

**THE WHEAT MEAL FERMENTATION TIME TEST AND ITS
VALUE IN PLANT BREEDING**

by

FREDERIC TYSON DINES

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INTRODUCTION

The present day plant breeder must have a thorough knowledge of the plant which he is endeavoring to improve. In addition to the necessity of securing strains that are more desirable from the agronomic viewpoint, and also resistant to various diseases and insects, he must strive to produce strains of superior quality. To the wheat breeder the latter requisite is a major problem.

In the past many efforts have been made to improve the wheat plant. However, until recently, attempts at improvement have been directed primarily toward producing varieties of superior agronomic characters rather than increasing the quality of the grain for the bake shop. Selection based on quality had probably not gone hand in hand with selection for other desirable properties due to the fact that no method was available by which the plant breeder could effect any large degree of progress in the quality of the grain of the wheat plant (Lyon, 1905).

Farrer, a pioneer Australian wheat breeder, in the early 1900's stated "before we can make any considerable progress in improving the quality of the grain of the wheat plant we shall have to devise a method for making a fairly correct quantitative estimate of the constituents of the

grain of a single plant and yet have seeds left to propagate from that plant" (Lyon, 1905).

Until comparatively recent years the wheat breeder has had no simple method by which the baking quality of wheats in the early stages of development could be determined accurately. Early studies on kernel appearance and texture to determine quality were not satisfactory. Such tests as the chewing test and gluten washing test were used with some degree of success. The necessity of continuing all promising lines until a sufficient amount of grain for a baking test was available made the task of breeding wheats of superior quality an enormous one. The procedure was not only laborious and wasteful, but the possibilities of success in combining baking quality with yielding ability were remote due to the inability of growing large enough numbers of strains in the nursery as well as the impracticability of testing any large number of lines by baking (Breakwell, 1934). There is beyond any doubt difficulty in combining baking quality with other desirable characters, but the development of such wheats is not impossible. The number of high quality cross-bred wheats now in commercial production illustrates the possibility of such combinations.

It has long been the desire of the plant breeder for a simple, quick, and reliable test for evaluating quality in the early generations. The test should be both rapid and

easy in operation. However, the detailed characteristics of the wheat samples from the quality viewpoint need not be revealed. It would be sufficient for the purpose if it would distinguish accurately between wheats of good, medium, and poor baking quality (Breakwell, 1934).

In recent years several tests of quality applicable to small quantities of wheat have been developed. Some of these tests have been used rather extensively by plant breeders to estimate the quality of wheat strains in the early stages of development. The tests are of two major types; namely, (1) chemical and (2) physical.

Of the chemical tests of wheat quality applicable to small quantities of grain the determination of the nitrogen content and reporting it as in the European countries and the conversion of the nitrogen content into protein percentage, as in other countries, are examples.

Several different types of physical tests are in use at the present time to indicate quality in wheat when only a small quantity of grain is available. One type is that of measuring the plasticity and elasticity of doughs as is done by such tests as the Chopin Extensimeter (Chopin, 1927), the Bühler Comparator (Swanson, 1936b), and the Engledow Distensometer (Engledow, 1928). The principle of such tests is that the greater the plasticity and elasticity of the doughs the stronger the wheat.

A physical test based upon the amount of water imbibed by the gluten when it is immersed in a weak lactic acid solution, namely, the Berliner and Koopman Swelling Method, is much used in Europe as a simple method of determining the gluten quality (Swanson, 1938). The more superior the colloidal properties of the gluten the more water will be imbibed.

Another type of test, that cannot be properly called a strictly physical test, that attempts to measure wheat quality when only a small quantity of grain is available is that based upon the time that a dough mass takes to break down in water such as in the Saunders test (Saunders and Humphries, 1928), the Pelshenke test (Pelshenke, 1933a), the Cutler and Worzella wheat meal fermentation time test (Cutler and Worzella, 1931), and the Kansas State College modification of the Cutler and Worzella wheat meal fermentation time test (Swanson, 1937). The longer the time that it takes for the dough mass to break down in water the stronger the wheat is considered to be.

The underlying principle of these tests based upon the time that a dough ball takes to break down in water appears to have been developed by Saunders in Coxes Lock Mill, Weybridge, England, (Wynot, 1926 and Saunders and Humphries, 1928) who developed the Saunders process on the basis of his observations in connection with his work of testing

wheat and flour for quality. In this test refined flour is used.

Pelshenke (1933a) developed the test bearing his name in which whole wheat meal is used in place of flour. Workers in wheat improvement, following the principles of the Pelshenke test, adopted the use of whole wheat meal in place of flour for the reason that when wheat meal is used the "time" is much shorter (Swanson and Parker, 1935). The Cutler and Worzella wheat meal fermentation time test and the Kansas State College modification are examples.

Winter and Gustafson (1934) have developed a modification of the wheat meal fermentation time test which in place of measuring the time that it takes a dough mass to break down in water the quantity of water displaced by the expansion of the dough mass during fermentation is measured. The greater the amount of water displaced the stronger the wheat is considered to be.

The present investigation was undertaken in order to bring together and summarize data on the wheat meal fermentation time of varieties and hybrid strains of wheat obtained previous to and since the investigation was begun in the fall of 1936. From these data an attempt has been made to arrive at a conclusion as to the value of the wheat meal fermentation time test to the plant breeder in selecting high quality strains of wheat early in the breeding program.

REVIEW OF LITERATURE

Value of the "Time Test"

There has been considerable disagreement among investigators as to the value of and the meaning of the "time test". (1) Swanson (1937) states that the reliability and especially the meaning of the "time test" results are far from settled. Chapman and Parquhar (1934a) are of the opinion that the "time test" does not give results that are proportional to the quality of the flour when judged by the baking test score. These investigators state further that a very high "time" does not necessarily mean that the flour obtained from the wheat will be of a high baking quality. On the other hand Cutler and Worzella (1937) believe that the "time test" is capable of giving very consistent results in appraising the quality of varieties of soft and semi-hard wheats. Griffiths and Cayzer (1934) do not claim that the "time test" gives an adequate or accurate conception of the baking quality of a given wheat variety, but they do believe that it gives an accurate picture of the protein

(1) The words "time test" will be used hereafter instead of the longer expression of the wheat meal fermentation time test, and the word "time" will be used when reference is made to the fermentation time of a variety.

quality, which though not the only factor, is certainly the main one affecting the baking quality.

Most of the investigators agree that the "time test", although not revealing all of the detailed characteristics of wheat samples, does distinguish fairly accurately between wheats of strong, medium, and weak strength. The accuracy with which the test evaluates samples of wheats within these three major groups is yet questionable.

It is admitted that other quality tests, including the baking test which has always been looked upon as the final criterion of wheat quality, are not by themselves adequate to judge definitely that any one wheat is better than another. Frankel and Donald (1933) state that the wheat breeder must have a test which will determine in one season the inherent gluten quality. These investigators further state that the baking test does not fit this need. Wheats must be tested many times and over a period of years to reach a definite conclusion, on this basis.

The "time test", regardless of criticism by a few investigators, is widely accepted as a reasonably reliable test for quality testing of wheat (Hickinbotham, 1934b). Objections must always be taken to any attempt to measure in total such a complexity as quality of a given wheat variety by means of a single test (Hickinbotham, 1934a).

This investigator states that it is not reasonable to suppose that the sum of the behavior of the numerous constituents in flour, which are subjected in dough making to the activities of a living organism, the yeast, and to reaction with the products of such activities, may be completely assessed in such a simple way.

Simple as the "time test" may be, the simplicity is certainly not that of making mud-pies as indicated in a journalistic account of the test. Despite the apparent simplicity of the "time test", it should be performed in just as careful a manner as the baking test or any other laboratory test.

Under certain circumstances, such as those imposed upon the wheat breeder by the limited amount of material available, only a simple test such as the "time test" can be used to select the best of the strains of wheat hybrids being studied in the nursery.

In the evolution of new varieties of wheat by hybridization large numbers of individual plants are grown, each of which probably differs in grain quality from the others. Some plants can be discarded on the basis of kernel texture when such would not meet the grain grading standards, but of differences in the quality of the gluten of those individual plants which have hard or vitreous grain the eye

can give no indication (Griffiths, Norris, and Wenholz, 1933).

Modern wheat breeding, therefore, requires a more extensive application of milling and baking tests which may be practiced not only in the final stages of breeding, but also in the period of primary selections when only small amounts of grain of a given strain are available (Shibaev, 1934). The "time test" is now being used by some wheat breeders for this purpose. The Wheat Research Institute at Christchurch, New Zealand uses the "time test" at the plant breeding station for testing the early hybrid generations, but in the early stages of yield-trials the Farinograph takes precedence over all other tests including the baking test (Hilgendorf, 1937). Breakwell (1934) states that the "time test" is the only test yet devised suitable to the needs of the plant breeder.

In most countries the buying of wheat is done by use of grades which are based practically without exception on outside quality features such as bushel weight, kernel texture, etc. However, in Germany probably the most modern and comprehensive standards for buying of wheat are practiced. Payment is made according to the quality of the wheat purchased (Pelshenke, 1937). The German system takes account of, for the first time, the baking strength of

wheat and its blending value. Wheats are classed as A, B, and C; A-wheats are those which due to their gluten quality are suitable to be blended with inferior quality wheats, B-wheats are those of a medium quality corresponding to German trade flours, and C-wheats are those that must be blended with better quality wheats if they are to be ground and baked into bread (Pelshenke, 1937). Premiums are paid for "gluten wheats" which are A or B-wheats having certain minimum quality standards. These quality standards are as follows: gluten wheat must have (1) at least twenty per cent wet gluten, (2) a swelling figure of fifteen, (the swelling number is that of Berliner and Koopman (Swanson, 1938)) and (3) a wheat meal fermentation time of at least twenty-five. If a wheat does not reach these minimum figures, it may be recognized as "gluten wheat" if a total quality figure of at least 3250 is obtained from the total of:

% moist gluten	x	25	=	_____
swelling figure	x	100	=	_____
"time" in minutes	x	50	=	_____
Total			=	3250

Thus separate values may compensate each other. This manner of buying wheat is entirely new and illustrates the possible value of the "time test" in grain buying.

In the crop season of 1935-36 the Ministry of Agriculture of Argentina (1936) established the types of the

Official Standards for wheat, oats, barley, rye and linseed. The Standards for each grade and type were formed by taking a part of each sample in proportion with the declared amount, which represents the average of the classified production in each of the three zones; namely, (1) Rosafé, (2) Buenos Aires, and (3) Bahía Blanca. Each type of each zone was thoroughly tested as to commercial qualities, such as test weight, foreign material present, smutted kernels present, etc., and as to industrial qualities, such as milling, baking, plastic, and gassing qualities. The "time test", using the Pelshenke method, was performed along with other quality measures for determining plastic qualities.

Cutler and Worzella (1936) state that a few millers in Indiana, Ohio, and Michigan are now using the "time test" as an aid in buying and binning wheat for their regular milling operations. These investigators are of the opinion that the test is of much promise in and will render an important service to the milling industry as, due to the small quantity of grain required, and the ease, simplicity, and quickness in making the test, large numbers of samples of wheat can be tested in a short time to determine their fitness for specific purposes, at a low cost. Griffiths and Cayzer (1934) state that in Australia the "time test"

is being used by many millers who desire a simple test of protein quality for purposes of purchasing and blending wheat.

Cutler (1932) finds that the possibilities that the "time test" offer to the miller for making blends are very encouraging, although further investigations are necessary before definite conclusions can be made. This investigator states that data indicate that as the amount of meal of a high or long "time" wheat is reduced the "time" or quality of the blends is correspondingly reduced, and furthermore, the observed reduction in "time" shows a remarkable agreement with the expected. Cutler (1932) states that the deviation in most of the cases of the observed from the expected is within the recognized standard, viz., ten percent.

To further show the practical value of the "time test" to millers, Cutler (1932) states that the cost of making the wheat meal fermentation time test on a group of 880 wheat samples tested in the Department of Agronomy of Purdue University was 7 cents per sample.

The cost of the "time test" is very reasonable and should not be prohibitive to progressive millers. The estimate given above does not include the overhead costs for grinder, cabinet, beakers, distilled water, etc.

Accuracy of the "Time Test"

In order to answer the question of the accuracy of the "time test" Cutler (1932) performed a series of experiments in which some 180 tests were made on a soft wheat variety and the variability was measured by the standard deviation (S.D.) and coefficient of variability (C.V.) respectively, as follows:

M (mean)	-	81.9	±	0.398	minutes
S.D.	-	7.92	±	0.282	minutes
C.V.	-	9.69	±	0.34	per cent

These results indicate that less than ten per cent variability may be expected among tests made from the same variety of wheat. Cutler (1932) states that when more than a ten per cent variability in "time" is obtained on a carefully performed test, it is possible that there is a wide variability in texture, or that the wheat is genetically impure. This investigator cites the example of the variety Michigan Amber which has given somewhat variable results in some years. Experience has shown that it is rather variable and probably impure in that it is possible to select from it strains manifesting a wide difference in "time", indicating instability with respect to quality.

Further evidence of the accuracy of the "time test" is shown by the fact that varieties tend to rank the same way

in different seasons (Cutler and Worzella, 1937).

Belmonte and Fischer (1935), having subjected the "time test" to an exhaustive statistical study, deemed the accuracy of the test as sufficient and have tentatively considered it as an index of industrial value.

Factors Influencing the "Time"

Chapman and Farquhar (1934a) state that the age of the wheat previous to the grinding affects the ultimate "time". These investigators working with Australian wheats have found that as the wheat ages the "time" lengthens.

Cutler and Worzella (1936) follow the practice of not testing wheats for quality by the "time test" until at least six weeks following wheat harvest, inasmuch as wheat continues to undergo changes in quality and condition for some time after harvesting. When the qualities of wheats being tested are to be directly compared, Cutler and Worzella (1936) perform the tests in a relatively short period of time. This practice is substantiated by Swanson and Parker (1935) who state that since wheat is biologically active the test should be made a considerable period after harvest and that when a number of samples are to be tested for "time" the work should not be spread over too long a period.

By increasing the amount of moisture in the wheat prior

to grinding, investigators have found that great differences in "time" are obtained. The data presented in Table 1 indicate that within certain limits the increase in the amount of moisture prior to grinding of the wheat causes the "time" to increase (Chapman and Farquhar, 1934a).

Chapman and Farquhar (1934b) consider that the moisture content of the wheat has a marked influence on the "time", and that unless the moisture is known, the "times" obtained by the test are of very limited value. These investigators have found no definite ratio between the percentage increase of moisture of the sample and the percentage increase in the "time" of the test.

Table 1 -- Effect of increasing the amount of moisture in the wheat prior to grinding.

Variety	Condition I		Condition II	
	H ₂ O %	"Time" Minutes	H ₂ O %	"Time" Minutes
Minister	9.4	93	13.4	103
Quality	10.0	47	13.7	55
Florence	9.8	46	13.3	50
Standard milling blend	10.6	45	13.7	50
Quality (bleached)	9.4	33	12.5	44
Baringa	9.9	32	13.2	38
"Fair Ave. Quality" 1933-34	9.9	26	15.0	33

Swanson and Parker (1935) state that the reason longer "times" are obtained by increasing the moisture content of the wheat sample prior to grinding is that more fine and less sharp material is produced, finer material having longer "time" than sharp material.

Swanson (1937) found that the "time" is increased by addition of water to the wheat prior to grinding only to that point where further addition of water stimulates the process of germination. The data obtained by Swanson are given in Table 2.

Table 2 -- Effect of treatment of wheat with water

Treatment	Variety			
	Tenmarq	Turkey	Quivira	Early Blackhull
"Time" in minutes				
Check	144	53	76	61
24 hours, 16% water (a)	152	75	101	67
24 hours, 40% water (a)	140	46	49	63
72 hours, 40% water (b)	67	34	36	37

(a) tempered for twenty-four hours before air drying.

(b) tempered for seventy-two hours before air drying.

Addition of water to make the moisture content 16% had little effect on Tenmarq and Early Blackhull, but increased the "time" of Turkey and Quivira markedly. When the moisture content of the wheat was brought to 40% for 24 hours the "time" of Turkey and Quivira was shortened, but not for

Tenmarq and Early Blackhull. Correspondingly short "times" were obtained from the samples tempered for 72 hours at a 40% moisture content.

The grinding process is an important phase of the "time test". The method of grinding as well as the degree of granulation affect the ultimate "time".

Pelshenke (1931) considers that high speed grinders are not desirable as there is the danger of "dead grinding", i.e. over-grinding. This investigator recommends a grinder that does not revolve more than 100 revolutions per minute. No data are available to illustrate the differences in "time" when a slowly revolving grinder is used in comparison to high speed grinders. In the opinion of Pelshenke (1931), the uniformity of the grinding speed is also a factor to be considered. Electrically powered grinders are therefore desirable.

Granulation of the wheat meal has a decided effect upon the "time". Data obtained by Bayfield (1935b) in which a 13.8% protein sample of Red Rock wheat was ground using three screens are presented in Table 3.

Table 3 -- Effect of various
Wiley sieves upon "time"

Doughball size	Screen used		
	0.5 mm.	1.0 mm.	2.0 mm.
	"Time" in minutes		
10 g. doughballs	over 300 (a)	202	164
5 g. doughballs	243	101	111

(a) * dough not entirely down after 18 hours.

The largest size screen gave a coarse meal and the finest screen gave a meal resembling a very granular low grade flour. These data show that the coarsest meal with the ten gram doughball received support from the beaker wall, thus prolonging the "time". The very coarse five gram doughballs also seem to have received some support. It is evident that a medium fine meal is the best for the test.

Swanson and Parker (1935) and Swanson (1937) state that as a rule the finer the meal is ground the longer the "time" will be, and the coarser or the more sharp the meal is the shorter the "time" will be. In a coarse meal the endosperm is in chunks and does not contribute as much to the dough mass as when the meal is fine.

To illustrate the effect of the variation in granulation by grinding, the data in Table 4 (Swanson, 1937) are presented.

Table 4 -- Effects of fineness of granulation on the "time"

Variety	Granulation		
	0.5 mm.	1.0 mm.	1.5 mm.
	"Time" in minutes		
Tenmarq	191	171	129
Turkey	116	100	72
Quivira	127	100	70
Early Blackhull	74	69	64

These data indicate that the method of grinding is not as important for varieties with inherently short "time" as for those with longer "time." Regardless of the degree of granulation the "time" was longest for Tenmarq and shortest for Early Blackhull. The data on the two intermediate varieties Turkey and Quivira indicate that in varieties which differ little in "time" the degree of granulation may entirely obscure varietal differences. Since the degree of granulation may have a greater effect on "time" than differences due to variety, the uniformity of granulation becomes exceedingly important (Swanson, 1937). There are, however differences in the physical texture of the kernels from various wheats which cause them to pulverize differently in making the meal regardless of the uniformity in the grinding procedure (Swanson and Parker, 1935). Hard wheats tend to grind into sharp,

coarse fragments while soft wheats tend to grind into soft, flaky fragments. This in itself could have an effect on the "time" without any other differences in the quality inherent in the endosperm (Swanson and Parker, 1935).

Investigations have shown that the "time" obtained is not the same if tests are made several days after grinding as if they were made the same or the next day. Cutler and Worzella (1936) found that the quality of ground wheat changed more rapidly than unground wheat, and that it varies to some extent with the variety of wheat. Swanson (1937), testing the meal from Tenmarq wheat ground the same day and after storing for various periods, found marked differences in "time". The data given in Table 5 illustrate the differences that this investigator obtained when the period between grinding and making the "time test" was varied.

The data presented in Table 5 show that the effect of storing after grinding is marked as there was a range in "time" from 149 to 242 minutes.

Table 5 -- "Time" obtained when samples were tested soon after grinding, as compared with testing after storing for various periods

Ground a short time before testing		Ground Nov. 7	
Date tested	"Time"	Date tested	"Time"
Nov. 8	143	Nov. 7	153
" 9	141	" 9	149
" 11	148	" 13	173
" 13	147	" 14	179
" 18	136	" 16	179
		" 21	176
Dec. 13	143	" 23	198
" 26	140		
" 31	140	Dec. 3	206
		" 6	210
Jan. 6	149	" 16	234
" 7	139	" 27	210
" 9	138		
" 14	148	Jan. 6	242
" 16	135		

The cause of this marked increase in "time" when the meal is stored is not fully understood (Swanson, 1937).

Some tests have shown that more consistent results are obtained if there is an interval of several days between grinding and performing the "time test" (Swanson, 1937). It is the general practice to grind the meal not more than two days before the test is to be made.

In experimenting with various wheat varieties Swanson (1937) found that the amount and manner of working the dough made a difference in "time". It is well known among

investigators of wheat quality that the amount of mixing required to develop dough varies with the variety of the wheat. The optimum mixing time is inherent in the wheat variety from which the wheat meal or flour is made. There is no fixed rule which can be established to guide one in the time to mix a dough for "time" testing. Careful observation of the dough while mixing is the best available guide.

Since it is desired to adapt the "time test", especially in wheat improvement work, to small samples, Swanson (1937) finds that a preliminary absorption determination is not practical. Investigators have found it best to start with a little less than the probable amount of water needed, then as the dough is being developed either by hand or in a mechanical mixer the approximate amount of additional water necessary can be added. Care must be exercised in determining the amount of water to add to the dough. Chapman and Farquhar (1934a) have found that by increasing the amount of water used to mix the whole meal into a dough, the "time test" on a sample of Gurka wheat gave a higher reading, but the difference was not more than the limit of error allowed by the test, viz. ten per cent. Cortabarría (1935) suggests that for convenience, a fixed amount of water (62.5%) could be used in mixing the whole wheat meals.

The concentration of carbon dioxide gas in the water in which the doughball is placed has been found by Swanson (1937) to affect the "time". This investigator noted that the "break" in the doughball and the evolution of carbon dioxide from the process of fermentation always took place from the under side of the doughball. Thus, since carbon dioxide is soluble in water, the escape is facilitated by its absence in the water and hindered by its presence. To learn the effect on "time" of placing doughballs of the same variety in various concentrations of carbonated water Swanson (1937) prepared different concentrations by mixing fully saturated carbonated water with various amounts of carbon dioxide free water. The proportions used were: (1) all carbonated, (2) two to one, (3) one to two, and carbon dioxide free water. For a comparison one set of containers was used containing ordinary distilled water which contains a small amount of carbon dioxide. These results are given in Table 6.

Table 6 -- Effect on "time" of floating dough balls in various concentrations of carbonated water

Variety	All Carbon- ated	2 to 1	1 to 2	CO ₂ free	Ordinary distilled
	"Time" in minutes				
Tenmarq	288	183	145	135	142
Early Blackhull	77	66	61	51	57

The data in Table 6 indicate that the presence of carbon dioxide in the water hindered the escape of carbon dioxide from the fermenting doughball, slowed down the fermentation process, and as a result increased the "time" in proportion to the concentration of the carbonated water. The effect was greater on Tenmarq than on Early Blackhull.

Temperature affects "time" greatly since the biological agent yeast is used in the meal. An increase in the temperature stimulates the yeast organism which stimulation hastens the process of fermentation and ultimately shortens the "time". Investigators have been using a set degree of temperature for "time" determinations. Cutler and Worzella (1936) make the "time test" at a temperature of 80° F. while in the K.S.C. modification (Swanson, 1937) a temperature of 30°C. (86°F.) is used. To maintain a given temperature investigators use temperature controlled cabinets provided with both heating and cooling devices. Swanson (1937) states that it is also necessary to have the room at a fairly even temperature.

A small variation in dough temperature is not serious in that the potential calorie value of the relatively large quantity of water in the container is large in comparison with the small doughball (Swanson, 1937).

Bayfield (1935b), Hickinbotham (1934a), and Pelshenke (1930) have found that the use of small containers may give support to the doughball and thus lengthen the "time". In addition Bayfield (1935b) shows that varying amounts of distilled water may cause a variation in the doughball "time". The data of Bayfield in Table 7 indicate that increasing the diameter of the container causes a large change in "time" when one uses a ten gram doughball.

Table 7 -- Effect of vessel diameter and volume of water upon "time" (13.8% protein Red Rock wheat, averages of 10 tests)

Am't. of Water Used	Vessel Dia.	"Time" 10 g. meal	"Time" 5 g. meal
cc.	cm.	Min.	Min.
Varying volumes of water			
80	5.3	205 ^a	83
120	5.3	177 ^a	81
200	5.3	173 ^a	76
Varying diameter of vessel			
80	5.4	202 ^a	85
120	6.6	85 ^b	87
200	7.4	76	84

a= "time" prolonged by vessel walls supporting dough mass.

b= one replication partially supported by vessel walls.

The data in Table 7 indicate that increasing the diameter of the beaker causes large changes in "time" with the ten gram sample. With this size ball varying the amount of

water alters the "time" but not as extensively as when the size of the vessel is changed.

Results obtained on a test made to gain further information regarding the influence of the size of the doughball on "time" are presented in Table 8 (Bayfield, 1935b). A series of wheats consisting of three varieties each grown at the same twenty locations in 1933 were tested in quadruplicate, using both the ten and five gram doughballs. The varieties used were Red Rock, a strong soft red winter wheat, Trumbull, a medium strength soft red winter, and American Banner, a weak white winter wheat. During these tests observations were made to note any support given the doughball by the vessel wall.

Table 8 -- A comparison of 10-and 5-g. doughballs
(Average results from 20 samples of each variety)

	Variety			Average 60 Samples
	Red Rock	Trumbull	American Banner	
Wheat protein %	11.2	11.0	10.4	10.9
Loaf volume, cc.	623	607	563	597
Time, 10 g.	133	57	33	74
5 g.	65	51	34	50
No. of samples supported by vessel,				
10 g.	15	2	0	
5 g.	0	0	0	

The data given in Table 9 indicate that the smaller sized doughballs tend to give the longer "time" when the vessel size is not a disturbing factor (Bayfield, 1935b). The data given also show that individually mixed doughballs give "time" readings which are different from "time" of doughballs formed by halving a single larger dough.

Determining the end point of the disintegration of the dough mass is a factor that may prove to be of some difficulty and result in a source of error (Wilson, Markley, and Bailey, 1933). The variation in types of disintegration is wide. The strong gluten wheats, generally the hard wheats, form dough masses during fermentation that tend to cover the surface of the water in a flat disc-like mass, while the weaker gluten wheats, generally the soft wheats, assume a spherical form. Swanson (1937) states that the end point is easier to observe when the "time" is short than when long.

This investigator also states that in long "time" doughballs, (1) the doughballs may start to droop around the edges and a part of the edge break away, or (2) the edges of the doughballs may droop and curl resulting in the whole mass sinking, or (3) thin bag-like films may form on the under side and break. Cutler and Worzella (1936) state that the doughballs of medium strong gluten wheats disintegrate

by, (1) pieces of different sizes breaking away, or (2) the bottom part of the ball may all fall away, or (3) the doughball may become "water-logged" and sink in a mass. These investigators find that doughballs from the weaker gluten wheats present a markedly different type of disintegration than the strong or medium strong wheats. They state that in the weaker gluten wheats minute dough particles begin to fall off in one or more places and this proceeds until in one to three minutes the particles become so numerous as to give the appearance of a "shower". Because of these vast differences in the way disintegration manifests itself in different wheats, the operator needs a large amount of experience in judging the behavior of the doughball "time".

Table 9 -- Comparison of two methods of making doughballs

Variety	Wheat % Pro- tein	"Time" in minutes		
		Undivid- ed 5 g. dough	10 g. dough divided in half	5 g. dough divided in half
Red Rock	12.8	62	59	69
Bald Rock	12.9	57	47	54
Michigan Amber	13.7	53	51	62
Nabob	12.1	48	42	45
Trumbull	12.2	39	39	43
Kharkov	12.8	36	33	39
Gladden	12.7	35	31	42
Fultz	12.3	33	27	35
Fulhio	12.9	32	29	31
American Banner	11.4	30	24	24
Average	12.6	43	38	44

The influence of enzymatic action on the "time" has been little studied by any investigators. Swanson and Parker(1935) reported that samples of wheat cut early, when moisture content was high, had higher diastatic activity and longer "time" than the samples cut later, when moisture content was lower. The samples of wheat were brought to the same moisture content before "time testing". These investigators state that in other experiments malted wheat flour or meal from germinated wheat was added to the mixture in making the doughball to increase the diastatic activity. Increasing the diastatic activity by these methods did not consistently influence the "time". The writer found no reports regarding the influence of proteases on the "time".

As one of the primary purposes of the tests based upon the time of a dough mass to break down in water is to shorten the time required to obtain the quality information on a given wheat, whole wheat meal instead of flour is now used by most investigators. It may be that at the very beginning in the development of the test it was shunted in the wrong direction due to this desire to save time (Swanson and Parker, 1935). These investigators state that the "time" obtained on flour is not the same as that obtained on the wheat meal. They state that after all, it is the flour which is used in bread making, and not the meal. Proof that

results obtained on meal can be interpreted in reference to the flour is not too convincing.

The evidence indicates that by using wheat meal the "time" is shortened considerably when weak wheats are being tested but not markedly when strong wheats are used. By using flour the "time" on different varieties of wheat is more nearly in the same range than when wheat meal is used.

Pelshenke (1931) states that the gas retention and gas production ability of wheat meal or flour are the two main factors affecting the baking quality. The gas retention factor is dependent upon the gluten quantity and quality, especially quality, and the gas production factor is dependent upon the ability of the wheat meal or flour to furnish sufficient sugar as food material to the yeast during the dough fermentation. The gas holding power of the dough may be used as a measure of gluten quality if doughs are used which have a continuous, uniform gas development. Pelshenke (1931) holds that flours show a considerable difference in their gas-producing power and are, therefore, not fitted for this determination of gluten quality. On the other hand, according to Pelshenke (1931), gas development in whole meal doughs is very uniform, if the wheat has not germinated, and for this reason the gluten quality of the grain may be determined in this

manner without testing the flour.

To learn the effects of various wheat substances on the "time" Swanson (1937) added bran alone, shorts alone, and a mixture of bran and shorts to separate samples of flour. Bran extracted with water and the extract of this bran were also used. The bran and shorts were from the same wheat variety as the flour used. A commercial sample of wheat germ was also added to the flour. The bran and shorts were ground to the usual fineness of wheat meal and added in the same proportion as would be in the normal wheat meal. The germ added was ground to a similar fineness but was added in a much greater proportion than that present in the wheat meal. The results of this work are presented in Table 10.

These results show that the "time" is very different on flour than it is on wheat meal, especially with Tenmarq. Turkey had the shortest "time" on the meal but had the longest "time" on the flour, while Tenmarq had the longest "time" on the meal.. Swanson (1937) states that since flour and not wheat meal is used in baking these results raise the question as to what the "time" in this test means in evaluating wheat quality.

