Study of Relationships between Wheat Protein Contents of Two U.K. Varieties and Derived Flour Protein Contents at Varying Extraction Rates. I. Studies on an Experimental Commercial Mill and a Laboratory Buhler Mill

E. A. FARRAND, Cereal Advisor, RHM Research Limited, The Lord Rank Research Centre, Lincoln Road, High Wycombe, Buckinghamshire, U.K.

ABSTRACT

Two varieties of wheat, Cappelle-Desprez (semisoft) and Maris Widgeon (semihard), were each studied at two protein levels. The experiments were conducted on a small commercial mill equipped with automatic band weighing devices to record weight of wheat to first break and all machine flours. From analysis of the wheat and machine flours a mathematical model employing transformed variables was deduced expressing a logarithmic relationship between wheat and flour protein contents and extraction rate. The wheats were also milled on a laboratory Buhler mill and, although the results obtained were substantially in agreement with the commercial results, there were significant differences. The model devised enabled calculation of flour proteins in terms of the moisture and protein content of a wheat for given extraction rates over the range 25 to 85%, according to the type of mill.

When flour has to be milled to comply with specifications defining exact levels of protein and color, certain problems arise concerning the relation between wheat and flour protein in terms of extraction rate. It is well known that a patent flour, representing inner endosperm, has significantly lower protein and ash content compared with a straight-run flour of 72 to 76% extraction rate. Previous work by Hinton (1–3) based on hand-dissection techniques has shown substantial differences for protein and ash between the inner and the outer endosperm layers. Kent (4) has reported protein contents for outer endosperm cells as high as 45%.

Experience over many years in our laboratories has shown that relationships between flour protein and wheat protein depended not only on extraction rate but also on the type of wheat. For example, hard spring wheat and hard winter wheat at the same protein content, milled to the same extraction rate, either on a Buhler or commercial mill, gave flour protein contents for winter wheats invariably lower than those from spring wheats. In addition, soft wheat of low protein showed lower relative flour protein contents, compared with high-protein hard wheats.

Generally, world prices of wheat show positive correlation with protein content. Consequently, when computing the relative value of wheats to be used in mixed grists, to produce flour at constant protein, particular attention had to be given to this problem, and a test parameter, i.e., solids-basis protein loss on milling at fixed extraction rate, was introduced as a basis for comparing the differences between wheats. The range obtained for wheats from all sources during the last decade was 0.5 to 2.5.

This paper examines in detail properties of two U. K. varieties, and attempts to derive an empirical mathematical relationship that would be helpful in elucidating the nature of the differences between wheat protein and flour protein over a range of extraction rates, applicable to laboratory and commercial milling.

MATERIALS AND METHODS

Milling

Ten-ton consignments of the two varieties of winter wheat, Cappelle-Desprez and Maris Widgeon, each at two protein levels, were obtained. There was no particular reason for selecting these wheats, other than that they were popular varieties and therefore most readily available. Maris Widgeon can be described as a semihard and Cappelle as a semisoft wheat. The consignments were continuously blended until uniform protein contents were obtained at approximately 11.0 and 9.5% for both varieties. This enabled varietal effects and protein levels to be studied. Representative subsamples of 2 kg. were made for laboratory millings.

The wheats were cold-conditioned for 24 hr. to the appropriate moisture content, and the commercial milling made on a 12-sack experimental mill equipped with automatic band weighers to record weights of wheat and all machined flours. The laboratory milling was made on a Buhler mill in an air-conditioned room, operating at 70°F. and 70% r.h.

Determinations

Protein was determined by the Kjeldahl method (N × 5.7). The flour sample (10 g.) was dried for 1.75 hr. in fan-ventilated oven at 127°C.

Mathematical Treatment

Figure 1 gives a pictorial representation of a well-known relationship between flour protein content and extraction rate. Point X on the curve indicates that at around 90% extraction the flour protein equalled the wheat protein, i.e., the protein loss on milling was zero. As the extraction rate decreased, the flour protein decreased with a corresponding increase in protein loss until zero extraction, where a hypothetical protein loss equalled the wheat protein, but had no real meaning. The shape of the curve was, to some extent, explained from analysis of constituent parts of the wheat grain obtained by hand-dissection. Differences in wheat protein

