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SOME METHODS OF DETERMINING
THE GLUTEN STRENGTH OF SOFT
WHEAT VARIETIES

THESIS FOR THE DEGREE OF M. S.

Ardie G. Gustafson

1933

Wheat

July: The gluten strength of
soft wheat varieties



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OF SOFT WHEAT VARIETIES**

THESIS

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SOME METHODS OF DETERMINING THE GLUTEN STRENGTH
OF SOFT WHEAT VARIETIES

THESIS

RESPECTFULLY SUBMITTED IN PARTIAL FULFILLMENT
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ARDIE G. GUSTAFSON

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INTRODUCTION

Gluten strength to a great extent determines the value of wheat for various purposes. Measuring the gluten strength is a problem which confronts the plant breeder, the miller, and the baker. Methods in use are especially adapted to hard wheat, although they have been used extensively on soft wheats. Two of these, the protein determination and the baking test, have been used for several years at the Michigan Station to evaluate the wheats grown on the station plots. More recently the expansion test and the wheat meal fermentation time test have been recommended as better measures of gluten strength of soft winter wheats. With this in mind, a comparative study was made of the four methods using Michigan soft winter wheats.

The first object of this study was to determine the relative values of these tests as methods of measuring the gluten strength of different varieties of soft winter wheat and to determine whether these varieties can be separated into different classes of gluten strength. The second object was to determine whether the same variety would produce differences in gluten strength, measurable by one of these methods, when produced under unlike environmental conditions.

Literature on previous investigations will be reviewed before this study is discussed.

PREVIOUS INVESTIGATIONS

The tests employed in this investigation have been discussed in literature by various workers. The protein determination and the baking test long have been used as methods of determining gluten strength, and only literature having a direct bearing on this problem will be discussed. The expansion test and the wheat meal fermentation time test have been developed more recently and a more complete review of previous work will be given for these two tests.

THE PROTEIN DETERMINATION

The protein determination is used more than any other one test in determining the value of different wheats. The test is desirable because only a few grams of material are required and can be made on either whole grain or flour.

In bread wheats, the protein content seems to be closely associated with the baking strength. Bailey (2)

reports, from his own investigations and those of other workers, that loaf volume indicates a positive correlation between the baking strength and protein content. He also states, that the protein content of soft wheat flours seemed to be less effective in producing large loaves than did the same concentration of protein in hard wheat flours.

THE BAKING TEST

The baking test, in which the volume of loaf is the measure, is used extensively to determine the gluten strength of flours. It has the disadvantage to the plant breeder that flour must be used. This requires a rather large sample of wheat, 600 to 2000 grams, and the sample must be milled before the test can be made.

The baking test used at the Michigan Station in 1931, described by Down, et al (5), is adapted to bread baking from soft wheat flours.

The baking test using "pup" loaves is reported by Werner (18). The formula originally suggested by Werner has been tested by the Committee on Standardization of the Baking Test of the American Association of

Cereal Chemists and the Basic formula has been adopted by the association. Harrel (7) reports the following supplements to the Basic Procedure: A. Absorption; B. Fermentation; and C. Addition of special oxidizing reagent, potassium bromate.

During recent years, the effect of bromate, the primary agent in Arkady, on doughs has received considerable attention.

Moen (11) found that the A.A.C.C. Baking Procedure with Supplement C, addition of bromate, emphasizes desirable characteristics or deficiencies which the Basic Procedure alone fails to reveal.

Geddes and Larmour (6) found that the bromate formula gives a much better measure of the relative strength in baking tests conducted on Western Canadian hard, red, spring wheats than the Basic formula. The bromate volumes were more highly correlated with protein content than the Basic, and the regression of loaf volume on protein was linear over a greater range. The bromate formula was found to be more sensitive than the Basic in indicating modifications in flour strength due to heat treatment or to the presence of green, frosted, or immature kernels in the wheat mix.

Treloar and Larmour (17) conclude that dough prepared by one worker and molded by different workers may show differences in loaf volume, due to variations in "molding personality". They also state that it appears possible that variations in molding technique may also be the cause of variations in replicate volumes by any one worker.

Cutler and Worzella (4) state that the baking test does not lend itself to the needs of the plant breeder, since five pounds or more of wheat are required.

Blish, et al, (3) reports that if a basic procedure applicable to the soft wheats is to be developed, the absorption should be decreased and the fermentation period shortened.

THE EXPANSION TEST

The expansion test has received some attention in recent years as a measure of gluten strength. In this test, the maximum expansion that a dough will reach during fermentation is the measure of gluten strength. Leach (10) described a method of testing flours by the "expansion of dough". One hundred grams

of flour was made into a dough ball, placed in a 500 cc. graduate cylinder, and the volume read when the dough reached its maximum expansion. Wilsie (19) reports that the expansion test showed differences between Red Rock and American Banner flours of from 250 to 300 cc. in volume reached during the second rise. He states that differences in volumes of less than 75 to 100 cc. are of little significance. Wilsie (20) describes and further reports the expansion test as a measure of the gluten strength of soft wheat flours. His methods differ from those of Leach in that the doughs were allowed to rise a second time. His results were apparently different in that much larger volumes were obtained.

Shiple (16) reported the test as was conducted at the National Milling Company laboratory. A fermentation factor or index is used to evaluate the flours. This factor is the product of the time in minutes for the dough to reach its maximum volume multiplied by the volume in cubic centimeters.

THE WHEAT MEAL FERMENTATION TIME TEST

The wheat meal fermentation time test is another measure of gluten strength. This method has

the advantage of using only small amounts of material and is conducted on whole wheat meal, which eliminates the necessity of milling. The test is a modification of one used by Saunders and Humphries (15) for testing the gluten strength of flours. The wheat meal fermentation time test was first reported by Pelshenke (12), a German investigator. In Pelshenke's (13) method, the same amount of water is added to all samples on the assumption that all whole-meals have the same absorption capacity. Gluten strength is measured by fermentation time which is called the "test number of gluten quality". A fermentation factor, "specific gluten quality", is obtained by dividing the time by the protein content. Cutler and Worzella (4) also report the test. Their method differs from that of Pelshenke in that different absorption percentages are used for different samples. They use the test in plant breeding work in the selection of strains of wheat and report a high positive correlation of the test with absorption and vitreous kernels. They also state that the test shows a high correlation between "time" and the quality of wheat desired for making flour for par-

tiocular purposes. The wheats preferred for bread flour have a high "time" test and the wheats preferred for pastry flour have a low "time" test.

PRESENT INVESTIGATION

This review of literature briefly shows the relation of previous investigations to this study. The present investigation, including experimental work and results, is discussed in the following sections of this report.