The data given in Table 10 indicate that it is the bran substance which increases the "time" and that extract-

Table 10 -- Effect on "time" of adding wheat substances to flour

Substances added	Variety				Remarks
	Ten-marq	Tur-key	Qui-vira	Early Black-hull	
"Time" in minutes					
Wheat meal	145	54	77	62	ave. of 2 trials
Flour	85	93	88	75	ave. of 3 trials
Flour+bran	290*	226*	215	174	12.5g.flour.2.5g.bran
Flour+shorts	199	201	172	164	" " shorts
Flour+bran + shorts	401*	335	278	175	10.8g.flour.2.4g.bran +1.8g.shortcuts
Flour+extract- ed bran	271*	267*	263	243	12.5g.flour.2.5g.extracted bran
Flour+water ex- tract of bran	124	126	95	125	15g.flour+extract from 2.5g. bran
Flour+wheat germ	135	126	127	124	12.5g.flour+2.5g.germ

* indicates that the doughball had not broken but the trial was stopped at the end of this time.

ing with water does not decrease its effectiveness. Shorts added to the flour did not decrease the "time" as much as the bran, probably explained by the fact that there is a less amount of bran material in the shorts. Swanson (1937) states that water extract of bran is sometimes used in baking to speed up fermentation; hence, the longer "time" when flour and bran extract are added compared to that when only flour and water are used was not due to a slower fermentation.

In an attempt to explain why branny substances increased the time when added to flour Swanson (1937) studied the mechanical effect of various inert substances upon the "time" of flour. This investigator used powdered pumice, alundum powder, and paper pulp by mixing with flour. The results obtained are given in Table 11.

Table 11 -- Effect on "time" of adding inert material to flour

Mixture	Variety			
	Ten- marg	Tur- key	Qui- vira	Early Blackhull
"Time" in minutes				
Flour alone	85	93	88	75
12.5g.flour.2.5g.alundum	81	77	83	80
12.75g.flour.2.25g.paper pulp	91	86	98	114
14.25g.flour.0.75g. " "	83	97	87	79
12.5g.flour+2.5g.pumice	127	112	114	125

Results given in Table 11 indicate that the physical form of some of the inert material does not seem to be the important factor, as neither alundum nor paper pulp made any marked difference in the "time" of any of the varieties, except Early Blackhull when 2.25 g. of paper pulp were added, although each differs greatly in its physical form. However, pumice, which differs in physical form from both alundum and paper pulp in that its particles are porous, did markedly increase the "time" over flour alone.

Studying further the reason for branny substances increasing the "time", Swanson (1937) investigated the effect of certain compounds such as lecithin and oleic acid, which may be present in the wheat fat, upon the "time". The saturated acids such as N-caproic and pelargonic were added also to compare the effects of these with the unsaturated oleic acid. Oxidizing salts such as KBrO_3 and KClO_3 were tried also. Results of this investigation are presented in Table 12.

Table 12 -- Effect of adding lecithin, organic acids^(a), and oxidizing agents^(b), to flour

Mixture	Variety			
	Ten-marq	Turkey	Quivira	Early Blackhull
"Time" in minutes				
Flour alone on 3 trials	85	93	88	75
" + lecithin	98	102	87	85
" + oleic acid	93	96	90	73
" + lecithin - oleic acid	97	98	84	82
" + N-capronic acid	100	122	114	60
" + pelargonic acid	200(c)	200(c)	200(c)	171
" + KBrO_3	105	123	94	76
" + KClO_3	95	98	86	73

- (a) = lecithin and the organic acids were added in the proportion of 1 mg. to each gram of flour.
 (b) = O_2 agents were used in the amount of 1 mg. to each 10 cc. of H_2O used making the doughball.
 (c) = Doughball not broken but trial stopped at end of this time.

The effects of lecithin and oleic acid either alone or in combination are not marked. Oleic acid may be produced when wheat meal is allowed to stand some time before testing. However, from these data it is evident that no unsaturated acid such as oleic acid is responsible for the increase in "time" when wheat meal ages. N-caproic and pelargonic acids had a marked influence on the "time" and it may be that the increase in "time" when wheat meal is stored is due to the production of some substances that have an effect similar to these two saturated substances. The effect of these acids was not as pronounced on Early Blackhull as on the other three varieties.

Other studies (Swanson, 1937), such as extracting both flour and wheat meal with solvents to learn the effect of removing certain substances from the flour or wheat meal on the "time", have been made in an attempt to explain the reason for branny substances increasing the "time" when added to flour. However, to date no satisfactory explanation of this phenomenon is available.

The effects of heredity and environment are in reality interlocked, regardless of what character is concerned. Hayes and Garber (1927) state that quality in wheat is dependent upon the genic make-up of the wheat plant, as

well as the environment. Although the environment may determine to a large extent the quality of gluten in the wheat, it is the variety (i.e. genic constitution) that determines for the most part the quality of the gluten (Pelshenke, 1937).

Given varieties of wheat tend to have the same ranking of the "time" from one year to the next (Cutler and Worzella, 1937). This fact in itself is evidence enough that the "time" is heritable and is influenced less by environment than it is by heredity.

Cortabarría (1935) states that, notwithstanding the fact that the "time" on samples belonging to the same variety may differ to a greater extent than the mean values of each variety, the "time" is firmly established as a variety character. This investigator further states that an excellent agreement was reached with two entirely independent sets of data.

Many reports have been published on quality in wheat, but few data are available on its inheritance. Worzella (1934) reported a study of the inheritance of gluten quality as evaluated by the "time test". This investigator used Michikof as a strong gluten wheat and Trumbull as a weak gluten wheat. These two wheats were crossed and tests were made on over 6000 samples, each sample representing the

seed from individual F_1 , F_2 , F_3 , or parent plants. The gluten strength of F_1 grain was found to be weak when Trumbull was used as the female parent and strong when Michikof was used as the female parent. The F_2 grain, on the average, was intermediate in gluten strength, although individual plants varied from weak to strong. In the F_3 grain the gluten strength was found to be intermediate on the average in quality. However, F_3 families as weak as Trumbull and as strong as Michikof were obtained. Some of these bred true while others segregated, as would be expected. The gluten quality character was assumed to be a quantitative character governed by three major independent factor pairs. By correlating the "times" of the F_2 and F_3 grain Worzella was able to show that in the early generations the gluten quality index as obtained by the "time test" can serve as a dependable guide in making selections for quality. Breakwell (1934) states that the chances that a single plant selection taken from a high quality line will be of good quality itself are high. Worzella (1934) is of the opinion that gluten strength is a hereditary, quantitative character that is apparently accurately measured by the "time test". Pelshenke (1933b) shows that the quality of the gluten as measured by the "time test" is a recessive character, but was unable to show the number of factors involved.

Hickinbotham (1934b) finds that within a given variety of wheat a wide range of quality may exist, due to different strains being present or that the variety is not fixed as to quality. This investigator holds that stronger lines may be obtainable by selection from at least some established commercial varieties. Further studies by this investigator revealed that there is a very high correlation, $r = -.72$, between the "time" and the grain weight of various lines of Ford wheat. This indicates a definite association of high quality with small kernels in so far as lines of Ford wheat are concerned. It cannot be inferred, of course, that small grains and high quality will be associated in like degree in other varieties.

The "time" is affected very markedly by the class of wheat. In a given class, a few varieties will not have "times" typical of that class, but taking the average of many varieties each class has a definite rating in relation to other classes. Cutler and Worzella (1931) found that in general the hard red spring wheats have the longest "time", average of 11 varieties, 337 minutes; hard red winter wheats stand next to the hard red spring wheats in "time", average of 8 varieties, 285 minutes; soft red winter wheats, average of 8 varieties, 110 minutes, stand next in "time"; white wheat, average of 5 varieties, 89 minutes, soft spring wheat and the durum class, 1 variety of durum, 84 minutes, fall

more or less together in the shortest "time" group.

As to varieties within the different wheat classes, Swanson and Parker (1935) showed that of the hard red winter class the varieties Cheyenne, Oro, and Tenmarq have long "times", the varieties Blackhull, Kanred, and Turkey have medium long "times", while the varieties Early Blackhull, Superhard Blackhull, Fulhard, and Nebraska No. 28 have low "times". In the class of soft red winter wheats these investigators showed that the varieties Harvest Queen, Michigan Amber, Red Rock, and Bald Rock have comparatively long "times". The varieties Poole, Currell, Fulcaster, Gladden, Nittany, and Forward have shorter "times" than the above named soft red winter wheats but longer "times" than the soft red winter wheat varieties Purple Straw, Fulhio, Valprize, and Clarkan. In the white wheat class these investigators found Honor and Junior No. 6 to have short "times". Cutler and Worzella (1937), in agreement with the data of Swanson and Parker (1935), found that in a four-year comparative test of soft red winter wheats the varieties Michigan Amber and Red Rock have comparatively long "times". These investigators showed that in this class Fultz and Red Cross also have comparatively long "times". The varieties Fulhio, Rudy, Trumbull, Nabob, Purdue No. 1, and Gladden were shown to have medium long "times" for soft red winter

wheats, while Poole and American Banner were shown to have low "times". Fifield, et al. (1937) found that in the hard red spring class Marquis and Ceres have very long "times". Among the white spring wheats, Hard Federation, White Federation and Onas have long "times" in comparison to short "times" for Pacific Bluestem, Baart, Dicklow, Pilcrow, and Erect. Jenkin and Union of the White Club sub-class have very short "time". Chapman and Farquhar (1934) found that in the South Australian white wheats the varieties Minister, Quality, Florence, Comeback, Pusa No. 4, and Ford have long "times", in comparison with the short "time" varieties Bena, Gurka, and Rancee. Pelshenke (1933b) has shown that of the winter wheats grown in Germany the varieties Mareuil and Brauner Fuchs have long "time", the varieties Russischer, Java, Rimpausfrüher Bastard and Heine III have medium long "time", and the varieties Panzer III, Standard, Carsten V, Strubes D, and Ella have low "time". In the spring wheat class the varieties Garnet and Marquis have long "time" and the variety Heines Kolben has a shorter "time". Belmonte and Fischer (1935) reported that in the wheats grown in Argentina the varieties in the hard wheat class having long "times" are Reliance, Klein Otto Wulff, and Klein Simmarq. Those Argentine hard wheats having medium long "times" are Lin Calel M. A., Klein Piramide, and Guatraché M. A. The

Argentine hard wheats of low "time" are Kanhard and Kanred. In the semi-hard wheats of Argentina the varieties Klein Granadero, La Prevision, No. 25, Klein Acero, No. 38 M. A., and Klein, No. 33, have relatively long "times" in comparison to Eureka, Klein, No. 32, and La Prevision, No. 32. Of the Argentine soft wheats Sola, No. 50, and General Urquiza have longer "times" than Rafaela, No. 6 M.A.

Griffiths and Cayzer, (1934) are of the opinion that the better the quality of the protein and the greater its elasticity, the better is the doughball able to withstand the pressure of gas within and to remain intact on the surface.

Correlation with Other Quality Tests

Correlations of significance between the data obtained by the use of the "time test" and those of other tests of quality such as the baking test, Berliner and Koopman gluten swelling method, Brabender farinograph, Chopin extensimeter, Engledow distensometer, and the protein test have been obtained by various investigators. Those investigators having obtained a significant correlation between the "time test" and one or more of the above named tests of quality are: Bayfield and Shipley (1937) with the protein test and loaf volume; Belmonte and Fischer (1935) with the Koopman and Berliner gluten swelling method; Cutler and Worzella (1933)

with the baking test; Griffiths and Cayzer (1934) and Griffiths, Norris, and Wenholz (1933) with the baking test; Hilgendorf (1933a and b) with the baking test and the Engledow distensometer; Pelshenke (1933a and b) with the baking test; Shollenberger (1937) with the Brabender farinograph, Chopin extensimeter, and the Berliner and Koopman gluten swelling method; and Wilson and Markley (1934) and Wilson, Markley, and Bailey (1933) with loaf volume and a bread strength score. The Ministry of Agriculture of Argentina (1936) reported data for the "time" of the Argentine Official Standards of the crop season 1935-36 which "times" correlated rather well with the results obtained on the same samples using the baking test, Berliner and Koopman swelling method, Chopin extensimeter, and the Brabender farinograph. Coleman and Fifield⁽²⁾ found a significant correlation of the "time" with both protein, $r = .58$, and loaf volume, $r = .54$, on samples grown at Akron, Colorado. However, on wheat samples grown at Denton, Texas and North Platte, Nebraska, there was neither a significant correlation between "time" and protein content nor between "time" and loaf volume.

(2) These results are taken from a letter received in March, 1938 from C. C. Fifield, associate baking technologist, Bureau of Plant Industry, United States Department of Agriculture.

The following investigators have found that the data obtained by use of the "time test" are in fair agreement with the known baking strength of the wheats studied: Albizzatti (1934), Borasio (1934), Breakwell (1934), Cutler and Worzella (1937), Frankel (1935), Griffiths and Cayzer (1934), Hickinbotham (1934a and b), Shollenberger (1937), and Swanson and Parker (1935).

MATERIALS AND METHODS

The data here presented were obtained from material gathered from diverse sources. For the most part material from the cereal breeding nursery was used. Samples from the wheat variety plots at the agronomy farm, from the wheat variety tests on farms in Kansas, and from miscellaneous sources were also used.

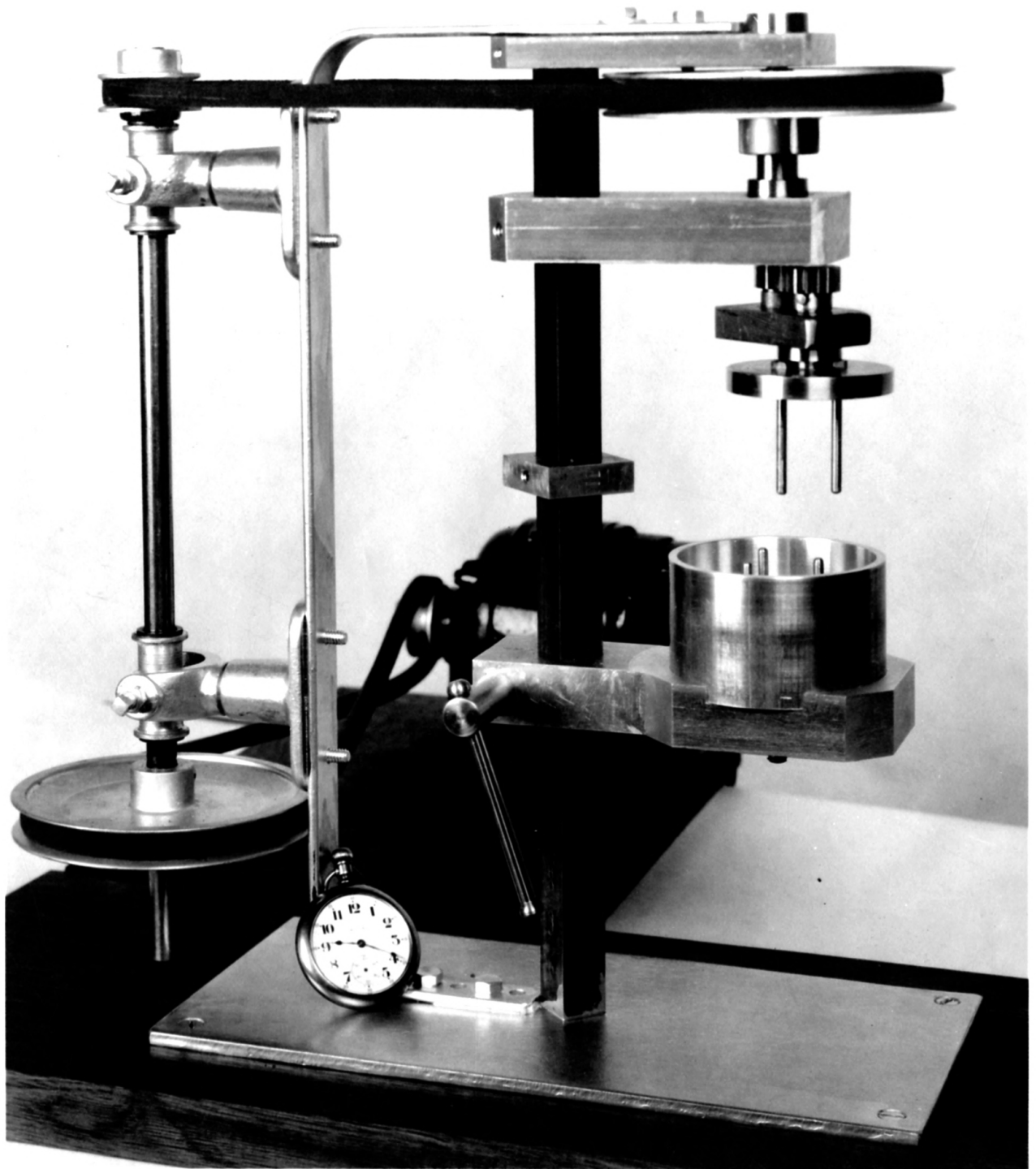
All data gathered previous to 1936 and used in this thesis have been obtained by earlier investigators in the Departments of Agronomy and Milling Industry. Some of the data gathered since 1936 have also been obtained by others. Credit is due Caleb Jorgensen, J. F. Wolf, Karl Finney, and Glen West for their contributions.

The methods used in obtaining the data gathered previous to 1936 are those described by Cutler and Worzella (1933). Since 1936 a modified procedure, found desirable

in work with hard wheats, has been used. Wheat to be tested for "time" by the Kansas State College method is carefully cleaned previous to grinding in order that as little foreign material as possible will be present in the meal. The whole wheat sample is then ground to a medium fineness, so that all the meal and branny particles will pass through a one millimeter screen. The meal is tested within a day after it has been ground.

For the preparation of the whole wheat meal dough for "time testing" the following procedure was followed: a 10% yeast suspension is prepared by placing 10 grams of Fleischmann's yeast in 100 cc. of distilled water. A new yeast suspension is made up each day that the "time test" is to be made from yeast kept fresh in a refrigerator. Fifteen grams of meal are placed in the Working micro-mixer, illustrated in Plate I, and 8 3/4 cc. of the well mixed 10% yeast suspension at 30° C (86° F.) are added. The whole wheat meal dough is then mixed. Sufficient distilled water is added by means of a 2 cc. capacity syringe to the dough as it is being mixed so that the dough mass will be of the correct consistency. Each dough is mixed to the peak, i.e. the point at which the dough smooths out and begins pulling on the pins of the mixer. The time of mixing varies from 50 to 180 seconds, depending upon the variety. After removing the dough from the mixer, it is shaped into a

Plate I



Micro-mixer designed by Dr. E. B. Working, Department of
Milling Industry, Kansas State College.

cylinder by rolling the dough between the palms of the hands. The cylindrical dough is then divided into 3 equal parts, each of which is rolled into a smooth sphere by rolling 20 times in the palms of the hands. Each 5 gram doughball is then placed into a glass containing 190 cc. of distilled water at 30° C. The glasses used in making the test have a capacity of 270 cc. and an inside diameter at the top of approximately 65 millimeters. The glasses are encased in a cabinet which is automatically controlled so that the temperature remains constantly at 30° C. The doughball upon immersion in the distilled water immediately falls to the bottom of the glass. The times of immersion of the triplicate samples are recorded as one time. There is only a few seconds difference between the time of immersion of each triplicate.

The temperature controlled cabinet used is illustrated in Plate II. The glasses used are also shown. The temperature control instrument is attached to the right side of the cabinet. The cabinet is equipped with a cooling device for summer use and a heating device for use in the winter.

Observations are made on the behavior of each doughball from time of immersion to the conclusion of the test. The doughball becomes buoyant and rises to the surface of the water as soon as fermentation within the doughball has



Temperature controlled cabinet, designed in the Department of Milling Industry, Kansas State College, for maintaining constant temperatures while "time testing" samples.

proceeded for a few minutes. The advantage of floating the doughball on water is (1) to allow the doughball to expand freely, (2) to protect the doughball from shocks, and (3) to keep the surface of the dough from drying out (Pelshenke, 1933a). The ball begins to swell, thus acquiring a larger volume. In the case of weak, soft wheats with short "time", less than 40 minutes, disintegration occurs while the doughball is in a more or less spherical form, while in strong, hard wheats with long "time" the doughball becomes flat and tends to cover the entire surface of the water. The volume of the fermenting mass gradually increases until the strength of the gluten has been weakened by the disruptive forces of expansion, together with the absorption by the distilled water of the natural salts contained within the meal particles (Saunders and Humphries, 1928). At this point, disintegration of the doughball takes place.

Disintegration of the doughball may take place in different ways, depending upon the variety. In a long "time" variety disintegration of the doughball usually takes place by the formation of a thin, bag-like film on the under side which breaks shortly after its formation. Occasionally a long "time" doughball will disintegrate by portions of the fermenting mass breaking away. In a short "time" variety disintegration of the doughball usually begins by

a few minute particles of dough breaking away from the fermenting mass. After a few seconds the speed with which these minute particles detach themselves becomes rapid. The time is again recorded when disintegration occurs. The period intervening between the time recorded at the immersion of the doughball and the time when disintegration of the doughball occurs is termed the fermentation time. The fermentation times of the triplicate samples of each wheat tested are averaged and the average "time" is recorded for that variety. This fermentation time recorded in minutes is used as the index or measure of quality in this method of quality testing.

A disintegrating doughball of Blackhull wheat, "time", 51 minutes, in comparison with a doughball of Tenmarq not yet showing any indications of disintegration, "time", 102 minutes, is shown in Plate III. The beaker shown in Plate III is no longer used at the Kansas station, as the cheaper water glasses are satisfactory.

Plate III



Doughballs in wheat meal fermentation time test of Blackhull (left) and Tenmarq (right). Breaking "time" for Blackhull, 51 minutes, and for Tenmarq, 102 minutes.

EXPERIMENTAL RESULTS

Factors Studied Affecting "Time"

In the earlier use of the "time test", results were often obtained which indicated great variability of this test when applied to the same samples. To illustrate the variability that was obtained in the early work there are presented in Tables 13 and 14 the original "times" and the recheck "times" of strains grown in the cereal breeding nursery and in plots at the agronomy farm in 1934. In the original test the "times" on the individual doughballs of the triplicates varied markedly from the mean.

Nineteen of the 26 retested strains listed in Table 13 had "times" longer than the original "times". The average retest "time" for this group of strains is 136 minutes, compared to 122 minutes for the original. Four of the retest "times" were in an entirely different range than the original "times". For example, Kanred x Hard Federation, Sel. 327076, had an original "time" of 97 minutes, and a retest "time" of 175 minutes. The marked differences in the "time" of these strains indicate that the experimental error was high. The correlation between the original and retest "times" was determined, $r = .68 \pm .07$.

Table 13 -- Original and recheck "time" of a few of the varieties grown in the agronomy nursery, Manhattan, Kansas, 1934.

Ks. or Sel.No.	C.I. No.	Variety	Original test (a)		Recheck test(b)	
			"Time"	Rank	"Time"	Rank
316080		Kanred x Hard Federation	131	7	181	1
2672		do	130	9	176	2
327062		do	97	24	175	3
285724		Tenmarq sel.	168	2	174	4
Nebr.1065	10095	Turkey sel.	148	4	173	5
306053		Kanred x Hard Federation	185	1	169	6
286107		Kawvale sel.	131	7	165	7
Nebr.						
3101650	11576	Turkey sel.	134	6	158	8
		Lin Calel	155	3	145	9
332370		Fulhard x Tenmarq	125	12	144	10
30C1025		Kanred x Kanmarq	130	9	143	11
316324		Tenmarq x Kanred	130	9	137	12
	11380	Purdue No. 1	118	15	136	13
342039		Oro x Tenmarq	120	14	134	14
	6683	Wisconsin ped.No.2	110	19	133	15
2594	8257	Fulhard	110	19	128	16
	5149	Minhardi	114	17	126	17
	11537	Progeny No.2 (Ill.)	138	5	123	18
2701		C7H10 (Joe Danne)	121	13	118	19
645	11523	Sibley No. 62	113	18	111	20
342009		Oro x Tenmarq	116	16	110	21
342021		do	110	19	106	22
Nebr.1070	10098	Turkey sel.	71	26	103	23
285191		Kanred x Hard Federation	101	23	100	24
	5620	Michigan Amber	81	25	89	25
292627		Prelude x Kanred	105	22	89	25
		Ave. original "time" of 26 strains			122	
		" recheck " " " " "			136	

Correlation of original and recheck "times"; $r = .68 \pm .07$

(a) original tests made in October

(b) rechecks made in December

Table 14 -- Original and recheck "time" of a few of the varieties grown in farm plots, Manhattan, Kansas, 1934.

Ks. or Sel.No.	Variety	Original test		Recheck test	
		"Time"	Rank	"Time"	Rank
495	Oro	115	3	156	1
518	(Eureka x Minhardi)x(Kanred x Hard Federation)	68	11	154	2
514	Tenmarq	129	2	139	3
483	Early Blackhull	79	9	127	4
2719	Turkey sel.	100	5	123	5
2644	Kanred x Marquis	99	6	120	6
2671	Kanred x Hard Federation	92	7	120	7
2672	Kanred x Hard Federation	135	1	120	8
343	Blackhull	82	8	116	9
2628	Quivira	105	4	111	10
519	(Prelude x Kanred)x(Turkey x Minessa)	72	10	107	11
Ave. original "time", 11 strains,		98			
" recheck " " " "		127			

Correlation of original and recheck "times", $r = .002 \pm .205$

The original and recheck "times" on a few of the varieties grown in farm plots in 1934 and presented in Table 14 are very erratic. A few of the varieties having long "times" in the original test had short "times" in the recheck and vice versa. The correlation coefficient between the original and recheck "times" is $.002 \pm .205$ which indicates no correlation between the two sets of data. It must be admitted that the number of tests correlated is very small and not enough for accurate statistical analysis. However, the lack of correlation gives an indication of the size of the experimental error in these tests.

Realizing that in a reliable test of wheat quality variability in the results obtained must not be too wide, several factors influencing the "time" were studied. Some of the factors affecting the "time" which have been studied extensively and reported by other investigators have purposely been omitted in this study. By investigating factors not previously studied and factors which have not been given sufficient emphasis and by pooling these studies with those of other investigators, it was hoped that a definite answer could be evolved to the question, "what does the 'time' indicate as to the quality of a wheat". Should this answer be attained, a valuable contribution to wheat quality testing in plant breeding would be made.

Investigators are generally agreed that the longer the period between harvest and date of grinding the longer the "time" will be, within certain limits. Data obtained on a sample of Tenmarq wheat in December, 1934, and January, 1935, when "time tested" at various intervals for 7 weeks are as follows:

<u>Date</u> <u>1934</u>	<u>"Time"</u> <u>minutes</u>	<u>Rank</u>
Nov. 27	123	11
Dec. 1	123	11
" 4	155	1
" 8	140	5
" 10	124	10
" 11	138	6
" 15	130	9
" 17	141	4
" 18	119	13
<u>1935</u>		
Jan. 5	143	3
" 7	134	7
" 8	133	8
" 12	145	2

Ave. "time" of 13 tests -----134 minutes

First observation of the above data might lead one to believe that there is a tendency for the "time" to lengthen with the increase in the age of the sample of Tenmarq being tested. However, the longest "time" was obtained on a sample tested early in the experiment while the shortest "time" was obtained on a sample tested late in the experiment. There is no progressive increasing of "time" as the age of the sample lengthens. The rather marked variability of individual "times" from the mean indicates a high experimental error.

The following data obtained in December, 1937, and January, 1938, also show no lengthening in the "time" of samples of wheat "time tested" over a period of time:

Date 1937	Variety	
	Tenmarq	Clarkan
	"Time" in minutes	
Dec. 8	128	43
" 10	117	46
" 13	107	37
" 15	107	39
" 17	100	41
" 20	107	37
" 22	106	36
1938		
Jan. 17	108	37
" 20	110	36

Ave. "time" of Tenmarq (hard red winter) 9 tests--110
 " " " Clarkan (soft red winter) 9 " -- 39

No great lengthening of "time" was noted in these tests, covering a period of about 6 weeks. The longer "times" obtained on the first 2 tests are probably due to the fact that these samples of wheat were brought into the laboratory from storage in a non-heated room at the agronomy nursery seedhouse the same day as the "time testing" was begun in this experiment. The samples were then kept in the laboratory until the experiment was completed. The difference in the temperature and the relative humidity of the two rooms may have caused the shortening of the "time" in the first few tests. After the samples had come into equilibrium with the moisture content and possibly the temperature of the air in the laboratory, no further significant differences in "time" were obtained. These data indicate that for comparable results it is important that samples of

wheat to be tested should be stored under similar conditions for some time before testing. The data also indicate that if the samples are stored under similar conditions and tested some weeks after harvest, comparable results may be obtained over a period of several weeks. If the samples are tested shortly after harvest, the period that comparable data may be obtained is shorter than if the testing is done a relatively long time after harvest, as it is known that the quality of wheat changes more rapidly immediately following harvest than later on.

The results obtained with flour are greatly different from those on the wheat meal of the same wheats. The differences in the "time" recorded on the flour and the whole wheat meal of 18 wheat varieties grown in the agronomy nursery at Manhattan in 1937 are shown in Table 15. The correlation between the "times" recorded for meal and flour was determined, $r = .165 \pm .62$. This correlation is of no significance. Swanson and Parker (1935) stated that "time testing" of wheat meal in place of flour may have shunted the test in the wrong direction, as flour, not meal, is used in bread making. In spite of the insignificant correlation obtained between the flour and whole wheat meal "times", it should be noted that the strains given the lowest ranking are identical in both tests. As other investigators have found, the "time" on the whole wheat meal is considerably

Table 15 --"Time" of flour and whole wheat meal of 18 varieties of wheat grown in the agronomy nursery, Manhattan, Kansas, 1937.

Ks. or Sel.No.	Variety	Flour		Whole meal	
		"Time"Rank		"Time"Rank	
		Minutes		Minutes	
2736	Oro x Tenmarq	220	1	119	7
344154	Fulhard x Kawvale	197	2	128	5
514	Tenmarq	189	3	102	13
343273	Oro x Tenmarq	179	4	126	6
316063	Kanred x Hard Federation	175	5	116	9
2739	Early Blackhull x Tenmarq	170	6	107	11
363595	Oro x Tenmarq	158	7	138	2
363594	do	155	8	139	1
363602	do	154	9	117	8
2730	do	142	10	93	15
343638	do	139	11	105	12
J34584	Kanred x Kawvale	139	12	63	17
285116	Kanred x Marquis	138	13	132	3
343249	Oro x Tenmarq	135	14	114	10
33FN499	Tenmarq x Kawvale	131	15	97	14
326795	Kanred x Marquis	127	16	130	4
La.35-95	Iobred x Kawvale	127	17	65	16
2735	Tenmarq x Kawvale	123	18	49	18

Ave. flour "time", 18 varieties -----155

" wheat meal "time", 18 varieties ---108

Correlation of flour "time" and meal "time", $r = .165 \pm .162$

shorter in most cases than on flour.

