# EFFECT OF MOISTURE CONTENT OF WHEAT AND FLOUR ON ENDOSPERM BREAKDOWN AND PROTEIN DISPLACEMENT[1]

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## ABSTRACT

The proportion of low-protein (intermediate particle size) air-classified fraction in flour roller-milled from three types of hard wheat and two of soft wheat increased progressively when wheat moisture content was raised over the range 14 to 23%. Proportions of high-protein (fine particle size) and low-protein (intermediate) fractions in hard wheat flours after grinding in a pinned-disk mill were similarly augmented, and the degree of protein shifting was increased, by raising the moisture content at which the wheat was roller-milled. Proportions of fine and intermediate air-classified fractions of hard wheat flours, the fine fraction of soft wheat flours, and the degree of protein shifting in hard and soft wheat flours were augmented when the moisture content of the flour fed to the pinned-disk grinder was reduced over the range 23 to 8%. Protein content of these fractions increased with decreasing flour moisture content over the range 23 to 14%, but was unaffected by moisture change within the range 14 to 8%.


The structure of the starchy endosperm of wheat has been described in detail (1,2). The starchy endosperm is made up of cells, each of which consists of a cell wall and cell contents. Shape and dimensions of the cells vary in different regions of the endosperm; the longest dimension of peripheral cells is reported as 60 μ, that of prismatic cells 200 μ, and of central cells 144 μ (3).

The cell walls, which are 3–7 μ thick (4), are relatively weak structurally in comparison with the cell contents (5). The cell contents consist of starch granules surrounded by and embedded in a mainly proteinaceous matrix. The starch granules are variable in size from 1 to 50 μ in diameter (6,7), the larger lens-shaped, the smaller spherical. Granules in the prismatic and central cells are mostly either large and lenticular, 15–40 μ in diameter, or small and spherical, 1–10 μ in diameter. Those in the peripheral cells are mainly intermediate in size, 6–15 μ in diameter (3).

Flour as normally milled on roller mills consists mainly of particles of endosperm ranging from 2 to 200 μ in major dimension. Particles larger than 40–50 μ are mostly whole endosperm cells or substantial parts of cells, whereas those smaller than 40–50 μ are structural units, namely, starch granules, fragments of protein matrix, clusters of starch granules embedded in protein matrix, and fragments of cell wall re-

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sulting from fragmentation of endosperm cells. The proportion of material present in the form of particles less than 40–50 $\mu$ in size has been termed the "degree of reduction" (8).

The nature of the fragmentation of endosperm cells in roller-milling is such that the starch granules, when released from the protein matrix, tend to remain intact (though some may be damaged). A large proportion of the free starch occurs as granules ranging from 17 to 35 $\mu$ in major dimension, a small proportion as granules up to 17 $\mu$ in major dimension. The protein matrix shatters to various extents during grinding into fragments of lengths from 1 $\mu$ or less up to about 20 $\mu$. Many of these have wedgelike shapes conforming to the interstices between the granules, which they fill. Particles consisting of clusters of starch granules and protein matrix range from below 13 $\mu$ to above 35 $\mu$ in major dimension (9).

Subdivision of flour into fractions of narrow particle-size range, e.g., by air-classification, results in displacement of some of the protein (7,10). Air-classification at cut sizes 17 and 35 $\mu$ yields three fractions, of which the fraction of smallest particle size (0–17 $\mu$) has a considerably higher protein content and that of intermediate particle size (17–35 $\mu$) a somewhat lower protein content, than that of the parent flour (9). Gracza (10) has proposed an index, "degree of protein shifting," for expressing numerically the percentage of the protein in the parent flour which is displaced out of or into the fractions. This index takes into account both yield and protein content of the fractions.

The degree of reduction (8) in ordinary roller-milled flours ranges from about 10 to 20% for hard wheat flours to about 60% for soft wheat flours (11). It can be increased by special grinding of the flour after roller-milling, but damage to the starch granules must be avoided in such special grinding because of the effect on baking quality and because fragmented starch granules would enter the fine particle-size fraction and lower its protein content. A satisfactory method of fine grinding is by impact, e.g., by means of a pin mill (9, and others).

Increase of moisture content of the wheat (1st break feed) over the range customarily employed in flour mills toughens the bran and increases the mellowness or softness of the endosperm, but hinders the clean separation of endosperm from bran, increases the degree of endosperm flaking during smooth roll reduction, and hinders the dressing of the flour by increasing its stickiness. When these factors alone are considered, there is, for any wheat, an optimum milling moisture content above which the flour yield decreases and below which flour quality deteriorates. Experimental work by Seeborg and Barmore (12) supports this conclusion.

The moisture content of the wheat also has a direct effect on the granularity, or distribution, of particle-size fractions of the flour milled from it. Wichser and Shellenberger (13) milled HRW wheat at 12, 16, and 20% moisture content, obtaining 66, 72, and 64% flour yields, respectively. Their graphs indicate that the proportion of the flour passing through a 400-mesh sieve (approximately 38 $\mu$ aperture width) was about 42% at 12%, 32% at 16%, and 52% at 20% moisture content.

Other investigators have referred to the effect of variation in moisture content in soft English wheat (14), HRW wheat (15), or HRW flour (16) on air-classification or protein displacement.

