Controlled Levels of Starch Damage in a Commercial United Kingdom Bread Flour and Effects on Absorption, Sedimentation Value, and Loaf Quality

E. A. FARRAND[1], Ranks Hovis McDougall (Research) Ltd.[2], Buckinghamshire, United Kingdom

ABSTRACT

A U.K. bread-flour grist used for conventional and mechanically developed doughs was commercially milled at three controlled levels of starch damage while other measurable parameters were kept constant. The flours were studied at three levels of water absorption and three levels of yeast for each level of starch damage. Dough consistencies were measured with a Brabender Farinograph and also a Do-Corder at variable mixing speeds; bread quality was characterized in terms of a standard laboratory baking test. Relationships between flour absorption, dough properties, starch damage, yeast levels, and loaf quality are developed and discussed. It is concluded that the physical state of the starch component of a flour has important effects on the meaning and application of rheological parameters, sedimentation values, and yeast utilization in relation to loaf quality obtained by conventional and mechanical development techniques used in the U.K.

The commercial importance of starch damage as a flour-quality parameter is now fairly well recognized. Recent papers (1,2,3) have reviewed different methods for estimation of starch damage, application to flour absorption, and significance of test-bake procedures. Farrand (4) developed a model equation to estimate absorption on the basis of flour moisture, protein, and starch damage, also optimizing starch damage in relation to bread quality.

The purpose of this paper is to consider some effects of varying levels of starch damage in flour milled from a uniform grist by applying conventional methods of testing including a Brabender Farinograph and Do-Corder, sedimentation value, and test bakes. Therefore, with the level of starch damage the only significant variable, the score and limitation of conventional data and the model equation (4) can be discussed in the context of flour absorption and bread quality.

Attention is drawn to the fact that U.K. bread does not contain added sugar and is normally produced within a specific volume range of 3.5 to 4.5. U.S. bread contains added sugar and has a much higher specific volume.

MATERIALS AND METHODS

Flour

A typical bread-flour grist was conditioned and milled on a 60-sack commercial mill. Appropriate tests were made during milling to ensure that basic characteristics such as homogeneity grist, extraction rate, and flour color were kept constant, while starch damage was controlled at three levels by varying roll pressures in the reduction system along with minor ancillary adjustments. The flour received normal commercial treatment consisting of 14 p.p.m. Diox, 16 p.p.m. bromate, 45 p.p.m. benzoyl peroxide, and supplementation with a fungal amylase.

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[1] Assistant Director.

[2] Cressex Trading Estate, Lincoln Road, High Wycombe, Buckinghamshire, U.K.

Rheological Absorption

The Brabender Farinograph and Do-Corder (Brabender OHG, Duisberg, W. Germany) were used with a 300-g. farinograph bowl. The absorption measurements were "as-is", and flour and water were used to a point of minimum mobility, 600 B.U. Farinograph and Do-Corder curves were analyzed in terms of development time and stability, as indicated in AACC Method 54-21 (5).

Estimated Absorption

Estimated absorption was by the model equation of Farrand (4).

Determinations

Flour color was determined with a Kent-Jones and Martin Color Grader; protein, by N X 5.7; moisture, by 10 g. flour dried for 1.75 hr. in a fan-ventilated oven at 127°C.; starch damage and α-amylase units, by Farrand (6); and sedimentation value, by AACC Method 56-60 (5).

Test-Bake Procedure

A battery of eight synchronized Morton mixers with varying speed was used. The doughs were, therefore, made and replicated in groups of eight, each group including two controls along with six experimental doughs. The positions of the controls in the groups of eight were varied at random. One-pound dough pieces were used throughout and baked in a Simon rotary oven for 40 min. at 435°F. Loaf volume was measured by seed displacement, and texture and color scored on an arbitrary scale of eight.