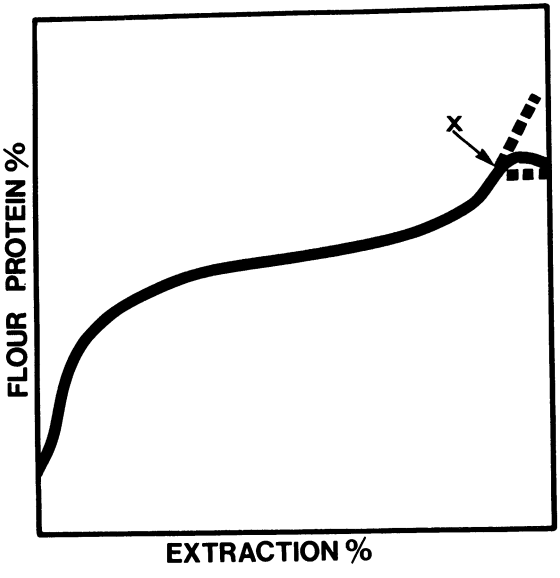

Fig. 1. Relation between percent flour protein and 0 to 100% extraction.

were mainly associated with major changes in endosperm protein content. The epidermal layers and aleurone were subject to much smaller changes. For example, when 8% bran at 6% protein was removed from two wheats at 14.0 and 10.0% protein, the calculated protein for an ideal 92% extraction showed increases to 14.70 and 10.35%, respectively. When the idealized extraction was continued by removing a further 10% consisting of aleurone and outer endosperm at 25% protein for the 14% wheat and 20% protein for the 10% wheat, the calculated flour proteins at 82% extraction were 13.45 and 9.15%, respectively, indicating a protein loss of 0.55 for the 14% wheat and 0.85 for the 10% wheat. This idealized analysis explained, in part, why the protein loss on milling low-protein wheats was generally greater than for high-protein wheats. However, as stated above, the protein loss was also known to be influenced by wheat variety, type of mill, and mill setting and dressing. Simply plotting flour protein content versus extraction rate gave insufficient information to fulfill the purpose of this investigation. Any effective relationship required the inclusion of the protein content of the wheat. Since both wheat and flour proteins were also influenced by variation in moisture content, required by and affected by the milling process, the necessary moisture determinations were made in order to convert all protein figures to zero moisture, i.e., solids basis.

Basically, the milling operation can be considered as an exercise in comminution and sifting. It was assumed that the protein contents at any point in a protein gradient from the inner to outer endosperm was correlated with structural hardness at that point, and the first flour sifted out consisted of lower-protein, finer particles from a relatively softer inner endosperm. Some effects of hard and soft wheats in relation to particle size and protein distribution in air-classified fractions were reported by Farrand (5). Consequently, it was thought feasible that adaption of

mathematical investigations on cumulative particle-size distributions (6–8) might be applied to cumulative flour protein figures versus extraction rate.

For the purpose of clarification it is appropriate to draw attention to conventional meanings of commercial flour extraction rates and laboratory milling, reported in terms of flour yield. Extraction rate normally represents the percentage ratio of flour to flour plus all other products produced. Flour yield may be either percentage flour calculated in terms of conditioned wheat to the first break, or clean wheat before conditioning. These expressions can show significant differences according to prevailing moisture content of the materials.

Theoretically, each procedure should give the same result if the calculations are made on a solids basis. In practice, small differences can persist, depending on physical loss of solids, but in well-controlled experiments, these have been found to be less than 0.5%.

A number of functional relationships were explored, using the ratio flour protein:wheat protein as the dependent variable, and the ratio flour extraction:100 minus flour extraction as the independent variable. The use of these ratios resulted in a range 0 to 1 for the dependent variable and 0 to ∞ for the independent variable. Application of simple functional relationships resulted only in linearity over a very limited extraction range 65 to 75%, but a relationship based on the following equation indicated possibility of a significant linearity over extraction range 25 to 85%.

$$1 - Y = K_1 \exp -X^k \qquad (1)$$

where Y represents the dependent variable, X the independent variable, and K_1 and k arbitrary constants.

Definition of Terms

All terms are expressed on a solids basis.