MATERIALS.

Samples used in this investigation are shown in Table I, which gives the varieties of wheat, the sources, and number of samples from each source for 1931 and 1932. Samples of American Banner, Red Rock, Bald Rock, 912203, and Berkeley Rock, grown at various places in the wheat producing section of Michigan, were used. The samples in the over-state tests were grown side by side. Some of the samples were mixed so badly that the data were not used in computing variety averages. Samples from farmers were obtained

Table I. Varieties of wheat, sources and number of samples from each source for 1931 and 1932.

	American Banner		Red Rock		Bald Rock		912203		Berkeley Rock		Total	
	1931	1932	1931	1932	1931	1932	1931	1932	1931	1932	1931	1932
Over-state tests	6	6	6	6	6	6	6	6	6	6	30	30
Farmers	40	24	6	6	--	14	--	--	--	--	46	44
Time of harvest	6	6	--	--	--	6	--	--	--	--	6	12
Irrigation		10	--	10	--	--	--	--	--	--	--	20
Sunshine cages	2	--	--	--	--	--	--	--	--	--	2	106
Total	54	45	12	22	6	26	6	6	6	6	84	

Sources of over-state tests

1931	1932
M.S.C., East Lansing	M.S.C., East Lansing
Monroe County Farm, Monroe	Monroe County Farm, Monroe
Potato Sub-station, Lake City	Potato Sub-station, Lake City
Kellogg Farm, Augusta	Arthur Baker, Coldwater
A. E. Rowland, Eagle	C. H. Richardson, Marlette
Art Solwinski, Lake Odessa	Felix Witt, Jasper

through the Michigan Crop Improvement Association and contained but little mixtures. The samples from the time of harvest trials, sunshine cages, and the irrigation experiments were produced at the East Lansing station.

Flour samples for the tests were milled with the Allis-Chalmers experimental mill in the Farm Crops laboratory. About 2000 grams of grain of the 1931 samples and 1500 grams of the 1932 samples were milled. All of the flours were thoroughly mixed before samples were taken for any of the tests.

Yeast was supplied by the Fleischmann Yeast Company and was delivered to the laboratory twice a week.

Other materials, such as lard, sugar, salt, glucose, and Arkady, were obtained at the Experiment Station Chemistry laboratory.

METHODS

THE PROTEIN DETERMINATIONS

Protein determinations were made on wheat and flour samples by the Kjeldahl method using 1 gram samples of material. The factor used to convert nitrogen

to protein was 5.83 for the grain analyses and 5.7 for the flour analyses.

Moisture determinations also were made and the protein percentages were corrected to a uniform moisture content of 13.5%.

THE BAKING TEST

1931 Method

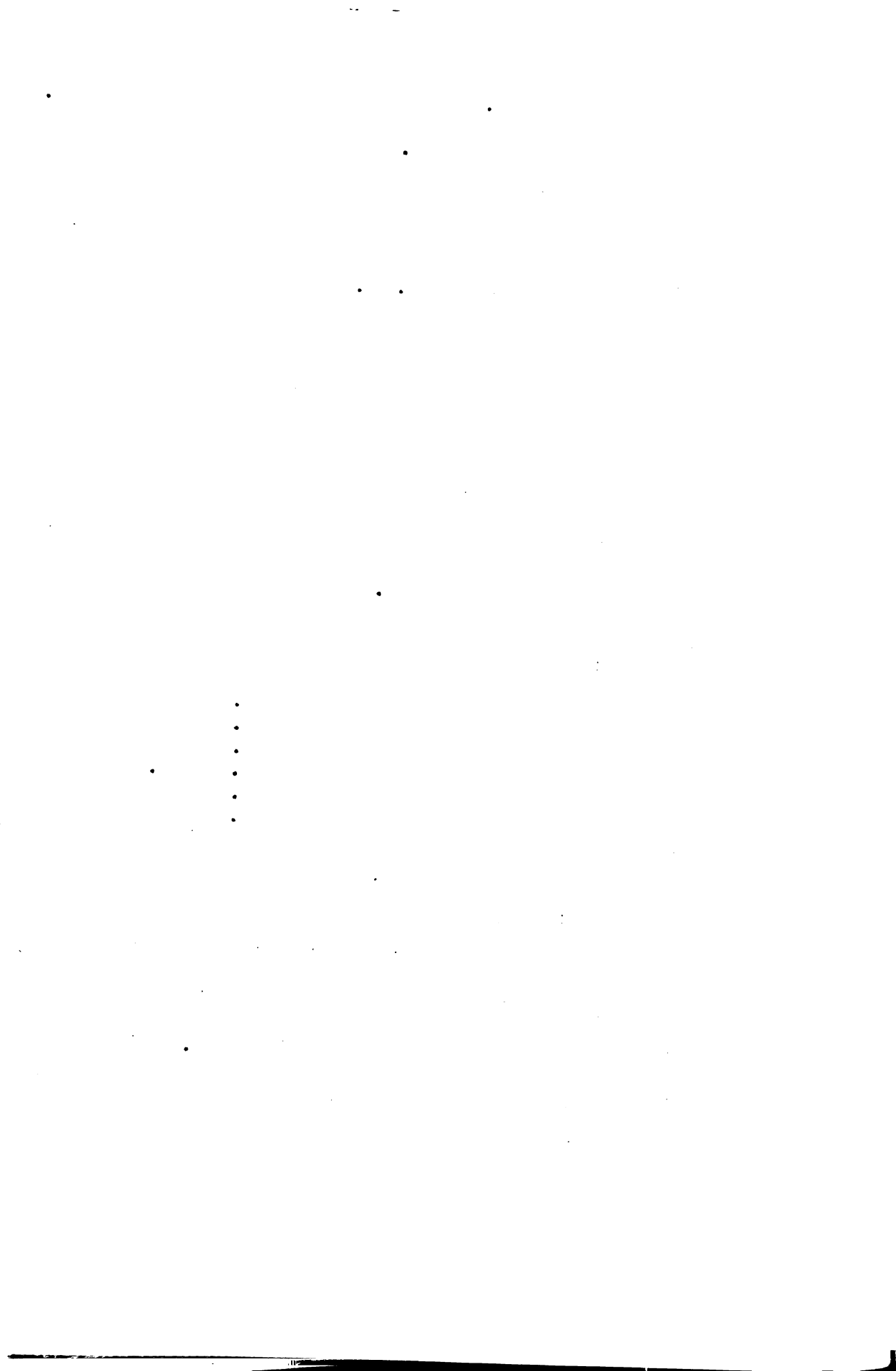
The baking of flour samples from wheats milled in 1931 was done by the old method in which pound loaves were baked.