Pelshenke (1931) states that the gas-producing power of whole meal doughs is very uniform in comparison to flour doughs. To determine the soundness of this statement when applied to wheat varieties grown at Manhattan, the time that it took for the doughballs to float from the time of submergence of each was recorded on all those varieties from

the agronomy nursery tested for "time" in 1937. The time that each doughball took to float was considered to be an indication of the rate of gas production in that doughball. The time from submergence to floating varied from 10 minutes to 15 minutes, thus indicating considerable variation in the rate of gas production in the different wheat varieties. No correlation was evident between the time to float and the time to disintegration of the doughballs. Among the wheat strains having long "time" of disintegration some had long times to float, while others had short times to float. Long and short times to float were also both found in wheat strains of short disintegration "times". The times to float on the 18 flour samples listed in Table 15 ranged from 13 to 20 minutes. These results furnish no evidence that the whole wheat meal doughs have more uniform gas production than flour doughs.

It has been known for many years that the enzymes in flour play an important role in determining the bread baking qualities of the flour. In recent years various investigators have given considerable attention to the effect of the proteases upon the baking value of a flour, either naturally occurring in flour or introduced in other ingredients. In the literature, references to physical methods as measures of protease activity are often found. No reference as to

the role of proteolytic enzymes in the "time test" was found. With the possibility that this factor might be an important one in determining the "time", a study was made of the effect of the protease activity on the "time" of the whole wheat meal fermentation time test.

Two varieties of wheat representing a hard red winter type, namely Tenmarq, and a soft red winter type, namely Clarkan, were used to determine the effect of additions of various concentrations of the protease pepsin. The data obtained are presented in Table 16.

Table 16 -- Effect of different concentrations of pepsin on the "time" of a strong and a weak wheat.

Pepsin added ^(a) (mg.)	Variety	
	Tenmarq	Clarkan
	"Time", minutes	
None (ave. of 2 checks)	123	45
0.1	118	47
0.2	108	45
0.3	103	54
0.4	87	47
0.5	82	41
1.0	69	46
1.25	61	43
1.50	53	43
1.75	55	43
2.00	51	40
2.25	46	45
2.50	49	41
Mean	77	45
Ave. deviation from mean	31.4%	5.8%

(a) the pepsin was added in solution, by means of a two cc. syringe, to the meal as it was being mixed in the Working micro-mixer.

These data indicate that to a certain extent the "time" of Tenmarq is markedly reduced with increases in concentration of pepsin, but that the "time" of Clarkan is not significantly changed by increased concentrations of this protease. Variations in "time" of the different samples of Clarkan are within the commonly accepted allowance of about 10% deviation from the mean for experimental error. The rather high "time" of the sample of Clarkan with 0.3 mg. of added pepsin in the meal is probably due to a variation in operative technic.

To learn the effects of pepsin on other wheat varieties, doughballs from a group of known hard wheat varieties and a group of known soft wheat varieties were subjected to the effects of pepsin. The results of this study are given in Table 17.

The results obtained show very definitely that the hard wheats tested are greatly affected by additions of pepsin while the soft wheats, with the possible exception of Fulcaster, are not affected to any significant degree. As grown in Kansas, Fulcaster does not always behave in baking as a typical soft wheat, exhibiting some hard wheat characteristics.

Table 17 -- Effect of pepsin on the
"time" of hard and soft wheats

Variety	Treatment		Difference %
	None	2 mg. pepsin	
"Time", minutes			
<u>Hard wheats:</u>			
Oro x Tenmarq, Ks. 2729	130	65	50.0
do, Ks. 2728	128	60	53.9
Oro	126	43	65.9
*Denton	108	49	54.6
Tenmarq, (ave. of 4 cks.)	105	44	58.1
Cheyenne	94	42	55.3
Cheyenne sel., C.I. 11666	91	44	51.7
Turkey sel., C.I. 10094	90	53	41.1
Kanhull	88	42	52.3
*Minturki	84	44	47.6
Quivira	66	34	48.5
Kanred	51	39	23.5
Blackhull	51	39	23.5
Early Blackhull	47	37	21.3
*Kawvale	46	33	28.3
*Iobred	41	31	24.4
Turkey	40	29	27.5
Chiefkan	37	30	18.9
Superhard	33	26	21.2
 <u>Soft wheats:</u>			
Clarkan (ave. of 4 checks)	39	37	5.1
Bald Rock	38	39	2.6
Mo. Early Premium	33	32	3.0
Michigan Amber	33	34	3.0
Harvest Queen	32	32	0
Red Rock	30	30	0
Mediterranean sel., C.I. 11567	30	28	6.7
Fulcaster	29	26	10.5
Currell	27	27	0
Michigan Wonder	27	28	3.7

* semi-hard wheat

The data obtained on the addition of pepsin as a protease supplying substance to various varieties of wheat representing both the hard red winter and soft red winter classes suggest the possibility that the hard red winter varieties either do not possess a large quantity of proteases or the proteases present are not completely active, while the soft red winter varieties, with the possible exception noted, seem to possess a large amount of active proteases. This apparent difference in enzymatic content or nature between hard and soft wheats is further substantiated by the fact that doughballs of the hard wheats when subjected to the "time test" having pepsin added to the system disintegrate in every respect as do typical soft wheat doughballs, i.e. as the pepsin concentration becomes greater in the hard wheat doughball the ball takes on characteristics of the soft wheat doughball.

A study was made of the effect of pepsin upon the "time" of flour. The normal "time" of the flour and the "time" of the flour with two mg. of pepsin added were obtained upon a group of 17 hybrid wheats and a Tenmarq check, grown in the agronomy nursery at Manhattan, submitted for milling and baking studies in 1937. The data resulting from the study are given in Table 18. These data show that the pepsin shortens the "time" of all hard wheat flours

tested, as in the case of the whole wheat meal. The degree to which the "time" of each sample is decreased by the pepsin is not the same for all strains possibly, indicating a difference in the resistance of the gluten of the samples to the protease.

Table 18 -- The effect of pepsin on "time" of flour.

Ks. or Sel. No.	Variety	Treatment				Diff- erence %
		No pepsin Time Minutes	Rank	2mg. pepsin Time Minutes	Rank	
2736	Oro x Tenmarq	220	1	121	6	45.0
344154	Fulhard x Kawvale	197	2	127	2	35.5
	Tenmarq	189	3	142	1	24.9
343273	Oro x Tenmarq	179	4	123	3	25.7
316063	Kanred x Hard Federation	175	5	121	5	30.9
2739	Early Blackhull x Tenmarq	170	6	123	3	27.6
363595	Oro x Tenmarq	158	7	117	8	25.9
363594	do	155	8	95	17	38.7
363602	do	154	9	116	9	24.7
2730	do	142	10	115	10	19.1
343638	do	139	11	110	12	20.9
J34584	Kanred x Kawvale	139	11	113	11	18.7
285116	Kanred x Marquis	138	13	99	16	28.2
343249	Oro x Tenmarq	135	14	122	5	9.5
33FN499	Tenmarq x Kawvale	131	15	104	13	20.6
326795	Kanred x Marquis	127	16	100	15	21.3
La.35-95	Iobred x Kawvale	127	16	83	18	34.6
2735	Tenmarq x Kawvale	123	18	102	14	17.1
Mean, 18 varieties		155		108		26.0

To secure information as to the effect of other proteases than pepsin on the "time" of wheat varieties, trypsin (Armour & Co.) and papain (Merck) were used on the varieties Tenmarq (hard), Kawvale (semi-hard) and Clarkan

(soft). The data obtained by using trypsin are presented in Table 19.

Table 19 -- Effect of trypsin on the "time" of Tenmarq, Kawvale, and Clarkan.

Trypsin added (mg.)	Variety		
	Tenmarq	Kawvale	Clarkan
	"Time", minutes		
None	108	49	39
0.5	58	41	35
1.0	38	37	36
1.5	39	33	35
2.0	40	31	37
2.5	36	34	36
Mean	53	36	36
Ave. deviation from mean	37.7%	13.4%	2.8%

As in the case of pepsin, trypsin markedly affects the "time" of the hard wheat Tenmarq. The medium strong semi-hard wheat Kawvale is affected significantly, though less than Tenmarq, while the typical, weak, soft wheat Clarkan is not affected.

The data obtained from the use of papain are given in Table 20.

These data show the same effects of papain on the "time" of hard, semi-hard, and soft wheats as were obtained with pepsin and trypsin, except that with high concentrations

of papain a decrease in the "time" of the soft wheat Clarkan was obtained, whereas in using pepsin and trypsin no such effect was noted.

Table 20 -- Effect of papain on the "time" of Tenmarq, Kawvale, and Clarkan.

Papain added (mg.)	Variety		
	Tenmarq	Kawvale	Clarkan
	"Time", minutes		
None	108	49	37
0.5	65	39	37
1.0	35	32	37
1.5	37	31	32
2.0	33	31	30
2.5	30	28	30
Mean	51	35	34
Ave. deviation from mean	52.9%	17.1%	8.8%

Low concentrations of papain had no effect on the "time" of Clarkan but with increased concentration marked changes in the system occurred and shorter "times" were obtained. This effect is possibly due to papain being present in such a high concentration that a change in the chemical complex of the protein system takes place, resulting in a protein system readily disintegrated by proteases.

To learn what influence an activator of protease enzymes would have on the hard, semi-hard and soft wheat varieties, cysteine-monohydrochloride (Merck) was used.

The data obtained are given in Table 21.

Table 21 -- Effect of cysteine-monohydrochloride on the "time" of Tenmarq, Kawvale, and Clarkan.

Cysteine-monohydrochloride added (mg.)	Variety		
	Tenmarq	Kawvale	Clarkan
	"Time", minutes		
None	110	51	36
0.5	107	46	43
1.0	100	41	39
1.5	76	48	42
2.0	64	36	36
2.5	55	35	43
Mean	85	41	40
Ave. deviation from mean	23.5%	12.2%	7.5%

These data show that the "times" of the hard and semi-hard wheat varieties were significantly lowered, presumably due to an activation of latent proteases naturally occurring in the wheat varieties. "Times" recorded on the Clarkan samples were somewhat erratic, in that one concentration seemed to increase the length of the "time" while a higher concentration had no effect.

Addition of an inhibitory agent, namely potassium bromate (KBrO_3), to the wheat meal of Tenmarq and Clarkan to be "time tested" produced the results shown in Table 22. These data show that KBrO_3 lengthens the "time" of both the hard wheat Tenmarq and the soft wheat Clarkan. This is

believed to be due to the inhibition of proteolytic activity.

Table 22 -- Effect of different concentrations of the oxidizing agent KBrO_3 on the "time" of a strong and a weak wheat.

KBrO ₃ added (mg.)	Variety	
	Tenmarq	Clarkan
	"Time", minutes	
None	106	36
0.25	141	40
0.50	155	43
0.75	188	46
1.00	222	49
1.25	223	55
1.50	247	52
1.75	244	52
2.00	233	48
2.25	277	55
2.50	250	50
2.75	279	54
Mean	214	48
Ave. deviation from mean	20.8%	10.1%

The influence of the inhibitory agent Cebione (Merck), which is vitamin C, on the "time" of the hard wheat Tenmarq, semi-hard wheat Kawvale, and soft wheat Clarkan was also studied. The results obtained are presented in Table 23.

The "times" on all three types of wheat were very markedly increased by even low concentrations of Cebione.

Table 23 -- Effect of Cebione (Merck) on the
"time" of Tenmarq, Kawvale, and Clarkan.

Cebione added (mg.)	Variety		
	Tenmarq	Kawvale	Clarkan
	"Time", minutes		
None	108	49	37
1	200+	158	120
2	200+	193	131
3	200+	183	143
Mean	177+	146	108
Ave. deviation from mean	20.9%	32.9%	32.4%

It seems reasonable to assume that in this case the Cebione not only inhibited the protease to some degree but probably caused a change in the protein complex which in itself may have greatly increased the resistance of the gluten to disintegration.

The effects of the pepsin and bromate were noted on representative varieties of the hard red spring wheat grown in Canada. The data are in agreement with those obtained on hard red winter wheat varieties, in that pepsin markedly decreased the "time" and bromate increased the "time".

The data obtained in this study of the effect of protease activity on the "time" of the wheat meal fermentation time test indicate that all wheat varieties probably

contain a rather large quantity of proteolytic enzymes, especially in the bran layer. In strong hard wheats these proteases apparently are more or less latent in their action but are readily stimulated by activators such as cysteine-mono-hydrochloride. In weak soft wheats the proteases seem to be active and, therefore, in general are not stimulated to any great degree by activators.

It is commonly known among investigators that the "time" of the flour of soft wheat varieties is more nearly like that of the hard wheat varieties than is the case when whole wheat meal is used. The differences between "times" of hard and soft wheats when flour is used are not as wide as when whole wheat meal is used. Assuming that the proteases or activators are much more concentrated in the bran tissue or germ than in the flour, it is conceivable that the reason that the "time" of soft wheat flour is more nearly like that of the hard wheats than when the whole wheat meal is used is due to the protease activity of the two types of flour being more nearly alike than in the whole wheat meal of the hard and soft wheats.

The data obtained suggest that one of the main causes if not the major cause that short "times" are obtained on weak soft wheats as compared to long "times" for strong hard wheats when whole wheat meal is used is that of the

high active proteolytic enzyme content of the bran layer of the former and the latent nature or the low content of proteolytic enzymes in the latter.

Swanson (1937) found that by adding bran to flour longer "times" were obtained. Should the proteases in the bran layer be a major factor in causing shorter "time" readings for whole wheat meal than for flour, it would seem that the addition of bran to flour should decrease the time rather than increase it. This apparent conflict suggests the need for further study of the role of protease activity in determination of "time".

This study indicates that in basing conclusions on results of the whole wheat meal fermentation time test, one must bear in mind that the proteolytic activity of the samples tested may play an important role in the observed "time".

Swanson and Parker (1935) reported that increasing the diastatic activity of the wheat meal does not consistently influence the "time". Thus, of the two groups of enzymes naturally present in wheat, the proteases seem to affect the "time" more than diastase.

Alsberg and Griffing (1934) have shown that the quality of wheat crops varies from region to region as the result of environmental changes. Studies made of the effect of the environment on the "time" of varieties "time tested"

are in line with the observations of these investigators. To learn how much variation there was among samples of the same wheat variety, grown under different soil conditions, tests were made in 1931 on wheat grown in the nitrogen fixation plots at the agronomy farm. The data obtained are given in Table 24. These data indicate that soil conditions may be an important factor influencing "time." There are differences in protein content but the longer "times" are not due to higher protein, as the samples of long "time" include some of high and others of low protein content. Among the samples of low "time" there are similar variations in protein content.

Table 24 -- Effect on "time" of wheat grown on different fertility levels, nitrogen fixation plots, agronomy farm, Manhattan, Kansas, 1931.

Plot No.	Description of plot	"Time" Minutes	Protein %
6	Inoculated with Azotobacter	95	14.90
15	Sweet Clover Ground	80	13.55
12	Alfalfa Ground	74	12.25
1	Sweet Clover Ground	68	11.55
16	Soybeans Ground	67	11.85
7	Sweet Clover Ground	67	13.20
8	Soybeans Ground	65	11.85
5	Unlimed	64	14.80
4	Limed	62	14.30
19	Alfalfa Ground	59	13.75
11	Sweet Clover Ground	56	12.20
2	Alfalfa Ground	53	11.70

To learn the effect of climate as well as soil differences on "time", 21 varieties of wheat (3) grown in the southern and central sections of the hard red winter wheat region in 1934, were "time tested". A few of the varieties grown in the southern district were not grown in the central district and vice versa. These data are presented in Table 25.

The data illustrate the combined effect of environment and heredity. In general, the varieties grown in the central district have longer "time" than those from the southern district. However, Tenmarq has a long "time" in both districts. It is the highest ranking variety in the southern district and also ranks well above most of the varieties in the central district. Tenmarq grown in the southern district has a "time" of 155 minutes as compared to 161 minutes for the central district.

Analysis of the data in Table 25 reveals that the protein content in general is somewhat higher in the cases of the varieties grown in the central district. However, there is no evidence that the protein content influenced the "time". The correlation between the protein percentage

(3) These varieties of wheat were obtained from Dr. K. S. Quisenberry, agronomist in charge of wheat investigations in the hard red winter wheat belt for the U. S. Department of Agriculture.

Table 25 -- "Time" of varieties received from
K. S. Quisenberry, U. S. Dept. of Agriculture,
grown at several experiment stations in 1934.

District*	Variety	Protein %	"Time"	
			Minutes	Rank
C	Minturki	17.35	167	1
C	Tenmarq	16.35	161	2
C	Oro	16.60	157	3
S	Tenmarq	15.30	155	4
C	Cheyenne	15.70	150	5
C	Blackhull	15.40	130	6
C	Quivira	16.70	109	7
C	Kanred	15.30	107	8
C	Nebraska No. 60	15.65	105	9
S	Kawvale	16.40	92	10
S	Kanred (Goodwell, Okla.)	17.50	91	11
C	Kharkov	16.40	89	12
C	Turkey sel. C.I. 10016	16.20	81	13
S	Quivira	15.90	74	14
S	Blackhull	15.25	71	15
S	Kharkov	16.10	60	16
S	Kanred	15.60	57	17
S	Nebraska No. 28 (Goodwell, Okla.)	16.65	53	18
S	Early Blackhull	15.00	52	19
S	Nebraska No. 60	15.20	49	20
S	Turkey sel., C.I. 10016	15.25	41	21

Ave. protein %, 21 strains - - -15.99

Ave. "time", 21 strains - - - - - 98

Correlation coefficient of protein %
and "time"; $r = .118 \pm .143$

*C = central
S = southern

and the "time" is not significant, $r = .118 \pm .143$. Although the amount of protein in wheat varies with the soil and climatic conditions, there seems to be no evidence that the amount of protein affects the "time". This point will be

further discussed in the section on correlations between "time" and other quality tests.

Further evidence of the effect of soil and climatic conditions upon the "time" is brought out by the results of "time testing" 29 samples of Tenmarq grown by as many farmers in central Kansas in 1935. These data, given in Table 26, illustrate the important role that environment may play. Analysis of the data shows no distinct region of the state having a beneficial or detrimental influence on the "time". The extremely short "times" for a few samples of Tenmarq may be due to some factor not normally present in Tenmarq, such as mixtures of other wheat varieties or of rye, immature or light weight kernels, imperfect development of protein, or the presence of damaged wheat kernels. Other data indicate that environment does not ordinarily have so great an influence on "time". Determinations of protein content of each sample reveal marked differences in protein percentages of the different samples. The correlation of the protein percentage and the "time" of the samples was determined, $r = -.157 \pm .128$. This low and insignificant correlation shows that the "time" does not depend primarily on protein.

Table 26 -- Wheat meal fermentation "time" of samples of Tenmarq grown in central Kansas, 1935.

District Grown in	County	Protein %	"Time" Minutes
Wichita	Sedgwick	10.75	240
Kiowa	Barber	13.75	185
Salina	Saline	11.55	170
Enterprise	Dickinson	11.50	145
Manhattan	Riley	13.15	137
Pratt	Pratt	11.55	136
Pratt	Pratt	13.55	134
Manhattan	Riley	13.80	132
Abilene	Dickinson	12.00	132
Eldorado	Butler	12.35	126
Moundridge	McPherson	13.05	121
Belpre	Edwards	13.10	120
Halstead	Harvey	10.90	120
Hutchinson	Reno	13.75	119
Abilene	Dickinson	10.40	117
Clay Center	Clay	12.60	115
Anthony	Harper	10.90	114
Manhattan	Riley	12.00	113
Salina	Saline	12.90	112
Winfield	Cowley	12.70	111
Cheney	Kingman	12.00	111
Abilene	Dickinson	13.65	108
Riley	Riley	12.60	107
Anness	Sedgwick	13.95	106
Hutchinson	Reno	12.20	103
Great Bend	Barton	13.40	102
Colwich	Sedgwick	11.65	90
Anness	Sedgwick	12.75	67
Harper	Harper	13.55	59

Ave. protein %, 29 samples - 12.48

Ave. "time" - - - - - 122

Correlation of protein % and "time", $r = -.157 \pm .128$

Varieties of wheat grown at Manhattan and Hays, Kansas, and in the cooperative wheat variety tests show the effect of the soil and climatic differences on the "time" of the

varieties tested. These data are given in Table 27.

Table 27 -- Effect of soil and climate on "time" of winter wheat varieties grown at different locations in Kansas in 1936.

Variety	Source								
	Farm	Plots	Field	Cooperative experiments (b)					Ave. "Time"
	Plots Man.	Hays	Hays	on farms (a)					
				N.C.	S.C.	C.	N.E.	E.	
Cheyenne	125	137							161
Tenmarq	77	144	184	143	120	110	101	94	122
Kanred x Hard	104	101			110				105
Federation Ks. 2672									
Kanred x Hard	55				64				59
Federation Ks. 2673									
Turkey	46	43		86	63		57	52	58
Kawvale	45					63	49	53	52
Quivira	56	46			48				50
Kanred	52	39		52	55				49
Blackhull	41	37		55	62		48	46	48
Early Blackhull	141	44		47	57				47
Clarkan	38					43	38	42	40
Fulcaster	37					43	39	37	39
Harvest Queen	40					41	36	37	38
Chiefkan	30	31							31

(a) N.C.=north central; S.C.=south central; C. = central; N.E.=north east; E.=eastern Kansas.

(b) Averages not comparable.

The data indicate that wheats grown in eastern Kansas tend to have shorter "time" than in Central Kansas. This additional moisture may be a factor in producing more starchy kernels of lower protein content and having gluten more

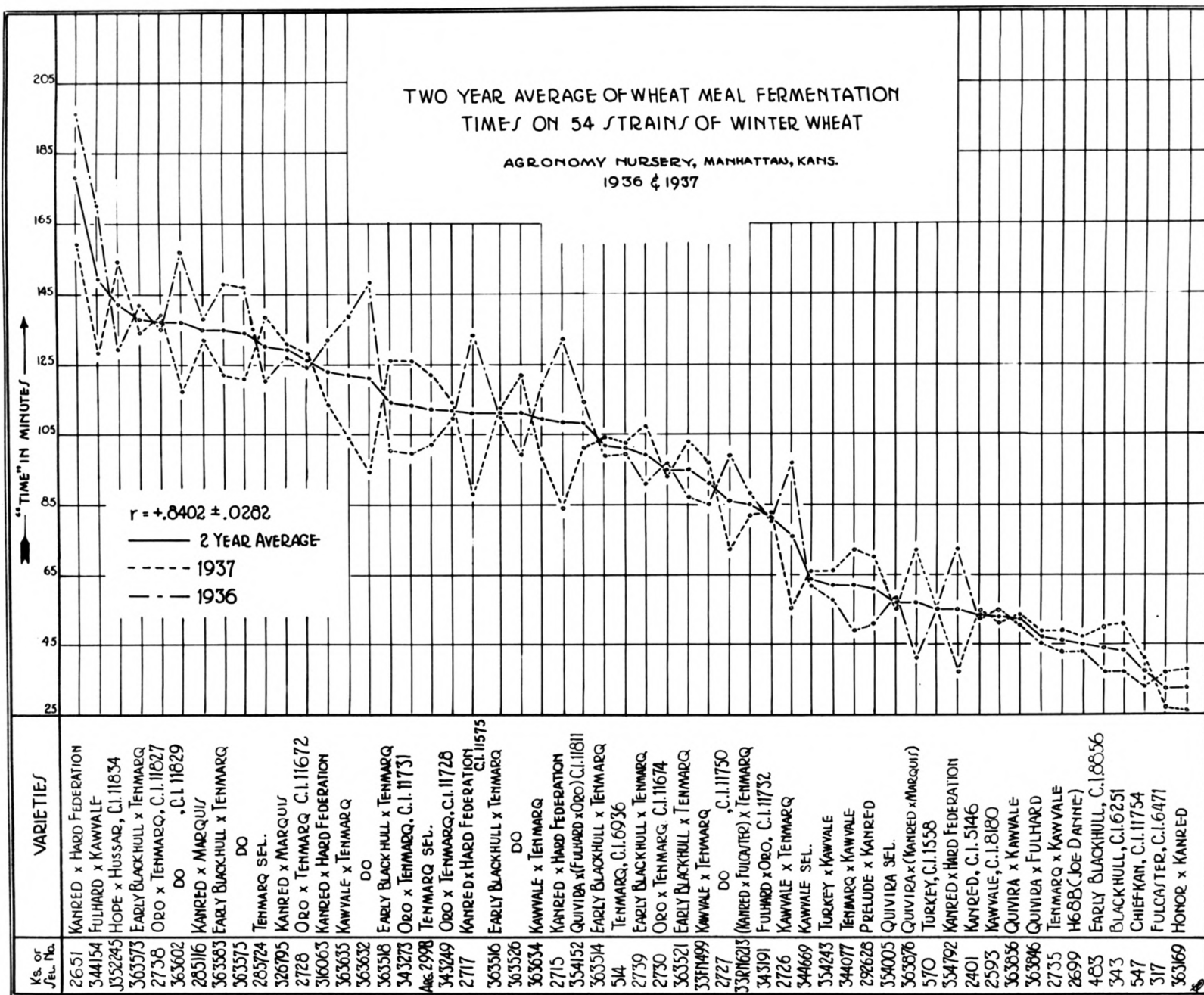
easily disintegrated in a water solution.

Variations in the "time" of wheat varieties grown in two seasons are illustrated in Figure 1. Fifty-four varieties "time tested" in 1936 and 1937, using the same technique and procedure, are included in this study. Although there are a few varieties showing rather marked deviations in "time" in the two seasons, there is a high correlation between the "time" in the two seasons, $r=.840 \pm .028$. This significant correlation indicates that the "time test" measures a characteristic that is little modified by seasonal fluctuations. The deviations in per cent of the "time" of the fifty-four varieties in the two seasons from the mean of the two "times" were determined. A quartile study of these data was made. The quartiles are as follows:

<u>Quartile</u>	<u>No. varieties</u>	<u>Ave. "Time"</u>	<u>Ave. deviation</u>	
		minutes	minutes	per cent
I	13	138	9.9	7.2
II	14	111	11.6	10.5
III	14	77	7.5	9.7
IV	13	46	4.3	9.8

The deviations on a percentage basis, for long "time" varieties are slightly less than for medium and short "time" varieties. The difference in percentage deviations of the

Figure 1



"time" of short "time" varieties is slightly larger than difference of the "time" of long "time" varieties, although the difference in minutes of short "time" varieties between the two seasons is less than the difference in minutes of the long "time" varieties.

The varieties graphically illustrated in Figure 1 having long "time" in one season will have a long "time" in other seasons, and those of short "time" in one season will have a short "time" in other seasons. Most of the strains showing the greatest variation between seasons are hybrid wheats of comparatively recent origin, of which the parental varieties differ widely in "time". For example, selections of Kawvale x Tenmarq and Kanred x Hard Federation show great variability in "times" in the two seasons. The Tenmarq parent in the Kawvale x Tenmarq cross, normally has a long "time", while the Kawvale parent normally has a much shorter "time". The Kanred parent, in the Kanred x Hard Federation cross, has a longer "time" than the Hard Federation parent, although only a few "time tests" of this Australian white wheat have been made. It is possible that these hybrid wheats showing great variability in "time" in 1936 and 1937 and whose parental varieties differ widely in "time" are heterozygous for genetic factors determining

"time", although homozygous for characters commonly observed in the field. It is commonly recognized that the effects of heredity and environment are closely interlocked. The variability of these hybrid wheats may be explained by the possibility of the quality factors of one or the other parent being expressed more prominently in one season than in another. Too much emphasis should not be placed on the part that the environment plays in causing a long or short "time". Heredity apparently plays as great if not a greater role than environment, in determining the "time" of wheat varieties. In agreement with Cutler and Worzella (1931) it has been found that the "time" of different market classes of wheat is characteristically different. A few varieties do not have "time" typical of their market class, but the average of varieties in a given market class has a definite rank in relation to other classes. In general, the market classes of wheat rank as follows in "time"; (1) hard red spring (2) hard red winter (3) soft red winter, and (4) white wheat. No data on the "time" of durum or red durum classes were obtained, but the work of other investigators places Kubanka durum wheat in a low rank. The following data obtained on varieties of four market classes in 1937 show this relationship:

<u>Market class of wheat</u>	<u>No. of vari- eties tested</u>	<u>"Time", minutes</u>
Hard Red Spring	7	153
Hard Red Winter	19	77
Soft Red Winter	12	32
White	3	26

These data are not strictly comparable in that it is impossible to obtain samples representative of all the market classes grown under the same soil and climatic conditions that are representative of these wheats as grown in their natural environment.

Of all the factors previously discussed, variety probably affects the "time" more than any other factor. It seems logical to conclude that variety is the factor on which "time" is based. Thus, the "time" of a variety is considered as a measure of the gluten quality or "strength" of the variety.

Meaning of the "Time"

The "time" of the wheat meal fermentation time test has been considered by investigators to be a measure of the gluten strength of a variety or sample of wheat being tested. The author has reached a modification of this meaning of the "time" after analyzing the literature and studying in the laboratory several of the factors influencing the "time".

In general all the factors affecting the "time" may be so standardized as to enable the careful operator to obtain readings on different days that will correspond very satisfactorily. The major cause for differences in the "time" obtained on various samples is due to differences in the inherent ability of the gluten of the sample being tested to resist the disruptive forces of the fermentation process at the water-dough interface, which in turn may be greatly influenced by other factors such as the proteolytic nature and content of the bran layer and the gassing ability of each sample being tested. Should only the inherent ability of the gluten to resist the disruptive forces of the fermentation under water be the factor causing differences in "time" among varieties, the "time test" would probably be a good measure of the gluten strength. If the proteolytic content of the bran layer of various varieties of soft wheats is more nearly constant than in hard wheats, as data previously discussed indicate, the "time test" may be a good measure of the gluten strength. However, in hard wheats other factors such as the nature and content of proteolytic enzymes in the bran layer and the gassing ability of the variety may have such a great influence that the inherent gluten quality of a variety may be partially obscured.

In general, weak soft wheats have short "time", while the strong hard wheats usually have long "time". However, within the strong hard red winter wheat group may be found varieties having "time" readings not representative of the group. Varieties with rather low "time" are not necessarily of an inferior quality for bread-making. For example, the varieties Turkey and Kanred are accepted as being high quality bread wheats, though the "time test" would indicate that these varieties are rather weak hard wheat types, or at least weaker than such long "time" varieties as Oro, Cheynne, and Tenmarq.

The exact meaning of the "time" is not fully understood. Until more extensive investigation of the possibilities of the "time test" are made, one must not hold too firmly that a long "time" indicates a high quality wheat, and vice versa. Much more value will be obtained from the "time test" if the "time" is thought of as an indication of the variety type. Within its limits, the "time test" can be of great value. In association with other tests, the "time test" has a place, but the possibility of extending its use to replace the baking test and other quality tests is not very great.