P = Wheat protein

p = Flour protein

$P-p$ = Protein loss

E_n = Normal flour extraction or flour yield

$E = \exp E_n/100-E_n - \exp -(E_n/100-E_n)^2$

E, the extraction function, contained a second term of no importance other than to make a conventional adjustment for the mathematical artifact log 0 = 1, indicated as follows:

When $E_n/100-E_n > 1$ $\quad \exp -(E_n/100-E_n)^2 \to 0$

$E_n/100-E_n \to 0$ $\quad \exp -(E_n/100-E_n)^2$ 1

Equation 1 was transformed by substitution and rearranged for computational purposes as follows:

$$1-p/P = K_1 \exp -E^k$$

$$\text{i.e.,} \quad P-p/P = K_1 \exp -E^k$$

Take natural logs,

$$\log_e P-p/P = \log_e K_1 - E^k \log_e e$$

Multiply both sides of equation by -1,

$$-\log_e P-p/P = -\log_e K_1 + E^k$$

Take logs to base 10 and put $-\log_e K_1 = K_2$,

$$\log (-[\log_e P-p/P]) = \log K_2 + k \log E \qquad (2)$$

where K_2 and k are arbitrary constants.

P–p, the solids-basis protein loss, was inclusive in the ratio P–p/P which varied $1 \rightarrow 0$ as E varied $0 \rightarrow \infty$. When the extraction rate E_n approached either 0 or 100%, the equation became virtually indeterminate. A plot of $-[\log_e P-p/P]$ versus E on logarithmic graph paper gave reasonable linearity for values of E equivalent to 25 to 85% extraction. Thus appropriate curve fitting was effected and a relationship between solids-basis protein loss and extraction rate obtained.

Because of the empirical nature of equation 2, the exact meaning of K_2 and k remained obscure. However, other experiments had shown that the value of k was affected by adjustment of mill setting and possibly related to the degree of dispersion of the protein gradients within the endosperm between the extraction fractions.

RESULTS

Data sheets giving full details of milling operations, including analysis of all machined flours, 18 for the commercial milling and six for the Buhler mill, were used to extract the relevant solids-basis protein data. The results were cumulated and grouped into fractions in order of increasing protein content, and generally this corresponded with the order of machines from the head to the bottom of the mill. The cumulative extraction figure was built up correspondingly. There were no problems with the commercial mill, where 18 machines were available to group appropriate fractions for mathematical analysis. However, the Buhler mill gave only six fractions, and since the first was less than 25% extraction, it was necessary to combine the first two, leaving five fractions for study.

TABLE I. COMMERCIAL MILL

Wheat	Fraction No.	Flour Fraction % Extraction	Flour Fraction % Protein	Cumulative % Extraction	Cumulative Extraction Function E	Cumulative Flour Protein p	Protein Loss P–p	Protein Ratio P–p/P	$-[\log_e P-p/P]$
	1	37.0	10.9	37.0	1.1	10.9	1.8	0.141	1.96
	2	15.0	11.3	52.0	2.7	11.1	1.7	0.133	2.02
Maris Widgeon,	3	7.7	11.9	59.7	4.3	11.2	1.6	0.125	2.08
protein 12.8%	4	7.1	12.9	66.8	7.4	11.4	1.4	0.109	2.22
	5	4.5	13.1	71.3	11.9	11.5	1.3	0.102	2.28
	6	3.3	16.1	74.6	18.8	11.7	1.1	0.086	2.45
	1	37.9	9.2	37.9	1.2	9.2	1.7	0.156	1.86
	2	16.1	9.8	54.0	3.0	9.4	1.5	0.138	1.98
Maris Widgeon,	3	13.4	9.9	67.4	7.9	9.5	1.4	0.128	2.06
protein 10.9%	4	3.3	11.6	70.7	11.2	9.6	1.3	0.119	2.13
	5	2.5	12.5	73.2	15.4	9.7	1.2	0.110	2.21
	6	1.1	14.6	74.3	18.1	9.8	1.1	0.101	2.29
	1	44.4	10.8	44.4	1.7	10.8	2.4	0.182	1.70
	2	13.1	12.1	57.5	3.7	11.1	2.1	0.159	1.84
Cappelle-Desprez,	3	5.2	13.5	62.7	5.3	11.3	1.9	0.144	1.94
protein 13.2%	4	8.4	13.8	71.1	11.8	11.6	1.6	0.121	2.11
	5	2.2	14.9	73.3	15.6	11.7	1.5	0.113	2.18
	6	3.7	15.9	77.0	28.4	11.9	1.3	0.098	2.32
	1	37.5	8.9	37.5	1.1	8.9	2.2	0.198	1.62
	2	5.9	9.6	43.4	1.6	9.0	2.1	0.189	1.67
Cappelle-Desprez,	3	12.3	10.4	55.7	3.3	9.3	1.8	0.162	1.82
protein 11.1%	4	10.1	11.2	65.8	6.8	9.6	1.5	0.135	2.00
	5	2.7	12.1	68.5	8.8	9.7	1.4	0.126	2.07
	6	0.9	17.4	69.4	9.7	9.8	1.3	0.117	2.15