Formula:

Flour	325.00 grams
Sugar	12.00 grams
Salt	6.00 grams
Glucose	1.00 cc.
Yeast	10.00 grams
Lard	6.50 grams
Water	According to absorption

Procedure:

The procedure in baking is essentially the same as that described later for the baking of samples milled from the wheats grown in 1932. With the exception that doughs were allowed to stand on the bench for 10 minutes after they had received the second punch



before being molded and placed in the pan, the only changes were minor ones made for convenience.

1932 Method

The flour samples from the wheats grown in 1932 were baked using the Basic formula for small loaves adopted by the American Association of Cereal Chemists. The method has been tested in recent years and is now replacing the method in which larger loaves are baked.

Formula:

Flour	100.00 grams
Sugar	2.50 grams
Salt	1.00 grams
Arkady	0.50 grams
Glucose	0.33 cc.
Yeast	3.00 grams
Lard	0.50 grams
Water	According to absorption

Procedure:

The water absorption for each flour was determined before the baking was started. This was done by making a dough ball, using 25 grams of flour and sufficient water, from 14 to 16 cc., to give the dough proper consistency for baking. The amount of water to add was judged from the appearance of the dough ball. This

amount of water, expressed as a percentage of the amount of flour used, is known as the water absorption and this percentage was used later in mixing the doughs for baking.

The fermentation cabinet, in which the doughs were allowed to rise or ferment, was kept at a constant temperature of 30 degrees C. by thermostatic control.

The flour samples were weighed on the day preceding mixing and were kept over night in the fermentation cabinet in small bowls covered with glass plates. Salt and sugar were dissolved in enough water so that 20 cc. of the solution contained 1 gram of salt, 2.5 grams of sugar, and about 18 cc. of water. A flask of the salt-sugar solution and one of the water used in making up the water absorption of each flour were kept in the cabinet over night so that both would be of proper temperature for mixing.

Yeast was made into a suspension with Arkady, glucose, and water. Twenty cc. of the suspension contained 3 grams of yeast, 0.5 grams of Arkady, 0.33 cc. of glucose and about 17 cc. of water. Twenty cc. portions of the suspension were pipetted into 100 cc.

beakers and placed in the cabinet for 30 minutes before the mixing was started. New suspensions were prepared later so that no yeast was used after being in the cabinet for more than two hours.

Before the mixing was started, some of the salt-sugar solution and some of the water were transferred to burettes for convenience of measuring into graduated cylinders. Additional portions of the liquids were transferred from the cabinet to the burettes as needed.

A Hobart electric mixer was used in mixing the dough. The flour was first sifted into the mixing bowl and next the lard was added. The salt-sugar solution was poured into the yeast suspension and both were poured into the mixing bowl together. The water was added last. It was poured into the beaker which had contained the yeast, in order to rinse the beaker, and was then transferred to the mixing bowl.

The dough was mixed for one minute at low speed. Then the dough sticking to the sides of the mixing bowl was scraped loose and the mixing continued for two minutes at medium and for one minute at high speed.

The dough was taken from the mixing bowl, kneaded into a round ball, put in a small bowl, covered with a glass plate, and placed in the cabinet. After allowing the dough to ferment for 40 minutes (first rise) it was taken out, punched (first punch), kneaded into a ball about the original size, replaced in the cabinet, and allowed to ferment again for 25 minutes (second rise). It was then punched (second punch), molded, placed in the pan, and again set in the cabinet and allowed to ferment for 45 minutes (third rise). The pan of dough was baked in an electric oven at a temperature of 220 to 230 degrees C. for 30 minutes. The loaf was removed from the oven and taken from the pan. After greasing the crust with lard, the loaf was numbered and allowed to cool to room temperature.

The volume of loaf was then measured by determining the amount of rape seed displaced. The equipment used was rape seed, a hopper, a glass jar, a container to catch the excess seed from the jar, and a 1000 cc. graduated cylinder. The hopper was placed so that the opening, 1 1/4 inches in diameter, at the bottom was two inches above the center of the

jar. The glass jar used was 5 3/8 inches in diameter, 5 inches high and had a capacity of about 1700 cc. Just enough rape seed was used to fill the jar. The amount of rape seed to use was found by placing an excess of rape seed in the hopper, allowing it to run into the jar until the latter overflowed all the way around the edge, and then removing the excess by means of a stroker. This amount was checked daily. The stroker was made of hardwood, had a smooth rounded edge, was 12 inches long, 1/4 inch thick, and 1 3/8 inches broad.

The loaf was measured by placing it in the jar, running in the rape seed from the hopper, and removing the excess seed heaped on top of the jar by means of the stroker. The excess seed was removed by three full-length zigzag motions of the stroker. This was collected in the container, poured into the hopper, and allowed to run in to the graduated cylinder. The reading was made to the nearest 5 cc.

Each day two samples of Red Rock flour were prepared and baked as checks. The average volume of these daily checks was used as a basis for correcting the volumes of the other loaves baked the same day.

To determine the variations in loaf volume that could not be controlled, 30 samples of the baking check were baked in one day. The loaf volumes varied from 520 to 580 cc. The mean loaf volume of the 30 samples were 546.33 cc. with a probable error of a single determination of 10.98 cc. Thus, a sample would have to be more than 35.14 cc. larger or smaller than the check to be significantly different from it. This value was used to determine which samples were to be baked in triplicate. A third loaf was baked, if duplicates differed from each other by more than 35 cc. in loaf volume.

THE EXPANSION TEST

Formula:

Flour	150.00 grams
Yeast	6.00 grams
Sugar	5.25 grams
Salt	1.80 grams
Water	According to absorption

Procedure:

The samples were prepared and mixed in the same manner as described for the baking test except that the doughs were mixed for one minute at low speed and three minutes at medium speed.

After the dough was mixed, it was kneaded into a ball, placed in a Chidlow expansion jar, and pressed into the bottom to exclude air. The jar was placed in the fermentation cabinet at 30 degrees C. and covered with a glass plate. The dough was then allowed to rise for one hour at which time the volume was read. The jar was removed from the cabinet and the dough punched and pressed into the bottom of the jar which was again placed in the cabinet. The dough was allowed to rise until the maximum volume was reached. The volume was read at 15 minute intervals during the second rise and recorded.

Each day, two samples of flour were used as checks and corrections made on the volumes of the other samples by dividing their volumes by the average volume of the two checks.

