FLOUR PROPERTIES IN RELATION TO THE MODERN BREAD PROCESSES IN THE UNITED KINGDOM, WITH SPECIAL REFERENCE TO ALPHA-AMYLASE AND STARCH DAMAGE[1]

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ABSTRACT

Methods developed for estimating starch damage, alpha-amylase activity, and water absorption of flours are presented. Rheological tests have been considered in terms of the modifying effects of alpha-amylase and starch damage, and it has been shown that a reappraisal of conventional interpretations is desirable. These considerations have been extended to mechanical development of doughs and the crumb structure of bread.

The basic factor controlling properties of bread doughs prepared by any process is the manner in which water is absorbed by flour. In this sense flour and water are most important ingredients. This is stated without prejudice to the importance of known effects of conventional chemical additions — fats and softening agents, milk powder and sugar — which markedly influence dough properties by interacting with the flour-water system.

Historically and traditionally, there is ample evidence that the breadmaking process has been developed from an art and craft by an intuitive understanding of the interchange of mixing, fermentation, and oxidation. Gradually fermentation times have been reduced from 8 hr. or more in the days of natural oxidation of flour by storage and slow-speed mixers, through chemical oxidation and high-speed mixers to the present mechanically developed "no-time" doughs. Consequently, the recently introduced concept of mechanical development is not a new discovery but merely a manifestation of a long-term trend.

In common with other traditional industries, the development of chemical, biochemical, and rheological tests, and fundamental knowledge concerning the bread process, have always lagged behind the opportunism of commercial development. Today, just as scientific methods for testing flour and theoretical knowledge for elucidating the mechanism of the process are beginning to bear fruit, we are confronted with problems of flour requirements for mechanically developed doughs. A reappraisal of conventional methods of testing is therefore desirable.

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Materials and Methods

The Starch Component of the Flour-Water System. Strong bread-making flours normally contain a starch-protein ratio at approximately 6:1. The major component of any flour is starch, but it is difficult to define the difference between damaged and undamaged starch in chemical terms. Damaged starch, as presented herein, is an arbitrary physical concept based on absorption measurements with the starch-water system. It was shown that increase in mechanical damage as measured by conventional dye-staining techniques correlated with increased absorbing capacity of the starch. It was also shown that increases in absorption correlated with the rate of attack by alpha-amylase. Assuming that all flours contain the necessary activating level of beta-amylase, then the rate of production of reducing sugars in the presence of a massive dose of alpha-amylase (1,500 units; see method below) sufficient to overshadow any naturally occurring alpha-amylase in the flour should correlate with the level of starch damage. This was found to be so, and an empirical relationship was deduced.

The sugars can be determined by a modified Blish (1) maltose procedure that is quick and easy to perform. The arbitrary level for zero starch damaged was based on studies with air-elutriated starch from soft wheat that gave the minimum number of stained grains obtainable in commercial practice, i.e., less than 2%. The 100% level of mechanically damaged starch was defined arbitrarily as the level at which the number of stained grains was just significantly less than 100%, i.e., approximately 98%. Starch with zero damage had an average measured absorption of 0.33 g. water per g. of starch, and 100% damaged, 1 g. water per g. of starch.

It should be clear that the test measures starch damage in arbitrary units, which, expressed on a percentage scale, give an estimated proportion of the total starch that is damaged. The range for the commercial milling of all types of flour on this arbitrary scale is approximately 0 to 45%. Most bread flours fall into a range of 15 to 30%. Because of the arbitrary nature of the zero, it is conceivable that the method could give a negative starch-damage percentage. This would not preclude comparison of levels of damage, but it would indicate abnormally low water-absorption characteristics.

Estimation of Starch Damage in Arbitrary Units Expressed as a Percentage of the Total Starch

Reagents (all A.R. grade):

1. Buffer solution. Make up 3 ml. glacial acetic and 4.1 g. anhydrous sodium acetate to 1 liter. Check pH, which should be 4.6–4.8.
2. Extracting solution. 20 g. sodium chloride and 0.2 g. calcium acetate per liter.