TABLE II. BUHLER MILL

Wheat	Fraction No.	Flour Fraction % Extraction	Flour Fraction % Protein	Cumulative % Extraction	Cumulative Extraction Function E	Cumulative Flour Protein p	Protein Loss P−p	Protein Ratio P−p/P	$-[\log_e P-p/P]$
Maris Widgeon, protein 12.8%	1	50.3	11.0	50.3	2.5	11.0	1.8	0.141	1.96
	2	10.6	11.5	60.9	4.7	11.1	1.7	0.133	2.02
	3	10.6	13.0	71.5	12.3	11.4	1.4	0.109	2.22
	4	2.6	13.6	74.1	17.5	11.5	1.3	0.101	2.29
	5	2.5	15.4	76.6	26.3	11.6	1.2	0.094	2.36
Maris Widgeon, protein 10.8%	1	49.1	9.0	49.1	2.2	9.0	1.8	0.167	1.79
	2	10.5	10.1	59.6	4.3	9.2	1.6	0.148	1.91
	3	7.9	10.5	67.5	8.0	9.3	1.5	0.139	1.97
	4	3.1	10.8	70.6	11.0	9.4	1.4	0.130	2.04
	5	2.8	11.9	73.4	15.8	9.5	1.3	0.120	2.12
Cappelle-Desprez, protein 13.1%	1	43.9	10.9	43.9	1.6	10.9	2.2	0.168	1.78
	2	12.1	11.6	56.0	3.4	11.1	2.0	0.153	1.88
	3	5.3	12.2	61.3	4.8	11.2	1.9	0.145	1.93
	4	7.5	12.5	68.8	8.3	11.3	1.8	0.137	1.99
	5	1.8	14.6	70.6	11.0	11.4	1.7	0.130	2.04
Cappelle-Desprez, protein 10.9%	1	47.8	8.8	47.8	2.1	8.8	2.1	0.192	1.65
	2	7.6	9.3	55.4	3.2	8.9	2.0	0.183	1.70
	3	8.6	9.9	64.0	5.9	9.0	1.9	0.174	1.75
	4	3.5	10.2	67.5	8.0	9.1	1.8	0.180	1.80
	5	1.3	10.7	68.8	8.9	9.2	1.7	0.186	1.86

The results from the commercial mill are given in Table I, and those from the Buhler mill in Table II. The relevant figures were plotted according to equation 2 in Figs. 2 and 3. Note that, for the commercial mill, the two levels of protein for Maris Widgeon gave parallel lines, whereas the two levels of protein for Cappelle-Desprez fell on one line of significantly different slope. The corresponding Buhler results gave four virtually parallel lines. A possible explanation is that the Buhler millings were carried out at constant setting and feed rate, whereas with commercial millings adjustments were made in terms of experience perceived in dealing with the known differences between the varieties. Therefore, there was some evidence that the value of k appeared to be related to mill setting. However, there were known interactions with variety because, for example, high-protein vitreous Manitoba wheats have given a greater slope when Buhler-milled at the same setting. Nevertheless, the results indicated that significantly different patterned dispersions occurred between the extraction fractions for Buhler-milling compared with commercial milling. In a routine situation the Buhler mill results would have been interpreted at the extraction rate obtained and further difficulties would have arisen because of the differences in extraction. The commercial milling for the two protein levels of Cappelle-Desprez gave significantly different extraction rates but the points fell on one straight line, indicating that the system responded according to the protein ratio. In addition, at high extraction rates the two Cappelle samples and the low-protein Maris Widgeon gave an almost identical ratio, and the high-protein Maris Widgeon only a slightly increased figure. Therefore, the protein losses in these instances were positively correlated with the wheat protein content, i.e., $P-p/P$ = constant and the protein loss $P-p$ = constant $\times$ P. Consequently, where a milling operation responded to the same protein ratio, a lower protein loss was indicated for low-protein wheats. This interacted with the effect described in Fig. 1, where low-protein wheats involved a greater loss, and revealed aspects of complexity of a system that needed dynamic functional interpretation.