This paper reports a study of the effect of moisture content variation in five types of wheat on endosperm fragmentation and protein displacement in roller-milled and in finely ground flours, and of moisture content variation in the flour upon endosperm fragmentation and protein displacement in the finely ground flours.

## Experimental

Five types of wheat, three hard and two soft (protein contents at 14% moisture content in parentheses) have been used: No. 2 Manitoba Northern (13.85%), U.S. Hard Red Winter (13.7%), U.S. Hard Red Spring (14.7%), U.S. Soft White (8.8%), and U.S. Soft Red Winter (10.0%). Each was cold-tempered to three or four moisture contents within the range 14 to 23%, and 1-kg. portions were milled on a Miag laboratory mill by a standard system of four breaks and six or eight reductions, using rolls 6 in. in diameter, and test sieves. The break rolls were fluted 18 cuts per in. for 1st to 3rd breaks, 32 cuts per in. for 4th break, with spirality of 1 in 7 and speed differential 2.5:1. The reduction rolls had a smooth-frosted surface, speed differential 1.25:1. The grinding process for each break or reduction was standardized for all samples, but sieving times were extended for the damper samples of the soft wheats.

The flours milled from any one type of wheat at varying moisture content were brought to a uniform moisture content (about 12%) by drying at 40°C. or lower before further treatment.

*Pinned-Disk Grinding.* Portions (100 g. in weight) of the straight-run flours from all the wheats, and of separate break and reduction flours from two of the wheats, were ground on a Minikek pinned-disk mill. This is a laboratory bench-scale model of the Kek pinned-disk mill, with horizontal disks carrying the three intermeshing concentric rows of round steel pins. The pins are 7/32 in. in diameter. The upper plate, 6 in. in diameter, is fixed to the housing (with bolts, which are removable for cleaning), while the lower plate, 5⅛ in. in diameter, is driven, in these experiments, at about 19,740 r.p.m. through a 7:1 pulley and belt drive from a 1.5-h.p. motor rated at 2,820 r.p.m. The rotation of this rotor causes a large volume of air to be drawn in through the inlet funnel. This air current carries the feed — maintained at about 24 g./min. in these experiments — into the mill and, from the exit port, into a fabric exhaust filter from which it is recovered to be weighed, mixed, and sampled.

The effect on endosperm fragmentation and protein displacement of varying the moisture content of the flour when fed to the pinned-disk mill was studied in experiments in which the roller-milled flour was adjusted to a range of moisture contents between 5 and 23% by drying it at 40°C. or by humidifying it by exposure in a thin layer to a saturated atmosphere. The flours, after thorough mixing and resting for 16 hr., were pinned-disk-milled at these moisture contents. The feeding mechanism of the pinned-disk mill was adjusted to compensate for the tendency of the damper flours to feed more slowly; a fairly uniform rate of feed (about 24 g./min.) for all the samples was thereby maintained. The moisture contents of the pinned-disk-milled flours were equilibrated (by exposure to the atmosphere) before air-classification.

*Air-Classification.* Portions of the flour as roller-milled, and also after pinned-disk grinding, were air-classified in a Bahco Centrifugal Air Elutriator, a laboratory batch analyzer for handling about 30 g. of material. Construction and operation of the Bahco classifier have been described (17,18) and its use with flour has been outlined (9). The vibratory feeder of the Bahco machine used in the present work had been partially reconstructed (by Jones *et al.*) to intensify the vibration.

Material was fed into the Bahco at a rate of about 2 g./min., using first the 15-mm. distance piece to make a separation at about 17 $\mu$ cut size. The coarse fraction was again fed, using the 12-mm. distance piece, making a second separation at about 35 $\mu$. The three air-classified fractions were not reground or further classified. More extended classification systems have been described (e.g. 7,15,16), but a relatively simple system was chosen for this work because it was considered more suitable for revealing the differences between flours milled and ground under varying conditions.

To facilitate regular feeding of finely ground flour, particularly flour from soft wheat which tends to cake, the flour was mixed in the proportion of 1:2 with an additive consisting of granular flour milled from Manitoba wheat, dressed through a No. 10 flour silk (aperture width 0.14 mm.) and over a No. 25 silk (0.06 mm.), as described by

Jones *et al.* (9). Check runs with the additive alone showed (Table I) that its contribution to the fine (0–17 $\mu$) and intermediate (17–35 $\mu$) fractions were about 0.1 and 0.9%, respectively. The remainder (99%) of the additive was recovered in the coarse (over 35 $\mu$) fraction.

TABLE I
AIR-CLASSIFICATION OF ADDITIVE ON BAHCO CLASSIFIER

| Batch | Weight Fed | Dry Matter Recovered | Proportions | | |
|---|---|---|---|---|---|
| | | | Fine | Medium | Coarse |
| | g. | % | % | % | % |
| II | 15.0 | 99.1 | 0.12 | 0.84 | 99.04 |
| III | 15.0 | 99.0 | 0.12 | 0.89 | 98.98 |
| IV | 15.0 | 99.9 | 0.08 | 0.74 | 99.18 |
| IV | 15.0 | 99.4 | 0.08 | 0.80 | 99.12 |
| IV | 15.0 | 99.7 | 0.17 | 0.97 | 98.86 |
| Mean | | 99.4 | 0.11 | 0.85 | 99.04 |

Runs carried out with and without coarse additive on flour from hard and soft wheats showed (Table II) that the presence of additive had a negligible effect on the air-classification of free-flowing hard wheat flour as milled. However, when soft wheat flour was fed alone, the proportion of fine fraction tended to be underestimated; it was ascertained by microscopic examination that in these cases the medium fraction contained a larger proportion of undersize particles than when additive was used.