3. Alkaline 0.10*N* ferricyanide solution. 33.0 g. pure dry potassium ferricyanide and 44.0 g. anhydrous sodium carbonate per liter. Keep in amber bottle away from sunlight.

4. Sodium thiosulfate solution, 0.10*N*. 24.82 g. sodium thiosulfate per liter.

5. Acetate acid-salt mixture. 200 ml. glacial acetic acid, 70 g. potassium chloride, and 40 g. zinc sulfate per liter.

6. Combined 2% soluble starch-50% potassium iodide solution. Suspend the soluble starch in a small quantity of cold water and pour slowly into boiling water with constant stirring. Cool, add potassium iodide, make up to volume, and add 1 drop of sodium hydroxide per 100 ml.

7. Sulfuric acid v/v, 10%.

8. Sodium tungstate, 12%.

Preparation of alpha-amylase extract. 200 ml. buffer solution, 200 ml. extracting solution, and 8 g. malt flour (approximately 10,000 units alpha-amylase ± 1,000 units activity). Mix buffer and extracting solutions, add to the malt flour at room temperature, and stir. Let stand for 15–30 min., and filter through No. 4 filter paper. The extract must be used as soon as possible after filtration.

Procedure:

Weigh a 5-g. sample (assuming the flour contains 70% starch at 14.5% moisture) into a wide-necked 125-ml. bottle, add sand, and bring to 30°C. Add 46 ml. alpha-amylase extract at 30°C. and shake to disperse sample. Digest for 1 hr., shaking by rotation every 15 min. After *exactly* 1 hr., add 2 ml. 10% sulfuric acid and *immediately* mix thoroughly. Add 2 ml. 12% sodium tungstate, shake, and allow to stand 1–2 min. Filter through No. 4 filter paper, discarding first few drops of filtrate. At the same time, prepare a blank containing 46 ml. alpha-amylase extract (BL_1).

Pipet 1 ml. flour extract into a boiling tube containing 10 ml. of 0.10*N* alkaline ferricyanide reagent plus 4 ml. buffer solution, cover with glass stopper, and immerse in vigorously boiling water bath for *exactly* 20 min. Cool in running water and pour into 100-ml. conical flask, rinsing boiling tube with 25 ml. acetic acid reagent. Add 1 ml. starch-potassium iodide reagent and titrate against 0.10*N* thiosulfate. At the same time prepare and test a further blank containing 5 ml. water (BL_2), purely as a check on the reagents. Allow for the factor of the thiosulfate, and calculate maltose using blank BL_1 and the maltose table. Multiply results by 5 to obtain maltose figure. (See Table I.)

$$\% \text{ Starch damaged} = (\text{Maltose figure} - 3.5) \times 6$$

Report the percentage starch damaged to the nearest whole number. Normally for routine work the starch content of most flours falls within the range 68–72% and no correction is necessary. If analysis indicates that the starch content is abnormal, a correction may be applied as follows:

$$\begin{aligned} \text{Where } P &= \% \text{ protein } (N \times 5.7) \\ S &= \% \text{ starch} \\ S + P &= 81 \\ M &= \% \text{ moisture} \\ \text{Then } S &= 81 - P - (M - 14.5) \end{aligned}$$

Adjust the weight of flour taken by taking a quantity 350/S g. instead of 5 g., carry out the test, and make calculation as indicated above.

Alpha-Amylase Activity and Measurement in Arbitrary Units. The test has been designed to detect the minimum quantity of alpha-amylase that is of significance in commercial practice. This is represented by 1 arbitrary unit on the scale and is equivalent to approximately ½ oz. of malt (10,000 units) per sack (280 lb.) of flour. Wheat from any source rarely contains less than 1 unit of alpha-amylase. The method has been developed from work published by Sandstedt, Kneen, and Blish (2), Hoskam (3), and Brakke and Nickell (4). The