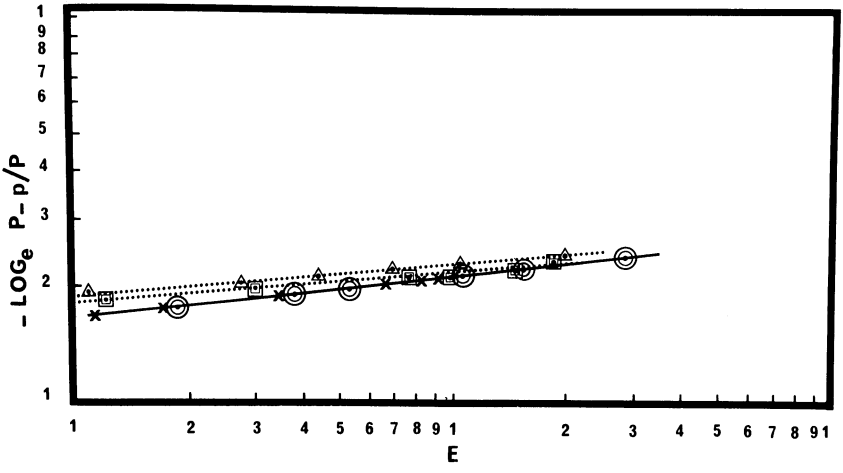

Fig. 2. Commerical mill. Plot of minus natural logarithm of protein ratio versus extraction function. Dotted lines = Maris Widgeon; triangles = high protein, squares = low protein; continuous lines = Cappelle-Desprez; circles = high protein; crosses = low protein.

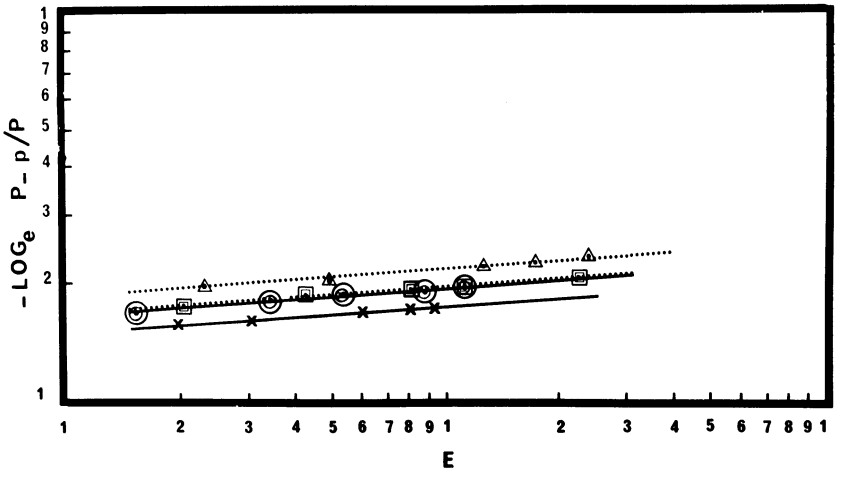

Fig. 3. Buhler mill. Plot of minus natural logarithm of protein ratio versus extraction function. Dotted lines = Maris Widgeon; triangles = high protein, squares = low protein; continuous lines = Cappelle-Desprez; circles = high protein, crosses = low protein.

Since elucidation of P-p, the protein loss, was of particular interest to this study, Table III was constructed to show protein losses at the extraction rates obtained compared with the corresponding results at an arbitrary extraction of 74%, derived from interpolation and extrapolation of the results plotted according to equation 2. It was clearly shown that the Buhler mill overestimated the figure in relation to commercial milling, even when corrected for differences in extraction rate. Nevertheless, the relative patterns of difference were similar. It is therefore important that particular attention be given to such discrepancies when Buhler mill-tested wheats are being evaluated on a quality/cost basis for inclusion in commercial grists to produce flour at a fixed protein content.

DISCUSSION

The wheat-flour milling operation involves high levels of technological skills, but there still remains some content of a craft developed over many centuries. Certain

TABLE III. COMPARISON OF COMMERCIAL AND BUHLER MILLS

	Mill Extraction, %		Protein Loss, %		Estimated Protein Loss at 74% Extraction	
Wheat	Commercial	Buhler	Commercial	Buhler	Commercial	Buhler
Maris Widgeon, high protein	74.6	76.6	1.1	1.2	1.1	1.3
Maris Widgeon, low protein	74.3	73.4	1.1	1.3	1.1	1.3
Cappelle-Desprez, high protein	77.0	70.6	1.3	1.7	1.4	1.6
Cappelle-Desprez, low protein	69.4	68.8	1.3	1.7	1.2	1.4

aspects of flour quality persist as an enigma, but as research defines more clearly the constituents and their distribution within the wheat grain, and new quality parameters are developed, it becomes increasingly clear how milling conditions become an integral part of overall flour performance. For example, bread-flour absorption can be adjusted by milling to controlled levels of starch damage as a routine operation (9).