THE WHEAT MEAL FERMENTATION TIME TEST

Formula:

Wheat meal	10 grams
Yeast suspension	5 cc.
(10 grams yeast and 100 cc. distilled water)	
Water	According to absorption

Procedure:

The meal for the wheat meal fermentation time test was prepared by grinding the sample of grain with a Wiley mill to a fineness that would pass through a sieve of 1 mm. mesh. The yeast suspension was prepared and allowed to stand in the fermentation cabinet at a temperature of 30 degrees C. for 30 minutes before using.

In conducting the tests on the wheats grown in 1931, the same absorption percentage was used for each wheat as that of the flour milled from a sample of the same wheat. A uniform amount of water, 1 cc., was added to each sample of the meal in addition to the water in the yeast suspension in preparing the dough balls from the 1932 crop. This was done because it was concluded that there is very little difference in the absorption of different wheat meals and because the samples did not vary greatly in original moisture content.

The dough ball was prepared by mixing the meal, yeast suspension, and water in a porcelain dish with a porcelain spatula. Mixing with the spatula was continued until the meal stuck together in a ball.

Then it was placed in the hand, kneaded, and rolled into a ball. Next it was placed in the cabinet at 30 degrees C. in a 100 cc. beaker containing 80 cc. of distilled water. The time of placing the dough ball in water was recorded and the time again recorded when the first fall of dough occurred.

The time in minutes, from the placing of the dough ball in water until the first fall of dough occurred, was divided by the protein content of the wheat meal sample to obtain the fermentation index of the gluten strength.

STATISTICAL METHODS

In the discussion which follows, single determinations and means of several determinations are compared on the basis of the probable errors. Values are said to be significantly different from each other, if the difference between them is greater than 3.3 times its probable error.

Coefficients of correlation were determined between various tests to find to what extent any two tests tended to measure the gluten strength in the same manner. The coefficient of correlation "r" is interpreted on the basis of its probable error and Wright's (12)

coefficient of determination " r^2 ". Babcock and Clausen (13) state, "a correlation coefficient which does not differ from zero more than four times its probable error is considered as of doubtful significance". A coefficient of correlation in this investigation is said to be significant if it is greater than four times its probable error. On the basis of odds, this means that the chances are 142 to 1 that the correlation is due to factors other than chance alone. Wright reports the coefficient of determination, " r^2 ", as a measure of the portion of variability of one of the variables which is determined by the other. Immer (14) and Richey (15) use " r^2 " to measure the amount of variance of one factor due to another factor. Richey states that $100 r^2_{xy}$ gives "the percentage of variance of X due to Y". In this study, a correlation is said to be strong if r is .71 or greater, which gives a coefficient of determination in percentage of 50% or more.

RESULTS AND DISCUSSION

VARIETAL CLASSIFICATION

The means, their probable errors, and ranks of the protein determination, the volume of loaf, the expansion test, and the wheat meal fermentation time test for the five varieties of wheat are given in Table II.

Table II. Means, their probable errors, and ranks of the five tests of gluten strength for five varieties of wheat from the oven state tests.

	Prot. of wheat %		Prot. of flour %		Vol. of loaf cc.		Expansion cc.		W.M.F.T. minutes	
	Mean $\pm$ P.E.	Rank	Mean $\pm$ P.E.	Rank	Mean $\pm$ P.E.	Rank	Mean $\pm$ P.E.	Rank	Mean $\pm$ P.E.	Rank
	1931									
American Banner	11.64 $\pm$.38	5	10.21 $\pm$.43	5	1750.50 $\pm$ 38.04	5	867.50 $\pm$ 10.85	5	29.00 $\pm$ 1.36	5
Red Rock	12.02 $\pm$.41	4	11.19 $\pm$.53	2	1940.00 $\pm$ 16.71	2	950.00 $\pm$ 11.43	3	154.33 $\pm$ 3.54	2
Bald Rock	12.31 $\pm$.36	2	10.71 $\pm$.34	3	1822.50 $\pm$ 25.17	4	949.25 $\pm$ 15.82	4	133.00 $\pm$ 4.79	3
912203	12.12 $\pm$.45	3	10.37 $\pm$.40	4	1963.90 $\pm$ 31.79	1	1045.93 $\pm$ 21.46	1	100.33 $\pm$ 8.21	4
Berkeley Rock	12.64 $\pm$.44	1	11.40 $\pm$.29	1	1852.30 $\pm$ 19.39	3	1002.50 $\pm$ 15.23	2	157.00 $\pm$ 5.04	1
	1932									
American Banner	9.78 $\pm$.29	5	8.22 $\pm$.27	5	526.25 $\pm$ 5.73	5	920.75 $\pm$ 14.64	3	27.78 $\pm$ 0.69	5
Red Rock	10.05 $\pm$.35	4	8.60 $\pm$.32	4	602.00 $\pm$ 3.56	1	1036.00 $\pm$ 15.56	2	142.40 $\pm$ 5.07	1
Bald Rock	10.32 $\pm$.26	3	8.85 $\pm$.25	3	532.67 $\pm$ 1.73	4	917.17 $\pm$ 16.01	4	126.50 $\pm$ 5.01	2
912203	10.56 $\pm$.18	2	9.10 $\pm$.16	2	534.33 $\pm$ 10.29	3	907.33 $\pm$ 11.68	5	90.50 $\pm$ 11.84	4
Berkeley Rock	10.79 $\pm$.34	1	9.44 $\pm$.34	1	577.50 $\pm$ 7.35	2	1041.00 $\pm$ 18.75	1	115.83 $\pm$ 10.84	3

THE PROTEIN DETERMINATION

The protein of wheat or the protein of flour showed no significant differences between varieties either year. All of the varieties, however, were significantly higher in 1931 than they were in 1932. More variation in protein content is caused by seasonal conditions than by differences in varieties in one season. A great range of protein content of varieties might not be expected because the varieties included in this study are all soft wheats.

THE BAKING TEST

The baking test ranks American Banner significantly lower than Red Rock in volume of loaf for both years, lower than 912203 in 1931 and lower than Berkeley Rock in 1932.

Red Rock was significantly higher than Bald Rock as well as American Banner for both years. It was also significantly higher than Berkeley Rock in 1931, and than 912203 in 1932.

Bald Rock, in addition to the differences mentioned was lower than 912203 in 1931, and lower than Berkeley Rock in 1932.

In 1932, Berkeley Rock was significantly higher than 912203.

The baking test used in 1931 was different from the one used in 1932 and comparisons of varieties between the two years cannot be made for this reason.