The greatest potential value of the "time test" probably lies in its use to the plant breeder in studying the progeny of two varieties having "time" readings differing widely. Only those segregates having a "time" reading in the same range as that of the parent of the most desirable quality, whether a variety of a long or a short "time", should be selected for further testing and possible increase and distribution. By making use of the "time test" the plant breeder can be relatively sure as to the inherent quality of the strains selected, as any strain having a "time" in the range of the poor quality parent will in all likelihood have the characteristics of the poor quality parent and vice versa. Any segregate of a cross between long and short "time" parents having a "time" greatly exceeding the limits of either parent, possibly due to transgressive segregation, is likely to have different quality than either parent. Most segregates of a cross between parents both of excellent quality, whether the parents have the same approximate "time" or different "time", is likely to have good quality gluten, with the possible exception of progeny having "time" readings significantly less than the "time" of the shorter "time" parent. The

"time test" will be of little or no value in evaluating progenies of a cross between two varieties having approximately the same "time" reading but of vastly different baking quality.

Thus, the "time test" is of great value in its original role as first used by Pelshenke (1933a), who intended the test for use by the plant breeder in obtaining an estimate of the quality of lines of wheat in the early stages of development when only a small amount of grain is available.

Use of the "Time Test" in Variety Testing and Plant Breeding

An intensive study of the "time" of a large number of wheat varieties must be made before the "time test" can be of any great use to the plant breeder in studying the inheritance of quality in the segregates of a cross. In order to determine the "time" of a large number of varieties grown in several seasons, samples from various sources were obtained. The sources from which wheat varieties were used for "time testing" are: (1) field plot variety tests on branch experiment station, and regional experimental fields, (3) wheat variety plots at the agronomy farm, Manhattan, and (4) the wheat breeding nursery at Manhattan.

Varieties in Cooperative Wheat Variety Tests on Farms in Kansas. The "time" was determined upon varieties of wheat grown in the cooperative experiments in Kansas in 1931, 1934, 1935, 1936, and 1937. The data for the year 1931 are given in Table 28.

Table 28 -- Wheat meal fermentation time of varieties of wheat grown in cooperative wheat variety tests on farms in Kansas, 1931.

Variety	District			Ave. "time" *
	Northwest	Southwest	Eastern	
	"Time", minutes			
Cheyenne	145	156	143	148
Tenmarq	145		148	147
Kanred	111	133	95	113
Turkey	87	108	120	105
Blackhull	85	111	100	99
Early Blackhull	69		84	77
Kawvale			76	76
Michigan Wonder			74	74
Clarkan			70	70
Harvest Queen			69	69
Fulcaster			45	45

*Averages not comparable

Although all varieties were not grown in all 3 districts, and for this reason the data are not comparable, it is evident that the varieties rank in a similar manner, regardless of the area where grown. The "time test" definitely separated wheats of inherently hard, semi-hard, and soft texture. The distinctly soft wheats such as Michigan Won-

der, Clarkan, Harvest Queen, and Fulcaster have short "time", while Cheyenne and Tenmarq, typical hard wheat varieties, have long "time". Varieties such as Kanred, Turkey, and Blackhull, with medium "time", are affected more by differences in environment than long "time" varieties such as Cheyenne and Tenmarq. The erratic behavior of these medium "time" varieties may be due to differences in texture of the grain in various districts. Within a variety, samples with hard kernels produce coarse, sharp meal, resulting in short "time", while soft kernels produce a finer meal, giving a longer "time". Kawvale, a semi-hard wheat grown in eastern Kansas, has intermediate "time" between the strong hard wheats and weak soft wheats. Early Blackhull has shorter "time" than Blackhull.

The data for the years 1934 and 1935 are presented in Tables 29 and 30. Results in these two seasons are similar to those obtained in 1931. In addition to the varieties tested in 1931, Iobred and Quivira were tested in 1934. Iobred, a semi-hard wheat had shorter "time" than Kawvale, as grown in eastern Kansas. Quivira, a hard wheat, had slightly longer "time" than Kanred. In 1935, two selections of the cross Kanred x Hard Federation, Kans. Nos. 2672 and 2673, were tested in addition to those varieties tested previously. Kans. 2672 had "time" similar to Tenmarq, while Kans. 2673 had "time" like Turkey.

Table 29 -- Wheat meal fermentation time of varieties of wheat grown in cooperative wheat variety tests in Kansas, 1934.

Variety	District			Ave. "time"*
	Northwest	Central	Eastern	
	"Time", minutes			
Cheyenne	157			157
Tenmarq	151		136	144
Turkey	121			121
Blackhull	120			120
Early Blackhull	113			113
Quivira	118		82	100
Kanred	106		73	90
Kawvale		52	114	83
Iobred			73	73
Fulcaster		56	53	55
Michigan Wonder			51	51
Clarkan		47	47	47
Harvest Queen		38	41	40

*Averages not comparable

Table 30 -- Wheat meal fermentation time of varieties of wheat grown in cooperative wheat variety tests in Kansas, 1935.

Variety	District(a)				Ave. "time"(b)
	N.C.	S.C.	C.	E.	
"Time", minutes					
Kanred x Hd. Fed., Ks. 2672		134			134
Tenmarq	127	125		144	132
Quivira	93	83		112	96
Kanred x Hd. Fed., Ks. 2673		78			78
Kawvale			46	98	72
Turkey	46	61		104	70
Iobred				66	66
Blackhull	41	54		84	60
Kanred	53	61			57
Early Blackhull	41	52			47
Michigan Wonder				44	44
Clarkan			30	49	40
Harvest Queen			31	48	40
Fulcaster			31	46	39

(a) N.C. = north central; S.C. = south central; C. = central; and E. = eastern.

(b) Averages not comparable.

The data for the year 1936 are given in Table 27, page 77, in the section on factors affecting the "time", where these data were used to illustrate the influence of environment on "time". The data obtained in 1936 also show that variety is a major factor in determining "time".

Data on "time" of varieties grown in cooperative experiments in 1937 are given in Table 31.

Table 31 -- Wheat meal fermentation time of varieties of wheat grown in cooperative wheat variety tests in Kansas, 1937.

Variety	District			Ave. "time"*
	N. Central	S. Central	Eastern	
	"Time", minutes			
Cheyenne	155	155		155
Tenmarq	122	124	128	125
Turkey	108	87	94	96
Quivira		94		94
Blackhull	82	99		91
Kanred x Hd. Fed., Ks. 2673		89		89
Kawvale			83	83
Kanred	73	90		82
Early Blackhull	79	60		70
Clarkan			61	61
Chiefkan	42	66		54
Harvest Queen			38	38
Fulcaster			34	34

*Averages not comparable.

As in previous years, these data show that in general the "time test" separated the hard, semi-hard, and soft wheats. However, the variety Chiefkan, with dark, hard grain, had shorter "time" than any other hard wheat tested, approaching the soft wheats. This indicates that this variety is of a type not comparable to the strong hard wheats such as Cheyenne and Tenmarq.

The following data for the average "time" of varieties grown in cooperative wheat variety tests for 5 years show that in general the "time test", as used at this station,

separated strong, semi-strong, and weak wheats:

<u>Variety</u>	<u>5 yr. ave. "time", minutes</u>
Tennarq	132
Turkey	91
Blackhull	85
Kanred	79
Kawvale	75
Early Blackhull	72
Clarkan	52
Harvest Queen	45
Fulcaster	43

Cheyenne has a 3 year average "time" of 157. This variety is known to be a strong wheat. This shows that the "time test" has a place in wheat quality testing. However, the test does not always accurately separate the strong wheats from the weaker wheats. For example, Turkey, a variety of accepted quality, does not have average "time" enough higher than Blackhull to distinguish quality differences by use of the "time test" alone.

Varieties In Plots on Branch Stations and Regional Experimental Fields. In 1934 the "time test" was made on varieties of wheat grown at the Hays and Colby branch experiment stations and in the experimental fields at Wichita and Kingman. Data obtained on varieties grown at Hays are given in Table 32.

Table 32 -- Wheat meal fermentation time of varieties grown at Hays, Kansas, 1934.

Variety	"Time", minutes
Oro	152
Cheyenne	151
Tenmarq	146
Turkey, Ks. 570	114
Quivira	103
Early Blackhull	93
Kanred x Hard Federation, Ks. 2672	90
Blackhull	87
Kanred x Hard Federation, Ks. 2671	83
Kanred x Hard Federation, Ks. 2673	81
Ave. "time", 10 strains - - - - -	110

The "time test" ranked the varieties very similarly to their known quality rating. The strong hard wheats of known high quality such as Oro, Cheyenne, Tenmarq, and Turkey have the longest "times". Varieties of medium or questionable quality, such as Quivira, Early Blackhull, Blackhull, and selections of Kanred x Hard Federation have shorter "time".

Data for varieties grown at Colby in 1934 are given in Table 33. The varieties Oro, Cheyenne, and Turkey have long "time" in agreement with other tests. Of the Kanred x Hard Federation strains, Ks. 2672 has the longest "time". This strain is known to be superior in quality to some other selections of this cross. Selections of Tenmarq x Minturki, and two crosses, Ks. 522 and 524, made in an attempt to combine

earliness and winterhardness, have long "time", but not much is known of the baking qualities of these hybrid wheats. The "time" does not depend upon the quantity of protein, as is shown by the data on the protein determinations. The variety with the longest "time" has the lowest amount of protein, and a few varieties of short "time" have a high protein per cent. Quivira also has long "time". The other varieties listed have shorter "time". All of these varieties of shorter "time" are known to be of questionable quality, as judged by experimental milling and baking tests.

Table 33 -- Wheat meal fermentation time of varieties grown at Colby, Kansas, 1934.

Ks. or sel. No.	C.I. No.	Variety	Protein %	"Time", minutes
2672	10091	Kanred x Hard Federation	14.90	185
495	8220	Oro	16.45	163
523		Tenmarq x Minturki	17.25	159
2667	8885	Cheyenne	15.40	154
570	1558	Turkey	15.95	150
522		((Kanred x Hard Federation) x (Minhardi x Minturki))	16.40	145
524		(Minhardi x Minturki) x Tenmarq	17.35	141
2628	8886	Quivira	15.65	127
483	8856	Early Blackhull	15.55	105
521		((Kanred x Minhardi) x (Prelude x Kanred))	16.70	99
2720	10016	Turkey sel.	15.60	98
343	6251	Blackhull	15.25	97
2673	10092	Kanred x Hard Federation	17.25	96
2671	11373	Kanred x Hard Federation	16.45	82
Ave. protein %, 14 strains - - - - -			16.30	
Ave. "time", " " - - - - -				129

Eight varieties of wheat grown on the regional experimental fields at Wichita and Kingman in 1934 were tested. The data are presented in Table 34.

Table 34 -- Wheat meal fermentation time of varieties grown at Wichita and Kingman, Kansas, 1934.

Variety	"Time", minutes		
	Wichita	Kingman	2 station average
Cheyenne	141	136	139
Kanred x Hard Federation, Ks. 2672	140	126	133
Tenmarq	124	111	118
Quivira	108	126	117
Kanred x Hard Federation, Ks. 2673	102	122	112
Turkey, Ks. 570	92	115	104
Kanred x Hard Federation, Ks. 2671	101	93	97
Early Blackhull	103	88	96
Ave. "time", 8 varieties	114	115	

The "time" readings of the varieties grown on these fields are not in full agreement with the known baking qualities of the varieties. Thus, in the Wichita group the "time test" ranks Turkey as the poorest of the varieties, although flour milled from Turkey usually bakes bread equal or superior to some of the varieties with longer "time". In the Kingman group, as at Wichita, Cheyenne had the longest "time". Quivira and two selections of Kanred x Hard Federation ranked higher than Turkey. Tenmarq

ranked lower than usual. Early Blackhull had the shortest "time".

Wheat Variety Plots at Agronomy Farm, Manhattan. Winter wheat varieties grown in field plots at the agronomy farm in 1931, 1934, 1935, 1936, and 1937 have been "time tested". The results of these studies are given in Tables 35 to 39.

In each of these tables the varietal differences are clearly shown. The distinctly soft wheats have short "time". The data for the 1931 crop, given in Table 35, show that the test places Kawvale in the range of the hard wheats. Milling and baking tests have shown that this variety is not a typical soft wheat. Blackhull, Early Blackhull, Superhard Blackhull, Kharkov (Hays No. 2), and Fulhard, although hard wheat varieties, have short "time" indicating that these varieties have a quality complex somewhat different from those hard wheat varieties with longer "time". The soft wheat variety Currell has longer "time" than the other soft wheats. Two of the 3 early x winterhardy selections, Ks. 517 and 518, have "time" in the range of the weak soft wheat varieties and hard wheat varieties of inferior baking quality. The other selection has a "time" somewhat longer than Turkey and Kharkov. The 4 strains of Kanred x Hard Federation show marked differences in "time", i.e. 2 strains are similar to the long "time" Cheyenne variety, 1 strain has a "time" in the range

Table 35--Wheat meal fermentation time of wheat varieties grown in plots, agronomy farm, Manhattan, Kansas, 1931.

Ks. No.	Variety	"Time", minutes
	Oro	195
	Cooperatorka	192
2668	Tenmarq sel.	180
	Tenmarq	161
	Cheyenne	154
2674	Kanred x Hard Federation	152
2644	Kanred x Marquis	146
2672	Kanred x Hard Federation	142
	Quivira	133
2673	Kanred x Hard Federation	128
	Minturki	123
	Kawvale	119
	Nebraska No. 60	109
2669	Tenmarq sel.	104
	Kanred	91
2670	Tenmarq sel.	87
519	(Prelude x Kanred) x (Turkey x Minnessa)	81
	Currell	81
2671	Kanred x Hard Federation	76
	Kharkov	72
	Turkey	72
	Nebraska No. 28	70
	Harvest Queen	63
518	(Eureka x Minhardi) x (Kanred x Hard Federation)	62
	Fulhard	61
	Early Blackhull	56
	Kharkov (Hays No. 2)	48
	Superhard Blackhull	47
517	(Turkey x Minnessa) x (Kanred x Hard Federation)	46
	Blackhull	44
	Clarkan	42
	Fulcaster	39
Average "time", 32 varieties		99

of the varieties Quivira and Minturki and one strain has a short "time" similar to Superhard Blackhull. The variety Turkey is known to have much higher quality than Nebraska No. 28, although the "time test" does not indicate it. The longer "time" varieties such as Oro, Cooperatorka, Tenmarq, and Cheyenne are of known high quality, as judged by milling and baking tests. As reported by Swanson and Parker (1935), who presented the data from the 1931 crop, this indicated that the long "time" seems to be definitely related to the character of the gluten.

Data for the 1934 crop given in Table 36 were subjected to statistical study by Laude (4) . This study, based upon the replicate tests of each variety, showed that differences in "time" as great as 19 minutes between the varieties tested may be accounted for by experimental error. Small differences between varieties may not be due to inherent differences. The chances or odds are 19 to 1 (95%) that differences in the average "time" of varieties greater than 19 minutes are explainable by inherent varietal differences. For example, Tenmarq, having an average "time" in this test of 129 minutes, cannot be said to be significantly different from any of the varieties having "time" between 110 and 135 minutes. However, Tenmarq has a significantly higher "time" than the varieties below

(4) Unpublished data of Dr. H. H. Laude, Department of Agronomy, Kansas State College.

agreement with the rating of these varieties according to milling and baking tests. With the possible exceptions of the Kanred x Hard Federation strains, Minturki, Quivira, Prelude x Kanred, and Kawvale, the varieties having a "time" of 100 minutes or more are of excellent bread making quality. Turkey and Kanred are of much different quality type than Blackhull which is rated the same as these two varieties by the "time test". Varieties, with the exception of Turkey, Kanred, and Kharkov, having "time" readings significantly below 100 are known to be weak soft wheats or hard wheats of inferior baking quality.

The "time" data, for wheat varieties grown in farm plots in 1935, are given in Table 37. These data indicate that the "time test" has separated distinctly strong and weak wheats. The strains of Kanred x Hard Federation have "time" readings somewhat higher than would be expected from the known baking behavior of the selections of this cross. As in previous years, Oro, Tenmarq, and Cheyenne have long "time". The "time test" ranked the two hard wheats, Nebraska No. 60 and Nebraska Turkey sel., Ks. 2720, in the range of the weak soft wheats. Baking tests show that these two varieties are weaker than most standard varieties of hard wheat. The semi-hard wheat variety Minturki has medium "time", 77 minutes.

Table 37 -- Wheat meal fermentation time of wheat varieties grown in plots, agronomy farm, Manhattan, Kansas, 1935.

Ks. No.	Variety	"Time", minutes
2690	Kanred x Marquis	163
	Oro	149
	Tenmarq	143
2717	Kanred x Hard Federation	140
	Cheyenne	130
2715	Kanred x Hard Federation	130
2716	do	126
2672	do	123
2714	do	121
2718	do	121
2644	Kanred x Marquis	88
2719	Turkey sel., C.I. 10094	86
	Kanred	83
	Minturki	77
	Quivira	72
2673	Kanred x Hard Federation	72
2689	Prelude x Kanred	69
2695	P1066 x Prelude	63
	Kharkov	61
	Turkey	52
518	(Eureka x Minhardi) x (Kanred x Hard Federation)	51
519	(Prelude x Kanred) x (Turkey x Minessa)	51
	Early Blackhull	50
	Blackhull	45
	Kawvale	43
517	(Turkey x Minessa) x (Kanred x Hard Federation)	42
2720	Turkey sel., C.I. 10016	37
	Clarkan	35
	Harvest Queen	33
	Nebraska No. 60	32
Ave. "time", 30 varieties - - - - -		83

"Time" data on varieties grown in farm plots in 1936 are given in Table 38. All of the varieties having "time"

Table 38 -- Wheat meal fermentation time of wheat varieties grown in plots, agronomy farm, Manhattan, Kansas, 1936.

Ks. No.	Variety	"Time", minutes
2690	Kanred x Marquis	139
2725	Kawvale x Tenmarq	132
2724	do	130
2728	Oro x Tenmarq	129
	Cheyenne	125
2729	Oro x Tenmarq	118
2718	Kanred x Hard Federation	110
2716	do	109
2672	do	104
2717	do	103
	Oro	99
2715	Kanred x Hard Federation	87
	Tenmarq	77
2714	Kanred x Hard Federation	65
2719	Turkey sel., C.I. 10094	61
2727	Kawvale x Tenmarq	60
	Quivira	56
2673	Kanred x Hard Federation	55
2726	Kawvale x Tenmarq	54
	Kanred	52
2689	Prelude x Kanred	47
	Kharkov	46
2695	P1066 x Prelude	46
	Turkey	46
	Kawvale	45
2723	Kawvale x Tenmarq	43
	Blackhull	41
	Early Blackhull	41
	Harvest Queen	40
	Kanred x Genessee Giant	40
2720	Turkey sel., C.I. 10016	40
	Nebraska No. 60	39
	Clarkan	38
	Kanhull	38
	Fulcaster	37
	Rupp, Red Bull	37
	Chiefkan	30
Ave. "time", 37 varieties - - - - -		69

above 45 minutes are hard wheats. Of the 9 varieties with "time" in the range of soft wheats, i.e., 40 minutes and less, five are hard wheats, viz., Chiefkan, Rupp Red Hull, Kanhull, Nebraska No. 60, and Nebraska Turkey sel., Ks. 2720. This indicates that the inherent quality of these low "time" hard wheats is significantly different from that of the known high quality hard wheat varieties such as Cheyenne, Oro, and Tenmarq. The Kawvale x Tenmarq and Kanred x Hard Federation strains having long "times" have not in general proved to be of the quality of the higher quality parents, Tenmarq and Kanred.

The data for the wheat varieties grown in farm plots in 1937 are presented in Table 39. Of the 7 varieties with "time" in the range of soft wheats, 53 minutes and less, 4 are hard wheats, viz., Nebraska No. 60, Chiefkan, Nebraska Turkey sel. (Ks. 2720) and Blackhull. No true soft wheat varieties have "time" above 53 minutes. The cross, ((Prelude x Kanred) x (Turkey x Minessa)), ranks in "time" with Tenmarq. Baking tests have shown that this early x winter-hardy cross is inferior to Tenmarq by a wider margin than indicated by the "time test". All the varieties having "time" of 100 minutes or longer are of good or excellent baking quality. The rank of Tenmarq in 1937 is lower than is normally the case. Tenmarq usually ranks in "time" with

Table 39 -- Wheat meal fermentation time of wheats grown in farm plots, Manhattan, Kansas, 1937.

Ks. No.	Variety	"Time", minutes
2690	Kanred x Marquis	149
2736	Oro x Tenmarq	145
2728	do	140
	Oro	137
2729	Oro x Tenmarq	136
	Cheyenne	130
2715	Kanred x Hard Federation	118
2719	Turkey sel., C.I. 10094	100
	Hope x Mediterranean	93
2695	Pl066 x Prelude	92
2727	Kawvale x Tenmarq	88
	Tenmarq	78
2717	Kanred x Hard Federation	78
519	(Prelude x Kanred) x (Turkey x Minnessa)	78
2673	Kanred x Hard Federation	77
2726	Kawvale x Tenmarq	71
	Early Blackhull	69
	Quivira	69
	Kanred	69
	Kawvale	67
	Turkey	65
	Kharkov	62
2723	Kawvale x Tenmarq	60
2735	do	57
	Blackhull	53
	Clarkan	53
	Harvest Queen	50
2720	Turkey sel., C.I. 10016	46
	Chiefkan	44
	Nebraska No. 60	43
	Fulcaster	38
Ave. "time", 31 varieties - - - - -		82

Cheyenne and Oro. Kanred, Turkey, and Kharkov rank lower in the "time test" than expected on the basis of their good baking qualities.

Average "time" of the varieties grown in the wheat variety plots at the agronomy farm for 5 years is as follows:

<u>Variety</u>	<u>"Time", minutes 5 year ave.</u>
Ore	139
Cheyenne	132
Tennmarq	118
Kanred x Hard Federation, Ks. 2673	85
Kanred	75
Kawvale	74
Turkey	64
Kharkov	61
Early Blackhull	59
Nebraska No. 60	56
Blackhull	53
Harvest Queen	46
Clarkan	44

These data show that the "time test" has separated the varieties tested into (1) weak soft wheat varieties with short "time", Harvest Queen and Clarkan, (2) hard wheat varieties of medium "time", and (3) hard wheats with very long "time" and good to excellent baking quality. The semi-hard variety Kawvale, ranks between Kanred and Turkey in "time", and has baking characteristics more like a hard wheat than a soft wheat. Kanred x Hard Federation has a 5 year average "time" higher than Kanred, but is not considered equal to Kanred in baking.

Strains Grown in the Wheat Breeding Nursery, Manhattan.
Varieties, Selections, and Advanced Hybrids. In an attempt to evaluate the quality of winter wheats grown in the wheat

nursery, the "time test" was made on a selected group of strains grown in 1931, 1934, 1935, 1936, and 1937. The "time" of 53 strains grown in 1931 is given in Table 40. The average "time" for the 53 strains was 90 minutes. The strains tested varied from the high "time" of 166 to the low "time" of 36 minutes. No typical soft winter wheats were tested. The short "time" of some of the hard wheats tested suggests that short "time" is not an absolute indication of a soft wheat. However, the differences in "time" among these hard wheat selections are probably highly significant.

Nine of the 14 strains of Kanred x Hard Federation tested have "time" over 100 minutes. The "time" of strains of this cross varied from 166 to 47 minutes. Of the 6 selections of the 3 back-crosses, Kanred x (Marquis x Kanred), Kanred x Kanmarq, and Kanred x Tenmarq, only 1 strain has "time" above 100 minutes. A selection of Kanred x Tenmarq has the longest "time", 146 minutes. A selection of Kanred x (Marquis x Kanred) has the shortest "time", 41 minutes. The remaining selections of these back-crosses have medium "time" ranging from 53 to 69 minutes. Nine of the 15 selections of Kanred x Marquis and of Tenmarq, which are of similar parentage, have "time" above 100 minutes. The longest "time" in this group of hybrid wheats, is 142 minutes, for a selection of Kanred x Marquis. A selection of

Table 40 -- Wheat meal fermentation time of winter wheats grown in the wheat breeding nursery, Manhattan, Kansas, 1931.

Ks. or Sel. No.	Variety	"Time", minutes
296608	Kanred x Hard Federation	166
2651	do	164
2648	do	152
286260	do	150
286218	do	147
311976	Tenmarq x Kanred	146
306189	Kanred x Hard Federation	145
306297	do	142
H.C.313	Kanred x Marquis	142
306353	Kanred x Hard Federation	140
2689	Prelude x Kanred	140
285846	Tenmarq sel.	136
295116	Kanred x Marquis	127
285859	Tenmarq sel.	125
285598	do	122
285569	do	122
285785	do	120
285620	do	107
254898	Kanred x Hard Federation	106
296548	Tenmarq sel.	101
292984	Kanred x Nebraska No. 28	100
286354	Kanred x Hard Federation	92
292878	Fulcaster x Marquis	87
311865	Kanred x Marquis	80
296574	do	79
285464	Prelude x Kanred	77
30LRN1047	Fulcaster x Marquis	75
296629	P1066 x Prelude	73
285637	Tenmarq sel.	73
285818	do	70
292628	Prelude x Kanred	69
304264	Kanred x (Marquis x Kanred)	69
2696	Fulcaster x Marquis	68
311849	Kanred x Kanmarq	67
311928	Tenmarq x Kanred	67
289117	Kanred x Nebraska No. 28	64
292637	P1066 x Prelude	60
285663	Tenmarq sel.	60
255441	Kanred x Marquis	59
311924	Tenmarq x Kanred	58
296614	Kanred x Hard Federation	58
254624	do	56
296576	Kanred x Marquis	56
292993	Kanred x Nebraska No. 28	54
311862	Kanred x Kanmarq	53
527	Smithsonian	49
306252	Kanred x Hard Federation	49
528	Red Hull	48
306162	Illini Chief x Marquis	48
306241	Kanred x Hard Federation	47
242212	Illini Chief x Marquis	44
312020	Kanred x (Marquis x Kanred)	41
29LRN259	Kanred x Fulhard	36
Ave. "time", 53 strains - - - - -		90

Kanred x Marquis has the shortest "time", 56 minutes. The Tenmarq selections, as might be expected from their common origin, show less variability in "time" than those of Kanred x Marquis. Most of the selections of Prelude x Kanred and of the related cross, Pl066 x Prelude, have "time" intermediate between the long and short "time" wheats grown in the nursery in 1931. Only 1 strain of these 2 crosses had a "time" longer than 100 minutes. This was a selection of Prelude x Kanred with a "time" of 140 minutes. The lowest "time", 60 minutes, was for a selection of Pl066 x Prelude. Of the 3 strains of Kanred x Nebraska No. 28, 1 had an intermediate "time" of 100 minutes, the other two had comparatively short "time" readings of 64 and 54 minutes. The 3 strains of Fulcaster x Marquis have "time" intermediate between the characteristic long "time" of the Marquis spring wheat parent and the short "time" of the Fulcaster soft red winter wheat parent. The remaining strains listed in Table 40 but not discussed have short "time", indicating that these strains may not be as suitable for bread making as the typical long "time" hard wheats. Red Hull, a selection made by a Kansas farmer, has short "time", 48 minutes. Smithsonian, a cross between emmer and bread wheat, also has short "time", 49 minutes.

One hundred and thirty-nine winter wheat strains grown

in the wheat breeding nursery in 1934 were tested by the "time test". The "time" and protein content of each wheat tested are shown in Figure 2, page 157. In general the soft wheats such as Valprize, Nittany, Currell, and Fulcaster have short "time", while the hard wheats such as Turkey, Oro, Tenmarq, and Lin Caliel have medium to long "time". The semi-hard wheats such as Kawvale, Progeny No. 2 (Ill.), Iobred, and Purkof, have medium "time". The marked differences in "time" between hard and soft wheats indicate that, in general the gluten of hard wheats is better able to resist disintegration in water than that of soft wheats.

However, a few exceptions are to be noted. Hard wheats such as Superhard Blackhull and some strains of Kanred x Hard Federation have medium to short "time" characteristic of weak wheats, while Harvest Queen, Michigan Amber, Red Rock, and Bald Rock have medium to long "time" characteristic of semi-hard wheats. No typical soft wheat has long "time". The gluten quality of these exceptions is probably not representative of the type.

The 139 strains of wheats grown in 1934 and "time tested" were divided into groups according to parentage. Selections of each cross in which 2 or more strains were tested are grouped. The hybrid groups were then ranked as to "time". These data are presented in Table 41. Strains

Table 41 -- Wheat meal fermentation time of winter wheats grown in the wheat breeding nursery, Manhattan, Kansas, 1934.

Ks. or Sel. No.	C. I. No.	"Time", minutes
<u>Kanred x Marquis and reciprocal</u>		
H.C. 317		186
285112		153
285116		152
ex. 2690		146
443		136
Ave. "time", 5 strains		155
<u>Tenmarq sel.</u>		
285724		168
514	6936 <u>Tenmarq</u> (check)	165
285928		154
285986		145
ex. 534		121
Ave. "time", 4 strains excluding Tenmarq ck.		147
<u>Turkey sel.</u>		
570	1558 <u>Turkey</u> (check)	172
Nebr. 1062	10015	150
Nebr. 1065	10095	148
Nebr. 1082	11576	134
Ave. "time", 3 strains excluding Turkey ck.		144
<u>Kawvale x Tenmarq</u>		
32LRX8304		168
514	6936 <u>Tenmarq</u> (check)	165
341855		150
32LRX8305		150
341882		144
341849		144
341870		130
341840		122
Ave. "time", 7 strains excluding Tenmarq ck.		144
<u>Fulhard x Tenmarq</u>		
514	6936 <u>Tenmarq</u> (check)	165
341930		138
332370		125
2594	<u>Fulhard</u> (check)	110
Ave. "time", 2 strains excluding Fulhard ck.		132
<u>Kanred x Hard Federation</u>		
2691		195
306353		185
306297		173
2651		168
306333		168
2674	10093	164
316063		160
316065		159
306361		153
2714		152
316066		147
ex2672		145
ex2674		144
316077		134
316080		131
ex2672		130
327053		122
ex285191		121
327103		116
316079		113
326883		102
ex285191		101
327062		97
326879		89
343415		85
343414		79
326602		73
326612		66
326615		52
Ave. "time", 29 strains		128
<u>Tenmarq x Kanred</u>		
514	6936 <u>Tenmarq</u> (check)	165
30C1163		141
316324		130
303766		122
30C1239		102
Ave. "time", 4 strains excluding Tenmarq ck		124
<u>Kanred x Kanmarq</u>		
30C1016		131
30C1025		130
303684		108
30C1013	11573	94
Ave. "time", 4 strains		115
<u>Oro x Tenmarq</u>		
514	6936 <u>Tenmarq</u> (check)	165
342003		122
495	8220 <u>Oro</u> (check)	120
342039		120
342009		116
342048		114
342021		110
342030		104
342036		100
342018		100
Ave. "time", 8 strains excluding parental cks.		111
<u>Kanred x (Marquis x Kanred)</u>		
304198		121
304229		119
	11592	107
303976		94
Ave. "time", 4 strains		110
<u>Prelude x Kanred</u>		
286465		127
292628		106
292627		105
341723	Quivira sel.	105
264136		78
Ave. "time", 5 strains		104
<u>Mediterranean sel.</u>		
Tex.5933-20	10085	84
Tex.3015-105-1	11587	83
Tex.3015-72		48
Ave. "time", 3 strains		72
<u>Harvest Queen sel.</u>		
19		
24-33	11612 <u>Harvest Queen</u> (ck.)	86
14-18		45
		41
Ave. "time", 2 strains excluding Harvest Queen ck.		43

of Kanred x Marquis and the reciprocal cross have the highest average "time", indicating that selections of this cross have inherited the superior gluten quality of Marquis. The Tenmarq selections rank slightly under Kanred x Marquis, but not significantly so. Tenmarq is from the cross Pl066 x Marquis, which is very similar to the Kanred x Marquis cross.