TABLE I

CONVERSION TABLE FOR DAMAGED STARCH

0.10N Ferricyanide Reduced	Maltose per 100 g. Flour	0.10N Ferricyanide Reduced	Maltose per 100 g. Flour	0.10N Ferricyanide Reduced	Maltose per 100 g. Flour	0.10N Ferricyanide Reduced	Maltose per 100 g. Flour
ml.	*g.*	*ml.*	*g.*	*ml.*	*g.*	*ml.*	*g.*
9.9	6.18	7.4	4.25	4.9	2.64	2.4	1.21
9.8	6.08	7.3	4.18	4.8	2.57	2.3	1.16
9.7	5.98	7.2	4.12	4.7	2.51	2.2	1.11
9.6	5.88	7.1	4.06	4.6	2.44	2.1	1.06
9.5	5.78	7.0	3.98	4.5	2.37	2.0	1.01
9.4	5.68	6.9	3.92	4.4	2.31	1.9	0.96
9.3	5.58	6.8	3.85	4.3	2.25	1.8	0.90
9.2	5.50	6.7	3.79	4.2	2.18	1.7	0.85
9.1	5.42	6.6	3.73	4.1	2.13	1.6	0.80
9.0	5.34	6.5	3.67	4.0	2.07	1.5	0.76
8.9	5.27	6.4	3.60	3.9	2.01	1.4	0.71
8.8	5.19	6.3	3.53	3.8	1.95	1.3	0.65
8.7	5.12	6.2	3.47	3.7	1.88	1.2	0.60
8.6	5.05	6.1	3.41	3.6	1.82	1.1	0.56
8.5	4.99	6.0	3.34	3.5	1.76	1.0	0.51
8.4	4.92	5.9	3.28	3.4	1.71	0.9	0.46
8.3	4.85	5.8	3.22	3.3	1.66	0.8	0.41
8.2	4.78	5.7	3.15	3.2	1.61	0.7	0.36
8.1	4.72	5.6	3.08	3.1	1.56	0.6	0.31
8.0	4.65	5.5	3.02	3.0	1.51	0.5	0.25
7.9	4.58	5.4	2.95	2.9	1.45	0.4	0.20
7.8	4.51	5.3	2.88	2.8	1.40	0.3	0.15
7.7	4.45	5.2	2.82	2.7	1.35	0.2	0.10
7.6	4.38	5.1	2.76	2.6	1.30	0.1	0.05
7.5	4.31	5.0	2.70	2.5	1.26		

activity is expressed in terms of a rigidly controlled beta-limit dextrin substrate prepared from standardized wheat starch. The method for preparing the substrate and the type of starch have been found to have a profound effect on the apparent alpha-amylase activity. The use of potato starch instead of wheat starch gives results which differ according to the level of alpha-amylase being determined. Consequently, no single factor can be used to convert arbitrary scales of alpha-amylase activity obtained with one substrate to another, or one method to another.

Preparation of wheat starch. The starch is prepared in 1-cwt. batches from flour milled from No. 2 Manitoba wheat by wet-separation and flash-drying. The dried starch is subjected to successive treatments through an air-elutriation plant with the cut set at 15 μ. This removes the small starch granules and also most of the damaged granules greater than 15 μ. Each batch is tested to preserve continuity of the test results in relation to the arbitrary scale. The following method gives details of the preparation of the beta-limit dextrin. However, for our own work we have recently developed and standardized a procedure using a citrate buffer for freeze-drying the

beta-limit dextrin. Rigid control of the freeze-drying procedure is necessary, and temperatures appreciably less than −25°C. must be avoided, otherwise modifications occur in the limit-dextrin that alter the enzyme kinetics. The freeze-dried powder is readily reconstituted with water, and can be prepared as and when required. Limited quantities of the starch, and also of the freeze-dried substrate, are available from The Central Laboratories, Joseph Rank Limited, Deptford Bridge Mills, London, S.E. 8.