Dough recipes were as follows:

	Bulk-Fermentation Doughs	*Mechanically Developed Doughs*
Flour	1,000 g.	1,000 g.
Yeast	13 g.	25 g.
Salt	18 g.	18 g.
Fat	...	7 g.
Ascorbic acid	...	150 p.p.m.
Water	As in text	As in text
Procedure	Mixed at 100 r.p.m. for 3 min.; 3-hr. fermentation. Dough temperature, 80° F. Proof, 95°F. for 50 min.	Mixed at 400 r.p.m. to a total work input of 0.4 h.p.-min./lb. at a rate of 0.1 h.p.-min./lb./min. Dough temperature, 85°F. Proof, 95°F. for 55 min.

RESULTS

The samples of flour milled at three levels of starch damage were designated low, medium, and high, and blended and bagged in polythene. The samples were then tested and the relevant data given in Table I, which showed the three levels of percentage of starch damage: 18, 25, and 30 Farrand units.

Reference to the model equation (4) gave the optimum level of starch damage for 12.2% protein as 25 units. The parameters measured (adjusted to constant moisture) for the three samples differed significantly only in the levels of starch damage. The theory and practice of modern commercial milling are considered compatible with a claim that the controlled operational conditions necessary to

TABLE I. DATA FOR BULKED AND BLENDED SAMPLES USED IN THE INVESTIGATION

Level of starch damage	Low	Medium	High
Moisture, %	14.4	14.2	14.1
Flour color grade	2.5	2.5	2.6
Protein, % (N X 5.7)	12.2	12.2	12.3
Starch-damaged, %	18[a]	25[a]	30[a]
α-Amylase units	11	11	10
Brabender absorption (600 B.U.)	55.6	58.0	60.6
Estimated absorption, model equation (4)	56.0	58.5	60.4
Estimated absorption, model equation (4), based on increased starch damage only, using low starch damage as reference	56.0	58.2	59.8
Brabender absorption (600 B.U.); flour-solids basis.	81.8	84.1	86.7

[a] Farrand units.

change the levels of starch damage over the range reported were such that it would be unlikely that unmeasured constituents would be involved in any significant manner to invalidate an assumption that the flours differed only in the physical state of the starch. The aforegoing technique is certainly preferable to ball milling the same flour to increase the starch damage, where it can be proved that the nature and distribution of the damaged starch granules are significantly different from that obtained by commercial roller milling.

The farinograph absorption showed normal agreement with the estimated absorptions. The agreement also indicated that the differences in absorption between the samples, adjusted for small deviations in protein and moisture, could be accounted for in terms of increased starch damage.

An inverse correlation between moisture and starch damage was noted: the heavier grinding to give higher levels of starch damage generated more heat, resulting in a significant increase in moisture loss on the mill.

In view of the small moisture differences and the need continually to redetermine moisture to correct for any subsequent small changes during the period of experimentation, all absorption figures were expressed on a flour-solids basis.

Characterization of Farinograms at Variable Absorptions

Farinograms were developed for each of the three levels of damaged starch, using appropriate absorptions to give a range of consistencies covering approximately 200 to 800 B.U. (Table II). Each curve was characterized in terms of development time and stability. Consistency vs. solids-basis absorption, plotted in Fig. 1, showed the usual curvilinear relationships, which over the normal breadmaking range of 400 to 600 B.U., were approximately linear, with the slope increasing as starch damage increased.

Figure 2, stability vs. solids-basis absorption, also shows curvilinear relationships for each level of starch damaged. At fixed levels of water, the stability increased with decreasing starch damage; and at fixed stability, the absorptions increased with increasing starch damage. At the solids-basis absorptions measured at 600 B.U. (low starch damage, 81.8%; medium, 84.1%; and high,86.7%), each sample gave the same stability figure: approximately 8 min.