The Turkey selections follow in rank. "Time" of all of the Turkey selections was high. Selections of Kawvale x Tenmarq and Fulhard x Tenmarq, follow in rank. As neither Kawvale nor Fulhard has strong gluten it seems evident that the gluten quality of these hybrid wheats, indicated by long "time", is more like that of Tenmarq than of the other parents. Twenty nine strains of Kanred x Hard Federation were tested for "time". The "time" for strains of this cross varied widely. Most strains of this cross have strong gluten, as indicated by long "time", over 100 minutes. However, 7 strains have "time" below 100 minutes, indicating medium to weak gluten strength. Those strains having the longer "time" have apparently inherited the superior gluten strength of Kanred, while those strains having the shorter "time" have apparently inherited the weaker gluten of the white spring wheat Hard Federation parent.

The next group in rank is that of Tenmarq x Kanred. This group is followed by the strains of Kanred x Kanmarq. The latter back-cross is similar to the former in parentage, as Tenmarq and Kanmarq are sister strains. In both of these groups of back-crosses, all strains tested have shorter "time" than Tenmarq, although they are probably acceptable as to quality. Most of the selections of Oro x Tenmarq have somewhat shorter "time" than the parental varieties, although there is no weak, short "time" strain in the group. Selections of the back-cross Kanred x (Marquis x Kanred) rank next in "time". This back-cross is closely related to Kanred x Kanmarq and gave similar results in the "time tests". Selections of Prelude x Kanred, including Quivira, have "time" indicating only medium strength. The Mediterranean selections rank next and include 2 strains of medium and 1 strain of short "time". This indicates that within the variety Mediterranean, are strains varying markedly in "time". Harvest Queen and 2 selections of this variety were tested. The selections have much shorter "time" than the parental variety. A few other strains are listed in Figure 2. These are miscellaneous strains that are not of major importance in Kansas. Thirty of these are included in the U. S. Department of Agriculture Eastern Winterhardiness Nursery grown at Man-

hattan and belong to the soft winter wheat group, adapted to conditions in the eastern states. Nearly all these soft wheats have short "time", indicating value for purposes other than bread making. Among the other strains in this miscellaneous group are (1) wheats with long "time" such as Ellenbecker (Kanocks), Early Kanred x Kanmarq, and Lin Calcl, (2) strains with medium "time" such as Wheat x Rye (Meister), Kawvale, Kawvale sel., Fulcaster x Marquis, Sibley No. 62 and No. 81, Danne selections H59C and C7H10, Blackhull, Fulhard x Oro, Fulcaster x Crimean, (Illini Chief x Kanred) x Tenmarq, and Kanred x Blackhull, and (3) short "time" wheats such as Harvest Queen x Kawvale, Illini Chief, sel. 223415, x Tenmarq, Tenmarq x Nebraska No. 28, and Kruse.

One hundred and seven strains of winter wheat grown in the wheat breeding nursery in 1935 were "time tested". The "time" and protein percent of each wheat tested are shown in Figure 3, p. 159. No typical soft wheat variety was tested. Of the 107 strains tested, 35 had "time" over 100 minutes. All but 3 of these strains with "time" over 100 minutes are hybrid wheats with Tenmarq as one parent. The 8 strains of Oro x Tenmarq having "time" over 100 minutes are the only strains of this long "time" group in which the long "time" of the hybrid cannot be attributed specifically

to the Tenmarq parent. In this cross, both parents are long "time", high quality wheats. The 72 strains having "time" below 100 minutes are (1) varieties having inherently short to medium "time", (2) hybrids of which neither parent had long "time", or (3) hybrids having 1 long "time" and 1 short "time" parent. In segregation of the latter type cross certain lines inherited "time" in the range of the short "time" variety.

The 107 strains of winter wheats grown in 1935 and tested for "time" were grouped according to parentage and the groups ranked in order of average "time". These data are given in Table 42. The 3 selections of Tenmarq have the highest average "time". The selections of Oro x Tenmarq rank in "time" only slightly under the Tenmarq selections. All of these strains have sufficiently long "time" to indicate that they have the high quality of the parents. In the group of 18 selections of Quivira x Tenmarq, there are individual strains varying in "time" from 82 to 206 minutes. The 13 strains above 100 minutes in "time" have apparently inherited the long "time" of Tenmarq, while the 5 strains below 100 minutes in "time" have evidently inherited the medium "time" of Quivira. Several of the long "time" strains of this cross have significantly longer "time" than the Tenmarq parent. This

Table 42 -- Wheat meal fermentation time of winter wheat strains grown in the wheat breeding nursery, Manhattan, Kansas, 1935.

Ks. or Sel. No.	Variety	"Time", minutes
<u>Termarq sel.</u>		
335170		179
335145		156
514	<u>Termarq</u> (Ave. 3 cks.)	128
335164		115
Ave. "time", 3 strains excluding ck.		150
<u>Oro x Termarq</u>		
354033		167
354030		160
343249		153
354038		148
343247		138
343273		137
343638		135
514	<u>Termarq</u> (Ave. 3 cks.)	128
342015		120
Ave. "time", 8 strains excluding ck.		145
<u>Quivira x Termarq</u>		
354122		206
354106		199
354112		175
354126		163
354088		159
354118		158
354102		140
354108		131
354123		131
354086		128
514	<u>Termarq</u> (Ave. 3 cks.)	128
354103		118
354083		105
354101		104
354097		99
354099		92
354094		90
354131		85
2628	<u>Quivira</u> (Ave. 2 cks.)	85
354098		82
Ave. "time", 18 strains excluding cks.		131
<u>Turkey sel.</u>		
Nebr.1062 (C.I.10015)		93
570	<u>Turkey</u> (Ave. 3 cks.)	76
Nebr.1082 (C.I.11576)		56
Nebr.1081 (C.I.11577)		53
Ave. "time", 3 strains excluding ck.		67
<u>Kanred x Hard Federation</u>		
306353		130
316063		123
326998		123
326879		79
326602		56
326612		52
326991		49
33FN211		45
33FN208		44
Ave. "time", 9 strains		78
<u>(Kanred x Fulcaster) x Termarq</u>		
514	<u>Termarq</u> (check)	128
33LRX6213		91
33LRX6214		75
33LRX6235		60
Ave. "time", 3 strains excluding ck.		75
<u>Quivira sel.</u>		
354009		99
353999		94
353939		90
354006		89
354007		87
354012		86
2628	<u>Quivira</u> (Ave. 2 cks.)	85
353938		85
354001		85
354004		85
292628	<u>Prelude x Kanred</u>	83
353922		83
354002		83
353976		81
354005		80
354008		80
292627	<u>Prelude x Kanred</u>	79
285465	do	77
353941		77
353971		77
353921		75
354014		75
353979		72
354003		71
354013		70
353958		69
353981		68
353998		68
353974		63
353995		60
353923		57
353926		54
353959		53
353936		51
353975		49
353978		45
Ave. "time", 35 strains excluding ck.		74
<u>Kawvale x Termarq</u>		
33LRX6194		130
514	<u>Termarq</u> (check)	128
344058		114
344041		107
344108		100
33FN499		88
344082		88
344084		62
344057		58
344056		52
33FN439		51
344075		48
33FN447		47
344033		45
Ave. "time", 13 strains excluding ck.		76

may be due to transgressive segregation of genetic factors governing doughball "time". Six of the strains of this cross have "time" intermediate between the parents, suggesting so-called "blended" inheritance. Three Nebraska Turkey selections tested have "time" unlike Turkey. One strain has significantly longer "time", while the other 2 have much shorter "time" than Turkey. The 9 selections of Kanred x Hard Federation have a wide range in "time", from 130 to 44 minutes. Three strains have long "time", 5 strains have short "time", and 1 strain has medium "time". The 3 strains of (Kanred x Fulcaster) x Tenmarq have not inherited the long "time" characteristic of Tenmarq.

About half of the 32 reselections of Quivira are significantly shorter in "time" than the parental variety. This indicates that Quivira is not homozygous for genetic factors determining doughball "time". Three strains of the cross Prelude x Kanred are included in the group of Quivira selections, because of the fact that Quivira originated from this cross. These selections of Prelude x Kanred are not significantly different in "time" from Quivira. Four of the 13 selections of Kawvale x Tenmarq have "time" of 100 minutes or more, approaching the "time" of Tenmarq. Nine selections of this cross have "time" in the range of Kawvale and below.

Other strains listed in Figure 3 that do not appear in

any of the hybrid groupings in Table 42 are of medium to low "time". Oro x Fulhard has "time" intermediate between the long "time" of the high quality Oro parent and the short "time" of the low quality Fulhard parent.

The hybrid strain (Illini Chief x Kanred) x Tenmarq does not have the long "time" of Tenmarq or the short "time" of Illini Chief, but has "time" in the range of Kanred. Kanhull, a beardless selection of Blackhull, has short "time", resembling Blackhull. Early Blackhull has still shorter "time", 49 minutes. Mutant, Akron Sel. No. 7, has very short "time", 34 minutes, indicating poor quality for breadmaking. Baking tests have shown the varieties Kanhull, Early Blackhull, and Mutant to be of questionable quality. The 2 strains, (Minhardi x Minturki) x Tenmarq, and Tenmarq x Nebraska No. 28, have "time" in the range of the poorer quality parents in each case. Neither strain has inherited the long "time" of the superior quality Tenmarq parent.

One hundred and forty-eight strains of winter wheat grown in the wheat breeding nursery in 1936 were "time tested". Data on these "time tests" are presented in Table 43, in which the hybrid wheats are grouped according to parentage and the groups ranked as to average "time". In general, those varieties of known quality are ranked by

the "time test" in accordance with their quality rating, based on the baking test. Most of the hybrids having Tenmarq as one parent have long to medium "time". Few hybrids involving only short "time" parents have "time" significantly higher than the parents.

The three high ranking groups of hybrids are Red Rock x Hope, Kanred x Hard Federation, and Hope x Hussar. The parents of these crosses, except for Kanred, are not considered to be of superior quality. As in 1935, the selections of Kanred x Hard Federation show a wide range in "time", from 202 to 72 minutes. Kanhard, appearing in the Kanred x Hard Federation group, is an Argentine reselection of this Kansas cross. Two selections of Kanred x Marquis rank high in "time", resembling the long "time" parent Marquis more than Kanred. Nine strains of Oro x Tenmarq have high average "time". Several selections of this cross have longer "time" than Tenmarq. None of the strains has significantly shorter "time" than the high quality parents. Thirty-four strains of the cross Early Blackhull x Tenmarq show a wide range in "time" between the two parents. Most of the 19 strains having longer "time" than the Tenmarq parent, are significantly different indicating that transgressive segregation has occurred. No strain has "time" shorter than the short "time" of the Early Blackhull parent.

Next in rank is the group of 9 Tenmarq selections. One selection has significantly shorter "time" than Tenmarq, indicating that this selection has quality unlike Tenmarq. Fourteen strains of Kawvale x Tenmarq and reciprocal have an average "time" of 105 minutes. Eleven strains of Kawvale x Tenmarq have "time" significantly longer than Kawvale. Seven of these 11 strains have significantly longer "time" than Tenmarq. Three strains have shorter "time" than the Kawvale parent. The 2 Quivira x Kawvale selections vary widely in "time". One strain has "time" that is much longer than might be expected in a cross of two medium "time" varieties. This is probably due to transgressive segregation. The other strain has short "time", closely approaching the Kawvale parent. In the Quivira x Tenmarq cross, 1 strain has longer "time" than the long "time" Tenmarq parent, while the other strain has "time" resembling the shorter "time" parent, Quivira. Two selections of the cross Mediterranean x Hope from the Texas station, have widely differing "time" indicating marked differences in quality.

Two selections of Tenmarq x Minturki have "time" readings indicating widely divergent types in quality. The longer "time" strain approaches Tenmarq. The short "time" of the other strain indicates quality more nearly like that of Minturki.

The 5 selections of the 2 back-crosses, Kanred x (Marquis x Kanred) and Kanred x Kanmarq, have much shorter average "time" than the average of the Kanred x Marquis group. In this case, back-crossing to the shorter "time" variety Kanred produced wheats having shorter "time" than the original crosses. One of these back-cross selections has "time" significantly longer than Kanred. One selection of Quivira x Fulhard has long "time", 107 minutes. The other 3 strains have short "time".

Next in rank is the group of 3 Quivira selections and 1 other selection of Prelude x Kanred. One of the selections has somewhat longer "time" than the others, but in general these Quivira types have only medium "time". The 5 selections of Kanred x Quivira have medium "time" characteristic of the parents. Two selections of Kanred x Nebraska No. 28 have "time" readings intermediate between the parents. Six selections of Quivira x (Kanred x Marquis), have medium to short "time", resembling the Quivira and Kanred parents. Three selections of Honor x Kanred, which have the shortest average "time" of all 148 strains tested, have individual "time" readings less than Kanred and approaching the short "time" of Honor.

Strains "time tested" in 1936 not included in Table 43 are listed in Table 44. Five hybrid selections have long

Table 44 -- Wheat meal fermentation time of 20 miscellaneous winter wheats grown in the wheat breeding nursery, Manhattan, Kansas, 1936.

Ks. or Sel. No.	Variety	"Time", minutes
344154	Fulhard x Kawvale	170
	Hope x Kawvale, C. I. 11814	168
J341724	Hard Federation x Kawvale	145
	Quivira x (Fulhard x Oro), C.I.11811	114
363645	(Kanred x Marquis) x Kawvale	113
343233	((Martin x Tenmarq) x Tenmarq) x Tenmarq)	79
	Lin Calcl	76
344669	Kawvale sel.	62
354243	Turkey x Kawvale	58
316324	Tenmarq x Kanred	55
34LRH6850	(Kanred x Fulcaster) x Iobred	54
363903	Kanred x (Kanred x Hard Federation)	51
500	Michigan Wonder	48
518	(Eureka x Minhardi) x (Kanred x Hard Federation)	47
519	(Prelude x Kanred) x (Turkey x Minnessa)	47
J34601	Kanred x Kawvale	46
2699	H58B (J. Danne)	43
517	(Turkey x Minnessa) x (Kanred x Hard Federation)	42
363881	Quivira x Harvest Queen	40
547	Chiefkan	33

"time", over 100 minutes. The Martin x (Tenmarq)₃ back-cross has not retained the long "time" of the Tenmarq parent. Lin Calcl, a standard hard red winter wheat of Argentina, has medium "time". Michigan Wonder, a soft red winter wheat, has short "time". The 3 winterhardy x early selections, Ks. Nos. 517, 518, and 519, have short "time". Chiefkan, a beardless selection of Superhard Blackhull, has very short

"time", indicating gluten quality weaker than Blackhull.

One hundred and fifty-nine winter wheat strains grown in the wheat breeding nursery in 1937 were "time tested". The "time" and protein content of 135 of these strains are presented in Figure 4, p.161. In general the "time test" has separated the wheats grown in 1937 into known strong, medium, and weak types.

"Time" of the wheats tested in 1937 is given in Table 45, in which the wheats are grouped according to parentage. The groups are ranked according to average "time". Three selections of Kanred x Marquis rank highest in average "time", approaching the long "time" of the Marquis parent. Thirteen selections of Oro x Tenmarq have second rank in average "time". One of these hybrid selections has "time" much shorter than either parent, indicating that its quality is unlike and probably inferior to Oro x Tenmarq. The other 12 strains of this cross have "time" similar to one or the other parent. Two selections of Quivira x Tenmarq rank next in average "time". Both strains are similar to the Tenmarq parent. Nine reselections of Tenmarq follow in rank. All of these are similar or superior to Tenmarq. The two selections of Hope x Hussar differ widely in "time". Nine selections of Early Blackhull x Tenmarq have an average "time" of 117 minutes. All strains having

Table 45 -- Wheat meal fermentation time of winter wheat strains grown in the wheat breeding nursery, Manhattan, Kansas, 1937.

Ks. or Sel. No.	Variety	"Time", minutes
<u>Kanred x Marquis</u>		
2690		137
285116		132
326795		130
2401	<u>Kanred</u> (check)	53
	Ave. "time", 3 strains excluding ck.	133
<u>Oro x Termarq</u>		
363596		148
2738		139
363595		138
495	<u>Oro</u> (check)	134
363615		131
2729		130
2728		128
343273		126
2736		119
363602		117
343249		114
343638		105
514	<u>Termarq</u> (check)	102
2730		93
343255		67
	Ave. "time", 13 strains excluding cks.	123
<u>Quivira x Termarq</u>		
354104		138
514	<u>Termarq</u> (check)	102
354088		100
2628	<u>Quivira</u> (check)	54
	Ave. "time", 2 strains excluding cks.	119
<u>Termarq sel.</u>		
285724		139
335170		124
Arg. 29913		122
343586		120
354642		119
354696		116
354577		109
354618		109
354711		106
514	<u>Termarq</u> (check)	102
	Ave. "time", 9 strains excluding ck.	118
<u>Hope x Hussar</u>		
J352245		154
J352247		81
	Ave. "time", 2 strains	118
<u>Early Blackhull x Termarq</u>		
363573		134
363518		126
363526		122
363583		122
363575		121
363516		112
2739		107
363514		104
363521		103
514	<u>Termarq</u> (check)	102
483	<u>Early Blackhull</u> (check)	61
483	do	50
	Ave. "time", 9 strains excluding cks.	117
<u>Hard Federation x Kawvale</u>		
J341961		149
J341717		84
2593	<u>Kawvale</u> (check)	51
2593	do	49
	Ave. "time", 2 strains excluding cks.	117
<u>(Kanred x Fulcaster) x Termarq</u>		
34LRX6893		135
514	<u>Termarq</u> (check)	102
33LRX6213		82
34LRX6897		67
2401	<u>Kanred</u> (check)	53
317	<u>Fulcaster</u> (check)	27
	Ave. "time", 3 strains excluding cks.	95
<u>Quivira x (Fulhard x Oro)</u>		
495	<u>Oro</u> (check)	134
354150		111
354152		101
354141		90
354145		76
2628	<u>Quivira</u> (check)	54
2594	<u>Fulhard</u> (check)	33
	Ave. "time", 4 strains excluding cks.	95
<u>Turkey x Kawvale</u>		
354244		122
354243		66
570	<u>Turkey</u> (check)	54
2593	<u>Kawvale</u> (check)	51
2593	do	49
	Ave. "time", 2 strains excluding cks.	94
<u>Kawvale x Termarq</u>		
36RN899		133
344062		129
J352549		128
J34808		120
J352548		106
344108		104
363635		104
514	<u>Termarq</u> (check)	102
363634		98
33FN499		97
363637		94
J352504		81
363632		75
2727		72
344077		72
344041		70
363633		67
363626		58
2726		55
J34748		53
2593	<u>Kawvale</u> (check)	51
2735	<u>Kawvale</u> (check)	49
2593	<u>Kawvale</u> (check)	49
	Ave. "time", 20 strains excluding cks.	88
<u>(Kanred x Marquis) x Kawvale</u>		
354904		81
354909		77
2401	<u>Kanred</u> (check)	53
2593	<u>Kawvale</u> (check)	51
2593	do	49
	Ave. "time", 2 strains excluding cks.	79
<u>(Kanred x Karmaq) x (Minhardi x Minturki)</u>		
354281		84
2464	<u>Minturki</u> (check)	79
354282		20
2401	<u>Kanred</u> (check)	53
	Ave. "time", 2 strains excluding cks.	77
<u>Kanred x Hard Federation</u>		
2651		159
316063		112
2717		88
2715		84
2401	<u>Kanred</u> (check)	53
2673		49
2673		46
354358		45
354792		37
	Ave. "time", 8 strains excluding ck.	76
<u>Quivira x Kawvale</u>		
363855		72
2628	<u>Quivira</u> (check)	54
563856		53
2593	<u>Kawvale</u> (check)	51
2593	do	49
	Ave. "time", 2 strains excluding cks.	63
<u>(Kanred x Hard Federation) x Quivira</u>		
363651		79
2628	<u>Quivira</u> (check)	54
2401	<u>Kanred</u> (check)	53
363782		45
	Ave. "time", 2 strains excluding cks.	62
<u>Kanred x Kawvale</u>		
J34643		70
J34582		65
J34584		63
2401	<u>Kanred</u> (check)	53
J34581		53
2593	<u>Kawvale</u> (check)	51
J34595		51
2593	<u>Kawvale</u> (check)	49
	Ave. "time", 5 strains excluding cks.	60
<u>Prelude x Kanred</u>		
354007	<u>Quivira sel.</u>	77
363782		73
292628		70
363779		64
354005	<u>Quivira sel.</u>	56
363778		56
2628	<u>Quivira</u> (check)	54
2401	<u>Kanred</u> (check)	53
354008	<u>Quivira sel.</u>	53
33FN152		40
35FN265	<u>Quivira sel.</u>	34
	Ave. "time", 9 strains excluding cks.	58
<u>Quivira x (Kanred x Marquis)</u>		
363876		72
363867		71
363874		58
2628	<u>Quivira</u> (check)	54
2401	<u>Kanred</u> (check)	53
363868		48
363877		40
	Ave. "time", 5 strains excluding cks.	58
363832		67
2628	<u>Quivira</u> (check)	54
2401	<u>Kanred</u> (check)	53
363821		44
	Ave. "time", 2 strains excluding cks.	56
<u>Iobred x Kawvale</u>		
431	<u>Iobred</u> (check)	77
La35-95		65
2593	<u>Kawvale</u> (check)	51
2593	do	49
33LRX6186		47
	Ave. "time", 2 strains excluding cks.	56
<u>(Kanred x Fulcaster) x (Kanred x Hard Federation)</u>		
363391		69
2401	<u>Kanred</u> (check)	53
J341524		44
317	<u>Fulcaster</u> (check)	27
	Ave. "time", 2 strains excluding ck.	54
<u>(Kanred x Hard Federation) x (Kanred x Marquis)</u>		
2401	<u>Kanred</u> (check)	53
363928		45
363931		33
	Ave. "time", 2 strains excluding ck.	39
<u>Quivira x C.I. 7078</u>		
2628	<u>Quivira</u> (check)	54
363893		41
363894		35
	Ave. "time", 2 strains excluding ck.	38

shorter "time" than Tenmarq were discarded in 1936. Two selections of Hard Federation x Kawvale vary widely in "time". The 3 strains of (Kanred x Fulcaster) x Tenmarq have "time" ranging from 67 to 135 minutes. The strain with the lowest "time" resembles Kanred, while the long "time" strain is similar to Tenmarq. The 4 lines of Quivira x (Fulhard x Oro) have "time" readings less than the long "time" high quality Oro parent but longer than Fulhard and Quivira. One of the strains of Turkey x Kawvale has "time" similar to Turkey, while the other strain has long "time" exceeding that of either parent. In the group of 20 strains of Kawvale x Tenmarq there are individual selections ranging from Kawvale to Tenmarq "time" types. Seven selections of this cross have "time" above 100 minutes. The 2 strains of (Kanred x Marquis) x Kawvale have "time" readings somewhat longer than either the Kanred or Kawvale parents, indicating an influence of the long "time" Marquis parent. Two strains of (Kanred x Kanmarq) x (Minhardi x Minturki) are significantly longer in "time" than the Kanred parent and are more like the Minturki parent. As in previous years the selections of Kanred x Hard Federation show widely differing "time" readings, ranging from 159 to 37 minutes. One of the 2 Quivira x Kawvale strains has somewhat longer "time" than either

parent. The other strain has "time" in the range of the parents. One selection of (Kanred x Hard Federation) x Quivira has "time" slightly lower than either Quivira or Kanred, the other strain has "time" somewhat higher than either of these varieties. Two of the 5 selections of Kanred x Kawvale have "time" readings in the parental range. The other 3 strains have slightly higher "time" than either parent. Among the Kanred x Prelude selections, including Quivira, 2 strains have significantly lower "time" and 4 strains have significantly higher "time" than these varieties. Two strains of Quivira x (Kanred x Marquis) have "time" similar to Quivira and Kanred, 1 strain has significantly lower "time" than these varieties, and 2 strains have longer "time", showing some influence of the long "time" Marquis parent. One strain of Kanred x Quivira has longer "time" than either parent, while one has shorter "time". One of the strains of Iobred x Kawvale has intermediate "time", while the other has "time" in the shorter "time" range of Kawvale. Both selections of the cross (Kanred x Fulcaster) x (Kanred x Hard Federation) have "time" closer to Kanred than to Fulcaster. The 2 strains of (Kanred x Hard Federation) x (Kanred x Marquis) have shorter "time" than Kanred. Two selections of Quivira x C.I. 7078 have the lowest average "time" of all

strains tested in 1937.

A few of the miscellaneous strains tested for "time" in 1937 which are not included in Table 45 are worthy of mention. Cheyenne and Turkey sel., C.I. 10094, two pure-line selections from the Nebraska station, have long "time" and good to excellent baking quality. Cheyenne sel., C.I. 11666 also has long "time". Kawvale sel. No. 344669 has "time" similar to Kawvale. Blackhull has medium "time", in the range of Turkey and Kanred. Chiefkan has an extremely short "time" for a hard wheat. The weak soft wheat varieties Bald Rock, Clarkan, Michigan Amber, Menno, Mediterranean sel., C.I. 11567, and Red Rock have short "time".

Early Generation Hybrids. The "time test" probably has its greatest value in the testing of hybrid wheats in the early generations. The test might be used as follows: (1) from F_3 through F_5 harvest all the plants in the row of each hybrid line having desirable agronomic characters, (2) select individual plants from each line and thresh the remaining plants in bulk, and (3) "time test" the bulk grain of each row from which selections have been made for planting. Although the "time" is not obtained on the individual plants selected, the chances are good and get better in each succeeding generation, that

a single plant selection from a high quality line will be of good quality. Only those lines possessing satisfactory quality as measured by the "time test" should be retained. In the F_5 generation the factors governing quality should be approaching homozygosity.

The inherent "time" of a large number of wheat varieties and fixed hybrid lines having been determined, the "time test" is probably most immediately useful to the wheat breeder in studying the early generation progenies of crosses between varieties or hybrid lines of known "time", especially the progenies of parents differing widely in "time". In the segregating progeny of such crosses only those lines should be selected having "time" in the same range as that of the parent having the desired quality, whether long or short "time". Thus, the plant breeder can be relatively sure as to the inherent quality of the strains selected, as any strain having "time" in the range of the undesirable parent will have been discarded. Any strain in a cross between long and short "time" parents having "time" greatly exceeding the limits of either parent, possibly due to transgressive segregation, would probably have different quality than either parent. Most segregates of a cross in which both parents are of good quality, such as Oro and Tenmarq, each having

approximately the same "time", would be likely to have good quality gluten. In a cross such as Turkey (medium "time") x Tenmarq (long "time") most segregates are likely to have acceptable quality but preference may be given to segregates resembling Tenmarq. In such crosses, segregates having "time" readings greatly transgressing the limits of the parents on the low side should probably be discarded. The "time" test probably has much less value in testing the progeny of a cross between two varieties, such as Turkey and Blackhull, having approximately the same "time", but of vastly different quality. The following data and discussion illustrate the use of the "time test" in wheat breeding.

The first trials of the "time test" were made at the Kansas station in 1931. Selections of Kanred x Blackhull, in the F_6 generation, grown in the agronomy nursery were tested. In 1933 Jorgensen⁽⁵⁾ summarized the data from this cross. These results are presented in Table 46.

These data indicate that during the process or selection based on agronomic characters most of the lines selected were of a lower "time" than the parents. Only one F_6 line has long "time". In such a cross between 2 varieties of similar "time", the "time test" cannot

⁽⁵⁾ Term paper of C. L. Jorgensen at Kansas State College.

distinguish the quality of the progenies as being of 1 or the other parental type.

Table 46 -- Wheat meal fermentation time of 35 F_6 lines of Kanred x Blackhull grown in agronomy nursery, Manhattan, Kansas, 1931.

"Time", minutes	Variety			
	Kanred x Blackhull	Kanred Blackhull		
	No.	%	No.	No.
31-40	3	8.6		
41-50	9	25.8		
51-60	14	39.9		
61-70	6	17.2	2	3
71-80	2	5.7	2	2
81-90			1	
91-100	1	2.9		1
Totals	35		5	6
Ave. "time"	56		72	75

In his term paper, Jorgensen also included the results of the "time test" on F_3 lines of Tenmarq x Kanred grown in the agronomy nursery. These data are presented in Table 47.

The data indicate some segregation for "time" factors, but the influence of the Tenmarq parent is pronounced. All 6 strains have "time" closer to Tenmarq than to Kanred. As both Kanred and Tenmarq have good bread making quality, the progeny of this cross can be expected to be of

good quality. The few lines of intermediate "time" are expected in crosses involving quantitative characters.

Table 47 -- Wheat meal fermentation time of 6 F_3 strains of Tenmarq x Kanred grown in agronomy nursery, Manhattan, Kansas, 1931.

"Time", Minutes	Varieties			
	Tenmarq x Kanred		Tenmarq	Kanred
	No.	%	No.	No.
89-110				1
111-130				
131-150	1	16.7		
151-170	2	33.4		
171-190	3	50.1	1	
Totals	6		1	1
Ave. "time"	168		182	99

In 1935 a rather large number of hybrid lines of several crosses were "time tested". The data obtained on bulk samples of F_2 populations are given in Table 48. The bulk sample of F_2 plants of Rudy x Kawvale has "time" intermediate between the parents. The F_2 hybrids of Gladden x Kawvale have short "time", approaching the Gladden parent. The numbers in all of these crosses are too small to warrant any definite conclusion as to the inheritance of factors for "time". The mode of inheritance of such a character can be studied in F_3 better than in F_2 or F_6 .

Table 48 -- Wheat meal fermentation time of 2 F_2 crosses grown in agronomy nursery, Manhattan, Kansas, 1935.