THE EXPANSION TEST

The volume of expansion ranks American Banner significantly lower than all of the other varieties in 1931 and lower than Red Rock and Berkeley Rock in 1932. Red Rock was higher than Bald Rock and 912203 in 1932. In 1931, Bald Rock was significantly lower than 912203 and lower than Red Rock and Berkeley Rock in 1932. In 1932, 912203 was significantly lower than Red Rock and Berkeley Rock.

Between the same varieties for the two years, there was a significant difference in only one variety, 912203. Although the protein contents were significantly different in all cases, the two seasons did not produce much effect on the comparative volumes of expansion.

THE WHEAT MEAL FERMENTATION TIME TEST

The wheat meal fermentation time ranks American Banner significantly lower than the other varieties both

years. Red Rock, in addition to being higher than American Banner also was significantly higher than all others except Berkeley Rock in 1931 and higher than 912203 in 1932.

Bald Rock was significantly different from all of the other varieties in 1931, being higher than American Banner and 912203 and lower than Red Rock and Berkeley Rock. In 1932, it was significantly higher than American Banner.

In 1931, 912203 was significantly different from all of the other varieties being higher than American Banner and lower than the other three. In 1932, it was significantly higher than American Banner and lower than Red Rock.

Berkeley Rock was significantly higher than all others except Red Rock in 1931 but, in 1932, it was only significantly higher than American Banner.

The wheat meal fermentation time test in 1932 showed fewer significant differences than it did in 1931. This is largely because 912203 and Berkeley Rock had such high probable errors in 1932.

These samples contained some mixtures of other varieties of wheat. It may be that the time is changed considerably by such small percentages of mixtures that the other tests would show no differences.

GENERAL DISCUSSION

Any one of the tests with the exception of the protein determination is sufficiently reliable to separate American Banner from Red Rock. The other varieties are so nearly alike in their reactions that the tests do not tend to separate them.

The protein determination of both wheat and flour ranked Berkeley Rock first and American Banner fifth both seasons although it did not show significant differences between them. The other three varieties were not in any definite order.

The volume of expansion is the least constant in ranking the varieties. It showed both seasons, however, that American Banner was significantly lower than Red Rock and Berkeley Rock.

Volume of loaf data from the two years indicate that Red Rock is stronger in gluten than either American Banner or Bald Rock. Bald Rock, 912203, and Berkeley Rock cannot consistently be separated from each other or from American Banner.

The wheat meal fermentation time test is the most constant in determining varietal differences of the three tests that show significant differences

between varieties. Berkeley Rock was the only variety that differed significantly between seasons. As was pointed out before, these differences may have been caused by mixtures. The other four varieties, American Banner, Red Rock, Bald Rock, and 912203 were in the same order both years and the values did not change to any marked extent.

The relative merits of the different tests are further shown in Table III which gives the number of cases in which significant differences were indicated between varieties. There were no significant differences indicated by the protein of wheat or the protein of flour. The volume of loaf and the volume of expansion indicated significant differences between varieties in five cases in 1931 and in six cases in 1932 out of a possible ten, or a total of 11 cases out of a possible twenty. The wheat meal fermentation time test indicated significant differences in nine cases in 1931 and 4 in 1932 out of a possible 10, making a total of 13 cases out of a possible 20 for the two years.

Table III. Significant differences between varieties indicated by five tests of gluten strength.

Year	Protein of wheat	Protein of flour	Volume of loaf	Expansion test	W.M.F.T. test	Possible number
1931	0	0	5	5	9	10
1932	0	0	6	6	4	10
Total	0	0	11	11	13	20

LOCATION CLASSIFICATION

The data on the four tests of gluten strength, protein content, volume of loaf, volume of expansion, and wheat meal fermentation time, which were obtained from samples from the over-state trials were analyzed statistically to determine the relative effects of environment and variety. These data are given in Tables IV, V, VI, and VII. Sections A and B of each Table include the gluten strength in units of the particular test for each variety at each location, the location averages, the variety averages, and the season averages. Section C shows the maximum differences between location averages, section D the maximum differences between variety averages, section E the maximum range of any variety at different

locations, and section F the maximum range of different varieties at the same location. Section G shows the standard deviation which was calculated from the deviation of each sample from its variety mean as described by Hayes and Garber (8). Section H shows the average deviations in units of the test from the location and the variety means. The average deviation from variety means was calculated from the individual deviations used in calculating the standard deviation. The average deviation from location means was calculated in the same manner from individual deviations from location means.

The effect of season on each test of gluten strength is shown by the differences between the season means. Three of the locations for the trials, East Lansing, Lake City, and Monroe, were the same both seasons which permits a comparison of means at these locations.

Significant differences, on the basis of probable error, are those in which the odds are 30:1 or more that the differences are due to factors other than chance.

Locations and varieties are referred to in Tables IV, V, VI, and VII as follows:

Varieties		Locations	
American Banner	A.B.	East Lansing	M.S.C.
Red Rock	R.R.	Lake City	L.C.
Bald Rock	B.R.	Monroe	Monroe
912203	912203	Augusta	Aug.
Berkeley Rock	Berk.	Eagle	Eagle
		Lake Odessa	Odessa
		Coldwater	Cold.
		Marlette	Marl.
		Jasper	Jas.

THE PROTEIN DETERMINATION

The protein content was affected more by location than by variety, as is indicated by the data in Table IV. There was a greater range between location averages both years than between variety averages. The maximum differences between high and low location averages were significant but the maximum differences between

Table IV. Percentages of protein of five varieties of wheat at six locations in the over-state trials, and other values for the statistical interpretation of the data.