TABLE II
AIR-CLASSIFICATION OF FLOUR, WITH OR WITHOUT ADDITIVE, ON BAHCO CLASSIFIER

| Feed to Classifier | Dry Matter Recovery [a] | Proportions | | |
|---|---|---|---|---|
| | | Fine | Medium | Coarse |
| | % | % | % | % |
| HRS flour | | | | |
| as-milled | 99.5 | 0.9 | 7.4 | 91.7 |
| + additive | 99.1 | 1.0 | 7.8 | 91.2 |
| p.d. ground | 98.4 | 8.4 | 36.7 | 54.9 |
| + additive | 98.5 | 8.5 | 34.5 | 57.0 |
| SRW flour | | | | |
| as-milled | 98.4 | 8.3 | 56.2 | 35.5 |
| + additive | 97.0 | 9.7 | 54.8 | 35.5 |
| p.d. ground | 95.9 | 16.0 | 76.2 | 7.8 |
| + additive | 96.0 | 19.6 | 71.3 | 9.1 |

[a] Recovery of dry matter from the flour portion of the feed alone, allowing 99.4% recovery of dry matter from the additive, where applicable.

*Calculation of Results.* The weight of dry matter in the feed and in the air-classified fractions was calculated from the recorded weights and the determined moisture contents. The calculated weights of dry matter contributed by the additive to the feed and to the fractions, determined from runs with the additive alone, were subtracted from the corresponding values in the runs with flour plus additive, and the results expressed as percentages of the total dry matter recovered from the parent flour alone. An example of the calculation is shown in Table III.

TABLE III
CALCULATION OF PROPORTIONS OF FLOUR FRACTIONS AIR-CLASSIFIED BY THE BAHCO CLASSIFIER, USING ADDITIVE IN THE FEED

| MATERIAL | WEIGHT | MOISTURE CONTENT | WEIGHT OF DRY MATTER | | | YIELD OF FRACTION |
|---|---|---|---|---|---|---|
| | | | Total | From Additive | From Flour | |
| | *g.* | % | *g.* | *g.* | *g.* | % |
| | | | Additive alone | | | |
| Feed | 30.00 | 13.8 | 25.86 | | | |
| Fractions | | | | | | |
| Fine | 0.04 | 11.5 | 0.03 | | | 0.1 |
| Medium | 0.26 | | 0.23 | | | 0.9 |
| Coarse | 28.93 | 11.8 | 25.52 | | | 99.0 |
| Total | 29.23 | | 25.78 | | | 100.0 |
| | | | Flour[a] plus additive | | | |
| Feed | | | | | | |
| Flour | 10.00 | 10.8 | 8.92 | | | |
| Additive | 20.00 | 13.7 | 17.26 | | | |
| Total | 30.00 | | 26.18 | | | |
| Fractions | | | | | | |
| Fine | 0.81 | 11.3 | 0.72 | 0.02 | 0.70 | 7.9 |
| Medium | 4.50 | 11.0 | 4.00 | 0.15 | 3.85 | 43.8 |
| Coarse | 24.08 | 11.7 | 21.26 | 17.01 | 4.25 | 48.3 |
| Total | 29.39 | | 25.98 | 17.18 | 8.80 | 100.0 |
| Recovery, % | | | | 99.5 | 98.6 | |

[a] S.R. flour, milled from HRW wheat at 15.8% moisture content, pinned-disk-ground at 22.6% moisture content.

Recovery of dry matter from the additive, fed alone, averaged 99.4%; recovery from the flour samples alone (fed with additive, but allowing for 99.4% recovery from the additive) was generally within the range 96 to 98%. Some of the dry matter loss is probably accounted for by failure of the Bahco machine to retain the very finest particles, which escape into the atmosphere over the top of the collecting ring (11); the remainder is due to loss of solids in brushing out the fractions, and to errors of weighing and moisture determination on small samples. No correction has been made for loss of dry matter, and the recorded proportions of the fine fraction are thus somewhat underestimated.