Estimation of Alpha-Amylase in Arbitrary Units

Reagents (all A.R. grade):

1. Extracting solution. 20 g. sodium chloride and 0.2 g. calcium acetate per liter.
2. Buffer solution. Dissolve 164 g. anhydrous sodium acetate (272 g. pure crystallized) in distilled water. Add 120 ml. glacial acetic acid, and make up to 1 liter, when the pH should be 4.7.
3. Iodine solution. (a) Stock solution: 6.5 g. iodine and 19.5 g. potassium iodide per liter. (b) Dilute solution: 10 ml. stock solution diluted to 1 liter immediately before use.
4. Beta-amylase solution I. Disperse 10 g. enzyme-active soy flour in 85 ml. water plus 15 ml. 0.10*N* sulfuric acid. Stir thoroughly, let stand for 15 min., and filter through No. 4 filter paper. This filtrate (beta-amylase solution I) is used in preparation of the beta-limit dextrin substrate (reagent 6).
5. Beta-amylase solution II. Heat part of the filtrate for 1 hr. at 60°–65°C. to coagulate the protein, and refilter through No. 5 paper. Dilute filtrate with equal volume of extracting solution. This solution is used as a source of beta-amylase where high dilutions are involved, e.g., malted preparations. Soy beta-amylase is heat-resistant at the temperature range 60°–65°C. used to coagulate the protein.
6. Beta-limit dextrin substrate solution. Disperse 5 g. standardized wheat starch in approximately 50 ml. distilled water in a 100-ml. beaker, and pour slowly into 100 ml. hot water (just below boiling point) containing 1 ml. 0.10*N* hydrochloric acid in a 250-ml. beaker. Bring to the boil while stirring, and continue boiling for 20 min. Cool to 30°C., and add 1 ml. 0.10*N* sodium hydroxide plus 5 ml. buffer solution. Add 50 ml. soy extract (beta-amylase solution I) and allow to react for 4 hr. at 30°C. Add powdered pumice, bring the solution slowly to the boil over a period of 10 min., and continue boiling for 5 min. longer. Cool to 20°C. Transfer to a 200-ml. graduated flask, and make up to the mark. Filter through No. 4 filter paper and store in a *sterile stoppered bottle*. The substrate should give consistent results for a period up to 2 to 3 days.

Procedure:

Preparation of flour extract. Place 7.5 g. flour, ground wheat, or malt flour in a 125-ml. wide-necked bottle with 1 tsp. of acid-washed dry sand. Add 50 ml. of extracting solution at 30°C. Shake vigorously and maintain at 30°C. for 1 hr. Shake at intervals of 15 min. Filter through No. 4 filter paper, discarding first few drops of filtrate. If the enzyme activity is high, dilution may be necessary at this stage; e.g., malt flours are diluted 5 ml. → 50 ml. and then 1 ml. → 50 ml. with extracting solution, i.e., 500 times dilution, and fungal amylase preparations 2 ml. → 50 ml., then 1 ml. → 100 ml. with extracting solution, i.e., 2,500 times dilution. Bread, cake, and biscuit flours normally do not require dilution.

Test flours (undiluted). Each determination requires two boiling tubes, one for each flour extract, marked F_1, F_2, etc., and one for each flour blank, marked B_2F_1, B_2F_2, etc. Each set requires one substrate blank, B_1.

Place these tubes in the water bath at 62° or 30°C. according to purpose of test, and add solutions as follows:

B_1 10 ml. limit-dextrin substrate + 10 ml. extracting solution
B_2F_1 10 ml. distilled water
F_1 10 ml. beta-limit dextrin substrate

These solutions should be in the bath at least 5 min. before the test is commenced.

Pipet 10 ml. of flour extract at approximately 30°C. into F_1, record the time, and shake contents of reaction tube. Add 10 ml. flour extract to B_2F_1 and place a 1-ml. graduated pipet in each reaction tube. After a suitable interval (not exceeding 20 min. at 62°C. or approximately 30–60 min. at 30°C.), pipet accurately 0.4 ml. of reaction mixture into test tube containing 10 ml. of dilute iodine solution and shake immediately.

Subsequently, accurately pipet also the 0.4 ml. of blank substrates into corresponding test tubes containing 10 ml. dilute iodine solution.

Flour and maltose (diluted with extracting solution). Where dilution of the original extraction is necessary and this dilution exceeds 10:1, the BF flour blanks can be omitted, but beta-amylase solution II is added to the flour extract to compensate for the dilution of any natural beta-amylase. Therefore place the following tubes in water bath at 62° or 30°C.:

B_1 10 ml. limit-dextrin substrate + 10 ml. extracting solution
F_1 10 ml. limit-dextrin substrate + 5 ml. beta-amylase solution II

These tubes should be placed in the bath at least 5 min. before commencement of test.