TABLE II. FARINOGRAPH DATA
(300-g. bowl)

Starch Damage	Flour-Solids Basis Absorption %	Consistency B.U.	Development Time min.	Stability min.
LOW	78.1	780	5.5	6.5
	81.0	640	7	7
	85.1	500	7	9.5
	91.5	360	11	14.5
	106.6	180	73	42
MEDIUM	81.8	780	5	5.5
	85.0	630	6.5	8
	88.2	510	7.5	10.5
	100.5	270	35	24
	108.6	190	75	50
HIGH	83.9	820	6	5.5
	86.2	700	6	7.5
	92.8	490	10	11
	102.1	290	35	29
	111.4	200	68	43

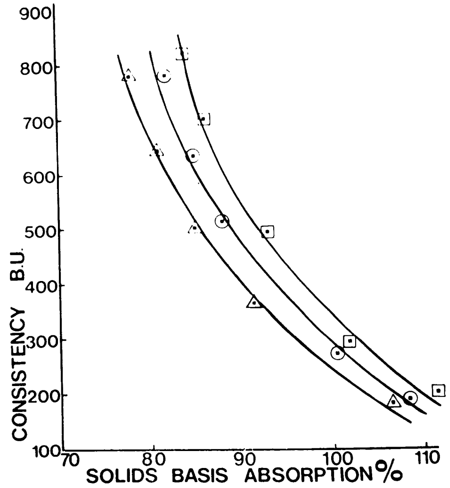


Fig. 1 (left). Solids-basis absorption vs. consistency (B.U.). Triangles = low starch damage; circles = medium starch damage; squares = high starch damage.

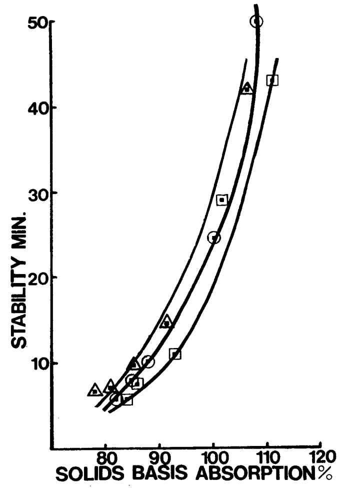


Fig. 2 (right). Solids-basis absorption vs. stability (min.). Triangles = low starch damage; circles = medium starch damage; squares = high starch damage.

Figure 3, stability vs. consistency, shows that all levels of starch damage fell on the same curve. Thus, the relationship between consistency and stability for the given flour was independent of the level of starch damage. Consequently, the consistency of the flour dough could be changed in two ways: a) by varying the water, and b) by varying the level of starch damage. Either procedure at the same consistency gave the same stability. However, the model equation (4) already predicted that the yield and baking characteristics would be modified, and further evidence was obtained to support the model hypothesis.

Development time has also been quoted as a flour-strength parameter (7). For the data given, the stability and development time were significantly correlated, r = 0.987***. Therefore, any remarks relevant to stability were considered applicable to development time.

Characterization of Farinograms at Variable Speeds

The 300-g. farinograph bowl used in these experiments was attached to a Do-Corder and operated at variable speeds. The absorption used for each flour was that which gave a maximum consistency of approximately 500 B.U. at normal farinograph speed. Separate curves were then obtained, at the same absorption but with increased speed, that gave an apparent consistency of 600 B.U. The mixing speed for approximately 600 B.U. was found to be 100 r.p.m., compared with the normal farinograph speed of 56 r.p.m. This procedure had been found useful in estimating the increased absorptions to be used in mechanically developed doughs.

Results in Table III were also plotted in Fig. 3. Again, all levels of starch damage fell on a single curve.

Sedimentation Value

The values for each sample were replicated and the results given in Table IV. As previously reported (6), the sedimentation value increased with increasing levels of starch damage.

Test-Bake Loaves, 3-hr. Bulk Fermentation, at Variable Absorptions

At each level of starch damage, test-baked loaves were made with absorption levels above and below the standard farinograph absorption measured at 600 B.U.

