A CRITICAL STUDY OF TECHNIQUE FOR MEASURING GRANULATION IN WHEAT MEAL[1]

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INTRODUCTION

Meal granulation, or degree of particle fineness, is regarded as an important component of wheat quality and is of considerable interest to the miller, cereal chemist, geneticist, and plant breeder. A simple method, therefore, of accurately measuring meal granulation would greatly facilitate a more thorough study and analysis of this character. Although a number of studies dealing with flour and meal granulation have been reported, few data are available to show the steps in the procedure used in establishing a satisfactory technique. In a preliminary paper Cutler and Brinson [2] described a method for measuring granulation of whole wheat meal. Further studies have been made with a view to perfecting and standardizing this method. This paper, therefore, presents data emanating from a systematic study of the steps in the procedure evolved in establishing a suitable technique for measuring meal granulation. New equipment and the nature of meal fractions are also described.

REVIEW OF LITERATURE

Several reports have been published in which separations of flour or meal particles of varying degrees of fineness were obtained by sifting on various sizes of bolting cloth and sieves. Since most of these are concerned with the chemical composition and baking quality of the various-sized fractions, only the more pertinent papers will be discussed.

Balakshin [3] used a farinogranometer to determine the relative coarseness of semolina, wheat flour, and buckwheat flour. Ten grams of the product were placed on the nest of sieves and sifted by hand. The fractions collected on the sieves were placed in a series of compartments forming columns from which a coarseness curve was plotted. In addition, cumulative coarseness curves were made from which it was possible to determine the relative coarseness of products by comparing the rectangles upon which the curves appeared.

According to Bailey,[4] "the simplest method of determining the granulation of flour involves sifting a weighed quantity, say 100 grams, through a series of bolting silks nested one above the other in order of increasing coarseness."

Kress[5] performed the granulation test by sifting 100 g of flour for 8 minutes in a seven-sieve experimental sifter. The eight fractions that

[1] Received for publication May 9, 1938.

[2] CUTLER, G. H., and BRINSON, G. A. THE GRANULATION OF WHOLE WHEAT MEAL AND A METHOD OF EXPRESSING IT NUMERICALLY. Cereal Chem. 12: 120–129, illus. 1935.

[3] BALAKSHIN, S. THE FARINOGRANOMETER—A NEW DEVICE FOR GRAPHICALLY SHOWING THE FINENESS OF PRODUCT. Amer. Miller 64 (1): 14–15, illus. 1936.

[4] BAILEY, C. H. FLOUR. Paper given before Biscuit and Cracker Manfr. Assoc. p. 14. 1926. [Typewritten.]

[5] KRESS, C. B. GRANULATION OF FLOUR AND ITS RELATION TO QUALITY. Cereal Chem. 6: 202–214, illus. 1929.

remained on each sieve and pan were collected, weighed, and the percentage of each calculated.

Cutler and Brinson [6] were the first to use wheat meal instead of flour for measuring the degree of particle fineness or granulation of strains and varieties of wheat. The relative granulation of the meal was determined by sifting 50 g of wheat meal for 1 hour in a two-sieve Ro-Tap. The weight of the meal on each sieve, as well as that in the pan, was used in calculating the granulation number for each sample. Likewise, Brinson [7] reported correlation coefficients of +0.90 and +0.83 in the 1931 and 1932 samples, respectively, between the meal in the pan and the "granulation number."

Fifield et al.,[8] using the method suggested by Cutler and Brinson [6] with modifications in sieve size, grinding, and method of expressing the results, found wide differences in degree of meal fineness in wheat varieties grown in the western region.

MATERIALS AND METHODS

In the investigations undertaken to study technique, three varieties of wheat having a wide range in meal granulation were used. The varieties were, in the order of increasing particle fineness, Michikof, Michigan Amber, and Purdue No. 1. Two thousand grams of sound, clean, normal wheat of each variety were prepared and stored in tight galvanized boxes. Representative samples for the study of each step in technique were obtained by reducing the 2,000-g lot in a Boerner sampler to an appropriate size. All steps in the procedure were studied with both medium and fine wheat meal, ground with the Labconco mill set at F and XF, respectively.