At start of reaction period, add 5 ml. of diluted flour extract to F_1 and continue procedure as above, "Flours undiluted."

To standardize instrument sensitivity, set up a Spekker Absorptiometer with the usual heat filters for use with 1-cm. cells, and place yellow green filters No. 605 (550 μ) in position. Obtain absorption readings for each colored solution in the usual manner.

Calculation of alpha-amylase units:

If T = time in minutes
S = Spekker reading (F_1, F_2 ..... etc.)
B_1 = substrate blank
B_2 = flour blank (B_2F_1, B_2F_2, ... etc.)

then alpha-amylase activity $= \frac{2{,}000}{T}\{\log B_1 - \log (S + 0.03 - B_2)\}$ (undiluted test based on 10 ml. extract)

alpha-amylase activity $= \frac{2{,}000}{T}(\log B_1 - \log S) \times \text{dilution factor} \times 2$ (diluted test based on 5 ml. extract)

Modification of Test for Routine Control. The test can be simplified if the flour blank measurement is replaced by the use of an average figure. The flour blank figure correlates with the protein content of the flour, and for the general commercial range of flours the average figure is 0.15 on the absorptiometer scale. This allows a simpler and cheaper instrument to be used with standardized test-tubes in place of the more expensive cells.

The formula for calculating the activity can now be replaced by suitable tables converting the instrument readings directly to activity. In Table II the figures are for the Hilger Biochem Absorptiometer, but figures for any similar instrument can be worked out. The reaction times and range of readings are designed to keep the errors due to the flour blank at a minimum, but some loss of precision compared with the full test must be expected.

TABLE II

ALPHA-AMYLASE TABLE FOR HILGER BIOCHEM ABSORPTIOMETER[a]

REACTION TIME	BIOCHEM READING	SUBSTRATE BLANK		
		0.60	0.65	0.70
15 min.	0.40	50	55	60
	0.35	65	70	80
	0.30	80	90	90
	0.25	100	110	120
30 min.	0.45	20	22	25
	0.40	25	27	30
	0.35	32	34	37
	0.30	41	43	45
	0.25	52	54	57
1 hr.	0.45	10	11	12
	0.40	13	14	15
	0.35	16	17	18
	0.30	20	22	23
	0.25	26	27	28
2 hr.	0.55	3	4	4
	0.50	4	5	5
	0.45	5	6	6
	0.40	6	7	8
	0.35	8	9	9
	0.30	10	11	11
	0.25	13	14	14
4 hr.	0.60	1	1	2
	0.55	2	2	2
	0.50	2	2	3
	0.45	3	3	3
	0.40	3	3	4
	0.35	4	4	5

[a] These figures are calculated on an average flour blank 0.15.

Preparation of Flour Samples. A bread flour milled from 65% No. 2 Manitoba wheats and filler wheats was specially prepared on a 60-sack commercial mill under the supervision of our quality-control laboratory. This ensured homogeneity of grist and mill control throughout the experiment so that the level of starch damage could be altered deliberately, while all other factors, including particle size, were not significantly changed. The samples were of patent grade and were uncomplicated by treatment or additions.

Estimation of Brabender Absorption in Terms of Moisture, Protein, Damaged Starch, and Total Starch. It is assumed that on average the starch content of a flour at 14.5% moisture and 12.0% protein is 69.0%. Therefore with the basic constants: moisture 14.5%, protein 12.0%, starch 69.0%, protein + starch = 81.0%.

$$\therefore \text{Total starch} = 81.0 + (14.5 - \text{flour moisture}) - \text{flour protein}$$

(for any flour except wheat meal and whole meal)

It is assumed that each fraction absorbs water as follows:

	unit wt.	*Water Absorbed unit wt.*
Damaged starch	1	1
Undamaged starch	1	1/3
Protein	1	2

Example: Moisture 15.0%, protein 12.0%, starch damaged 33%.