A. Season of 1931												
	M.S.C.	Monroe	Lake City	Augusta	Eagle	Lake Odessa	Variety Mean	Season Mean				
American Banner	11.17	9.58	13.42	11.40	12.16	12.11	11.64					
Red Rock	10.70	9.88	14.57	11.01	14.34	11.61	12.02					
Bald Rock	12.56	10.21	13.86	12.04	12.79	12.38	12.31					
912203	10.78	10.31	14.32	11.79	13.28	12.26	12.12					
Berkeley Rock	12.07	10.50	14.63	12.11	13.79	12.74	12.64					
Location Mean	11.46	10.10	14.16	11.67	13.27	12.22		12.15				
B. Season of 1932												
	M.S.C.	Monroe	Lake City	Coldwater	Marlette	Jasper	Variety mean	Season mean				
American Banner		9.19	*	9.18	10.55	10.20	9.78					
Red Rock	9.44	9.43	9.42	10.13	11.82	*	10.05					
Bald Rock	9.68	10.29	9.59	9.66	10.94	11.75	10.32					
912203	9.96	10.79	9.91	10.24	11.40	11.06	10.56					
Berkeley Rock	10.32	10.34	9.83	10.06	12.71	11.50	10.79					
Location Mean	9.85	10.01	9.69	9.85	11.48	11.13		10.35				
C. Maximum differences between location averages				D. Maximum differences between variety averages								
High			Low			High			Low			
Year	Location	Average	Location	Average	Difference	Variety	Average	Variety	Average	Difference		
1931	Lake City	14.16	Monroe	10.10	4.06	Berk.	12.64	A.B.	11.64	1.00		
1932	Marlette	11.48	Lake City	9.69	1.79	Berk.	10.79	A.B.	9.78	1.01		
E. Maximum range of any variety at different locations.				F. Maximum range of different varieties at the same location								
High			Low			High			Low			
Year	Variety	Location	Protein	Location	Protein	Difference	Location	Variety	Protein	Variety	Protein	Difference
1931	R.R.	Lake City	14.57	Monroe	9.88	4.69	Eagle	R.R.	14.34	A.B.	12.16	2.18
1932	Berk.	Marlette	12.71	Lake City	9.82	2.88	Marlette	Berk.	12.71	A.B.	10.55	2.16
G. Standard Deviation			H. Average deviations from means									
			All Locations				All Varieties					
Year			Per cent Protein	Per cent of Season mean			Per cent Protein		Per cent of Season Mean			
1931		1.35		.45		3.7	1.08		8.9			
1932		.81		.43		4.2	.67		6.5			

*Not included in averages.

the high and low variety averages were not. There were greater differences between the protein contents of one variety at different locations than between those of different varieties at the same location. The differences between protein contents of one variety at different locations were significant but those between samples of different varieties at the same location were not. The average deviation of all samples from their location means was lower than the average deviation from their variety means.

There was a seasonal effect on protein content as is shown by the significant difference between the average protein contents for the two years. Significant differences were also shown between the location averages at East Lansing for the two seasons and between the location averages at Lake City. At Monroe, the average protein contents for the two seasons were not significantly different from each other.

THE BAKING TEST

The volume of loaf is affected less by location than by variety, as is shown in Table V. There was

Table V. Volumes of loaf of five varieties of wheat at six locations in the over-state trials, and other values for the statistical interpretation of the data.

A. Season of 1931												
	M.S.C.	Monroe	Lake City	Augusta	Eagle	Lake Odessa	Variety Mean	Season Mean				
American Banner	1710	1740	1880	1775	1795	1603	1750	1866				
Red Rock	1980	1860	1970	1960	1880	1990	1940					
Bald Rock	1735	1735	1800	1830	1940	1895	1822					
912203	1860	1960	2070	2000	2070	1820	1963					
Berkeley Rock	1803	1755	1863	1820	1930	1943	1852					
Location Mean	1818	1810	1917	1877	1923	1850						
B. Season of 1932												
	M.S.C.	Monroe	Lake City	Coldwater	Marlette	Jasper	Variety Mean	Season Mean				
American Banner	*	544	*	508	525	528	526	555				
Red Rock	606	593	591	603	617	*	602					
Bald Rock	528	540	534	529	539	526	533					
912203	508	535	553	507	510	593	534					
Berkeley Rock	600	575	597	543	554	596	578					
Location Mean	561	557	568	538	549	561						
C. Maximum differences between location averages				D. Maximum differences between variety averages								
Year	High		Low		Difference	High		Low		Difference		
	Location	Average	Location	Average		Variety	Average	Variety	Average			
1931	Eagle	1923	Monroe	1810	133	912203	1963	A.B.	1750	213		
1932	Lake City	568	Coldwater	538	30	R.R.	602	A.B.	526	76		
E. Maximum range of one variety at different locations					F. Maximum range of different varieties at the same location							
Year	High			Low			High			Low		
	Variety	Location	Vol. of loaf	Location	Vol. of Loaf	Difference	Location	Variety	Vol. of loaf	Variety	Vol. of loaf	Differ
1931	A.B.	Lake City	1880	Odessa	1603	277	Odessa	R.R.	1990	A.B.	1603	387
1932	912203	Jasper	593	Coldwater	507	86	M.S.C.	R.R.	606	912203	508	98
G. Standard Deviation		H. Average deviations from means										
		Location means				Variety means						
Year		Vol. of loaf		Per cent of season mean		Vol. of loaf		Per cent of season mean				
1931	77	84		4.5		84		3.4				
1932	19	30		5.4		14		2.5				

* not included in averages.

Table VI. Volumes of expansion of five varieties of wheat at six locations in the over-state trials, and other values for the statistical interpretation of the data.

A. Season of 1931									
	M.S.C.	Monroe	Lake City	Augusta	Eagle	Lake Odessa	Variety Mean	Season Mean	
American Banner	845	880	880	920	890	820	867		
Red Rock	980	1015	935	1000	935	1015	980		
Bald Rock	935	865	950	970	1030	945	949		
912203	975	990	1105	1080	1140	985	1046		
Berkeley Rock	990	910	1000	1050	1035	1030	1002		
Location Mean	945	932	968	1004	1006	959		969	
B. Season of 1932									
	M.S.C.	Monroe	Lake City	Coldwater	Marlette	Jasper	Variety Mean	Season Mean	
American Banner	*	875	*	905	951	952	921		
Red Rock	992	983	1081	1076	1048	*	1036		
Bald Rock	936	905	1009	848	903	902	917		
912203	855	894	926	875	942	952	905		
Berkeley Rock	1008	994	1127	963	1074	1080	1041		
Location Mean	948	930	1036	933	984	972		965	
C. Maximum differences between location averages					D. Maximum differences between variety averages				
Year	Location	Average	Location	Average	Year	Location	Average	Difference	
1931	Eagle	1006	Monroe	932	1931	912203	1046	74	
1932	Lake City	1035	Monroe	930	1932	Berk.	1041	105	
E. Maximum range of one variety at different locations					F. Maximum range of different varieties at same location				
Year	Variety	Location	Expansion	Location	Expansion	Year	Variety	Location	Expansion
1931 (1)	B.R.	Eagle	1030	Monroe	865	1931	Lake City	912203	1080
(2)	912203	Eagle	1140	M.S.C.	975				
1932	Berk.	Lake City	1127	Coldwater	963	1932	Coldwater	R.R.	1076
G. Standard deviation					H. Average deviations from the means				
Year			Location Means				Variety means		
1931	47		Expansion	Per cent of season mean		38	Expansion	Per cent of season mean	
1932	45		59	6.1		39	59	4.0	

*Not included in averages.

Table VII. Wheat meal fermentation time of five varieties of wheat at six locations in the over-state trials, and other values for the statistical interpretation of the data.