Moisture content of the wheat varied from 9.6 to 10.1 percent. From 12 to 32 replications were made in appraising each variable involved in the procedure.

Except for the variable under investigation the following method was used: 50 g of wheat were ground with the Labconco mill and placed in an airtight glass bottle. From this lot representative 2.5-g samples were placed on the top sieve and sifted for 1 hour in the granulometer, illustrated and described in this paper. The material passing through the finer sieve or into the pan was weighed and expressed in percent of the total, and designated as particle-size index. The higher the index the finer the sample, and the lower the index the coarser the sample. All tests involving any one step in the technique were completed within 6 days.

In tests comparing the two methods commonly used in designating meal granulation, 197 F_2 hybrids originating from a Michikof × American Banner cross and selected at random, were used. These hybrids furnished samples that not only possessed a wide range in degree of meal fineness, but were also suitable for statistical analysis.

[6] CUTLER, G. H., and BRINSON, G. A. See footnote 2.

[7] BRINSON, G. A. THE RELATION OF GRANULATION OF WHOLE WHEAT MEAL TO "QUALITY" IN WHEAT WITH SPECIAL REFERENCE TO THE INFLUENCE OF FERTILIZER TREATMENT. 103 pp., illus. 1933. (Thesis submitted for M. S. degree, Purdue Univ.)

[8] FIFIELD, C. C., BODE, C. E., BAYLES, B. B., HAYES, J. F., WEAVER, R., and CHRISTIE, A. CHEMICAL MILLING AND BAKING RESULTS FOR WHEAT VARIETIES GROWN IN THE COOPERATIVE VARIETAL EXPERIMENTS IN THE WESTERN REGION IN 1934. U. S. Dept. Agr. 41 pp. 1936. [Mimeographed.]

——— BODE, C. E., BAYLES, B. B., HAYES, J. F., WEAVER, R., and CHRISTIE, A. QUALITY STUDIES OF WHEAT VARIETIES GROWN IN THE WESTERN REGION IN 1935. U. S. Dept. Agr. 24 pp. 1937. [Mimeographed.]

Coefficients of correlation and differences necessary for significance between two samples or means were calculated to aid in the interpretation of the data.

DESCRIPTION OF EQUIPMENT

In developing new equipment for meal-granulation determinations, particular emphasis was placed upon its suitability for testing a large number of samples and using small amounts of wheat meal as well as for assuring accurate and dependable results. Such equipment, if available, would greatly aid the plant breeder and geneticist in studying the relative meal fineness in wheat varieties and hybrids. A large

FIGURE 1.—Granulometer used for granulation tests.

number of preliminary experiments were conducted in which various types and sizes of motors, speeds of sifting, width of sieves, agitating devices, etc., were used. As a result of these tests, the granulometer shown in figure 1 was developed.

The granulometer is of simple, sturdy construction mounted on rubber floor cushions on a concrete block. Six nests of sieves are held firmly to the sieve carriage by bolts with wing nuts. Each nest of sieves includes the following: cover, two 2¼-inch sieve frames fitted with United States standard 60- and 270-mesh wire cloth, and a pan. Passage of the material through the sieves is accomplished entirely by the force of gravity. The sieve carriage rotates in a

vertical plane as a result of the eccentricity of the driving shaft, and is given a sudden jarring by a cam mounted on the outer end of the eccentric shaft. The impulses are generated by a 1/20-horsepower induction motor with built-in reduction gear which gives a speed to the main shaft of 216 revolutions per minute. A time switch is mounted on the base of the shaker. The granulometer is not only self-contained and cheap, but permits the testing of as many as 36 to 42 samples per day.