Recovery of protein was calculated from the recorded weights and

## TABLE IV
### Effect of Variation in Moisture Content of Wheat on Yield and Characteristics of the Roller-Milled Flour

| Wheat | Moisture Content of Wheat | Flour as Milled | | | | | Air-Classified Fractions | | | | Degree of Protein Shifting |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Yield | Ash[a] | Color | Protein[a] | Maltose | Proportions: Fine | Proportions: Intermediate | Protein Content[a]: Fine | Protein Content[a]: Intermediate | |
| | % | % | % | GCV | % | % | % | % | % | % | % |
| **Straight-Run Flour** | | | | | | | | | | | |
| Manitoba | 16.3 | 68.5 | 0.40 | 2.75 | 13.5 | 0.95 | 0.7 | 6.7 | 17.0 | 10.4 | 1.7 |
| | 18.1 | 66.8 | 0.40 | 2.2 | 13.6 | 0.85 | 1.0 | 8.8 | 17.1 | 9.9 | 2.7 |
| | 20.5 | 60.0 | 0.40 | 2.0 | 13.0 | 0.70 | 1.4 | 13.3 | 16.3 | 9.2 | 4.1 |
| | 22.8 | 52.0 | 0.44 | 2.7 | 12.7 | 0.60 | 1.6 | 18.7 | 14.7 | 8.8 | 6.0 |
| Hard red winter | 14.7 | 69.8 | 0.46 | | 12.8 | 0.95 | 2.1 | 14.9 | 19.1 | 9.4 | 4.9 |
| | 17.9 | 66.4 | 0.46 | | 12.6 | 0.75 | 2.4 | 20.1 | 18.4 | 8.7 | 7.9 |
| | 21.3 | 52.7 | 0.46 | | 12.2 | 0.65 | 3.0 | 30.4 | 15.9 | 8.5 | 9.6 |
| Hard red spring | 14.4 | 66.6 | 0.54 | 4.4 | 14.4 | 1.6 | 0.6 | 6.8 | 16.2 | 11.3 | 1.5 |
| | 17.2 | 63.8 | 0.51 | 3.5 | 14.2 | 1.4 | 1.1 | 9.5 | 15.7 | 10.6 | 2.5 |
| | 22.0 | 61.9 | 0.57 | 4.3 | 13.9 | 1.0 | 1.7 | 17.9 | 14.9 | 9.8 | 5.4 |
| Soft white | 14.9 | 69.4 | 0.38 | 2.5 | 7.6 | 1.05 | 6.9 | 45.3 | 14.5 | 5.3 | 19.6 |
| | 18.1 | 65.1 | 0.37 | 2.1 | 7.2 | 0.9 | 6.6 | 50.7 | 13.9 | 5.3 | 18.9 |
| | 21.5 | 55.0 | 0.40 | 1.9 | 6.8 | | 5.9 | 58.0 | 12.2 | 5.7 | 14.0 |
| Soft red winter | 14.3 | 69.9 | 0.34 | 2.5 | 8.5 | 0.65 | 8.1 | 47.3 | 17.2 | 5.5 | 24.9 |
| | 18.1 | 65.6 | 0.32 | 1.6 | 8.3 | 0.55 | 7.7 | 48.6 | 17.5 | 5.5 | 25.2 |
| | 20.6 | 59.3 | 0.34 | 1.8 | 8.0 | 0.6 | 6.6 | 61.8 | 15.1 | 6.0 | 21.0 |
| **Break Flour** | | | | | | | | | | | |
| Hard red winter | 14.7 | 16.3 | 0.61 | | 16.1 | | 2.1 | 17.7 | 21.6 | 10.5 | 6.8 |
| | 17.9 | 16.2 | 0.58 | | 15.7 | | 2.3 | 23.3 | 20.2 | 9.7 | 9.5 |
| | 21.3 | 10.2 | 0.54 | | 12.2 | | 2.6 | 35.9 | 15.1 | 8.7 | 11.1 |
| Soft red winter | 14.3 | 30.8 | 0.35 | | 8.2 | | 9.6 | 55.9 | 17.5 | 5.1 | 32.1 |
| | 18.1 | 32.5 | 0.32 | | 7.9 | | 8.3 | 59.3 | 18.3 | 5.2 | 31.3 |
| | 20.6 | 29.9 | 0.34 | | 7.4 | | 7.1 | 68.6 | 15.2 | 5.8 | 22.2 |
| **Reduction Flour** | | | | | | | | | | | |
| Hard red winter | 14.7 | 53.5 | 0.41 | | 11.8 | | 2.6 | 12.9 | 18.4 | 8.6 | 5.0 |
| | 17.9 | 50.2 | 0.42 | | 12.0 | | 2.5 | 17.6 | 19.0 | 8.5 | 6.5 |
| | 21.3 | 42.5 | 0.44 | | 11.8 | | 3.4 | 29.2 | 15.2 | 8.5 | 9.2 |
| Soft red winter | 14.3 | 39.1 | 0.33 | | 8.8 | | 6.8 | 41.3 | 17.4 | 5.9 | 20.3 |
| | 18.1 | 33.1 | 0.30 | | 8.8 | | 6.7 | 39.4 | 17.2 | 5.8 | 20.0 |
| | 20.6 | 29.4 | 0.34 | | 8.6 | | 6.2 | 54.7 | 15.5 | 6.7 | 17.1 |

[a] At 14% moisture basis.

the determined moisture and protein contents of the parent flour, additive, and air-classified fractions. Protein recovery was generally as good as that of the dry matter.

Moisture content was determined on the wheat as loss during drying at 120°C. for 4 hr. in an electric air oven after coarse grinding in a coffee grinder or a Glen Creston S.80 Sample Grain Mill (setting 6). Samples with moisture content in excess of 18% were dried by a two-stage process. Flour moisture content was determined as loss at 120°C. for 1.5 hr. Moisture content of small fractions from the Bahco was determined with a Marconi electrical moisture meter.