A. Season of 1931

	M.S.C.	Monroe	Lake City	Augusta	Eagle	Lake Odessa	Variety Mean	Season Mean
American Banner	27	29	38	28	25	27	29	
Red Rock	169	150	157	144	166	140	154	
Bald Rock	132	122	112	127	154	151	133	
912203	124	135	64	89	110	80	100	
Berkeley Rock	154	136	160	175	176	141	157	
Location Mean	121	114	106	113	126	108		115

B. Season of 1932

	M.S.C.	Monroe	Lake City	Coldwater	Marlette	Jasper	Variety Mean	Season Mean
American Banner	*	28	*	28	30	25	28	
Red Rock	160	133	156	138	125	*	142	
Bald Rock	146	120	148	109	113	123	127	
912203	34	99	151	103	91	65	91	
Berkeley Rock	142	118	143	129	48	118	116	
Location Mean	121	100	150	101	81	83		105

C. Maximum differences between location averages

Year	High		Low		Difference	D. Maximum differences between variety averages				
	Location	Average	Location	Average		Variety	Average	Variety	Average	Difference
1931	Eagle	126	Lake City	106	20	Berk.	157	A.B.	29	128
1932	Lake City	149	Marlette	81	67	R.R.	142	A.B.	28	114

E. Maximum range of one variety at different locations

F. Maximum range of different varieties at the same location

Year	Variety	High		Low		Difference	Location	Variety	High		Low		Difference
		Location	Time	Location	Time				Location	Time	Location	Time	
1931	912203	Monroe	135	Lake City	64	71	M.S.C.	R.R.	169		A.B.	27	142
1932	912203	Lake City	151	M.S.C.	34	117	Coldwater	R.R.	138		A.B.	28	110

G. Standard deviation

H. Average deviations from means

Year	Location means			Variety means		
	Time	Per cent of season mean		Time	Per cent of season mean	
1931	42	36.5		13	11.3	
1932	30	28.6		17	16.2	

locations than between samples of different varieties at the same location. Differences in both cases were significant.

There was but little seasonal effect on the wheat meal fermentation time, as is shown by the similarity of results for the two years. The only significant differences produced between seasons was at Lake City, and American Banner was not included in the 1932 average which may account for the high time value.

GENERAL DISCUSSION

The protein determination tends to measure differences produced by environmental conditions of location and season to a greater extent than it measures varietal differences.

The other three tests, volume of loaf, volume of expansion, and wheat meal fermentation time, tend to show varietal differences to a much greater extent than location or seasonal although significant differences are produced by changes in location.

CORRELATIONS

Coefficients of correlation were made between the different tests of gluten strength to deter-

mine whether any two of the tests tended to measure gluten strength in a similar manner and whether one of the newer tests could replace the older ones. These correlations are given in Table VIII. Section A gives the correlation coefficients between the different tests when determined on all samples of all of the varieties. Correlations of samples of American Banner, Red Rock, and Bald Rock are shown in sections B, C, and D, respectively. No correlations were determined for Red Rock or Bald Rock in 1931 because there were not enough samples of either variety.

All of the correlations in section A are positive and all are significant with the exception of those between volume of expansion and protein determination in 1931. Volume of loaf and volume of expansion were strongly correlated both years. Volume of loaf was strongly correlated with the wheat meal fermentation time and with the wheat meal fermentation time factor in 1932.

The correlations for American Banner in section B include only three significant correlations. Volume of loaf and volume of expansion show a significant positive correlation in 1931, as do volume of

Table VII. Correlations between the various tests of gluten strength.

	Vol. of loaf	Vol. of expansion	Vol. of loaf	Vol. of expansion
	1931		1932	
A. All Samples	84 Samples		106 Samples	
Protein of wheat	.44 ± .09	.33 ± .11	.48 ± .07	.51 ± .07
Protein of flour	.48 ± .08	.38 ± .09	.48 ± .08	.51 ± .07
Volume of loaf	—	.82 ± .03	—	.86 ± .03
Volume of expansion	.82 ± .03	—	.86 ± .03	—
W.M.F.T.	.66 ± .06	.64 ± .07	.78 ± .04	.69 ± .05
W.M.F.T. Factor	.63 ± .07	.62 ± .07	.74 ± .05	.66 ± .05
B. American Banner	54 Samples		43 Samples	
Protein of wheat	.30 ± .12	—	.30 ± .14	.42 ± .13
Protein of flour	—	—	.27 ± .14	.41 ± .13
Volume of loaf	—	.58 ± .09	—	.79 ± .06
Volume of expansion	.58 ± .09	—	.79 ± .06	—
W.M.F.T.	.52 ± .10	.24 ± .13	*none	*none
W.M.F.T. factor	—	—	*none	*none
C. Red Rock				
Protein of wheat	—	—	.10 ± .22	.16 ± .21
Protein of flour	—	—	.09 ± .22	.21 ± .21
Volume of loaf	—	—	—	.38 ± .19
Volume of Expansion	—	—	.38 ± .19	—
W.M.F.T.	Not enough samples	—	.17 ± .21	.07 ± .22
W.M.F.T. factor	—	—	.12 ± .22	.02 ± .22
D. Bald Rock	for correlations			
Protein of wheat	—	—	.20 ± .19	.12 ± .19
Protein of flour	—	—	.10 ± .19	.05 ± .20
Volume of loaf	—	—	—	.12 ± .19
Volume of expansion	—	—	.12 ± .19	—
W.M.F.T.	—	—	.03 ± .20	.03 ± .20
W.M.F.T. factor	—	—	.07 ± .20	.03 ± .20

*Not determined because most of the samples were in a single class when tested by the W.M.F.T. test.

loaf and wheat meal fermentation time. In 1932, there is a strong positive correlation between volume of loaf and volume of expansion.

The correlations for Red Rock and Bald Rock, in sections C and D, do not show any significant correlations.

If all samples of the five varieties are combined, the data give positive correlations, of which most are significant, and some are strong. If the values from only one variety are used, the data give very few significant correlations. The range in gluten strength within any one variety is probably so short, and the variability in methods of measuring gluten strength so great, that the correlations in most cases are not significant. There was significant correlations both years between volume of loaf and volume of expansion for American Banner. Variations in technique may have had less effect on American Banner doughs than on doughs from the stronger varieties which did not indicate significant correlations between any tests. In other words, the stronger the gluten strength of a variety, the greater is the chance for variation due to methods.