NATURE OF MEAL GRANULATION

It is a matter of common knowledge that flours derived from different classes and types of wheat differ in respect to granulation. Cutler and Brinson[9], using wheat meal, not only showed that granulation of the meal varied widely among different classes, but from a study of a large number of commercially grown soft and hard wheat varieties they demonstrated that bread flours originate from varieties that grind into a coarse meal, while pastry flours come from varieties that produce a fine meal.

Although considerable work has been reported on meal granulation, no information was found that showed the exact shape or form and nature of meal particles. In order to study the nature of the particles found in wheat meal, the meal fractions collected on top of the 60- and 270-mesh sieves and in the pan have been examined under the microscope. Studies were made with meal fractions representing varieties in the hard and soft wheat classes and with samples ground to varying degrees of fineness. In figure 2 are illustrated meal particles varying in size, shape, and angularity, of the three fractions originating from hard and soft wheats ground on the Labconco mill set at XF.

An examination of the individual fractions shown in figure 2 reveals a distinct difference in shape and angularity of the granules in the two samples. The granules in the hard wheat sample (*A*, *B*, and *C*) are characterized by sharp angular edges, while those in the soft wheat sample (*D*, *E*, and *F*) possess dull edges with rounded corners. The hard wheat sample is made up of gritty, vitreous particles, while those in the soft wheat are soft, starchy, and mealy in appearance. In addition to the great variations manifested in the meal granules, the proportion of meal collected on each sieve and pan varied greatly in the two samples. In the hard wheat, Michikof, 65 percent of the meal remained on top of the 60-mesh sieve, 25 percent on the 270-mesh sieve, and only 10 percent passed through the finer sieve and into the pan, whereas, in the soft wheat, Purdue No. 1, these proportions were 52, 28, and 20 percent, respectively. Moreover, flour milled from Michikof is of the coarse granular character usually associated with hard wheat flour, while that from Purdue No. 1 is soft, velvety, and smooth, characteristic of soft wheat flour.

EXPERIMENTS IN TECHNIQUE

The experiments dealing with technique were conducted over a period of 2 years, during which time more than 2,000 samples were sifted. The following steps in procedure were studied: (1) Numerical expression of meal granulation, (2) variation between tests, (3) varia-

[9] CUTLER, G. H., and BRINSON, G. A. See footnote 2.

tion among sieve sets, (4) duration of sifting, (5) size of sample, (6) amount of wheat ground, (7) speed of sifting, (8) moisture content of wheat, (9) age of meal, (10) fineness of grinding, and (11) experimental error in the test.