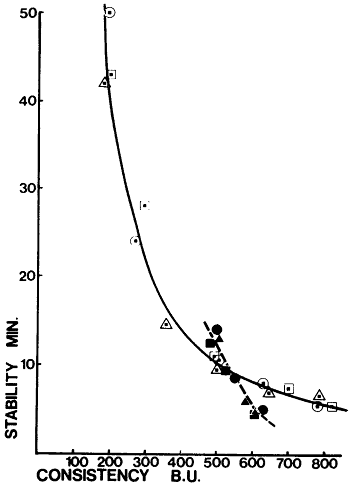


Fig. 3. Consistency (B.U.) vs. stability (min.). Open symbols indicate Farinograph at standardized r.p.m.; closed symbols indicate Do-Corder at variable r.p.m. Triangles = low starch damage; circles = medium starch damage; squares = high starch damage.

TABLE III. BRABENDER DO-CORDER DATA
(300-g. Farinograph bowl)

Starch Damage	Flour-Solids Basis Absorption %	R.P.M.	Consistency B.U.	Development Time min.	Stability min.
LOW	84.0	56	510	10	13
		75	580	6.5	6
		100	620	4.5	5
MEDIUM	87.0	56	500	5.5	14
		75	550	5.5	8.5
		100	630	4	5
HIGH	90.0	56	480	8	12.5
		75	530	6	9.5
		100	610	5	4.5

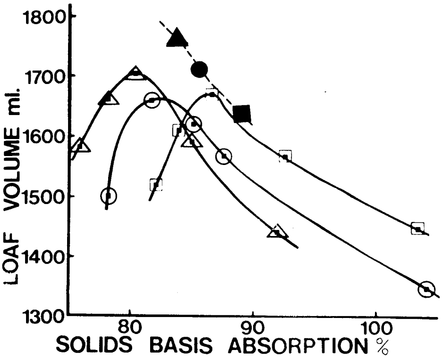
TABLE IV. ZELENY SEDIMENTATION VALUE

Flour Moisture %	Starch Damage %	Sedimentation Value
14.1	18	33 ±0.5
14.2	25	36 ±0.5
14.4	30	38 ±0.5

TABLE V. TEST-BAKE OF 1-lb. DOUGH PIECES (453 g.)
(3-hr. bulk fermentation)

Starch Damage	Flour-Solids Basis Absorption %	Loaf Volume ml.	Bread Score Texture	Bread Score Crumb color
LOW	92.1	1,440	3	5
	85.1	1,590	6	6
	80.4	1,700	7	6
	78.1	1,660	7	6
	75.8	1,580	5	5
MEDIUM	100.5	1,350	3	5
	87.6	1,570	7	6
	85.3	1,620	7	6
	81.8	1,660	7	6
	78.3	1,500	5	5
HIGH	103.3	1,450	3	5
	92.8	1,570	6	6
	86.9	1,670	7	6
	84.0	1,610	6	6
	82.2	1,520	5	5

The results, shown in Table V, were plotted in Fig. 4. Loaf quality in terms of volume, texture, and color, peaked at or near farinograph and model absorptions (4). Considering the conventional test-bake used to interpret commercial-quality acceptance of a bread flour at 12% protein, any volume greater than 1,600 ml. and any texture-color score greater than 5 would be considered satisfactory. The low level of starch damage gave the greatest volume, the greatest area under the curve above the 1,600-ml. line and the curve was virtually symmetrical about peak



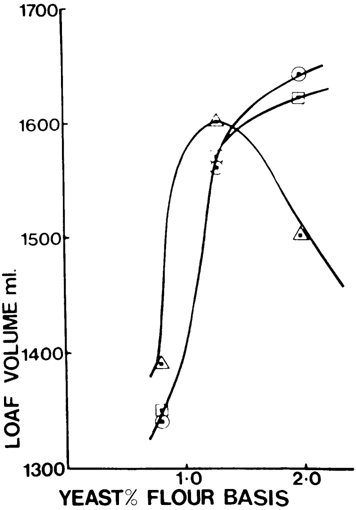


Fig. 4 (left). Solids-basis absorption vs. loaf volume (ml.). Open symbols indicate bulk fermentation; closed symbols, mechanical development. Triangles = low starch damage; circles = medium starch damage; squares = high starch damage.