Flour grade color was determined with the Kent-Jones & Martin Colour Grader, Mark II (19).

Ash content was determined by ashing in an electric muffle furnace at 600°C.

Protein content (N × 5.7) was determined by the Kjeldahl method, or by micro-Kjeldahl on small fractions from the Bahco air-classifier.

Degree of protein shifting, expressed as a percentage, has been calculated according to the procedure of Gracza (10) as the sum of the protein shifted out of the intermediate air-classified fraction and that shifted into the fine air-classified fraction.

Maltose was determined by the Blish and Sandstedt method (20).

Analytical results are expressed on 14% moisture basis.

## Results

The results obtained on flours milled from the five types of wheat when the moisture content of the *wheat* was varied over the range 14 to 22% are summarized in Tables IV and V. The data in Table IV relate to the roller-milled flours; those in Table V to the same flours after pinned-disk grinding.

Results obtained on pinned-disk-ground flour when the moisture content of the *flour* fed to the grinder was varied over the range 5 to 23% are shown in Table VI for flour from Manitoba, HRW, and the soft wheats. Similar results for HRS wheat roller-milled at three different (wheat) moisture contents, and the flours then adjusted to ranges of moisture levels before pinned-disk grinding, are presented in Table VII, which thus shows the combined effects of variation in moisture levels of the wheat and of the flour.

## Discussion

*Variation in Moisture Content of the Wheat When Roller-Milled. As-milled straight-run flours.* Increase in moisture content of the wheat led to a lowering of the yield of roller-milled flour; the fall in flour

TABLE V

EFFECT OF VARIATION IN MOISTURE CONTENT OF WHEAT ON GRANULARITY OF PINNED-DISK-GROUND FLOUR, AND ON PROTEIN CONTENT OF AIR-CLASSIFIED FRACTIONS

| Wheat | Moisture Content of Wheat[a] | Parent Flour | | Air-Classified Fractions | | | | Degree of Protein Shifting |
|---|---|---|---|---|---|---|---|---|
| | | | | Proportions | | Protein Content[a] | | |
| | | Yield | Protein Content[b] | Fine | Intermediate | Fine | Intermediate | |
| | % | % | % | % | % | % | % | % |
| | | | | Straight-Run Flour | | | | |
| Manitoba | 16.3 | 68.5 | 13.4 | 11.6 | 41.5 | 18.9 | 10.0 | 15.2 |
| | 18.1 | 66.8 | 13.5 | 13.5 | 46.7 | 19.4 | 10.0 | 18.1 |
| | 20.5 | 60.0 | 13.1 | 16.6 | 55.8 | 19.7 | 9.5 | 23.6 |
| | 22.8 | 52.0 | 12.5 | 17.5 | 62.3 | 19.3 | 9.2 | 26.1 |
| HRW | 14.7 | 69.8 | 12.8 | 13.5 | 52.0 | 21.3 | 8.6 | 26.0 |
| | 17.9 | 66.4 | 12.7 | 16.2 | 57.1 | 21.0 | 8.3 | 30.3 |
| | 21.3 | 52.7 | 11.9 | 18.3 | 68.1 | 20.7 | 7.9 | 36.6 |
| HRS | 14.4 | 66.6 | 14.3 | 9.2 | 35.5 | 18.3 | 11.2 | 10.4 |
| | 17.2 | 63.8 | 14.1 | 11.0 | 43.6 | 18.5 | 10.8 | 13.7 |
| | 22.0 | 61.9 | 14.0 | 17.4 | 60.8 | 19.0 | 10.8 | 19.6 |
| Soft white | 14.9 | 69.4 | 7.7 | 20.0 | 71.0 | 15.7 | 5.0 | 45.6 |
| | 18.1 | 65.1 | 7.5 | 18.0 | 73.9 | 15.8 | 5.0 | 44.3 |
| | 21.5 | 55.0 | 7.2 | 16.7 | 77.7 | 15.7 | 5.1 | 42.0 |
| SRW | 14.3 | 69.9 | 8.6 | 19.0 | 71.0 | 17.7 | 5.5 | 46.0 |
| | 18.1 | 65.6 | 8.3 | 18.2 | 73.3 | 17.6 | 5.3 | 46.8 |
| | 20.6 | 59.3 | 7.9 | 17.2 | 76.2 | 17.8 | 5.4 | 45.7 |
| | | | | Break Flour | | | | |
| HRW | 14.7 | 16.3 | 15.7 | 15.5 | 51.7 | 23.9 | 10.6 | 24.8 |
| | 17.9 | 16.2 | 15.4 | 15.6 | 57.2 | 21.6 | 9.1 | 29.6 |
| | 21.3 | 10.2 | 11.9 | 16.0 | 68.3 | 21.5 | 8.0 | 35.1 |
| SRW | 14.3 | 30.8 | 8.4 | 19.2 | 71.6 | 18.1 | 4.9 | 51.3 |
| | 18.1 | 32.5 | 8.0 | 16.7 | 75.1 | 17.7 | 5.0 | 48.2 |
| | 20.6 | 29.9 | 7.2 | 14.7 | 78.8 | 17.9 | 5.0 | 45.6 |
| | | | | Reduction Flour | | | | |
| HRW | 14.7 | 53.5 | 11.9 | 12.9 | 52.1 | 20.4 | 8.0 | 26.0 |
| | 17.9 | 50.2 | 11.9 | 16.4 | 57.0 | 20.8 | 8.0 | 30.8 |
| | 21.3 | 42.5 | 11.9 | 18.8 | 68.1 | 20.5 | 7.8 | 37.0 |
| SRW | 14.3 | 39.1 | 8.8 | 19.1 | 70.5 | 17.3 | 5.8 | 42.0 |
| | 18.1 | 33.1 | 8.5 | 19.7 | 71.6 | 17.6 | 5.7 | 45.1 |
| | 20.6 | 29.4 | 8.5 | 19.7 | 73.6 | 17.7 | 5.8 | 44.7 |