Total starch: $81.0 - 0.5 - 12.0 = 68.5\%$
Starch damaged $(68.5 \times 33)/100 = 22.6\%$
(as % of the flour)

Therefore, absorption of 100 parts of flour is made up as follows:

Damaged starch		22.6%
Undamaged starch	68.5 − 22.6/3 or	15.3%
Protein	12.0 × 2	24.0%
	Total	61.9% absorption

Protein was determined by the Kjeldahl procedure. For moisture determination, 10-g. samples were heated at 127°C. for 1 hr., 45 min. in an electric oven using forced convection.

Results

Experimental results are given in Figs. 1 to 5, Table III, and leader table.

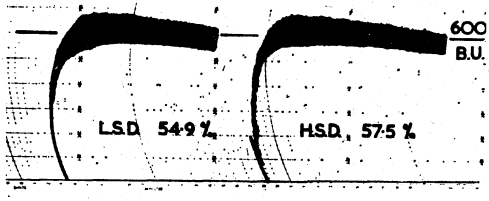

Fig. 1. Farinograph water absorption; no salt.

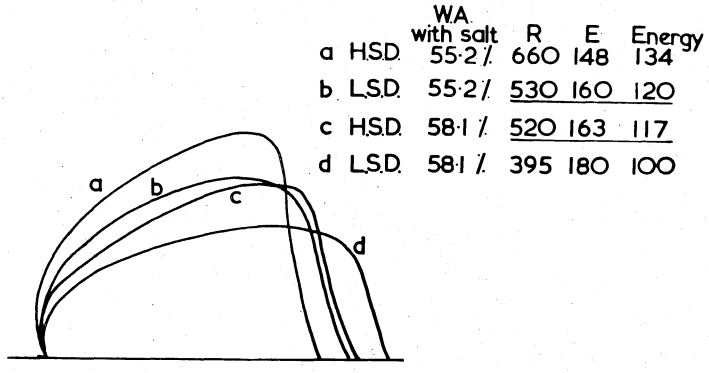

Fig. 2. Brabender extensigraph curves at 135 minutes.

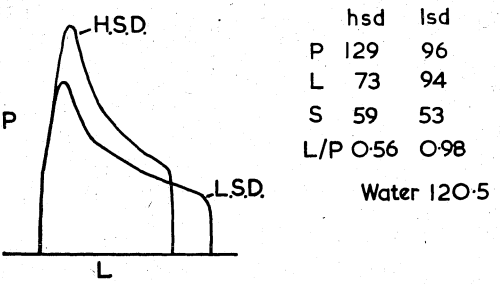

Fig. 3. Chopin Alveograph curves.

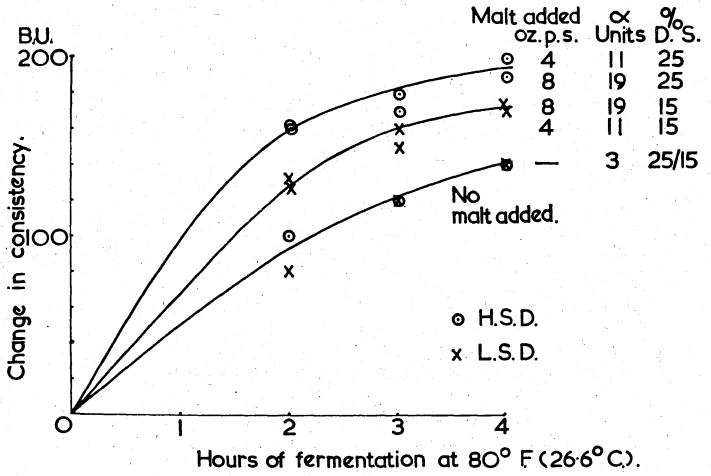

Fig. 4. Influence of starch damage and alpha-amylase on dough consistency during fermentation.