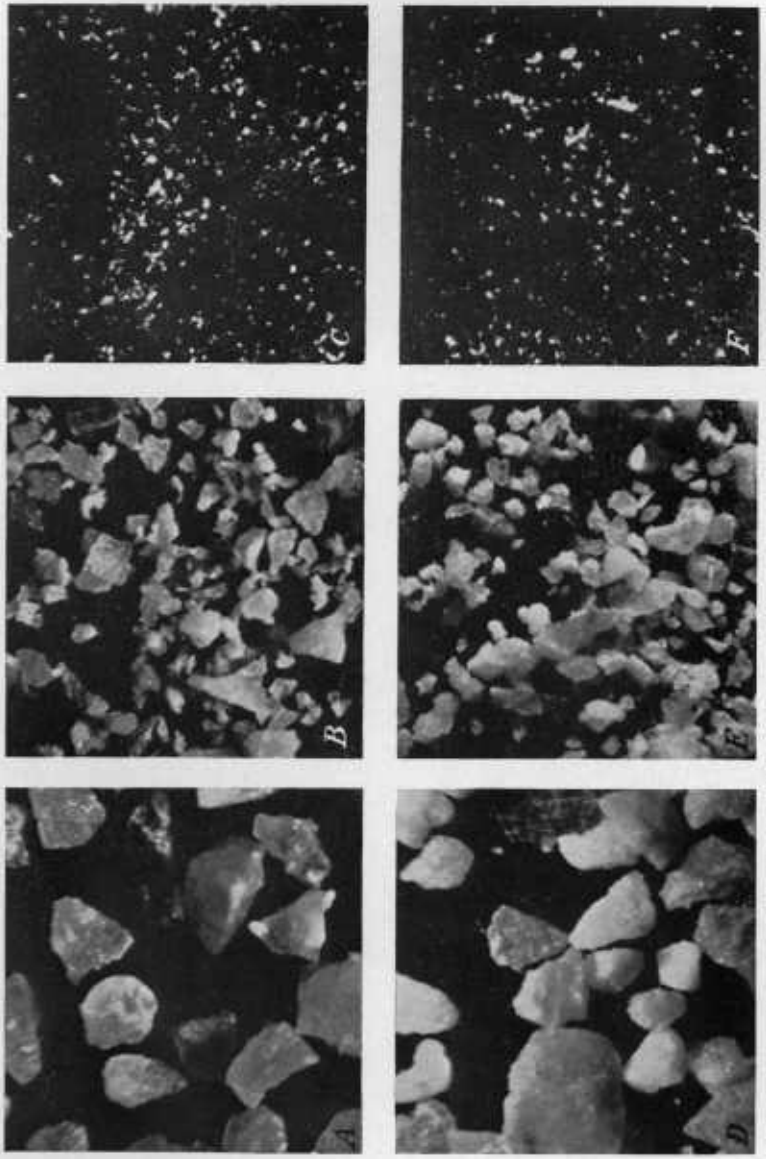

FIGURE 2.—Photomicrographs of coarse (*A* and *D*), medium (*B* and *E*), and fine (*C* and *F*) fractions of wheat meal. Fractions *A*, *B*, and *C*, representing a hard wheat, and *D*, *E*, and *F*, a soft wheat, illustrate the relative size, shape, angularity, and nature of particles or granules. × 20.

A large number of preliminary tests were conducted in which the various steps in procedure were tested in order to obtain information for carrying out the further tests which formed the basis for establishing a standard technique for measuring wheat meal granulation.

Only the data from these later experiments are reported. In presenting the data, averages of the three varieties used are reported, except in cases in which the individual varieties did not react uniformly to the particular variable under investigation.

NUMERICAL EXPRESSION OF MEAL GRANULATION

Obviously, there are many advantages in numerically designating the fineness of a given wheat meal. Two methods of expressing granulation results have been reported; namely, (1) granulation number in which all fractions are used in its calculation,[10] and (2) percentage of material that passes through the finest sieve or into the pan.[11] In these studies a comparison was made of the two methods. Samples of meal from 197 F_2 hybrids of Michikof×American Banner, selected at random were used. The samples varied greatly in degree of fineness. The relation between granulation number and percentage of material in the pan, as well as the interrelation between the proportions collected on the 60-mesh sieve, 270-mesh sieve, and pan are shown in the following tabulation:

Correlations between—	*Coefficient of correlation and standard error*
Meal in pan and granulation number	+0. 95±0. 007
Meal in pan and meal on 270-mesh sieve	+. 51± . 053
Meal in pan and meal on 60-mesh sieve	−. 97± . 004
Meal on 270-mesh and on 60-mesh sieves	−. 82± . 024

The very high positive coefficient of correlation obtained between the percentage of material in the pan and granulation number indicates that the two methods are equally useful and efficient in numerically designating the relative fineness of wheat meal. However, inasmuch as fewer weighings are required and the subsequent calculations are greatly simplified, it was decided to use the percentage of material passing through the finer sieve or into the pan as an index of meal granulation. The percentage of the finest fraction was designated "particle-size index," and is used throughout this paper.

In comparing the relationship of the various proportions of coarse (on 60-mesh sieve), medium (on 270-mesh sieve), and very fine (pan) particle fractions resulting from the sifting tests of 197 hybrid samples, coefficients of correlation were calculated. The data show the following: (1) Increases in the proportion of very fine separations associated with increases in amount of medium-size fractions, or vice versa, (2) negative relation between the amounts of very fine and coarse meal fractions, and (3) negative relation between the medium and coarse particle fractions.