[a] Moisture content of wheat when fed to 1st break rolls.
[b] At 14% moisture basis.

yield was accompanied by a fall in protein content and maltose value and, in some cases, by improved flour color (Table V). Pelshenke and Schäfer (21) found that increase in moisture content of Manitoba 5 wheat from 15.2 to 17.9% decreased the Buhler mill flour yield from 58.2 to 51.9%, increased the flour ash content, and decreased amylose number. Seeborg and Barmore (12) found that the Buhler mill flour yield and the ash content of the flour decreased when moisture content of soft wheat from the Pacific Northwest was increased over the range 9 to 17%.

The proportion of low-protein intermediate particle-size (17–35 μ) air-classified fraction in the roller-milled flours from all five types of wheat increased when wheat moisture content was raised throughout the range 14 to 22%. The proportion of the high-protein fine (0–17 μ) fraction increased with wheat moisture content in the flours from the three hard wheats, but decreased slightly with increasing wheat moisture content in the flours from the two soft wheats. The results of Wichser and Shellenberger (13) regarding the effect of increasing the moisture content of HRW wheat are in agreement with these findings.

Baker and Greer (14) have reported that increasing the moisture content of Cappelle Desprez wheat from 13.0 to 16.5% at the 1st break led to an increase from 56.0 to 63.8% in the proportion of intermediate air-classified fraction (17–35 μ) in the 1st break flour.

Stringfellow *et al.* (15), in papers published when this work was nearing completion, examined the air-classification response of flours from HRW wheats after premilling treatments. When milling moisture content was increased from 14 to 16% (1-stage temper) or from 14.5 to 16% (2-stage temper) they found progressive decrease in flour yield, and progressive increase in yield of fine (high-protein) and intermediate (low-protein) air-classified fractions, and in degree of protein shifting.

The protein contents of both fine and intermediate fractions of the hard wheat flours decreased as wheat moisture content was raised; the fall was proportionately greater than the fall in protein content of the parent flours. When moisture content of the soft wheats was raised before roller-milling, the protein content of the fine air-classified fraction decreased, but that of the intermediate fraction increased. The degree of protein shifting increased with wheat moisture content in the hard wheats, but decreased in the soft wheats at moisture contents above 18%.

*As-milled break and reduction flours.* The trends, with moisture-content variation, in yield and protein content of air-classified fractions and degree of protein shifting, shown by break and reduction flours of HRW and SRW wheats, were similar to those of the straight-run flours.

The protein content of the break flours was considerably higher than that of the reduction flours from the HRW wheat milled at 14.7 and 17.9% moisture content; the protein content of the fine and intermediate air-classified fractions from these break flours was augmented in comparison with those from the reduction flours. In SRW flour, however, the break flours were lower than the reduction flours in protein content, and the intermediate air-classified fractions from the break flours were correspondingly lower in protein content than those from the reduction flours.

The proportion of intermediate fraction in the break flour from HRW and SRW wheats was considerably higher than that in the corresponding reduction flours regardless of the difference in protein trends between HRW and SRW flours, and led to a consistently higher degree of protein shifting in break than in reduction flours.

*Pinned-disk-ground flours.* After pinned-disk grinding of the hard wheat flours (adjusted to uniform moisture content of about 12%), the effects of roller-milling the wheat at elevated moisture contents were still shown in the increased proportions of both fine and intermediate air-classified fractions (Table V). The degree of protein shifting increased progressively as the moisture content at which the wheat was roller-milled was raised over the range 14 to 23%.

After pinned-disk grinding of the soft wheat flours, the effects of increase in moisture content of the wheat to the roller mill were shown in a decrease in proportion of fine air-classified fraction, increase in that of the intermediate fraction, and slight fall in the degree of protein shifting. Both break and reduction flours contributed to the effect of wheat moisture content on proportion of intermediate fraction in the straight-run flour from HRW and SRW wheats; however, the reduction flour alone was responsible for the increase in proportion of fine fraction in the HRW straight-run flour, whereas the break flour alone was responsible for the fall in proportion of fine fraction in the SRW straight-run flour.

*Variation in Moisture Content of the Flour When Pinned-Disk-Ground.* The proportions of fine (high-protein) and intermediate (low-protein) air-classified fractions in the hard wheat flours increased steadily when the moisture content of the flour was reduced from 23 to 5% before pinned-disk grinding (Tables VI and VII).