"Time", minutes	Variety				
	Rudy x Kawvale	Rudy	Kawvale	Gladden	Gladden x Kawvale
21-30				1	
31-40		1			1
41-50					
51-60	1				
61-70					
71-80			1		
"Time"	59	34	74	29	39

The data obtained on F_3 lines of 3 crosses grown in the agronomy nursery in 1935 are given in Table 49. Most of the F_3 lines of Kawvale x Cheyenne have "time" in the range of the Cheyenne parent. There are a few lines with intermediate "time" and some lines greatly exceeding the "time" of Cheyenne, the long "time" parent. One line has shorter "time" than Kawvale. The quality of such lines is not known, as the "time test" merely indicates that transgressive segregation has taken place for this measure of quality. These transgressive segregates may have cumulative quality factors different from the parents and from lines resembling the parents. The F_3 lines of (Kanred x

Table 29 -- Wheat meal fermentation time of various F₃ lines grown in the agronomy nursery, Manhattan, Kansas, 1936.

"Time", minutes	Variety								
	Kaw- vale		(Kan.x Hd.Fed.)		Kan.x Hd.Fed.		Mal- akov		
	x		x		x		x		
	Chey- enne	Chey- enne	Kaw- vale	Fulhard	(306268)	Ful- hard	Ten- marq	Ten- marq	Mal- akov
31- 50	1			1		1	2		2
51- 70	1		1	1					
71- 90	1						1	1	
91-110	2	1		1			3		
111-130	2			1			1		
131-150	4			1	1				
151-170	3			1	2				
171-190	1			1	1				
191-210									
211-230	1								
Totals	16	1	1	7	4	1	7	1	2
Ave. "time"	129	109	56	119	163	32	86	87	36

Hard Federation) x Fulhard are mostly of the quality type of the long "time" Kanred x Hard Federation parent. However, 2 of the 7 lines are in the range of Fulhard, the short "time" parent. Two lines have intermediate "time". The 2 lines having the "time" of the short "time" parent Fulhard could be discarded. Four lines of Malakov x Tenmarq have "time" exceeding the Tenmarq parent, indicating transgressive segregation. Two lines have the short "time" of Malakov, and could be discarded if the strong quality of the

Tenmarq parent is desired.

The results of "time testing" small numbers of F_4 lines of several crosses grown in the agronomy nursery in 1935 are presented in Table 50.

Table 50 -- Wheat meal fermentation time of F_4 lines grown in agronomy nursery, Manhattan, Kansas, 1935.

"Time", minutes	Variety						
	Qui- vira		Michigan Wonder		Malakov		
	x		x		x		
	Ten- marq	Ten- marq	Qui- vira	Quivira	Michigan Wonder	Quivira	Malakov
31- 60					1		1
61- 90			3	2		3	
91-120	2						
121-150	2	1					
151-180	2						
181-210	3						
211-240	1						
241-270	1						
Totals	11	1	3	2	1	3	1
Ave. "time"	171	138	85	83	34	72	34

The F_4 lines of the cross Quivira x Tenmarq show great diversity as to "time", although most of the lines have "time" as long as Tenmarq, and some have "time" greatly exceeding that of Tenmarq, illustrating transgressive segregation. None of these hybrid selections have "time" so short as to warrant discarding. The 2 lines of Michigan Wonder x Quivira have "time" readings in the same range as

Quivira. The 3 lines of Malakov x Quivira also have "time" in the range of the Quivira parent.

The results of "time testing" F_5 lines of Kawvale x Cheyenne grown in the agronomy nursery in 1935 are given in Table 51.

Table 51 -- Wheat meal fermentation time of F_5 lines of Kawvale x Cheyenne grown in agronomy nursery, Manhattan, Kansas, 1935.

"Time", minutes	Variety		
	Kawvale x Cheyenne	Cheyenne	Kawvale
	No.	%	
41-70	2	12.5	1
70-100	3	18.8	
101-130	2	12.5	1
131-160	6	37.5	
161-190	2	12.5	
191-220	1	6.3	
Totals	16		1
Ave. "time"	129		109
			56

Several F_5 lines of Kawvale x Cheyenne have "time" significantly longer than the Cheyenne parent, indicating transgressive segregation. The range in "time" is from readings similar to Kawvale to those much longer than Cheyenne. Several F_5 lines have intermediate "time". This is typical of quantitative inheritance and suggests

that multiple factors are involved. If it is desired to produce strong bread wheats from this cross, the lines of Kawvale "time" should be discarded.

In 1936, 86 F₃ lines of (Kanred x Hard Federation, Ks. 2672) x Tenmarq were "time tested". The inherent "time" of the two parents is very similar. The data are given in Table 52.

Table 52 -- Wheat meal fermentation time of 86 F₃ lines of (Kanred x Hard Federation, Ks. 2672) x Tenmarq grown in the agronomy nursery, Manhattan, Kansas, 1936.

"Time", minutes	Variety			
	(Kan. x Hd.Fed., Ks. 2672)		Kan. x Hd.Fed. Tenmarq	
	x Tenmarq		Ks. 2672	
	No.	%	No.	No.
71-90	3	3.5		
91-110	4	4.6		
111-130	8	9.2	1	1
131-150	24	27.6		1
151-170	18	20.7	2	2
171-190	15	17.2	1	1
191-210	11	12.6		
211-230	2	2.3		
231-250	1	1.2		
Totals	86		5	5
Ave. "time"	156		166	161

The data presented in Table 52 show that the greatest percentage of the hybrid lines have "time" in the same

general range as the parents. A few lines exhibit "time" significantly lower than the parents and a larger number of lines exhibit "time" significantly higher than the parents, indicating that transgressive segregation in both directions has occurred. The 7 lines having significantly lower "time" than the parents could be discarded, as the quality of these short "time" strains is probably inferior to the lines having "time" equal to or longer than the parents. The rather wide diversity of "time" among the individual samples of the Tenmarq and Kanred x Hard Federation, parental varieties is probably due to the fact that the progenies of individual plant selections were used as checks. These pure-line selections within the parental varieties may differ genetically in "time". Since the actual quality of the Tenmarq parent is good to excellent and the quality of the Kanred x Hard Federation parent is fairly good, most of the strains having "time" in the same general range as the parents may be expected to be of good quality. These data indicate that the progeny of two parents of long "time" and good quality will have good quality with the possible exception of a few short "time" lines which may appear as a result of transgressive segregation.

In 1936, 34 F_6 lines of Early Blackhull x Tenmarq were "time tested". The F_6 lines having the short "time" of Early Blackhull were discarded so that only long "time" strains of the F_7 generation were grown in 1937. Data on both generations are given in Table 53.

Table 53 -- Wheat meal fermentation time of 34 F_6 and 9 F_7 lines of Early Blackhull x Tenmarq grown in the agronomy nursery, Manhattan, Kansas, in 1936 and 1937, respectively.

"Time", minutes	Variety		
	Early Blackhull x Tenmarq	Tenmarq	Early Blackhull
	No.	%	
<u>Crop season, 1936</u>			
35-55	6	17.7	1
56-75	2	5.9	
76-95	5	14.7	
96-115	4	11.8	1
116-135	2	5.9	
136-155	5	14.7	
156-175	6	17.7	
176-195	2	5.9	
196-215	1	2.9	
216-235	1	2.9	
Totals	34		1
Ave. "time"	118		37
<u>Crop season, 1937</u>			
35-55			1
56-75			
76-95			
96-115	4	4.4	1
116-135	5	5.6	
Totals	9		1
Ave. "time"	117		50

Of the 34 F_6 lines tested in 1936, 17 had significantly longer "time" than the Tenmarq parent. No strains of this cross had lower "time" than the Early Blackhull parent. Nearly all of the strains had significantly higher "time" than the Early Blackhull parent. It is probable that those strains having shorter "time" than Tenmarq have gluten strength weaker than Tenmarq. On this assumption the strains of shorter "time" were discarded. All of the 9 F_7 lines grown in 1937, which were selected on the basis of long "time" in F_6 , have long "time" in the F_7 generation. Some of the strains having long "time" were discarded because of undesirable agronomic characters or because of susceptibility to leaf rust.

Twenty-two F_5 lines of Quivira x Cheyenne were "time tested" in 1936. These data are given in Table 54.

Of the 22 F_5 lines, 8 are similar in "time" to the Cheyenne parent, one is significantly longer in "time" than Cheyenne, 7 are similar in "time" to the Quivira parent, and 5 are significantly shorter in "time" than the short "time" parent, Quivira. The strains of shorter "time" than Quivira probably are inferior in quality to both parents and could be discarded.

Table 54 -- Wheat meal fermentation time of 22 F₅ lines of Quivira x Cheyenne grown in the agronomy nursery, Manhattan, Kansas, 1936.

"Time", minutes	Variety		
	Quivira x Cheyenne	Quivira	Cheyenne
	No.	%	
25-44	5	22.7	
45-64	7	31.8	3
65-84	1	4.5	
85-104	1	4.5	
105-124	1	4.5	
125-144	3	13.6	2
145-164	3	13.6	
165-186	1	4.5	
Totals	22		3
Ave. "time"	87		54
			141

As Cheyenne is generally considered of higher baking quality than Quivira, segregates in the range of the Quivira parent could also be discarded.

Twenty-one F₅ lines of Quivira x Tenmarq were "time tested" in 1936, as shown in Table 55.

Five of the F₅ lines of Quivira x Tenmarq have significantly longer "time" than the Tenmarq parent, 2 are similar to Tenmarq, 8 are intermediate, 3 are similar to Quivira, and 6 have lower "time" than Quivira.

Table 55 -- Wheat meal fermentation time of 21 F₅ lines of Quivira x Tenmarq grown in the agronomy nursery, Manhattan, Kansas, 1936.

"Time", Minutes	Varieties		
	Quivira x Tenmarq	Quivira	Tenmarq
	No.	%	
24-43	3	14.3	
44-63	3	14.3	1
64-83	7	33.3	
84-103	1	4.8	
104-123			
124-143	1	4.8	2
144-163	1	4.8	
164-183	4	19.0	
184-203	1	4.8	
Totals	21		1 2
Ave. "time"	96		57 143

The 14 F₅ lines having significantly lower "time" than Tenmarq could be discarded.

Selections of several crosses involving genes for Hessian fly resistance obtained from Marquillo, a hard red spring wheat, were tested in 1937 (6). The results obtained are presented in Table 56.

(6) These selections of wheat were obtained from Dr. R. H. Painter of the Department of Entomology, Kansas State College.

Table 56 -- Wheat meal fermentation time of Marquillo hybrids grown in the wheat breeding nurseries, Manhattan, Kansas, 1937.

Variety	"Time", minutes						To- tals	Ave. "Time"
	41-60	61-80	81-100	101-120	121-140	141-160	161-180	
Kanred x Hard Fed., 306269						1	1	155
Marquillo (Kanred x Hard Fed.) x Marquillo				1		1	1	149
Minturki		1					1	97
Marquillo x Minturki				1		4	1	146
Tenmarq					1		1	122
Marquillo x Tenmarq		1		2	5	4	12	133
Oro						1	1	141
Marquillo x Oro			1	3	11	1	16	125
Kawvale	1						1	60
Kawvale x Marquillo			2	5	1	2	10	119
Kawvale x Tenmarq	1						1	53
Valprise x Tenmarq	1						1	41

These data show that in general the progeny of the long "time" Marquillo parent crossed with any long "time" winter wheat have long "time". In each of the crosses of Marquillo on Tenmarq, Oro, and Kanred x Hard Federation, 1 strain has significantly shorter "time" than the parents. The quality of the short "time" strains is probably inferior to the longer "time" strains and they could be discarded. Although Marquillo has long "time", it is not acceptable to spring wheat millers. For this reason the "time test" is not a safe index of quality in Marquillo crosses. In crosses of the long "time" Marquillo with shorter "time" parents, a few of the progeny have significantly shorter "time" than Marquillo. For example, in the Marquillo x Minturki cross, 1 strain approaches the Minturki parent in "time", while 5 resemble Marquillo in "time". As neither Marquillo nor Minturki is a high quality bread wheat, the progeny of this cross are not likely to have high quality. Two selections of Kawvale x Marquillo approach Kawvale in "time", while the other 8 lines are more like Marquillo. Since the primary purpose of this cross is to obtain (1) resistance to the Hessian Fly of the soft red winter wheat region and (2) resistance to stem and leaf rusts, selections of this cross may have plant breeding value whether or not they have high quality. One strain in each of the crosses Kawvale x Ten-

marq and Valprize x Tenmarq was tested. Each of these strains has the short "time" of the short "time" parent.

The data presented in Tables 46 to 56 indicate the value of the "time test" to the plant breeder in discarding strains of crosses, early in the plant breeding program, between parents of long and short "time" that do not have "time" similar to the longer "time" better quality parent. The test also may be an aid to the plant breeder in discarding transgressive strains on the short side of the parental "time" range in crosses between two high quality varieties of similar "time". As has been pointed out the test probably has no value if applied to crosses between (1) parents differing in quality but having similar "time", such as Kanred and Blackhull, or (2) parents of which 1 is discriminated against because of poor qualities not affecting gluten strength, such as high carotene content. Marquillo is an example of a long "time" variety that is discriminated against by the miller because of a high carotene content.

Use of the "Time Test" in Grain Grading and Judging, Marketing, and Crop Testing

The differentiation of the grain of closely related varieties of wheat presents a difficult problem. The need of such differentiation on a quality basis is of great economic importance to the miller.

Varietal distinction is not given major emphasis under the present United States Official Grain Standards. Except for discriminating against (1) the variety Humpback in the Dark Northern Spring and Northern Spring sub-classes, (2) the variety Sonora in the Hard White and Soft White sub-classes, (3) the Red Russian western red type in the Red Winter sub-class, and (4) red durum as distinct from durum, no variety distinctions are made. The present grades are based on observable physical properties such as kernel color, test weight, moisture content, mixtures of foreign material and wheats of other classes, and percentage of damaged kernels. There is need of a simple test of gluten quality.

The following data obtained on 5 samples of wheats deliverable on contract at the Chicago Board of Trade illustrate the relation of the "time test" to the market classes of wheat:

<u>Market Class and Grade</u>	<u>"Time", minutes</u>
Dark Northern Spring (No. 1)	106
Dark Hard Winter (No. 2)	95
Dark Winter (No. 2)	90
Dark Hard Winter (No. 1)	82
Soft Red Winter (No. 2)	56

These data show that the "time test" has separated the 3 market classes of wheat represented.

Wheat samples exhibited at grain shows are usually placed according to grade, and external appearances, especially dark red color and hard texture. External appearances are not always associated with desirable inner qualities. As farmers, grain dealers, exporters, millers, and bakers become more "quality minded", grain show judges will need to place more emphasis on inherent quality. The quality of grain show wheats may readily be estimated by the use of the "time test", especially where the quality differences are due to variety. The following data were obtained on 8 prize winning wheat samples at the Kansas State Fair at Hutchinson in 1937:

<u>Placing</u>	<u>"Time", minutes</u>
3	139
1	118
6	118
2	64
8	54
7	52
5	44
4	37

Three of these prize samples have long "time", while 5 samples have medium to short "time". The 3 long "time" samples are probably Tenmarq, while the 5 short "time" samples are of the Blackhull family, probably Chiefkan. The sample placed third, "time" 139 minutes, is known to be

certified Tenmarq. The 3 long "time" samples have short kernels of Tenmarq type, while the 5 shorter "time" samples have the kernel type of the Blackhull wheats. If these wheats had been placed on the basis of inherent quality, in addition to outside appearance, the 5 shorter "time" samples would probably not have won prizes.

The variety Chiefkan, under most conditions in Kansas, has high test weight, dark hard kernels of good lustre, and is often bought at premiums at country elevators, has been found by baking tests to be inferior to the standard hard red winter wheats such as Turkey, Kanred, Cheyenne and Tenmarq. Some millers and cereal chemists object seriously to Chiefkan, but this variety is not distinguished from other hard red winter wheat varieties under the present United States Official Grain Standards. Chiefkan has "time" much shorter than any hard red winter wheat of accepted high quality. The comparative "time" of Chiefkan and other hard red winter wheat varieties has been shown in Tables 27 (page 77), 31 (page 91), 38 (page 102), and 39 (page 104).

To illustrate the possible use of the "time test" as an aid in determining the "inner qualities" of wheats for export trade, the "time" of a number of export samples was obtained. These data are presented in Table 57.

Table 57 -- Wheat meal fermentation time of 15 samples
of export wheat, 1938

		"Time", Protein minutes %	
Check samples			
Tenmarq grown at Hays, Kansas, 1937		147	
Bulk of 81 samples of Tenmarq, certified seed, from 81 farmers in Kansas, 1937		118	
GALVESTON (Via Chief Grain Inspector)			
<u>Sample No.</u>			
3	No. 2 Dark Hard Winter	98	
2	No. 1 Dark Hard Winter	91	
4	No. 1 Hard Winter	90	
1	No. 1 Dark Hard Winter	79	
5	No. 2 Hard Winter	74	
GALVESTON (Via a Kansas City grain company)			
<u>Sample No.</u>			
5	No. 1 Dark Hard Winter, Tex. and Okla.	94	15.0
2	do, Tex. and Okla.	91	15.0-15.4
3	do, Tex., Okla., and Kansas	77	13.0-13.5
4	do, Tex., Okla., and Kansas	74	13.0-13.5
1	do, Okla.	47	16.3
NEW YORK CITY			
<u>Sample No.</u>			
42	No. 2 Hard Winter	108	
78	No. 1 Dark Hard Winter	84	
81	No. 1 Hard Winter	73	
67	No. 2 Hard Winter	66	
120	No. 2 Dark Hard Winter	60	

The data presented in Table 57 show that none of these export samples is in the "time" range of Tenmarq. Sample No. 1, with "time" of 47 minutes, of the Galveston export shipment received from a Kansas City grain company, and possibly Sample Nos. 67 and 120, of the New York export shipments, "time" of 66 and 60 minutes, have "time" enough shorter than the general average of the market class to indicate probable inferior quality. Sample No. 1 of the Galveston export shipment received from a Kansas City grain firm was considered by the exporter to be the best quality shipment exported by that concern in several months. The exporter had judged the quality of the shipment by grade, external appearances, and protein per cent. The "time test" shows that this shipment probably was inferior in gluten quality and of weaker strength than the other samples. The other export samples do not show wide range in "time". The "time test" might be useful in differentiating export wheats of the same grade and general external appearances that are markedly different in "inner qualities".

The "time test" is used in Argentina and Germany as one of several quality tests to inform the purchaser of the quality of the wheat. The data presented in Table 58 give the "time" readings obtained on the 1936 and 1937 official samples of Argentina standard wheats. "Time" readings obtained by the methods used at Kansas State College and by

Table 58 -- Wheat meal fermentation time of the Official Standard Wheats of Argentina, crop years, 1936 and 1937*

Bahia Blanca Zone					Buenos Aires Zone					Rosafe' Zone				
Class & Grade	Crop Year				Class & Grade	Crop Year				Class & Grade	Crop Year			
	1936		1937			1936		1937			1936		1937	
	(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)
HARD					HARD					HARD				
Grade 1	179	102	136	84	Grade 1	183	128	103	78	Grade 1	182	125	143	79
" 2	173	98	146	87	" 2	195	124	-	74	" 2	193	114	140	79
Ave. of class	176	100	141	86	Ave. of class	189	126	103	76	Ave. of class	188	120	142	79
SEMI-HARD					SEMI-HARD					SEMI-HARD				
Grade 1	122	64	94	61	Grade 1	108	58	59	48	Grade 1	135	68	82	55
" 2	139	69	110	72	" 2	128	64	63	36	" 2	145	73	93	55
Ave. of class	131	67	102	67	Ave. of class	118	61	61	42	" 2 P.B.	-	-	82	57
SOFT					SOFT					Ave. of class	140	71	85	56
Grade 1	77	43	60	44	Grade 1	63	41	40	29	SOFT				
" 2	71	50	77	48	" 2	74	45	39	30	Grade 1	92	49	57	41
Ave. of class	74	47	69	46	Ave. of class	69	43	40	30	" 2	104	-	49	38
Ave."time" for zone					Ave."time" for zone					Ave. of class	98	49	53	40
(3 class ave.)	127	71	104	66	(3 class ave.)	125	77	68	49	Ave."time" for zone				
										(3 class ave.)	142	80	93	58

Ave. "time" of all Argentine Standard Wheats, three zones

Crop season, 1936.

(a) Kansas State College test - - - - - 131

(b) Argentine test - - - - - 76

Crop season, 1937.

(a) Kansas State College test - - - - - 88

(b) Argentine test - - - - - 58

* "Time tests" of the 1936 and 1937 Official Standard Wheats were made in 1937.

the methods used in Argentina are given on each grade of the 3 texture classes grown in each of the 3 major wheat producing zones in Argentina. The data show that regardless of the zone the "time" of hard wheats is longer than either semi-hard or soft wheats and that the semi-hard wheats have "time" intermediate between the hard and soft wheat types. Varieties of inferior quality are discriminated against by the National Grain and Elevator Commission of Argentina. Certain varieties of medium strength such as Blackhull, that are classed as hard wheat under the United States Grain Standards are graded as semi-hard under the Argentine system. Having the semi-hard class makes it possible to properly class certain varieties which are neither hard nor soft, genetically. Under the United States grading system, certain varieties are classed as hard wheats, others as soft, which in reality are neither hard nor soft, but semi-hard wheats. Examples of such wheats are; Kawvale, Furkof, Minturki, et al. The "time" readings of samples tested at Manhattan are all longer than samples tested in Argentina. However, the ranking of the samples of the same description is similar. The differences in "time" are in all likelihood due to differences in the manner of testing, or to differences in the age of samples when tested.

The grain standards of the Dominion of Canada allow only varieties of excellent bread making quality equal to Marquis to be placed in the upper grades. Poor quality varieties must be placed into the lower grades or given separate varietal designation as in the case of Garnet. The following data show the "time" readings of a few varieties of hard red spring grown in Canada in 1937:

<u>Variety</u>	<u>"Time", minutes</u>
Garnet	228
Apex	172
Reward	171
Thatcher	139
Marquis	134
Ceres	126
Renown sel.	104

The variety Garnet, although having the longest "time" of any of the varieties tested, is considered inferior and graded separately under the Canadian system of grading. Garnet is not entirely unsuitable for bread making if the baking procedure is governed to suit the inherent qualities, but it is so different from Marquis that separate grading is deemed necessary.

The Renown sel. with the shortest "time" of the group is a selection from Renown made at the Dominion Rust Research Laboratory, Winnipeg. Renown is considered of slightly lower quality for bread-making than Marquis.

A sample of the hard red spring wheat variety Humpback grown in Nebraska in 1937 was tested and found to have "time" of 48 minutes. This variety, with short "time", has vastly poorer bread-making quality than most hard red spring wheat varieties. The "time test" may be useful in determining the "inner qualities" of spring wheat varieties.

Use of the "time test" on wheat samples submitted for planting in the initial Crop Testing plot⁽⁷⁾ in Kansas at Junction City in 1937 showed the value of the test as an aid in identifying unknown samples and showing whether the variety name given to the sample by the farmer is correct or incorrect. The varieties grown in the Crop Testing plot were all examined by competent cerealists and the correct variety name with the names and percentages of any variety mixtures recorded.

The name given to the sample by the farmer, the correct variety name, if otherwise, the per cent of mixtures, and the "time" of each sample submitted are given in Table 59. In this table, the wheats are ranked according to "time". The long "time" readings are for the most part on Tenmarq

(7) The Crop Testing plan as used in Kansas is modeled after the Canadian plan originated by Dr. L. H. Newman, Dominion Cerealists, and Major H. G. L. Strange, Director of Research, Searle Grain Co., Winnipeg. Credit is due Robert J. Anderson, student in the Dept. of Milling Industry, for determining the "time" of these samples.

Table 59 -- Wheat meal fermentation time of 98 samples of wheat grown in the initial Kansas Crop Testing nursery, Junction City, Kansas, 1937.

1937 row no.	Variety listed as	If otherwise, identified as	% other varieties	"Time", min- utes
131	Tenmarq		0	290
42	do		5.4	221
35	do		6.4	182
67	Blackhull		1.3	177
58	Tenmarq		6.5	168
59	do		8.1	162
62	do		6.2	162
88	Hard Wheat	Turkey	16.6	152
23	Turkey		14.9	151
33	Tenmarq		4.9	151
57	Turkey	Blackhull	25.6(Turkey 17.1)	151
53	Tenmarq		7.7	148
9	<u>Cheyenne</u> (check)			144
32	Turkey		24.6(Redhull)	144
45	Tenmarq		18.5	139
136	Russian Wheat	Blackhull	28.5(Kanred 25.9)	138
37	Tenmarq		7.3	137
79	Turkey		2.1	132
39	Mixed Tenmarq, Turkey	Tenmarq	(Turkey 32.1) 54.4(Blackhull 22.3)	127
115	Tenmarq		0	125
137	Blackhull	Kanred	28.4(Blackhull)	125
118	Tenmarq		0	123
22	do		6.7	121
85	do		0	119
117	do		2.1	119
72	do		4.8	118
139	do		6.0	118
56	Mediterranean	Redhull	36.3(Blackhull 34.5)	117
106	Tenmarq		.9	113
84	Russian	Cooperatorka	5.7	105
91	Hard Wheat	Turkey	4.2	105
54	Soft Wheat	Harvest Queen	1.0	101
132	Tenmarq		0	101
3	<u>Tenmarq</u> (check)			100
125	Tenmarq	Kawvale	1.0	96
127	do		0	83
74	Soft Wheat	Harvest Queen	25.2(Turkey 16.5)	78
71	Turkey		15.1	75
24	Tenmarq		26.6(Turkey 21.8)	70
76	Turkey + Kanred	Kanred	38.3(Turkey 34.9)	65
102	Blackhull		10.2	63
44	do		6.0	61
29	Turkey		13.1	59
36	Blackhull	Kanred	51.2(Blackhull 35.5)	59
41	Turkey		35.3(Blackhull 29.4)	59
49	Blackhull		13.8	59
48	Hard Wheat	Blackhull	52.0(Redhull 46.4)	58
81	Superhard Blackhull	Blackhull	1.8	58
134	Kharkov	Kanred	0	58
26	Mixed Wheat	Harvest Queen	17.6	56
00	Turkey (check)			55
14	<u>Kawvale</u> (check)			55
38	Turkey	Kanred	26.2(Turkey)	55
28	do		19.5	54
55	do		48.7(Blackhull 45.3)	54
108	do		0	54
43	Red Chaff	Redhull	10.2	53
2	<u>Kanred</u> (check)			52
107	Turkey		21.8(Kawvale 9.4) (Blackhull 7.8)	61
52	do	Blackhull	16.6	50
73	do		26.2(Blackhull 18.0)	50
135	do		22.4(Kanred 11.6)	50
89	do		20.2(Fultz 14.9)	49
103	Blackhull		2.8	49
112	Beardless	Harvest Queen	13.1	49
17	<u>Michigan Wonder</u> (check)			48
66	Blackhull		8.3	48
96	Mixed	Blackhull	37.4(Harvest Q. 31.2)	48
104	Mixed Hard & Soft	Harvest Queen	50.5(Turkey 45.8)	48
122	Beardless Soft Wheat	Harvest Queen	28.2(Turkey 25)	48
133	Iobred		11.0	48
95	do		4.3	47
119	Blackhull		4.0	47
83	Turkey		7.4	46
21	Blackhull		23.5(Kanred)	45
77	Turkey		22.7(Blackhull 11.4)	45
129	Blackhull		53.3(Turkey 21.7) (Kanred 20.0)	45
16	<u>Harvest Queen</u> (check)			44
25	Beardless Soft	Harvest Queen	1.6	44
69	Blackhull		11.4	44
98	Harvest Queen		0	44
105	Kharkov	Kanred	4.5	44
111	Blackhull		22.9(Turkey 18.5)	44
20	<u>Penquite</u> (check)			43
61	Beardless	Harvest Queen	6.5	43
116	Hard Wheat	Turkey	11.5	43
126	Beardless Hard Wheat	Turkey	50.7(Harvest Q. 47.0)	43
128	Blackhull		10.7	43
18	<u>Clarkan</u> (check)			42
34	Turkey		28.7(Redhull 19)	42
78	Mixed Beardless (Hard)	Turkey	50.7(Harvest Q. 23.3)	42
92	Hard Wheat	Blackhull	29.6(Harvest Q. 22)	42
99	do	Turkey	26.5(Redhull 20.7)	42
109	Blackhull		22.1(Harvest Q. 13.3)	42
46	do		4.2	41
65	Turkey		6.6	41
51	do		21.9(Kanred 14)	40
97	do		22.5(Redhull 19.2)	40
101	Kanred	Turkey	23.6(Kanred 23.6)	40
113	Blackhull		7.4	40
75	Turkey		2.9	39
86	Kharkov	Turkey	2.7	39
87	Hard Wheat	Blackhull	12.2	39
93	Blackhull		6.1	39
94	Beardless	Harvest Queen	9.3	39
124	Hard Wheat	Turkey	36.3(Harvest Q. 19.7)	38
4	<u>Blackhull</u> (check)			37
6	<u>Early Blackhull</u> (check)			37
15	<u>Fulcaster</u> (check)			37
27	Kawvale		34.6(Blackhull 21.8)	37
63	Turkey	Redhull	41.7(Turkey 41.7)	37
64	Blackhull		14.9	37
82	Mediterranean	Blackhull	18.9	37
114	Kawvale		2.8	37
121	Mixed Wheat	Harvest Queen	20.6(Blackhull 16.5)	37
31	Harvest Queen		31.5(Tenmarq 11.4)	36
123	Turkey		13.0	36
68	do		34.6(Blackhull 30.0)	35
138	Harvest Queen		2.0	34
7	<u>Chiefkan</u> (check)			33
47	Soft Wheat	Michigan Wonder	68.2(Harvest Q. 28.0) (Fulcaster 22.4)	31

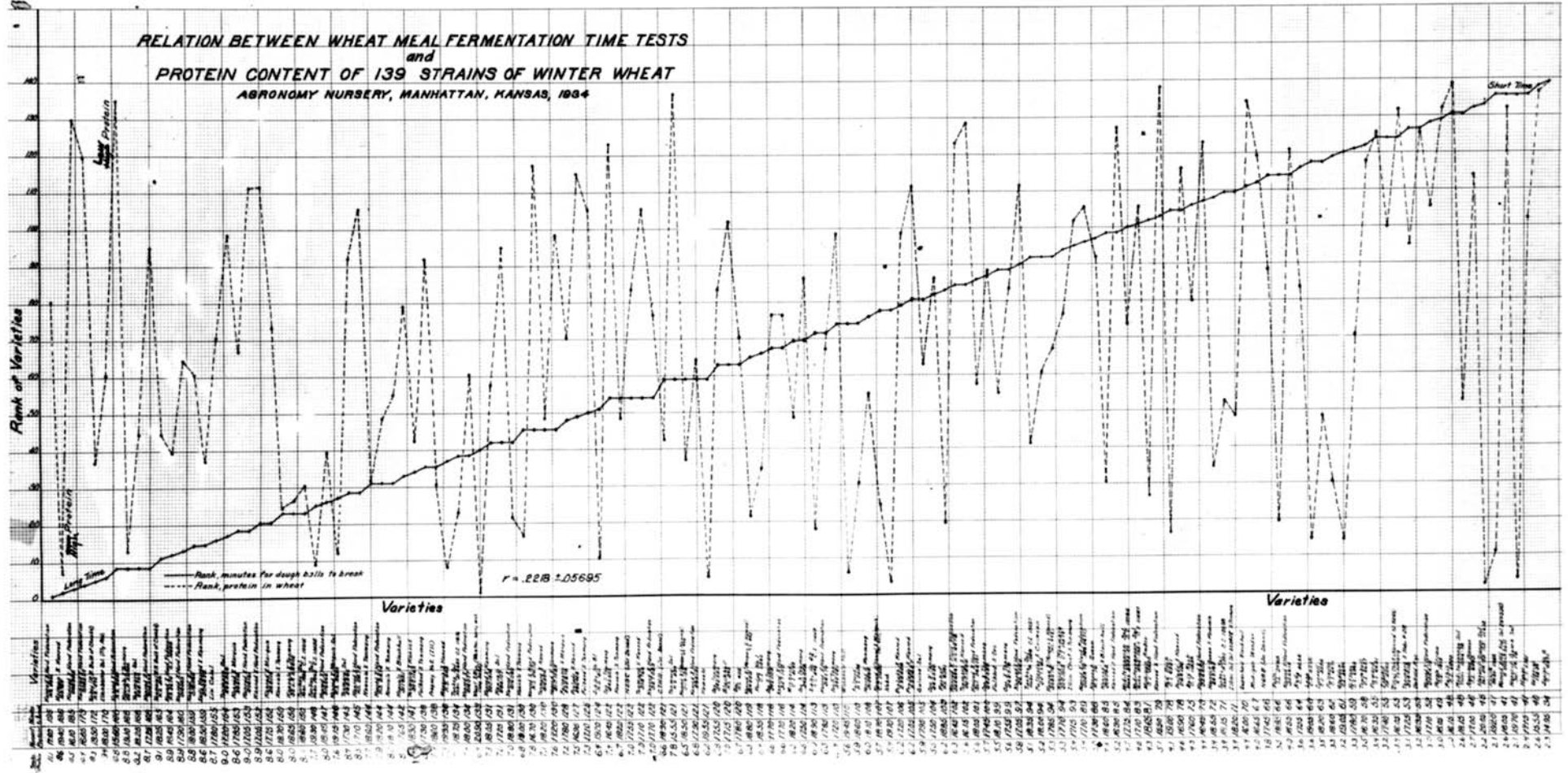
samples. Occasional long "time" readings on samples described as Blackhull suggest that the identity may be incorrect, as known pure samples of Blackhull nearly always have short "time". The Blackhull check in this nursery had "time" of 37 minutes. A few samples of wheats described and identified as Turkey had long "time". One sample of Tenmarq, "time" 83 minutes, had "time" shorter than usually found in pure samples of this variety. One sample of a soft wheat identified as Harvest Queen with a 1% mixture of another variety has "time" of 101 minutes. This long "time" is not at all characteristic of Harvest Queen. Although there are a few cases of samples identified as varieties having "time" not typical of these varieties, the "time" readings of the great majority of samples are in full agreement with the "time" of pure samples of these varieties, previously tested.