VARIATION BETWEEN TESTS

In determining the amount of variation that exists between different sieving tests, 16 separate tests were conducted in which medium and finely ground wheat meal were used. Each test included duplicate 2.5-g samples of Michikof, Michigan Amber, and Purdue No. 1, sifted for 60 minutes. The data obtained from each test were averaged and are shown in table 1.

[10] BRINSON, G. A. See footnote 7.
CUTLER, G. H., and BRINSON, G. A. See footnote 2.
[11] BRINSON, G. A. See footnote 7.
FIFIELD, C. C., BODE, C. E., BAYLES, B. B., HAYES, J. F., WEAVER, R., and CHRISTIE, A. See footnote 8, both references.

The results from the different sieving tests are very consistent. An experimental error of less than 1 percent was obtained with either medium or finely ground meal. The variability of this factor is smaller than that usually found in laboratory and chemical tests, and should have little effect on the end results.

TABLE 1.—*Variation between different sieving tests* [1] *with medium- and finely-ground meal from three varieties of wheat*

Test No.	Particle-size index of meal		Test No.	Particle-size index of meal	
	Ground medium	Ground fine		Ground medium	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
1	10.9	18.3	6	10.8	18.4
2	10.9	18.7	7	11.0	18.5
3	10.8	18.6	8	10.7	18.7
4	11.0	18.6	Standard deviation	.11	.15
5	10.9	18.7	Coefficient of variability	.98	.82

[1] 12 samples used in each test.

VARIATION AMONG SIEVE SETS

Since six different sets or nests of sieves are employed on the carriage of the granulometer in determining the particle-size index of the meal, a study was made to determine the variation among the sieve sets and their location on the carriage. In studying this variable, 18 separate tests were made with medium and finely ground meal from three varieties of wheat. The data obtained are shown in table 2.

Small differences were found in the results obtained from the six different sets of sieves used in determining meal granulation. With medium ground meal the coefficient of variability was 0.92, while among sets in the fine meal it was 1.42 percent. No consistent relation was obtained between sieve sets and particle-size index either in the individual determinations or in the average of several tests.

DURATION OF SIFTING

To determine the duration of time of sifting needed for complete or nearly complete separation of the finest fraction, 2.5-g samples of meal were sifted for 15, 30, 45, 50, 60, 75, and 90 minutes in the granulometer.

TABLE 2.—*Variation in sieving tests* [1] *made with six different sets of sieves when medium and finely ground wheat meals were sifted simultaneously in the granulometer*

Sieve set No.	Particle-size index of meal		Sieve set No.	Particle-size index of meal	
	Ground medium	Ground fine		Ground medium	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
1	11.0	17.6	5	10.8	17.2
2	10.9	17.6	6	11.0	17.0
3	10.8	17.2	Standard deviation	.10	.24
4	10.8	17.2	Coefficient of variability	.92	1.42

[1] 18 samples used in each test.

The average data obtained for the three varieties are shown in table 3.

TABLE 3.—*Influence of duration of sieving process upon the percentage of material sifted through a 270-mesh sieve from medium and finely ground wheat meal* [1]

Minutes sifted	Particle-size index of meal [2]		Minutes sifted	Particle-size index of meal [2]	
	Ground medium	Ground fine		Ground medium	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
15	7.9	11.8	60	10.9	18.9
30	9.3	16.7	75	10.9	19.2
45	10.1	17.9	90	11.2	18.9
50	10.3	18.2			

[1] 12 samples used in each test.
[2] Difference necessary for significance between two means, odds 19:1=0.37.

The data in table 3 show a gradual increase in the percentage of material passing through the finer sieve as the time of sifting was increased from 15 to 60 minutes. No significant differences were obtained between samples sifted for 60, 75, and 90 minutes. Consequently, in all comparative granulation tests, samples of wheat meal were sifted for 60 minutes in the granulometer.