Fig. 5 (right). Yeast (% flour basis) vs. loaf volume (ml.) at 84.9% flour-solids basis absorption. Triangles = low starch damage; circles = medium starch damage; squares = high starch damage.

volume. The higher levels of starch damage decreased peak volume, skewed the curve, and reduced the area above the 1,600-ml. line so that volume decreased more rapidly at low absorptions and less rapidly at high absorptions. Consequently, increasing starch damage forced increased absorptions but impaired tolerance to variations in absorption.

Figure 4 also shows that at 84 to 85% absorption all three levels of starch damage gave loaves of approximately 1,600 ml. However, the consistency of the doughs for the low and medium starch damage was below, and the high starch damage above, optimum consistency 600 B.U., with corresponding changes in stability. While the figures for volume, texture, and color were similar, small differences in crumb structure were associated with the original dough consistencies.

Test-Bakes, 3-hr. Fermentation at Constant Absorption and Variable Yeast Levels

The three flours were test-baked at the same absorption (84.9%) with corresponding consistencies, using normal yeast (1.3% flour basis), and with reduced and increased levels. The results (Table VI) were plotted in Fig. 5. The three levels of starch damage gave similar results at normal and low yeast additions, but the low starch damage was clearly separated from other levels at the high yeast addition.

The low starch damage showed intolerance to yeast levels above normal, compared with the medium and high starch damage. Efficient and profitable bread production depends on maximizing absorption and minimizing yeast addition without prejudice to loaf quality. Increase in starch damage to higher levels resulted in a corresponding increase in absorption but with a tendency to decrease loaf volume. At higher levels of starch damage, yeast utilization was more efficient.

Thus manifest was a facet of problems associated with starch damage optimization in terms of economic and technological criteria. In this sense the medium starch damage was considered at an optimum for a protein (12.2%) and in agreement with the model equation (4), but clearly satisfactory bread can be made over the range of starch damages examined.

Test-Bake, Mechanically Developed Doughs

The U.K. mechanical development for bread doughs, based on the Chorleywood Process (8), involves five essentials: a) a total work input 0.4 h.p.-min. per lb., b) increased absorption, c) increased yeast, d) the addition of 0.7% fat on a flour basis, and e) increased oxidizing agents. The increased absorption used for the three flours was measured at 100 r.p.m. at 600 B.U. on the Do-Corder with the standard farinograph bowl. The results are shown in Table VII and plotted in Fig. 4.

The increase in absorption was approximately two units of percentage flour-solids-basis absorption. The loaf volume of the mechanically developed bread also decreased with increasing levels of starch damage. The differences between the volumes of the mechanically developed bread and conventional bread, at both the same starch damage and absorption, decreased with increasing starch damage. It was, therefore, deduced that the water-absorption increase related to high levels of

TABLE VI. TEST-BAKE, 1-lb. DOUGH PIECES, 3-hr. BULK FERMENTATION, VARYING YEAST LEVELS AT CONSTANT ABSORPTION[a]

Starch Damage	% Yeast Flour Basis	Volume ml.	Bread Score: Texture	Bread Score: Crumb color	Crust Appearance
	0.8	1,390	4	5	Normal
LOW	1.3	1,600	6	6	Slightly pale
	2.0	1,500	5	5	Very pale
	0.8	1,340	4	5	Normal
MEDIUM	1.3	1,560	6	6	Normal
	2.0	1,640	6	6	Pale
	0.8	1,350	4	5	Normal
HIGH	1.3	1,570	6	6	Normal
	2.0	1,620	6	6	Slightly pale

[a] Flour-solids basis; absorption 84.9%.