The protein contents of the fine and intermediate air-classified fractions of the pinned-disk-ground flours from hard wheats tended to increase as flour moisture content was reduced from 23 to 13–14%, but showed little variation over the flour moisture content range 13–14 to 5%.

In soft wheat flours there was little change in proportions of fine and intermediate fractions as a result of drying the flour from 13 or 14 to 6% before pinned-disk grinding, although the proportion of the fine fraction fell when the flour moisture content was raised from 14 to 17 or 22% (Table VI).

TABLE VI

EFFECT OF VARIATION IN MOISTURE CONTENT OF STRAIGHT-RUN FLOUR FED TO PINNED-DISK MILL ON PROPORTIONS AND PROTEIN CONTENTS OF AIR-CLASSIFIED FRACTIONS

| Wheat | Moisture Content | | Air-Classified Fractions | | | | Degree of Protein Shifting |
|---|---|---|---|---|---|---|---|
| | | | Proportion | | Protein Content [c] | | |
| | Wheat [a] | Flour [b] | Fine | Intermediate | Fine | Intermediate | |
| | % | % | % | % | % | % | % |
| Manitoba | 16.3 | unground [d] | 0.7 | 6.7 | | | |
| | 15.0 | 8.5 | 12.4 | 45.0 | 18.3 | 9.9 | 15.7 |
| | 15.0 | 10.1 | 12.0 | 43.5 | 18.5 | 9.9 | 15.3 |
| | 15.0 | 13.6 | 10.7 | 40.3 | 18.2 | 9.9 | 13.6 |
| | 15.0 | 15.3 | 9.7 | 39.7 | 18.1 | 9.9 | 13.1 |
| | 15.0 | 20.3 | 6.5 | 31.4 | 16.6 | 9.2 | 10.7 |
| HRW | 15.8 | unground [d] | 1.8 | 15.3 | | | |
| | 15.8 | 4.9 | 18.6 | 56.5 | 20.8 | 8.6 | 30.3 |
| | 15.8 | 8.0 | 17.0 | 56.1 | 20.7 | 8.5 | 29.3 |
| | 15.8 | 14.8 | 14.8 | 52.1 | 20.5 | 8.6 | 25.9 |
| | 15.8 | 17.1 | 13.3 | 51.1 | 20.8 | 8.9 | 23.5 |
| | 15.8 | 22.6 | 7.9 | 43.8 | 17.4 | 8.7 | 16.7 |
| | 15.8 | 23.2 | 6.9 | 40.0 | 16.8 | 8.7 | 14.9 |
| Soft white | 14.9 | unground [d] | 6.9 | 45.3 | | | |
| | 14.9 | 6.4 | 21.2 | 71.8 | 14.8 | 4.2 | 52.2 |
| | 14.9 | 10.7 | 22.0 | 70.5 | 15.5 | 4.7 | 50.1 |
| | 14.9 | 13.4 | 20.7 | 71.1 | 15.3 | 4.7 | 48.2 |
| | 14.9 | 17.3 | 17.3 | 72.8 | 15.3 | 4.9 | 43.7 |
| | 14.9 | 22.1 | 13.4 | 71.5 | 14.4 | 5.5 | 31.4 |
| SRW | 15.6 | unground [d] | 7.7 | 54.3 | | | |
| | 15.6 | 5.2 | 21.6 | 72.5 | 17.4 | 4.9 | 53.4 |
| | 15.6 | 8.7 | 20.1 | 73.0 | 17.0 | 4.6 | 53.0 |
| | 15.6 | 14.7 | 19.3 | 72.8 | 17.5 | 5.1 | 49.4 |
| | 15.6 | 17.6 | 14.2 | 75.2 | 17.7 | 5.9 | 38.9 |
| | 15.6 | 20.2 | 12.5 | 73.7 | 17.1 | 6.1 | 33.4 |
| | 15.6 | 21.5 | 12.3 | 75.1 | 17.2 | 6.2 | 33.0 |

[a] Wheat fed to 1st break rolls.
[b] Flour fed to pinned-disk grinder.
[c] Moisture basis, 14%. Protein contents of the parent flours were: Manitoba 12.8, HRW 12.7, Soft white, 7.4, SRW 8.6%.
[d] Results for roller-milled flour before pinned-disk grinding.

Protein content of the fine (high-protein) fraction from the soft wheat flours showed little variation, but protein content of the intermediate (low-protein) fraction tended to increase when moisture content of the flour fed to the pinned-disk mill was raised over the range 14 to 22%.

Degree of protein shifting increased progressively when flour moisture content was reduced over the range 22 to 5% before pinned-disk grinding in both hard and soft wheat flours. In the soft wheat flours, the increase in protein shift was relatively steeper over the range 22 to 14% than over the range 14 to 6%.