SIZE OF SAMPLE

In the development of a suitable technique for measuring meal fineness special attention was given to the possibility of testing small samples. A series of experiments was conducted in which 1-, 2-, 2.5-, 3-, 4-, 5- and 10-g samples were sifted for 60 minutes in the granulometer. The average results obtained from medium and fine meal of three varieties are reported in table 4.

The data show no significant difference between the results obtained with 1-, 2-, 2.5-, and 3-g samples. In the larger samples, especially the 10-g sample, complete separation of the finest fraction was not accomplished during the 60-minute period of sifting. In all regular tests, the 2.5-g sample has been adopted as standard, because of the ease in sampling, reliability, and suitability for testing a few grams of wheat.

TABLE 4.—*Influence of size of sample* [1] *of medium and fine meal on completeness of separation of finest meal fraction*

Meal (grams)	Particle-size index of meal [2]		Meal (grams)	Particle-size index of meal [2]	
	Ground coarse	Ground fine		Ground coarse	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
1	10.7	17.4	4	9.9	17.6
2	10.7	17.5	5	10.0	17.7
2.5	10.6	17.6	10	10.0	17.3
3	10.5	17.8			

[1] 12 samples used in each test.
[2] Difference necessary for significance, 0.37.

AMOUNT OF WHEAT GROUND

From preliminary trials it was found that the quantity of wheat ground influenced the degree of fineness of the resulting wheat meal. To determine the effect of the amount of wheat ground on the percentage of the finest fraction or particle-size index, tests were made in which 5-, 10-, 15-, 25-, and 50-g lots of wheat were used. Separate lots of each sample size were ground with the Labconco mill set at F and XF to represent the medium and fine degrees of granulation. Since the varieties used did not react uniformly to the different amounts ground, the data for the three varieties are reported separately (table 5).

It will be noted that the size of the wheat sample ground greatly influenced the degree of particle fineness in the three varieties studied. In the soft wheat varieties Michigan Amber and Purdue No. 1, the larger the size of sample ground the finer was the meal, and the smaller the sample, the coarser the meal. With the hard wheat variety Michikof, on the other hand, the larger the quantity ground the coarser was the meal. Since the amount of wheat ground with the Labconco mill greatly affects the fineness of meal, it is necessary to grind samples of uniform size in all comparative tests. A 10-g sample is recommended. It may be that the 10-g sample will not prove best with all wheats and under all conditions. For the conditions of the present experiments, however, it serves as a basis for standardizing a suitable technique.

TABLE 5.—*Influence of size of sample*[1] *ground on the fineness of medium and fine meal from three varieties of wheat*

Wheat ground (grams)	Particle-size index of meal[2]					
	Ground medium			Ground fine		
	Michikof	Michigan Amber	Purdue No. 1	Michikof	Michigan Amber	Purdue No. 1
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5	7.0	10.8	12.6	13.4	17.6	22.2
10	7.2	10.6	13.8	12.4	18.8	23.2
15	7.0	11.2	13.4	12.2	18.4	23.4
25	6.8	11.4	14.2	12.0	18.4	24.0
50	6.8	12.4	14.4	11.4	19.2	24.6

[1] 12 samples used in each test.
[2] Difference necessary for significance between 2 means, odds 19:1=0.68.

SPEED OF SIFTING

It was found, from preliminary trials, that a speed of at least 200 r. p. m. was necessary before a satisfactory sifting of meal was obtained. In later tests the speed of the shaft was 190, 200, 220, and 240 r. p. m. The data obtained are given in table 6.

The data show that, under the conditions of these experiments, complete or nearly complete separation of the finest meal fraction was accomplished at a rate of speed of 220 and 240 r. p. m. As a result of these tests, a speed of 216 [12] r. p. m. was selected in making the new equipment and was adopted as standard.

[12] Standard equipment.