Twenty-six Crop Testing plots were planted in the fall of 1937 in 25 counties in the eastern half of Kansas. The "time test" is being used to test many of the samples in these plots. It is expected that the "time test" will again give valuable data in aiding to determine the variety of the unknown or misnamed samples. Informing farmers of the "time test" results on their wheats will place before the wheat producer the idea of growing high quality wheats desired by the grain trade, the miller, and the baker.

Correlation of "Time Test" with Other Quality Tests

"Time Test" and Protein Test. The "time" readings of a large number of winter wheat strains grown in the agronomy nursery in 1934, 1935, and 1937 were correlated with the protein percentages of the same strains. These data are presented in Figures 2, 3, and 4. The data presented in Figure 2 are given in rank order and not in terms of actual "time" and protein percentages. The strain having the longest "time" is ranked as number 1, and the shortest "time" strain is ranked as number 139. The strains tested are ranked according to "time". The solid line ascending from left to right represents "time" ranks of the strains tested. The strains are ranked also according to their respective protein content, i. e., the strain with the highest protein percentage is designated as number 1, etc. The protein percentages are not plotted on the graph in consecutive rank but are allowed to fall where they may. The broken line represents the rank of the strains as to protein content. The graph shows that as "time" decreases, there is no corresponding decrease in protein percentages. The correlation of the "time" and protein percentage for the 139 strains tested in 1934 was determined, $r = .222 \pm .057$. Thus, long "time" is not dependent upon a large quantity of

Figure 2



protein. Following the practice of Pelshenke, a quality index number for each of the strains was determined by dividing the "time" in minutes by the protein percentage. This quality index number is not given much emphasis, as quantity and quality of protein are not synonymous and such an index may not reveal the important quality differences in wheats due to inherent differences in the gluten quality. The quality index number has not been determined on strains tested since 1934.

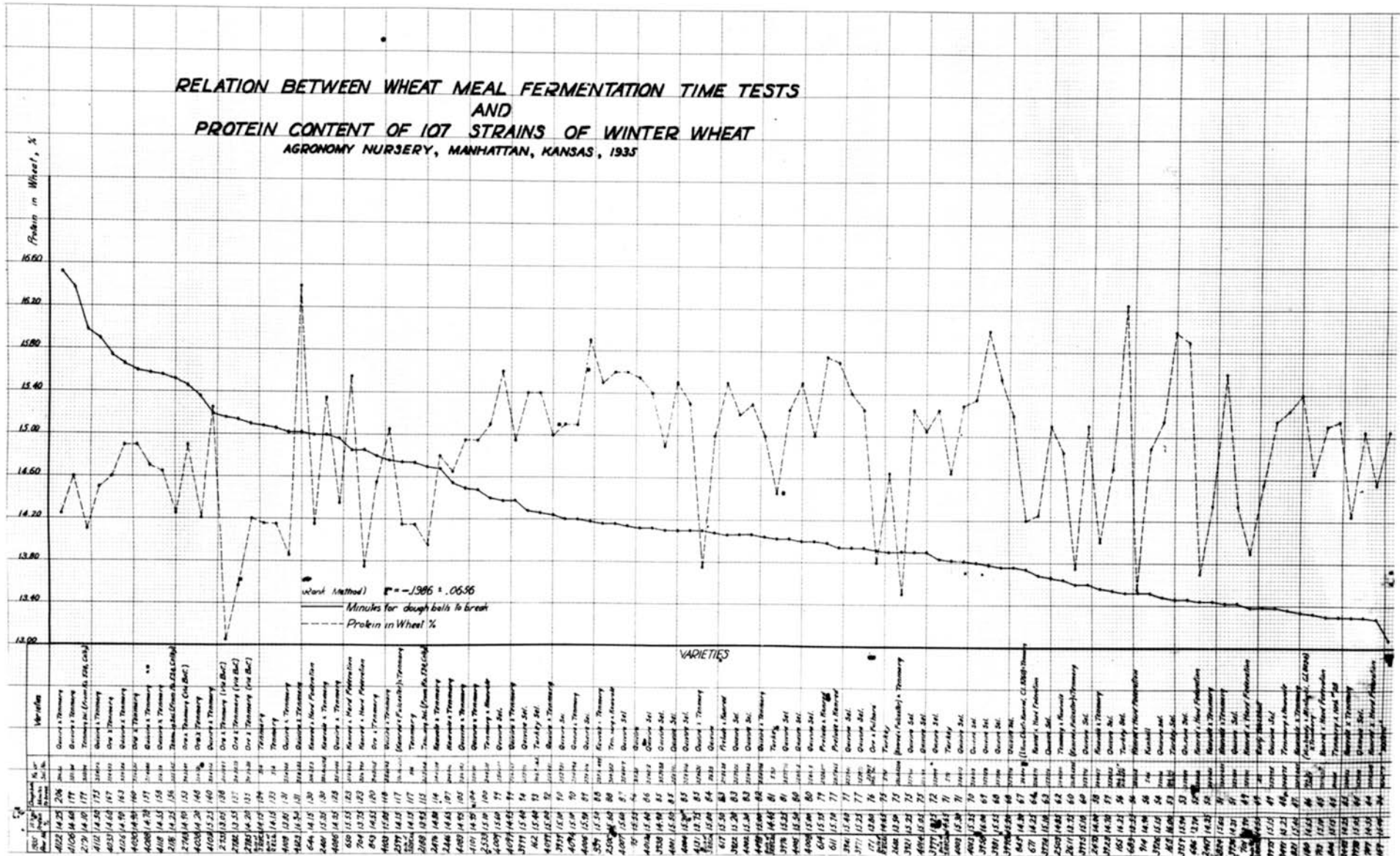
A quartile study of "time" and protein content of 31 varieties listed in Table 36, page 99, reveals that there is no significant decrease in protein percentage of varieties as the "time" becomes shorter. The quartiles are as follows

<u>Quartile</u>	<u>No. of varieties</u>	<u>"Time", minutes</u>	<u>Protein %</u>
I	8	125	12.03
II	8	96	11.89
III	8	71	11.90
IV	7	40	12.29

The shortest "time" quartile has the highest average protein percentage. The two middle quartiles have the lowest average protein percentages.

The "time" and protein determinations of 107 strains of winter wheat tested in 1935 are presented in Figure 3. The strains tested are ranked from left to right on the graph in high to low order of "time". The "time" in min-

Figure 3



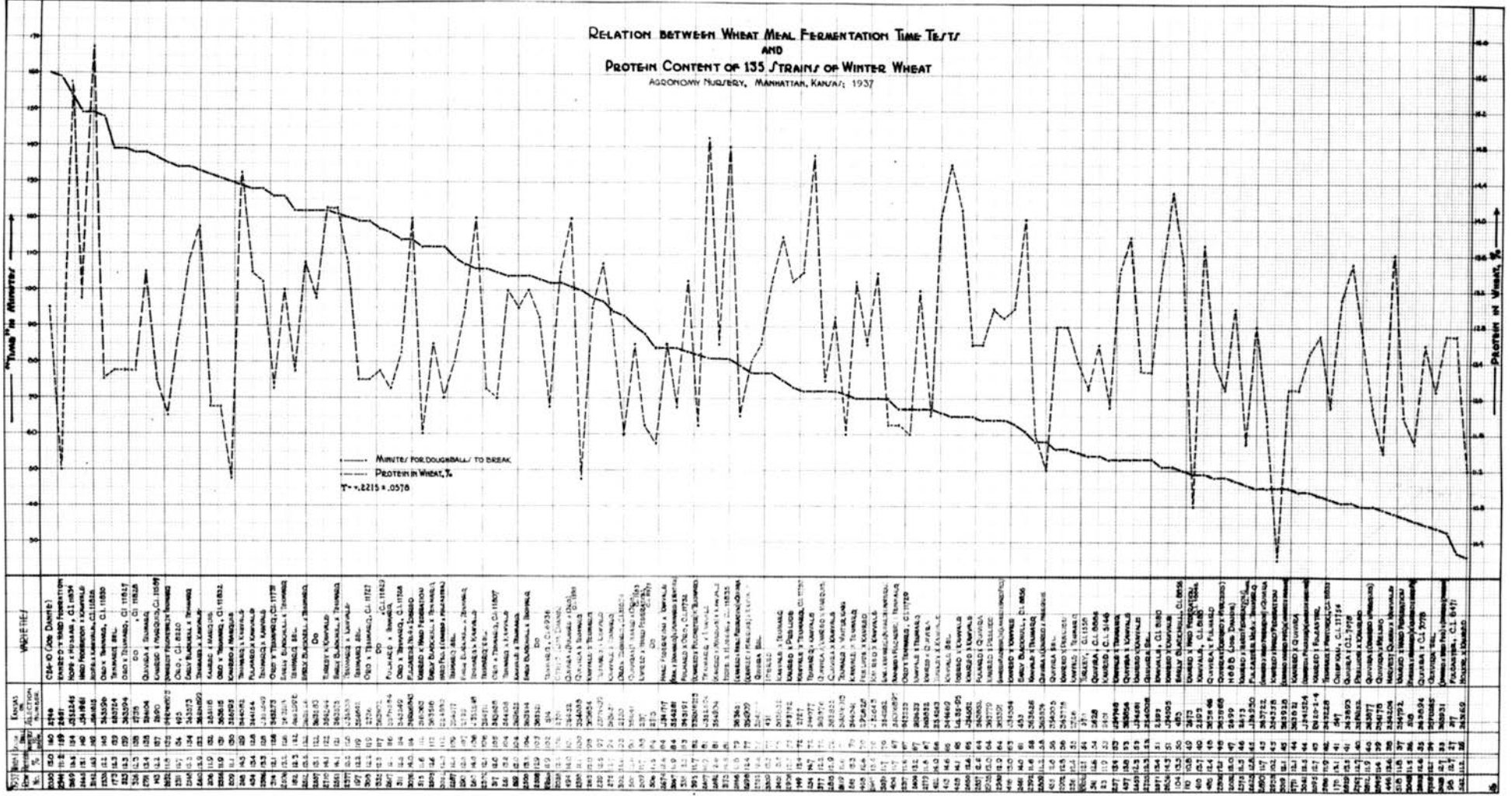
utes and protein percentages are plotted directly. Each large square on the graph indicates a "time" of 20 minutes and a protein content range of 0.40. The solid line represents the "time", and the broken line the protein percentages. As in 1934, these data show no decrease in protein percentage as the "time" decreases. The correlation of "time" and protein percentages for the 107 strains grown in 1935 was determined, $r = -.199 \pm .066$. In 1936 only a few of the 148 strains grown in the nursery which were "time tested", were analyzed for protein content. The number of strains available for determining a correlation between "time" and protein percentage was too small to give reliable results.

One hundred and thirty-nine strains of winter wheat grown in the nursery in 1937 were tested for "time" and protein content. These data are presented in Figure 4. The strains are ranked according to "time", from long (left) to short (right). The solid line represents the "time" of the strains, while the broken line represents the protein percentages. The "time" and protein determination lines show no relationship. The correlation of "time" and protein percentages for these 135 strains was determined, $r = .222 \pm .058$.

In the 3 years in which "time" and protein percentages

Figure 4

RELATION BETWEEN WHEAT MEAL FERMENTATION TIME TEST
AND
PROTEIN CONTENT OF 135 STRAINS OF WINTER WHEAT
AGRONOMY HUBBARD, MANHATTAN, KANAS, 1937

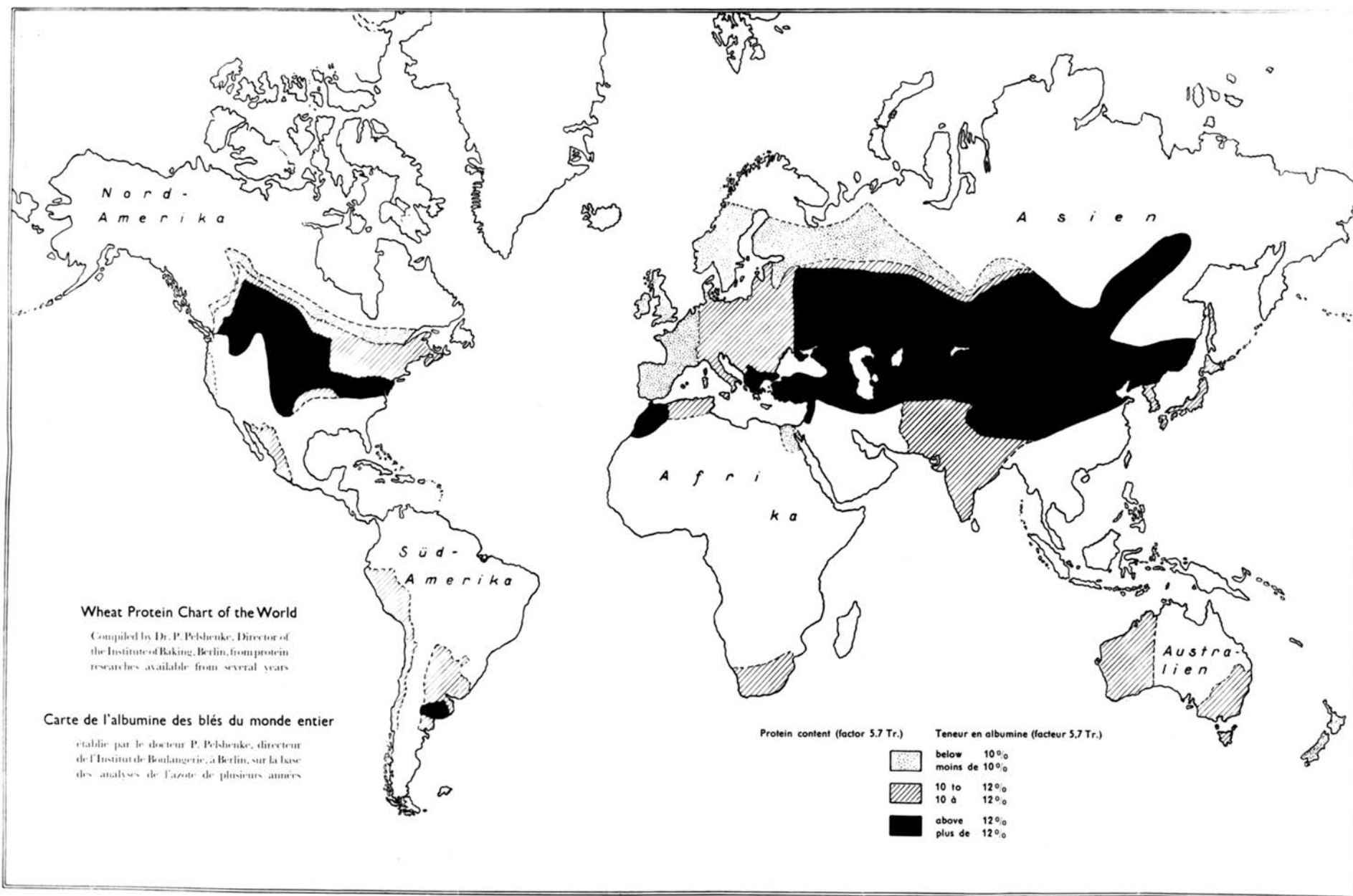


were determined and correlation studies made, no significant correlations were obtained. This shows that in the hard and soft red winter wheats tested, "time" is not dependent upon the amount of protein.

The gluten strength of wheat has been shown to vary with the variety and the soil and climatic conditions in which the crop is grown. It is known (1) that in general hard red spring wheats grown in the prairie provinces of Canada have long "time", (2) that hard red spring and hard red winter wheats grown in the Great Plains area of the United States have medium to long "time", (3) that soft red winter and white wheats grown in the eastern United States are mostly short "time" types and (4) that wheats produced in the 3 major wheat growing zones of Argentina range from short to long "time", in accordance with the 3 texture classes, soft, semi-hard and hard. The Wheat Gluten Quality Chart of the World, Figure 5, prepared by Dr. Paul Pelshenke, Director of the Institute of Baking, Berlin, shows the areas of the world in which high gluten quality wheats are produced. Samples so far tested at the Kansas station gave results in agreement with this map.

Pelshenke (1937) determined good gluten quality wheat as wheat that has at least (1) 20% wet gluten, (2) a gluten swelling figure of 15, as determined by the Berliner-Koopman method, and (3) a "time test" figure of 25. A

Figure 5

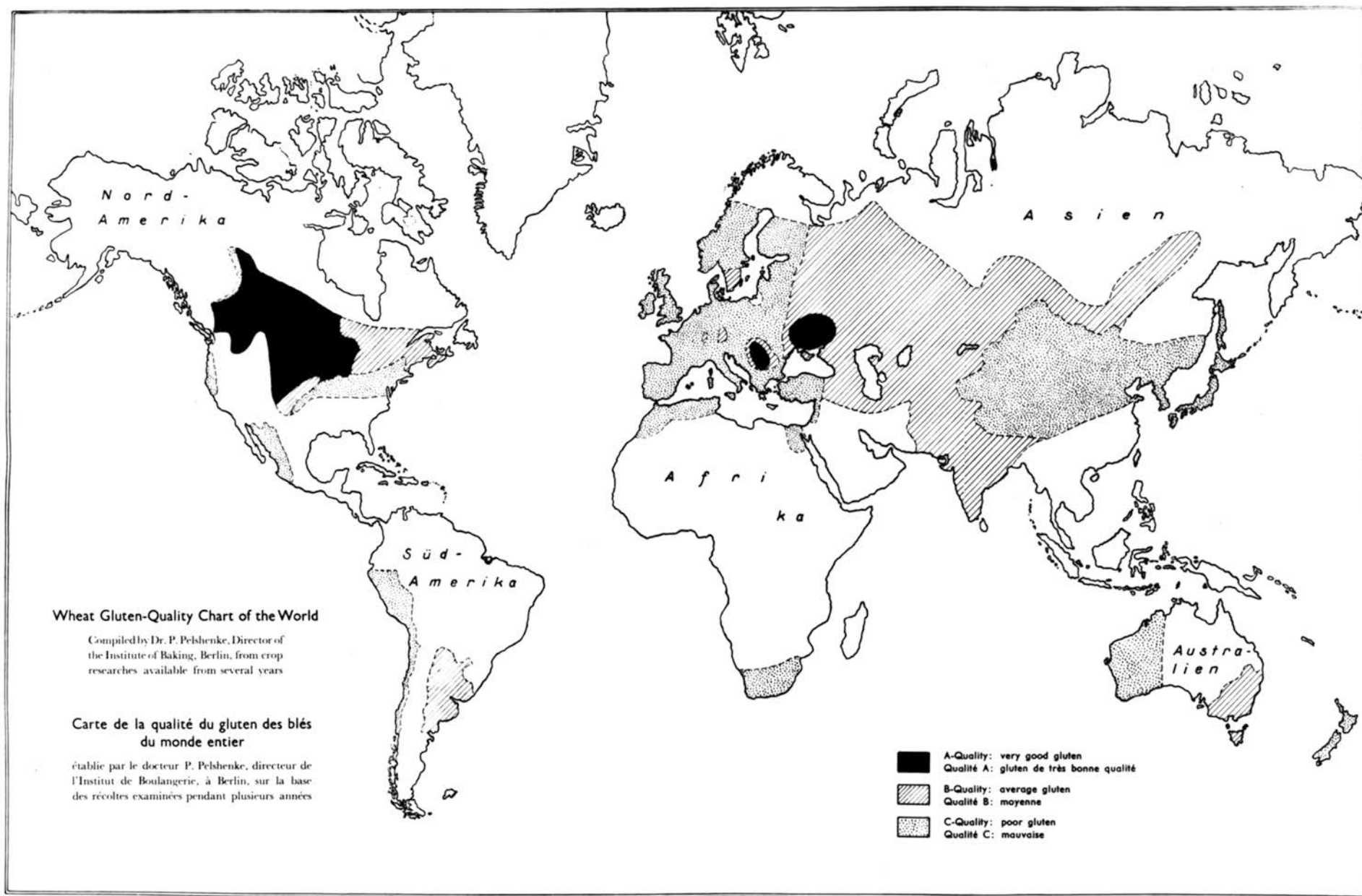


wheat may be recognized as a good gluten quality wheat even though deficient in one of these requirements, providing any of these quality measures are enough higher than the minimum requirement to offset the deficient characteristic.

The Wheat Protein Chart of the World, Figure 6, prepared by Pelshenke, shows that the high gluten quality areas are located in areas of high protein, but high protein areas are not necessarily the same as high gluten quality areas. Thus, as data presented in Figures 2, 3, and 4 show, high gluten quality is not dependent upon high protein content alone.

"Time Test" and Dough Development Curves. A recording dough mixer designed in the Department of Milling Industry, Kansas State College, gives curves for different varieties that reappear from season to season, in which respect the results are similar to those of the "time test". The curves of most wheat varieties desirable for bread making ascend and descend gradually and have a rounded top. Desirable varieties produce wide bands, showing high plastic value. The height of the curve from the base line is influenced by the amount of protein and is not considered to be of as great significance as the angle of ascent, width of band, roundness of the top, and angle of descent. The curves illustrated in Plates IV and V are typical of the standard varieties they represent.

Figure 6

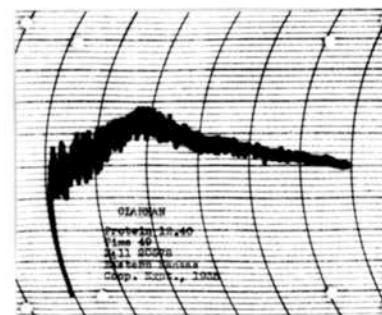
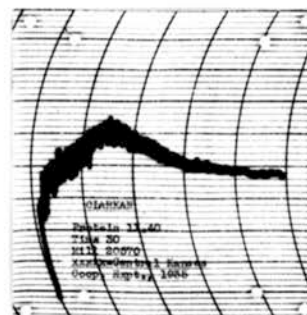
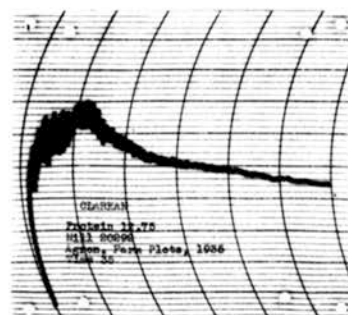
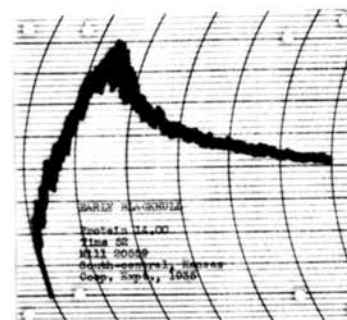
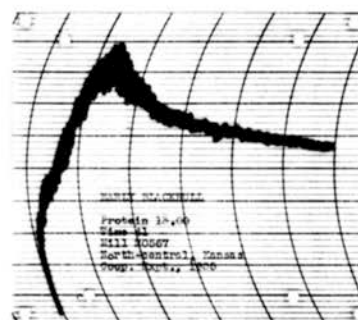
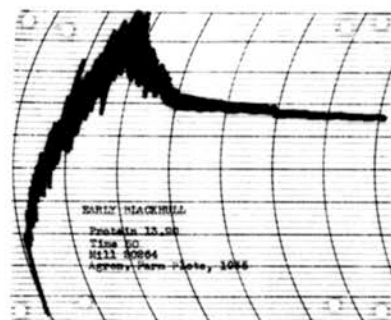
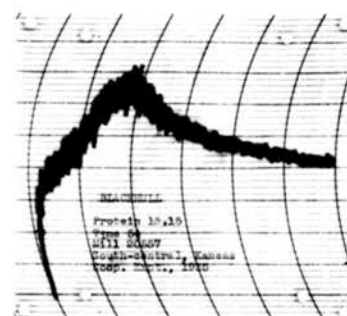
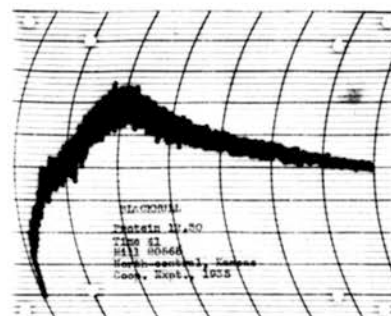


The curves illustrated in Plate IV show the constancy of the curve type for Blackhull, Early Blackhull, and Clarkan grown at different locations in the same season. The curves for the Blackhull samples have a rather sharp peak, rather sharp angles of ascent and descent, and fair width. This curve type is considered as indicating only fair tolerance in the bake-shop. The short "time" readings of the two samples of Blackhull are listed with the curve, showing that the quality ratings of this variety by the "time test" and the curve type are very much alike.

The 3 curves of Early Blackhull illustrated in Plate IV are similar, but differ characteristically from the Blackhull curves. These curves have sharp angles of ascent and descent and have sharp peaks. The width of the band is narrow. The undesirable curve characteristics of Early Blackhull are in agreement with the inferior quality rating given to this variety by its short "time". Dough curves of Clarkan, a soft red winter wheat variety have some of the characteristics of Blackhull, and some of the characteristics of typical soft red winter wheats.

