTY, ENGEBRETSON, W. E., and ANDERSON, M. L. The relation of particle size to certain flour characteristics. Cereal Chem. **37:** 436–455 (1960).
9. KNEEN, E., and SANDSTEDT, R. M. *In* Enzymes and their role in wheat technology, ed. by J. A. Anderson, chap. 3, pp. 89–126. Interscience: New York (1946).
10. KENT-JONES, D. W., and AMOS, A. J. Modern cereal chemistry (5th ed.), chap. 9, pp. 272–280. Northern Pub. Co.: Liverpool (1957).
11. PONTE, J. G., JR., TITCOMB, S. T., ROSEN, JOCELYN, DRAKERT, W., and COTTON, R. H. The starch damage of white bread flours. Cereal Sci. Today **6:** 108–110, 112, 121 (1961).

12. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Cereal laboratory methods (7th ed.). The Association: St. Paul, Minnesota (1962).
13. KNEEN, E. A comparative study of the development of amylases in germinating cereals. Cereal Chem. **21:** 304–314 (1944).
14. FLEMING, J. R., and JOHNSON, J. A. Some recent advances in the chemistry of malting. Cereal Sci. Today **9:** 67–68, 88 (1964).
15. REED, G., and THORN, J. A. Enzymes. *In* Wheat: Chemistry and Technology, ed. by I. Hlynka, chap. 9, pp. 397–434. American Association of Cereal Chemists: St. Paul, Minn. (1964).
16. FARRAND, E. A. Flour properties in relation to the modern bread processes in the United Kingdom with special reference to alpha-amylase and starch damage. Cereal Chem. **41:** 98–111 (1964).