MOISTURE CONTENT OF THE WHEAT

In determining the effect of moisture content of wheat on granulation of the meal, wheat samples varying widely in moisture content were used. Fifty-gram samples of each variety for each condition were placed in a humidifier and a dehydrator respectively for various periods of time. Immediately after the samples were taken out and ground, moisture-content determinations and sieving tests on the resulting meal were made. The data are shown in table 7.

TABLE 6.—*Influence of speed of sifting upon the completeness of separation of the finest fractions from medium and finely ground wheat* [1] [2] *meal*

Revolutions per minute	Particle-size index of meal [3]		Revolutions per minute	Particle-size index of meal [3]	
	Ground medium	Ground fine		Ground medium	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
190	7.9	11.0	220	8.4	14.7
200	8.4	12.7	240	8.5	15.1

[1] Data are not comparable with those in other tables since the moisture content, source of samples, and the equipment used were different.
[2] 12 samples used in each test.
[3] Difference necessary for significance, 0.37.

TABLE 7.—*Influence of moisture content of the wheat used for grinding upon the percentage of material collected in the pan after sifting medium and finely ground meal* [1]

Moisture in wheat (percent)	Particle-size index of meal [2]		Moisture in wheat (percent)	Particle-size index of meal [2]	
	Ground medium	Ground fine		Ground medium	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
7.6	9.1	16.2	10.0	10.4	17.6
8.7	10.5	17.3	10.9	12.0	20.8
9.0	10.3	17.4	12.4	11.7	[3] 16.7
9.6	10.3	18.1	13.3	12.3	[3] 15.3

[1] 12 samples used in each test.
[2] Difference necessary for significance, 0.37.
[3] A layer of meal formed on part of the 270-mesh sieve preventing complete separation of the fine meal.

Under the conditions of these experiments, wheat samples possessing a lower moisture content ground into a coarser meal than those of higher moisture content. The meal from samples containing 12.4 and 13.3 percent moisture formed a solid layer on a portion of the 270-mesh sieve. This prevented complete separation of the finest fraction and resulted in a lower particle-size index. Since the moisture content of wheat greatly influences meal granulation, it is necessary, in all comparative tests, to use samples of uniform moisture content. Considering all factors, wheat samples containing from 9 to 10 percent moisture have been found most suitable for granulation studies.

AGE OF THE MEAL

To determine the effect of age of meal on the results from granulation tests, 50-g samples of each variety were ground to the desired fineness and stored in airtight bottles. At weekly intervals representative samples from each lot were subjected to the regular sieving test. The results with meal stored for 0, 7, 14, 21, and 28 days are reported in table 8. They show that, in general, as the age of the meal increased, the particle-size index decreased. No significant difference is shown between the results obtained from meal tested immediately after grinding and that stored for 7 days in a tight bottle.

TABLE 8.—*Influence of age of coarse and finely ground wheat meal upon the results obtained in successive sievings made at weekly intervals* [1]

Aging period after grinding (days)	Particle-size index of meal [2]		Aging period after grinding (days)	Particle-size index of meal [2]	
	Ground coarse	Ground fine		Ground coarse	Ground fine
	Percent	*Percent*		*Percent*	*Percent*
0	10.6	18.1	21	9.8	17.1
7	10.9	17.8	28	10.1	17.1
14	10.3	17.8			

[1] 12 samples used in each test.
[2] Difference necessary for significance, 0.37.

FINENESS OF GRINDING

One of the main objectives in establishing a suitable technique for granulation studies was to emphasize the difference between hard and soft wheat samples. From preliminary trials it was observed that greater differences in granulation appeared between hard and soft varieties in finely ground wheat meal than in meal ground coarse. In order to obtain specific data on this point, sieving tests were conducted with coarse, medium, medium fine, and fine meal ground with the Labconco mill set at 1, F, between F and XF, and XF, respectively. The data for the three varieties, together with the amount of difference that exists between Michikof and Purdue No. 1, are given in table 9.