Correlations between volume of loaf and volume of expansion indicate that the two tests are strongly correlated and that the expansion test can be used with success to determine the baking strength of flours. It seems,

however, that the expansion test has little, if any, advantage over the baking test. Less flour is used in baking "pup" loaves than is used in the expansion test. The baking can be done as rapidly as the expansion can be determined. As many as 30 loaves were baked in a day, and it would be difficult to make as many or more expansion tests. The routine of the baking is easier to follow than that of the expansion test because a great number of readings have to be made at very close intervals if many expansions are made at one time. With the exception of an oven, just as much equipment is needed for the expansion test as for baking. The volume of loaf is just as accurate as the volume of expansion as is shown by their coefficients of variability.

Correlations between the wheat meal fermentation time and the volume of loaf indicate that the two tests tend, to some extent, to measure gluten strength in a similar manner. The wheat meal fermentation time has many advantages which the baking test does not have. Flour does not need to be milled and very small amounts of material, in relation to that needed for baking, are

required. The test is also more simple, more rapid, and requires much less equipment than is needed for baking. These advantages make the wheat meal fermentation time test valuable in the early selection of wheat strains in plant breeding work.

SUMMARY

Methods of measuring the gluten strength of wheat, with particular attention given to the needs of the plant breeder, have been studied in this investigation.

Four tests of gluten strength, the protein determination, the baking test, the expansion test, and the wheat meal fermentation time test, were made on 84 samples of wheat in 1931 and on 106 samples in 1932.

The objects were, first, to determine whether different varieties of wheat can be separated into classes of gluten strength by these tests; and second, whether the same variety would produce differences in gluten strength, measurable by one of these methods, when produced under unlike environmental conditions.

The protein determination and the baking test long have been used as methods of determining gluten strength. The expansion test and the wheat meal fermentation time test are rather new and are not thoroughly tested.

Data from the various tests were analyzed statistically. The relation of the various tests to each other were determined by the coefficient of correlation. Means and single determinations were compared on the basis of their probable errors.

The protein determination failed to separate the varieties into classes either year. The variety means in 1931, as well as the season means, varied significantly from those of 1932. The protein determination was not strongly correlated with any other test in any case.

The baking test separated American Banner and Red Rock into different classes of gluten strength both years. Red Rock was also higher than Bald Rock both years. Berkeley Rock and 912203 were not consistently significantly different from each other or from the other varieties. Location produced significant differences

in the same variety of wheat. These differences, however, were smaller than those produced between varieties. If all samples were combined, the baking test was strongly correlated with the expansion test both seasons and with the wheat meal fermentation time test in 1932.

The expansion test separated American Banner from all other varieties in 1931 and from Red Rock and Berkeley Rock in 1932. In 1931, the mean of only one variety, 912203, was significantly different from its mean in 1932. Location produced significant differences in the expansion test. These differences, as in the baking test, were smaller than differences produced by varieties. The expansion test, as indicated before, was strongly correlated with the baking test. There were significant, but not strong correlations, between the expansion test and the wheat meal fermentation time test if all samples were combined.

The wheat meal fermentation time test ranks four of the varieties in the same order both years and is the most constant of the tests in showing varietal differences. More significant differences are shown by

this test than are shown by any of the others. Locations have less effect on the time than do varieties. The test, both years, showed significant correlations with volume of expansion, with the volume of loaf in 1931, and also a strong correlation with the volume of loaf in 1932, if data including all samples were used.

CONCLUSIONS

1. Varieties affect the protein content of Michigan soft winter wheats less than do locations or season.
2. Varieties affect the volume of loaf more than do locations or seasons. The baking test, using "pup" loaves, is probably more desirable than the expansion test as a measure of gluten strength of soft wheats.
3. Varieties affect the volume of expansion more than do locations or seasons. The expansion test does not have enough advantages to recommend its use in place of the baking test, although it tends to measure gluten strength in a very similar manner.

4. Varieties affect the wheat meal fermentation time more than do locations or seasons. The wheat meal fermentation time test is the most constant of the tests in evaluating varieties. It tends to measure gluten strength in somewhat the same manner as do volume of loaf and the expansion test. The test should be very valuable in early selection of varieties because of the small amount of grain needed for the test, the rapidity with which the test can be made, and the ability of the test to determine varietal differences.

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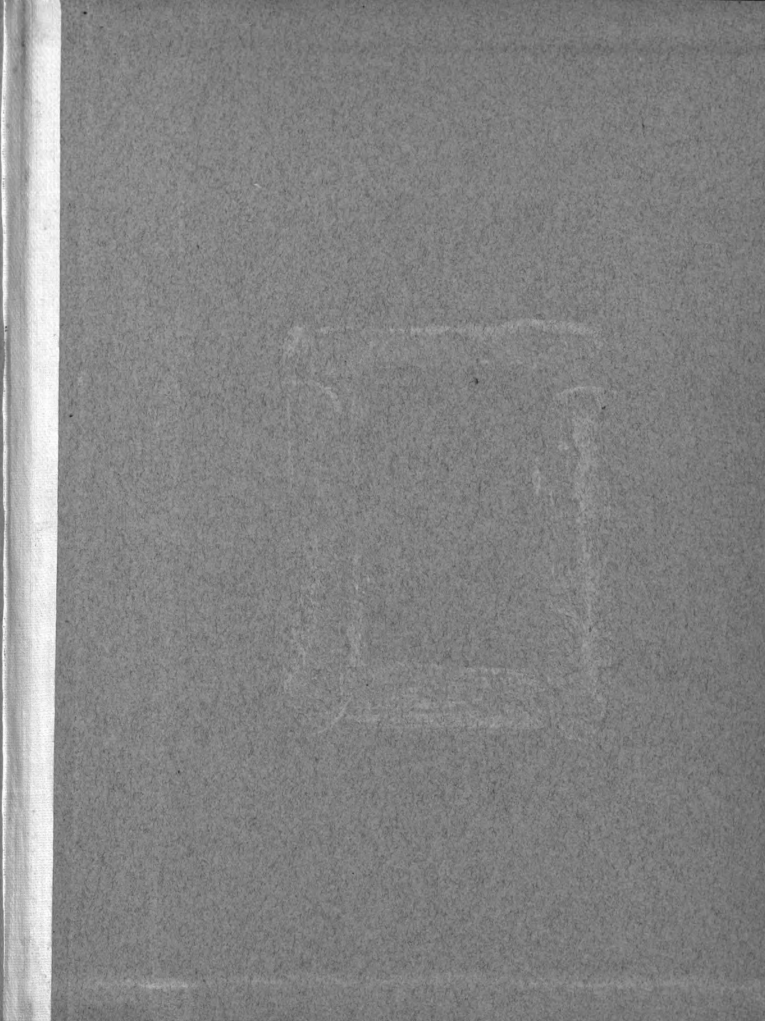
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