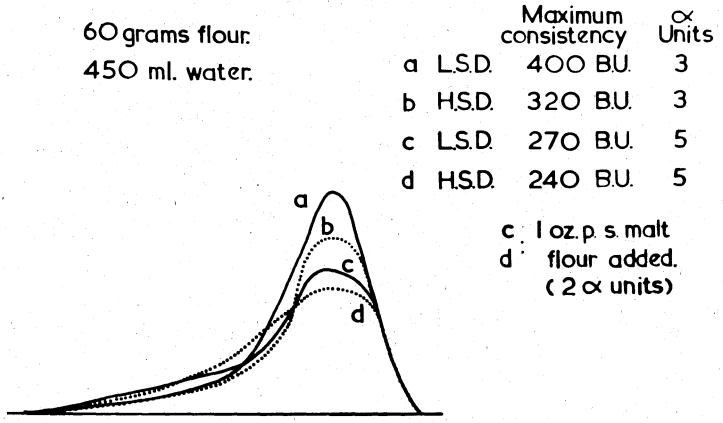

Fig. 5. Brabender Amylograph curves.

The flours examined in Figs. 1 to 5 are coded HSD (high starch damage) and LSD (low starch damage).

The analytical data confirm the similarity of the flours, apart from the level of starch damage (Table III).

TABLE III

HIGH AND LOW STARCH DAMAGE IN RELATION TO DOUGH PROPERTIES

	HIGH	LOW
Protein, % (N × 5.7)	11.4	11.5
Moisture, % (1.5 hr., 127°C.)	14.3	14.4
Starch damaged, %	25	15
Alpha-amylase units	3	3
Farinograph absorption		
600 B.U. without salt	57.5	54.9
500 B.U. with salt	58.1	55.2
Calculated (moisture, protein, starch, starch damaged)	57.7	53.2

Modification of the level of mechanical starch damage from 15 to 25%, which is well within the normal range of commercial milling practice, has a highly significant effect on the rheological characteristics of flour-water doughs (Table III).

The change in absorption in terms of Brabender consistency can be calculated with a fair degree of accuracy in terms of the measured difference in starch damage (Table III).

Brabender farinograms for the two flours at 600 B.U. consistency and at 55.2 and 58.2% absorption respectively for LSD and HSD are almost identical (Fig. 1).

Brabender extensigrams at 135 min. show a considerable variation in resistance and extensibility, according to whether these were done at constant consistency or constant absorption (Fig. 2).

Chopin alveograms show marked differences, the HSD one giving a tough and short curve compared with the LSD, in spite of the fact that glutens in both samples were identical (Fig. 3).

Dough slackening during fermentation as measured in terms of Brabender consistency is independent of the level of starch damage at low alpha-amylase activity. When the level of alpha-amylase is significantly increased from 3 to 11 and 19 units, the decrease in consistency is dependent on the level of starch damage and independent of the alpha-amylase activity (Fig. 4).

The maximum consistency obtained on the Brabender Amylograph is reduced by increasing starch damage. The maximum consistency for both samples is reduced by small additions of cereal alpha-amylase (2 units, equivalent to approximately 1 oz. malt per sack). This instru-

ment measures the combined effects of starch damage and alpha-amylase activity, and is extremely sensitive to small changes in low levels of alpha-amylase activity (Fig. 5).

The Zeleny sedimentation values (5) give significantly different results for the two levels of starch damage. It is suggested that the conventional interpretation of sedimentation values in terms of protein quality may be seriously influenced by the level of starch damage (see leader table below) (5).

Starch Damage	*Flour Sedimentation Value*		
	1	*2*	*Av.*
Low	55.0	56.0	55.5
High	62.0	62.0	62.0

Both samples produced satisfactory and similar bread at their respective absorptions, with a conventional 3-hr. fermentation process.

Attention is drawn to the fact that while these observations are based on samples from a single milling of flour, every effect reported has previously been checked at the highest level of statistical significance, using hundreds of samples of flour milled from grists containing wheats from all over the world.