TABLE VII. TEST-BAKE, 1-lb. DOUGH PIECES, MECHANICAL DEVELOPMENT[a]

Starch Damage	Flour-Solids Basis Absorption at 600 B.U. %	Loaf Volume ml.	Bread Score: Texture	Bread Score: Crumb color	Crust Appearance	Increase compared with Bulk Fermentation: Absorption units, solids basis	Increase compared with Bulk Fermentation: Volume ml.
Low	83.9	1,760	6	6	Normal	2.1	140
Medium	85.9	1,710	6	6	Normal	1.8	100
High	88.9	1,640	5	5	Normal	2.2	10

[a] Total work, 0.4 h.p.-min./lb.; rate 0.1 h.p.-min./lb./min.

starch damage was not completely additive, with the increased absorption required to give a lower consistency for mechanical development in terms of optimizing loaf volume.

DISCUSSION

Reconciliation of theory and practice in breadmaking is still beyond the grasp of both fundamental scientist and technologist. This is as much due to the eclectic nature of the theories as to incongruities in the empiricism.

Dough rheology as practiced in the U.K. and U.S. is pertinent, and exemplifies limitations of a heuristic approach where utility depends more on the whims of the investigator than on fundamental science. However, there are recent publications attempting to resolve the problem, including the work of Lerchenthal and Funt (9), which implies that the solid-fluid transition of gluten under stress is rheologically unstable, both below and above the yield point; consequently, conclusions based on thermodynamic equations must be treated with caution. Nevertheless, evidence is presented that elastic properties of gluten appear more related to strong entanglements whose severance under prolonged stress is revealed in flow, than to a simple involvement of relatively high-energy cross-links. A model for the functionality of gluten based on randomized entanglements has also been proposed (10).

If gluten alone exhibits such complexities, so much more must a fermenting dough containing gluten, starch, pentosans, enzymes, and other minor constituents. Further, differential hydration between the components at varying absorptions and at varying work levels must play a dominant role in the overall rheological entity.

The work in this paper offers little to bridge the gap between theory and practice, but it does draw attention to one aspect of the problem: a dichotomy in the interpretation of farinograph consistency and characterized curves. Flour specifications are often written in terms of farinograph parameters without reference to starch damage. It is also quite common to find that subsequent test-bakes are conducted at different absorptions and consistencies. It has been shown that for a given flour: a) at variable absorption, consistency and stability were significantly and negatively correlated, and the relationship was independent of the level of starch damage; and b) loaf volume and crumb structure were significantly correlated with variations in starch damage at constant consistency and stability.

A corollary is that any apparent effects on loaf characteristics attributed to variations in consistency and stability will be partly dependent on the level of starch damage. Consequently, unless all tests are either conducted at the same starch-damage level, or the consistency and absorption used in farinograph tests are the same as used in commercial bread production, the practical value of the test parameters must be diminished.

Gluten 'quality' is a term most technologists claim to understand but none seem able to explain. Some difficulty arises from tacit acceptance that 'strong' flour has 'strong' gluten and 'weak' flour has 'weak' gluten. Examination of the relevant glutens has shown that this widely held view can be erroneous (11). It is suggested that the time may be opportune to reconsider this simple generic concept and replace it with something more dynamic and consistent with modern milling and baking practice.

Future research directed to elucidate the nature of rheological instability could lead to an appreciation that so-called gluten 'quality' can be changed by the type of mixing process. This, combined with research to define and measure modifications in the 'quality' of starch damage in terms of manifold changes that occur over the surface and within the structure of the granule, could result in a significant contribution towards reconciliation of theory and practice.

CONCLUSIONS

1) The physical state of the starch component of a flour, in terms of an applied concept of starch damage, affected the meaning of conventional rheological parameters and sedimentation values in relation to loaf quality.

2) At a given protein level, the functionality of damaged and undamaged starch has been usefully expressed in terms of a model equation (4).

3) Permissible increases in absorption of bulk-fermentation processes attributed to increases in starch damage (4) were only partially additive, with increased absorption required to reduce dough consistency for mechanical-development processes.

4) Permissible increases in the levels of starch damage were also related to effective utilization of yeast.

5) Combining an appreciation of rheological instability in gluten with a technological ability to effect any prescribed level of starch damage indicated a far greater range of flexibility in flour quality than would normally be expected from a conventional laboratory assessment of wheat quality.

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