Results of Stringfellow *et al.* (16) with HRW flours are in agreement with those reported here. These authors found that the degree

TABLE VII

EFFECT OF VARIATION IN MOISTURE CONTENT OF WHEAT AND OF FLOUR ON PROPORTIONS AND PROTEIN CONTENTS OF AIR-CLASSIFIED FRACTIONS (HRS WHEAT)

| Moisture Content | | Air-Classified Fractions | | | | Degree of Protein Shifting |
|---|---|---|---|---|---|---|
| | | Proportion | | Protein Content [c] | | |
| Wheat [a] | Flour [b] | Fine | Intermediate | Fine | Intermediate | |
| % | % | % | % | % | % | % |
| 14.4 | unground [d] | 0.6 | 6.8 | | | |
| | 6.1 | 12.7 | 41.3 | 18.5 | 11.3 | 12.5 |
| | 9.4 | 11.1 | 40.4 | 18.3 | 11.3 | 11.5 |
| | 13.1 | 9.2 | 35.5 | 18.3 | 11.2 | 10.4 |
| | 17.9 | 6.2 | 31.9 | 17.1 | 10.8 | 9.0 |
| | 21.9 | 4.7 | 27.1 | 15.8 | 10.4 | 7.9 |
| 17.2 | unground [d] | 1.1 | 9.5 | | | |
| | 6.2 | 13.9 | 48.7 | 18.7 | 10.9 | 15.8 |
| | 9.5 | 12.2 | 47.3 | 18.3 | 10.8 | 14.9 |
| | 13.4 | 11.0 | 43.6 | 18.5 | 10.8 | 13.7 |
| | 17.8 | 7.3 | 38.4 | 17.4 | 10.6 | 11.3 |
| | 20.7 | 5.7 | 33.3 | 16.6 | 10.1 | 10.4 |
| 22.0 | unground [d] | 1.7 | 17.9 | | | |
| | 6.5 | 19.6 | 62.4 | 19.1 | 10.9 | 20.7 |
| | 9.2 | 19.1 | 62.0 | 19.0 | 10.8 | 20.8 |
| | 13.6 | 17.4 | 60.8 | 19.0 | 10.8 | 19.6 |
| | 17.6 | 14.9 | 58.7 | 18.5 | 10.7 | 18.4 |
| | 22.9 | 8.9 | 51.0 | 17.2 | 10.6 | 14.5 |

[a] Wheat fed to 1st break rolls.
[b] Flour fed to pinned-disk mill.
[c] Moisture basis, 14%. Protein contents of pinned-disk-ground flours before classification, milled from wheat at 14.4, 17.2, and 22.0% moisture content, were 14.3, 14.1, and 14.0% respectively.
[d] Results for roller-milled flour before pinned-disk grinding.

of protein shifting was increased from 37 to 44% when the moisture content at which flour was reground was reduced over the range 14 to 4%.

*Moisture Variation in Wheat and Flour.* The results reported indicate marked differences 1) between soft and hard wheats in their response to moisture content variations, and 2) between the roller-milling and the pinned-disk grinding processes, in the effect of variation in moisture content of the feed.

Raising the *wheat* moisture content before roller-milling increased the proportions of intermediate air-classified fraction in the flours (as-milled, and after pinned-disk grinding) from hard and soft wheats alike, but the proportion of fine fraction and the degree of protein shifting increased in hard wheat flours, whereas both decreased in soft wheat flours. Raising the *flour* moisture content over the range 14 to 22% before pinned-disk grinding decreased the proportion of fine fraction and the degree of protein shifting in hard and soft wheat flours alike, but affected the proportion of intermediate fraction of the hard wheat flour only; lowering the flour moisture content over the range 14 to 8% before grinding increased the proportion of fine and intermediate fractions and the degree of protein shifting in hard wheat flours, but had relatively little effect on the soft wheat flours.

The proportion of both fine and intermediate air-classified fractions in the flour from the hard wheats increased (indicating a greater degree of endosperm fragmentation) 1) when the *wheat* was roller-milled at successively *higher* moisture contents, and 2) when the *flour* was pinned-disk-ground at successively *lower* moisture contents.

The difference in effect of moisture variation in wheat and flour is probably related to the nature of the grinding processes. While the pinned-disk grinding of the flour is an impact process in which particles, impinging on a hard surface at high speed, are shattered instantaneously, the first breaking of wheat is more gradual and involves squeezing or compression of the grain, because the nip, or gap between the rolls (0.0275 in.), is much narrower than the grains that must pass through it. Moreover, while being drawn through this gap the grain is subjected to shear because of the roll speed differential (2.5:1). Other evidence obtained in these laboratories suggests that the compression is probably the major factor (provided that the grain is in a suitable physical state, e.g., at an elevated moisture content) in producing a softening of the endosperm that is permanent and capable of influencing the extent of comminution produced by subsequent grinding processes.

That this softening involves the production of cracks in the endosperm is suggested by its association with the development of mealiness in originally vitreous grain.

The breaking of wheat at an elevated temperature also produces mealiness and softening of the endosperm (22), but it appears not to affect the response of the flour to pinned-disk grinding and air-classification. Presumably, this apparent paradox must depend on the production of different finenesses of cracking in the two cases, but no data on this aspect are available.

It should further be mentioned that particles of semolina (ex mill) respond in density to moisture change differently from coarse endosperm particles dissected from (vitreous) grains of the parent wheat, the difference being attributed (23) to the effect of the breaking operation in disturbing the endosperm structure present in the coarse particles.

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