Discussion

The theme of this presentation is the interaction of flour and water and the properties of the resultant dough. It is considered important for any modern bread process to yield the maximum number of loaves per unit weight of dough, controlled by the quantity of water that flour can usefully absorb. This might be construed as the desirability to use the highest possible level of starch damage and minimum enzyme activity. However, other factors operate that preclude the starch damage being increased and the enzyme activity being reduced indefinitely. These are considered in relation to the bread process as follows:

While increasing starch damage enables the flour absorption to be increased at constant consistency measured at 30°C., it does not increase the inherent starch absorption over the range of gelation at about 60°C. when cereal alpha-amylase reaches its maximum activity during the baking process.

Only damaged starch is readily attacked by cereal alpha-amylase during fermentation, but both damaged and undamaged starch becomes available for attack during the gelation period.

The viscous component of the forces stabilizing the air-dough interface during the gelation period of baking is reduced when the water-starch mass ratio is increased. This results in a more rapid decrease

in the air-dough interface due to coalescing of the air cells, with a consequent loss of volume and coarsening of texture. A relationship between the nature of the air-mix interface and volume and texture of cakes has already been shown by Farrand (6).

Claims are made for the mechanical development process that additional water up to 1 gal. per sack can be used as a consequence of elimination of fermentation losses. This results in lower initial dough consistency and an increase in the water-starch mass ratio.

A more cogent statement would probably be that lower dough consistencies are necessary for the high rates of shear used in mechanical development, irrespective of any correction for fermentation losses. A high level of work input can effect a considerable increase in air-dough interface, and a resultant increase in stability permits higher water-starch mass ratios during the gelation period without apparent adverse effects on loaf volume and texture.

Minimum cereal alpha-amylase activity compatible with adequate gas production is essential at increased water-starch mass ratios, irrespective of whether this increased water is due to increased starch damage at normal consistency and/or the use of doughs at lower consistencies.

Increased absorptions due to the use of lower consistencies used for mechanical development and to increasing starch damage levels to 30 to 40% are not additive. Otherwise absorption measurements at constant consistency giving a figure of 57% (16 gal. per sack) for a normal flour could be increased to 71% (20 gal. per sack) or more for the mechanical development process.

Wide fluctuations in starch damage invalidate conventional interpretations of rheological tests and make it difficult to understand a concept of a single, constant, optimum work level for all types of flour.

The water-starch mass ratios in relation to alpha-amylase activity are important in any bread process. The optimum level of starch damage for mechanically developed "no-time" doughs may be lower than for the conventional fermentation process, because the lower consistency required for development can also be obtained by reducing the starch damage and retaining normal levels of water. This could be used as evidence to support claims that differences between weak flours and strong flours are less on the mechanically developed "no-time" doughs compared with the conventional 3-hr. process. Soft wheats almost invariably show a lower response to mechanical damage compared with hard wheats, and therefore have lower absorption characteristics at the same protein content.

Finally, it is stressed that consideration of protein absorption, the

effects of oxidation, and proteolytic activity are also essential for the interpretation of rheological tests, but should not be allowed to dominate completely the over-all interpretation for the purpose of breadmaking.

Conclusions

Measurement of water-starch absorption and enzyme activity of flour in terms of an arbitrary scale of percentage starch damage and alpha-amylase activity in arbitrary units facilitates the interpretation of rheological tests on flour doughs in terms of potential baking characteristics. Conventional interpretations in terms of protein quality alone cannot characterize completely flour-water systems, either for conventional or mechanically developed doughs.

It is suggested that the optimum conditions for "no-time" mechanically developed doughs may usefully be studied in terms of 1) dough consistency in relation to the water-starch mass ratio; 2) effective work used to develop the protein network in relation to the total work input; and 3) the area of the air-dough interface formed during development. The first offers alternative methods for controlling the basic consistency by starch damage and amylolytic enzymes; 2 and 3 are mainly dependent on gluten development, oxidation requirements, and proteolytic enzymes. It is suggested that the level of work input for optimum bread is a function of dough consistency and protein content. The lower consistency used for mechanical development facilitates the use of softer, lower-absorption flours, thereby maintaining the water-starch mass ratio at a figure similar to that used in the conventional process working at a higher consistency. Consequently, economic incentive for mechanical development may lie more in the direction of the use of softer, cheaper flours requiring lower work levels and giving normal yields, rather than with increased yields obtained from the present flours milled from predominantly hard wheats.

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