Many types of wheat have been characterized in terms of solids-basis protein loss at variable extraction rate, according to equation 2 with experimentally derived values for K_2 and k. The model equation had proved to be invaluable for computer-programmed evaluation of different wheats offered at guaranteed protein content, when used for producing flour at constant protein from mixed grists at variable extraction according to empirically calibrated constants for different mills. Extension and modification of this type of work to include other relevant parameters will undoubtedly lead eventually to reliable mathematical models, capable of practical wheat evaluation on a quality/cost basis and gristing entirely by computer.

The work also indicates quantitative differences that can occur in the dispersion of protein between extraction fractions according to the type of mill and mill setting, the importance of which will be related to gluten characteristics of protein derived from different parts of the gradient from the inner to outer endosperm. Gluten washed from a patent flour at 40 to 50% extraction has significantly different rheological properties compared with straight-run flour at 70 to 75% extraction, when using the same wheat. However, this is no proof that the gradient sources of protein are different, because proteolytic and lipolytic enzymes and di- and tripeptides, the latter especially involving reactive disulfide-sulfhydryl systems, are also subject to dispersion variations between extraction fractions. The importance of the contribution of di- and tripeptides to the functional properties of flour protein has been discussed by a number of workers (10,11).

While this work was exploratory rather than comprehensively conclusive, it should have clarified some difficulties that have arisen in connection with the effect of milling procedures on flour quality in relation to wheat characteristics. Consequently, little real progress can be expected where simple laboratory mills are used for research to characterize flour properties. Even a carefully standardized Buhler mill operating in an air-conditioned room has significant limitations, and raises the question as to whether the operation should be carried out at constant setting or adjustments made according to the milling characteristics of a wheat. This is indeed a vexing situation, because the only known reliable procedure for ascertaining commercial milling characteristics is to carry out a milling procedure. And when this has been done, problems still arise in separating those flour properties characteristic of a particular mill from those directly related to a wheat. For the time being, complete objectivity appears to recede beyond grasp, at least until more precise details concerning the actual distribution of constituents within individual wheat grains are available and reconciled with milling operations.

Section II of this paper discusses results for protein distributions within individual grains of the aforegoing four samples of wheat.

Literature Cited

1. HINTON, J. J. C. The distribution of vitamin B_1 and nitrogen in the wheat grain. Proc. Roy. Soc. Ser. B 134: 418 (1947).

2. HINTON, J. J. C. The distribution of ash in the wheat kernel. Cereal Chem. 36: 19 (1959).
3. HINTON, J. J. C. Note on the distribution of ash in an Australian wheat. Cereal Chem. 39: 341 (1962).
4. KENT, N. L. Subaleurone cells of high protein content. Cereal Chem. 43: 585 (1966).
5. FARRAND, E. A. The influence of particle size and starch damage on the characteristics of bread flour. Baker's Dig. 46(1): 22 (1972).
6. HATCH, T., and CHOATE, S. P. Statistical description of the size properties of non-uniform particulate substances. J. Franklin Inst. 207(3): 369 (1933).
7. ROSIN, P., and RAMMLER, E. The laws governing the fineness of powdered coal. J. Inst. Fuel 7: 29 (1933).
8. ROLLER, P. S. Laws of size distribution and statistical description of particulate materials. J. Franklin Inst. 223: 609 (1937).
9. FARRAND, E. A. Starch damage and alpha-amylase as bases for mathematical models relating to flour water-absorption. Cereal Chem. 46: 103 (1969).
10. COVENTRY, D. R., CARNEGIE, P. R., and JONES, I. K. The total glutathione content of flour and its relation to rheological properties of dough. J. Sci. Food Agr. 23: 587 (1972).
11. TKACHUK, R. L-Cysteinylglycine: its occurrence and identification. Can. J. Biochem. 48: 1029 (1970).

[Received February 9, 1973. Accepted June 6, 1973]