Great differences are noted in the degree of meal fineness caused by grinding the wheat coarse, medium, medium fine, and fine. The data show that the greatest differences between a hard and a soft wheat were obtained from the samples that were ground the finest. Since the difference necessary for significance between two individual samples is not much greater in the fine meal than in the coarser samples, and since there are obvious advantages associated with a greater difference between hard and soft heats, wheat ground into a fine meal was adopted and used in all regular tests.

TABLE 9.—*Influence of fineness of grinding of wheat samples upon the difference between results in sieving tests with meals from hard and soft wheats* [1]

Variety	Particle-size index of meal			
	Ground coarse	Ground medium	Ground medium fine	Ground fine
	Percent	*Percent*	*Percent*	*Percent*
Michikof	5.0	5.7	7.0	9.9
Michigan Amber	8.4	11.1	13.8	19.6
Purdue No. 1	10.5	13.8	16.6	24.3
Difference between Michikof and Purdue No. 1	5.5	8.1	9.6	14.4
Difference necessary for significance between 2 samples—odds 19:1	.60	.56	.54	.81

[1] 32 samples used in each test.

EXPERIMENTAL ERROR IN THE TEST

To determine the error that exists in the technique used, and the amount of variation that could be expected from sifting several hundred samples, 50 separate tests with meals from three varieties of wheat, ground medium and fine, were conducted over a period of 1 month. Variations caused by sampling, weighing, date of grinding, tests, sieves, and moisture content are involved. The data for each variety as well as the difference necessary for significance between two samples, in medium and fine meal, are shown in table 10.

A variation of about 5 percent is shown in the technique recommended for granulation studies of wheat meal. Although the wheat samples for this study were stored in a tight galvanized container, the moisture content in the wheat gradually decreased from 9.9 to 9.6 percent during the period of this investigation. As a result, the first samples tested possessed a somewhat higher particle-size index than those tested at the end of the period. Moisture content, therefore, caused a great part of the variability obtained in the 300 samples tested. The data show that differences of 1.24 for medium and 2.00 for fine meal are necessary for significance between two samples in comparing results obtained under conditions somewhat similar to those in this experiment.

TABLE 10.—*Experimental error in technique adopted for meal-granulation studies in tests of three varieties of wheat ground medium and fine* [1]

Fineness of grinding	Variety	Mean	Generalized standard deviation	Coefficient of variability	Difference necessary for significance between 2 samples: odds 19:1
Medium	Michikof	6.0	0.53	4.91	1.24
	Michigan Amber	12.1			
	Purdue No. 1	14.4			
Fine	Michikof	10.4	.86	4.80	2.00
	Michigan Amber	19.1			
	Purdue No. 1	24.1			

[1] 50 samples used in each test.

SUMMARY

Experiments dealing with a critical study of technique for measuring meal granulation were conducted over a period of 2 years during which time more than 2,000 samples were sifted.

A new apparatus, the granulometer, was developed, and the nature of meal fractions are illustrated and described.

Steps in the study of procedure included (1) numerical expression of meal granulation; (2) variation between tests; (3) variation among sieve sets; (4) duration of sifting; (5) size of sample; (6) amount of wheat ground; (7) speed of sifting; (8) moisture content of the wheat; (9) age of the meal; (10) fineness of grinding; and (11) experimental error in the test.

From the results obtained in a systematic study of each step in the procedure, the following technique for measuring meal granulation has been adopted: 10 g. of clean, sound, normal wheat, containing about 10 percent of moisture, are ground into a fine meal with the Labconco mill set at XF. Immediately after grinding, a 2.5-g sample is weighed and transferred to the larger sieve (60-mesh and 270-mesh sieves used) and sifted for 1 hour in the granulometer. The material that passes through the finer sieve or into the pan is weighed. The weight of this fraction is expressed as percent of the total and is designated as particle-size index. A low index indicates a coarse meal and a higher index indicates a relatively finer meal.