The 3 curves of Clarkan show some variation but each has the sharp angle of ascent, rather sharp peak, and the rather rapid break-down from the peak, characteristic of poor bread quality wheats. The "time" readings of Clarkan

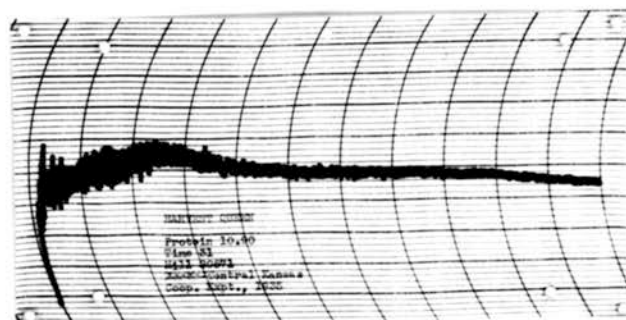
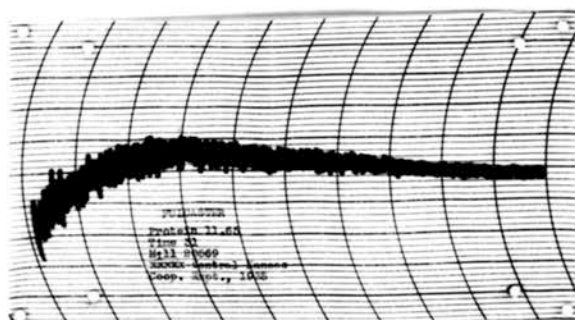
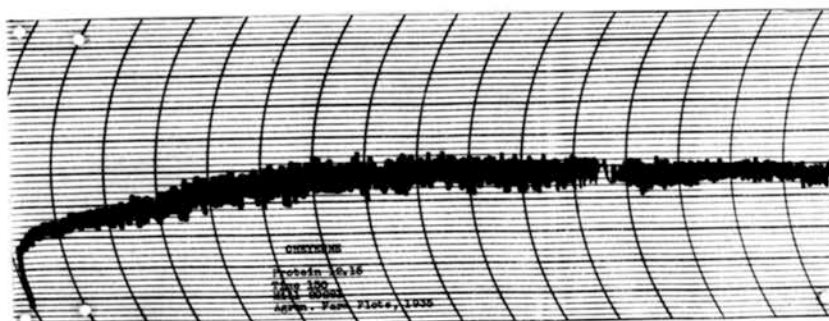
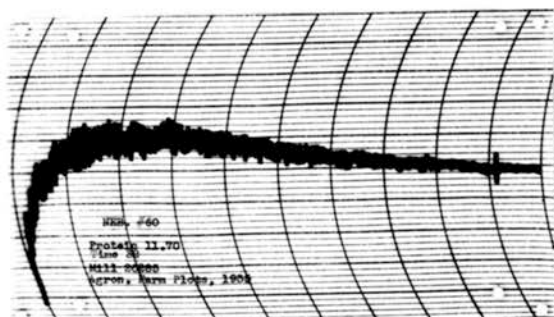
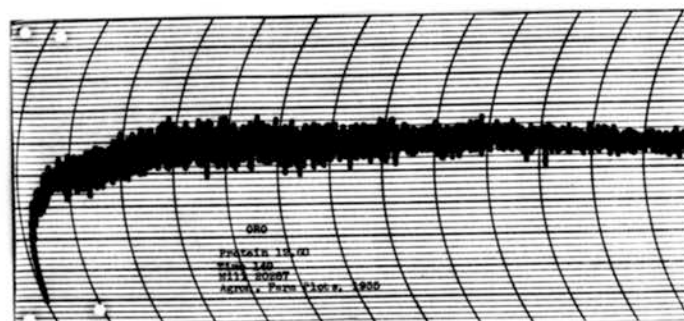
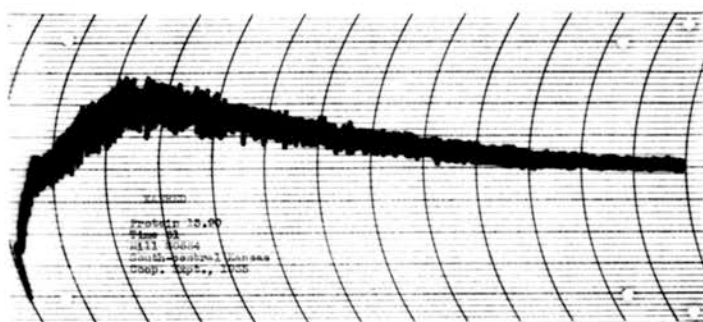
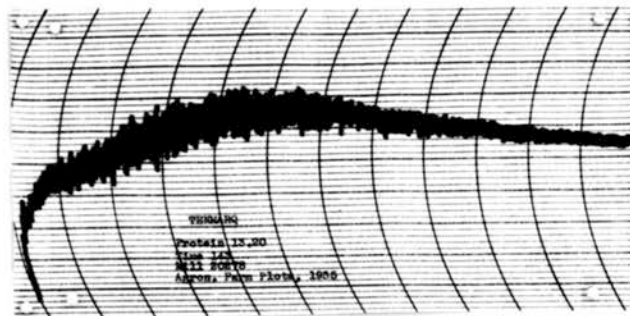
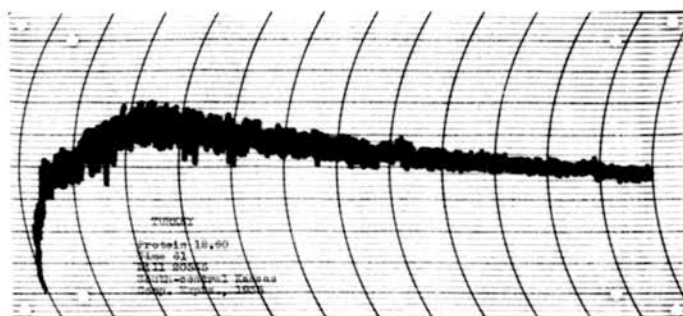
Plate IV CURVES FROM KANSAS STATE COLLEGE RECORDING DOUGH MIXER



are shorter than those of Blackhull and Early Blackhull, in agreement with the classification of Clarkan as a soft red winter wheat.

The curve of Turkey wheat, illustrated in Plate V, has a rather rapid ascent, a rounded top, and a gradual descent. The "time" of this Turkey sample is higher than of Blackhull and Early Blackhull and is in full agreement with the better type curve and better quality rating of Turkey. Tenmarq has a very long "time" and a desirable curve. The Tenmarq curve ascends gradually in a wide band to a rounding top and descends gradually. Kanred, with a medium "time", has a curve type similar to Turkey. Oro has a gradually ascending wide banded curve, showing that the peak level is retained for several minutes of mixing and that the dough loses its plasticity very slowly. The long "time" of Oro is in full agreement with the curve type. Nebraska No. 60, with a short "time" has a curve of rather undesirable character in that the angle of ascent is rather sharp, the top although of rounded nature, thins out rapidly, indicating low plasticity. Cheyenne, a long "time" variety of hard red winter wheat, has a curve that builds up to a flat plateau and thins out gradually. The 2 short "time" soft red winter wheats, Fulcaster and Harvest Queen, have curves typical of this market class. Fulcaster has a better curve type, for

CURVES FROM KANSAS STATE COLLEGE RECORDING DOUGH MIXER



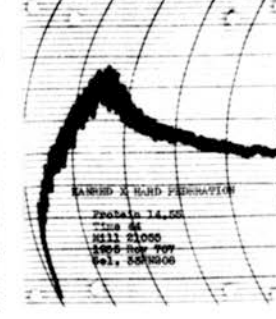
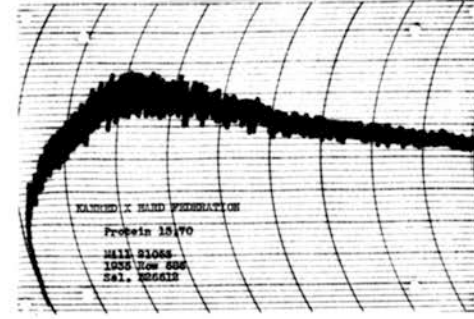
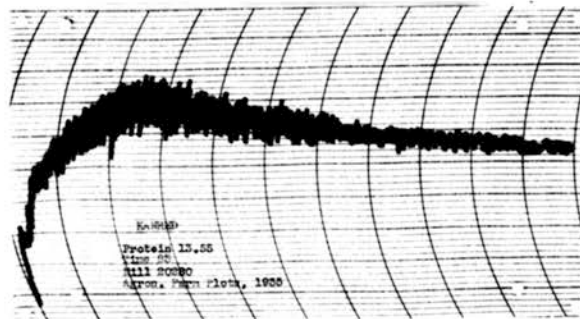
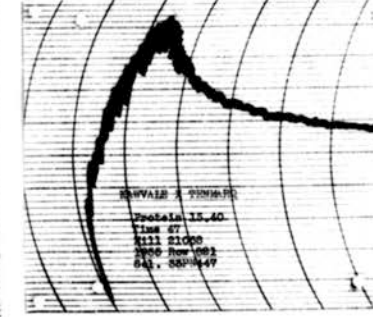
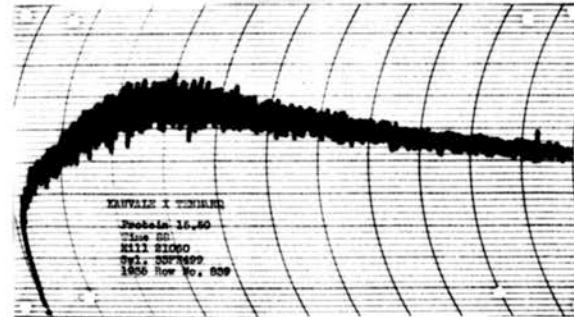
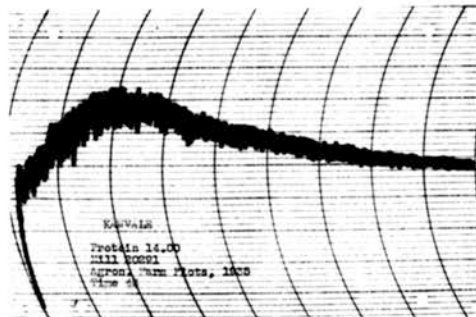
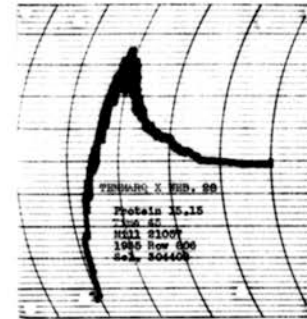
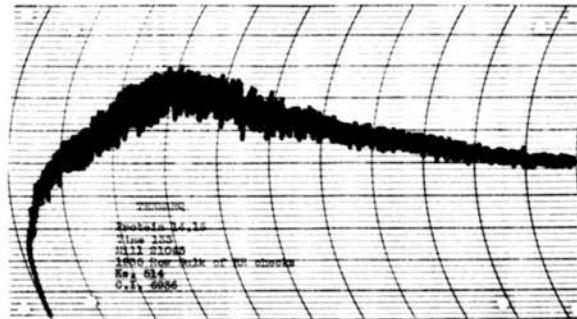
a bread wheat, than Harvest Queen.

Curves given in Plate VI illustrate the value of the recording dough mixer in indicating the quality type of progeny of crosses between varieties having unlike curve type. The 3 curves in the top row illustrate the inheritance of quality type in the cross, Tenmarq x Nebraska No. 28. Tenmarq (left) has curve type and "time" characteristic of high quality wheats. The curve type of the hybrid closely resembles the undesirable curve type of Nebraska No. 28. "Time" readings of the Nebraska No. 28 parent and of the hybrid are short, in agreement with the undesirable curve types.

The 3 curves in the middle row of Plate VI illustrate Kawvale and two selections of Kawvale x Tenmarq, one having desirable and one having undesirable curve. The Kawvale curve resembles that of a strong hard wheat more than a soft wheat. "Time" readings of Kawvale are usually more like strong hard wheat than weak soft wheat. Selection No. 33FN499 (center) has a curve resembling the Tenmarq parent, with gradual ascent, rounded top, and gradual descent. The plastic characters are also similar to Tenmarq. The "time" is intermediate in respect to the parents. The other hybrid selection, No. 33FN447 (right) has a poor curve type and short "time". The "time" of the hybrid sel-

Plate VI

CURVES FROM KANSAS STATE COLLEGE RECORDING DOUGH MIXER



ection, No. 33FN447 is similar to that of Kawvale, but the curve type is distinctly inferior to Kawvale.

Curves in the bottom row illustrate 2 hybrid selections of Kanred x Hard Federation. One of the hybrids (center) has a curve similar to Kanred. The other hybrid (right) has a distinctly inferior curve. Both hybrids have shorter "time" than Kanred. The curve and "time" of the Hard Federation parent are not available.

The dough development curves illustrated in Plates IV to VI show that this quality test gives a clear graphic illustration of the gluten strength of the wheat varieties and hybrids tested. In most cases, there is good agreement between curve type and "time", i. e., long "time" wheats usually produce curves of desirable type and vice versa.

"Time Test" and Loaf Characteristics. Investigations have shown that in general the longer "time" varieties have higher bread making value than short and medium "time" varieties, although there are important exceptions. "Time" was determined and experimental baking tests were made on 69 samples of winter wheat grown in Kansas in 1937. Results of these tests are given in Table 60. Statistical studies of correlation show no significant relation between loaf volume or total bread score and "time" in the strains tested.

Table 60 -- Relation between wheat meal fermentation time, loaf volume, external and internal bread characteristics, and total bread score of 69 strains of winter wheat grown in Kansas, 1937.

* Source	Ks. or sel.no.	Variety	"Time" min-utes	Loaf vol. c. c. Arkady (with sponse c.c.)	Arkady re-sponse c.c.	Loaf char-acteristic Form Grain	Total bread score	
n.c.		Cheyenne	155	710	75	G	7	90
s.c.		do	155	640	85	G	4	85
p	2690	Kanred x Marquis	149	625	--	F	4	83
p	2736	Oro x Tenmarq	145	590	15	F	7	92
p	2728	do	140	710	--	F	5	96
n	363595	do	138	700	210	F	6	90
p		Oro	137	540	-50	J	3	78
p	2729	Oro x Tenmarq	136	670	--	F	7	90
n	285116	Kanred x Marquis	132	725	160	F	6	93
n	326795	do	130	755	220	F	6	94
p		Cheyenne	130	515	10	J	3	76
n	344154	Fulhard x Kawvale	128	685	-5	J	5	93
e		Tenmarq	128	685	75	G	5	92
n	343273	Oro x Tenmarq	126	680	-10	G	4	82
s.c.		Tenmarq	124	570	-10	J	7	86
n.c.		do	122	710	75	F	7	92
n	2736	Oro x Tenmarq	119	725	140	F	4	89
p	2715	Kanred x Hard Federation	118	650	60	F	7	91
n	363602	Oro x Tenmarq	117	770	260	F	4	89
n	316063	Kanred x Hard Federation	116	680	105	F	7	92
n	343249	Oro x Tenmarq	114	720	175	J	7	91
n.c.		Turkey	108	680	75	G	4	84
n	343638	Oro x Tenmarq	105	605	85	J	7	85
n		Tenmarq	102	655	70	F	5	94
p	2719	Turkey sel., C. I. 10094	100	695	90	F	7	93
s.c.		Blackhull	99	615	40	J	5	90
n	33FN499	Tenmarq x Kawvale	97	625	115	H	7	87
s.c.		Quivira	94	625	45	F	6	84
e		Turkey	94	710	100	G	4	84
p		Hope x Mediterranean	94	770	140	F	7	94
n	2730	Oro x Tenmarq	93	640	65	G	5	90
p	2695	P-1066 x Prelude	92	655	--	F	6	88
s.c.		Kanred	90	610	25	F	7	90
s.c.	2673	Kanred x Hard Federation	89	690	115	F	5	94
p	2727	Kawvale x Tenmarq	88	625	50	J	6	82
s.c.		Turkey	87	565	-5	J	4	81
e		Kawvale	86	680	--	F	3	86
n.c.		Blackhull	82	705	55	F	6	82
n.c.		Early Blackhull	79	640	110	G	4	86
p	2717	Kanred x Hard Federation	78	635	35	F	7	92
p	519	(Prelude x Kanred) x (Turkey x Minessa)	78	685	135	J	7	88
p		Tenmarq	78	595	--	J	7	85
p	2673	Kanred x Hard Federation	77	620	--	J	4	84
n.c.		Kanred	73	630	-25	F	7	89
p	2726	Kawvale x Tenmarq	71	650	50	J	7	89
p		Early Blackhull	69	645	--	F	5	93
p		Kanred	69	555	45	J	4	79
p		Quivira	69	590	--	J	4	78
p		Kawvale	67	630	95	J	6	85
s.c.		Chiefkan	66	580	--	H	7	85
n	La.35-95	Iobred x Kawvale	65	710	90	F	4	90
p		Turkey	65	645	50	G	6	88
n	J34584	Kanred x Kawvale	63	675	0	F	5	95
p		Kharkov	62	650	75	F	4	86
e		Clarkan	61	685	90	G	3	81
s.c.		Early Blackhull	60	640	130	F	5	90
p	2723	Kawvale x Tenmarq	60	660	45	J	6	87
p	2735	do	57	635	80	J	6	88
n		Turkey	54	660	40	G	6	85
p		Blackhull	53	635	20	J	6	87
p		Clarkan	53	575	60	H	6	83
p		Chiefkan	52	580	-5	J	4	81
p		Harvest Queen	50	640	15	H	4	82
n	2735	Tenmarq x Kawvale	49	625	25	F	7	90
p	2720	Turkey sel., C. I. 10016	46	610	--	G	6	82
p		Nebraska No. 60	43	615	55	J	4	85
n.c.		Chiefkan	42	590	75	J	4	84
p		Fulcaster	38	585	60	J	4	81
e		do	34	685	75	G	3	83

Ave. "time", 69 strains - - - - - 90
 " loaf volume in c.c., 69 strains - - - - - 649
 " total bread score, 69 strains - - - - - 87

Correlation of "time" and loaf volume, $r = .2067 \pm .0808$
 " " " " total bread score, $r = .4025 \pm .0750$

*n.c. = Cooperative wheat variety tests on farms in north central Kansas.
 s.c. = " " " " " " " " south central " "
 e = " " " " " " " " eastern Kansas.
 p = Wheat variety plots at the agronomy farm, Manhattan.
 n = Wheat breeding nursery, Manhattan.

In the baking tests made at the Kansas station in 1937, the sponge dough method was used. Four "pup" loaves of each variety were baked. Each loaf represents a given fermentation time in the dough stage, i. e., 15, 30, 45, and 50 minutes of fermentation. Optimum water absorption and optimum mixing time were used for each variety, as determined empirically by an experienced cereal chemist. Two test bakes were made on the 69 samples. In the first series of tests made in the autumn, one-eighth of one per cent Arkady was used in each loaf, while in the second series of tests made in mid-winter, no Arkady was used. The data on loaf volume and total bread score given in Table 60, are based on the best loaf of each variety baked with Arkady. Data showing the response in loaf volume from the use of Arkady are also given in Table 60.

These limited data indicate only low correlation between "time" and total bread score, $r = .4025 \pm .0750$. "Time" and loaf volume showed low and insignificant correlation, $r = .2067 \pm .0808$. There is a tendency for greater response to Arkady by longer "time" varieties than by shorter "time" varieties.

A high correlation could hardly be expected between "time" and total bread score, as factors not directly associated with gluten quality are given heavy weight in the total bread score here used. The following bread score is

used at the Kansas station:

<u>Loaf characteristics</u>	<u>Value</u>
Volume	10
Crust color	8
Symmetry of form	3
Evenness of bake	3
Character of crust	3
Break and shred	3
Grain of crumb	10
Texture of crumb	15
Taste	20
Flavor	15
Color of crumb	10
Total	100

The low correlation between "time" and loaf volume, $r = .2067 \pm .0808$, shows that these two quality measures are not closely interrelated, in so far as one can judge by the 69 samples grown at several locations in Kansas in 1937.

Quartile studies of the relation of "time" and total bread score and of "time" and loaf volume show the tendency for wheat strains in the two longer "time" quartiles to have larger loaf volume and higher bread score than varieties in the two shorter "time" quartiles. The quartiles are as follows:

Quartile	No. varieties	"Time", minutes	Loaf vol. in c. c.	Total bread score
I	18	134	660	88
II	17	100	669	89
III	17	74	633	86
IV	17	52	632	85

Quartile studies of the number of wheat strains commonly classed as high quality, in which the strains are ranked according to (1) "time", (2) loaf volume (with Arkady), and

(3) total bread score (with Arkady), show that of the three measures of quality, the "time test" has indicated strains of good bread making quality most consistently. The following quartiles indicate the value of the "time test" in determining good bread quality in strains of wheat being tested:

		Varieties ranked in order of		
		(1)	(2)	(3)
Quartiles	No. of varieties	"Time"	Loaf vol. with Arkady	Total bread score
No. of strains commonly classed as high quality				
I	18	16	12	10
II	17	9	7	8
III	17	5	4	7
IV	17	2	9	7

The different types of symmetry of form of loaf, as described by Blish⁽⁸⁾ (1928) are shown in Plates VII to XII. The highest value for symmetry of form, 3 points in a total of 100, is assigned to loaves similar to the F type illustrated in Plate VII. Loaves similar to the G and H types illustrated in Plates VIII and IX are considered less desirable, receiving 2 points in the scoring system. Type G is considered somewhat more desirable than type H. Loaves resembling I, J. and K types shown in Plates X, XI, and XII are considered undesirable, receiving a score of 1 on symmetry of form.

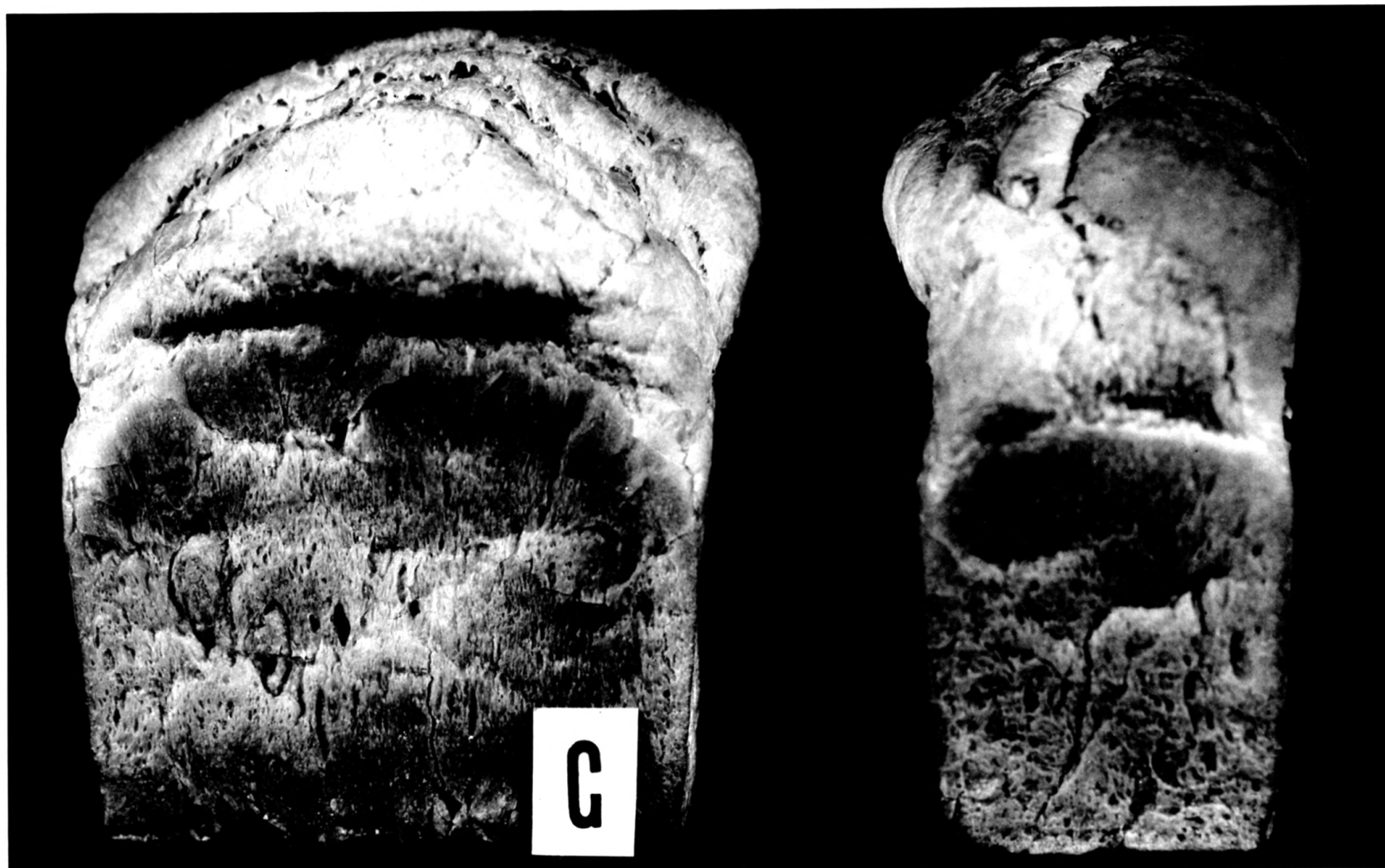
(8) Thanks are due Dr. M. J. Blish of the Department of Agricultural Chemistry, University of Nebraska, for the loan of the negatives showing the various loaf symmetry of form types and grain of crumb types.

Plate VII



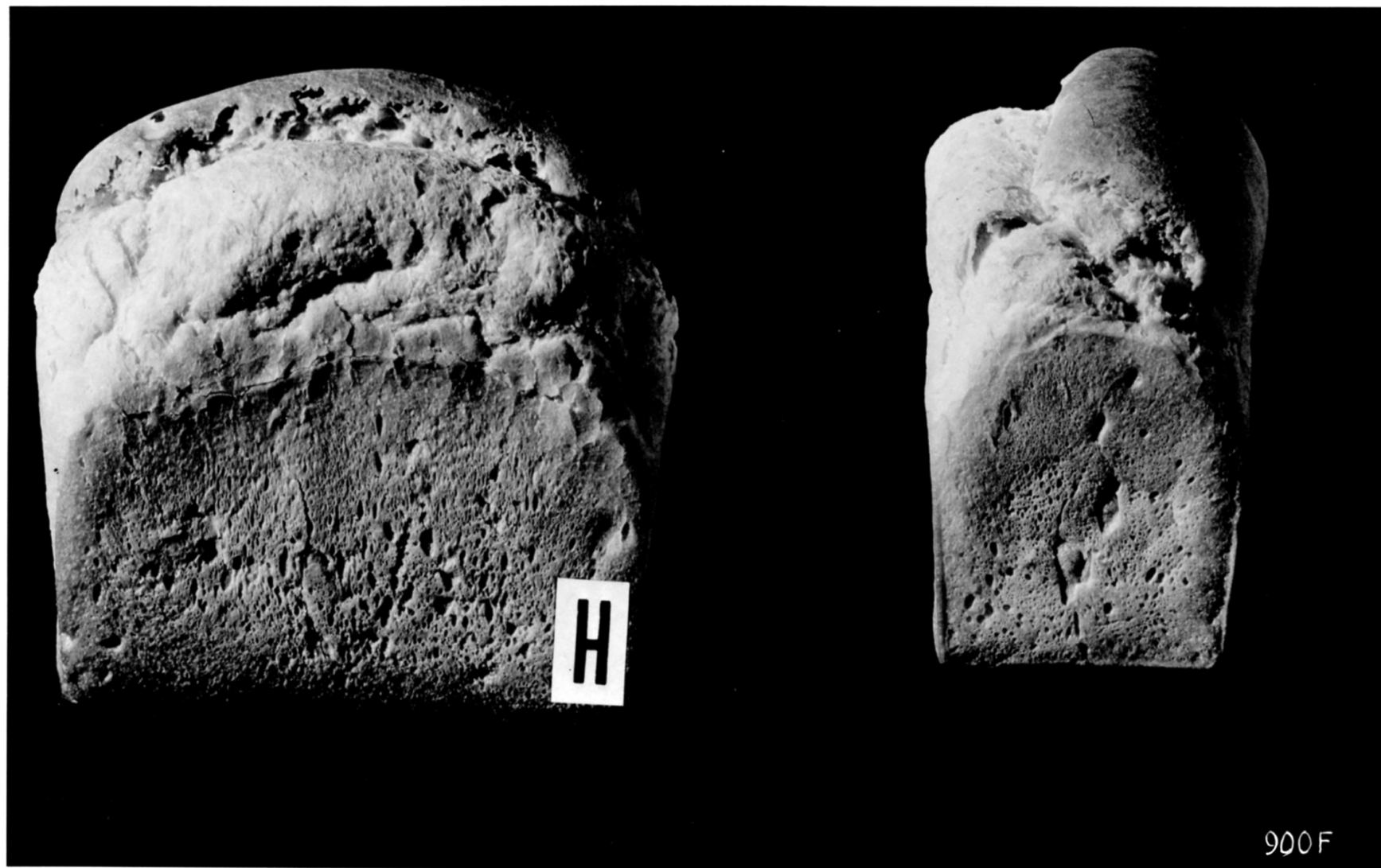
Symmetry of form of loaf.

Plate VIII



Symmetry of form of loaf.

Plate IX



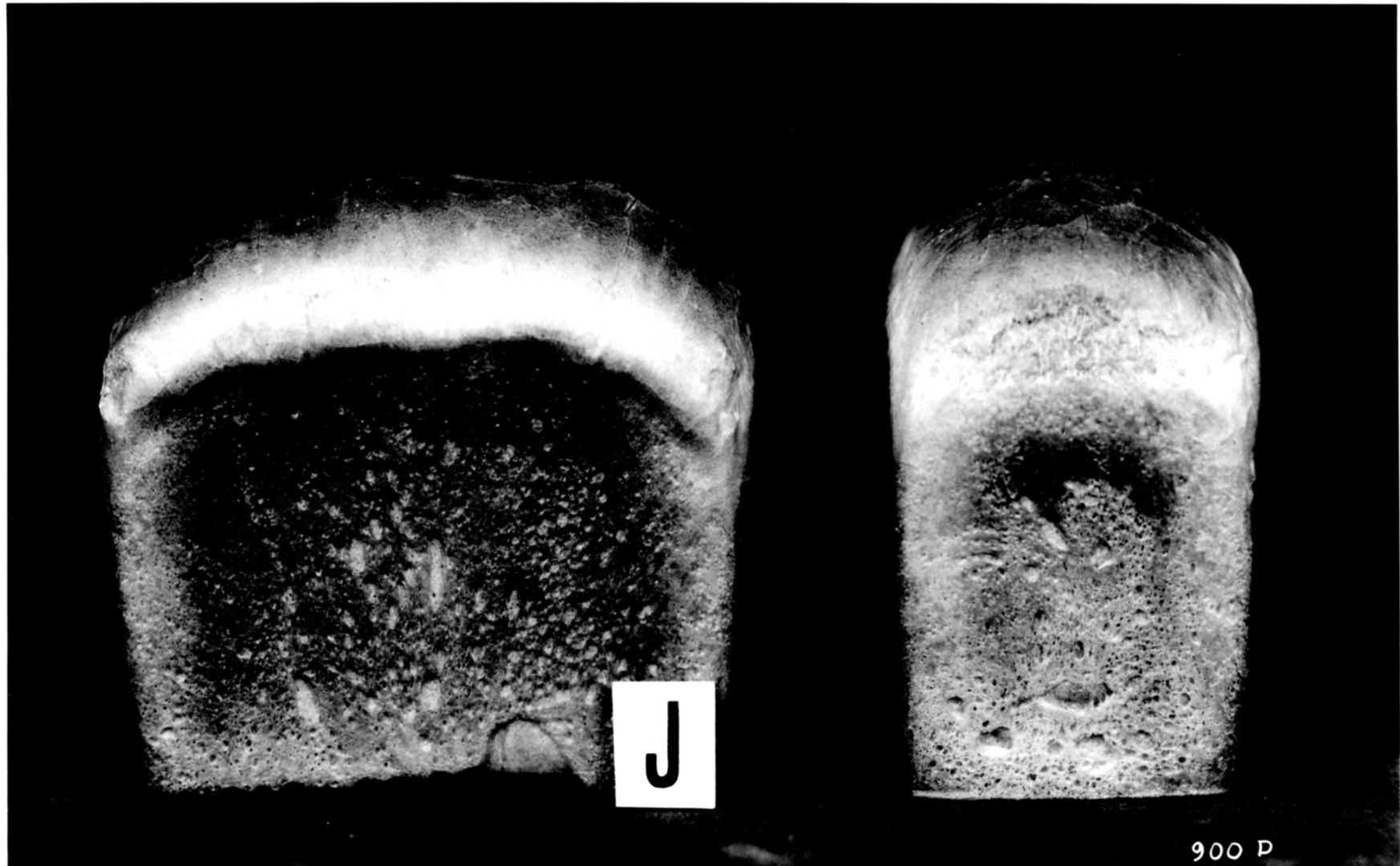
Symmetry of form of loaf.

Plate X



Symmetry of form of leaf.

Plate XI



Symmetry of form of loaf.

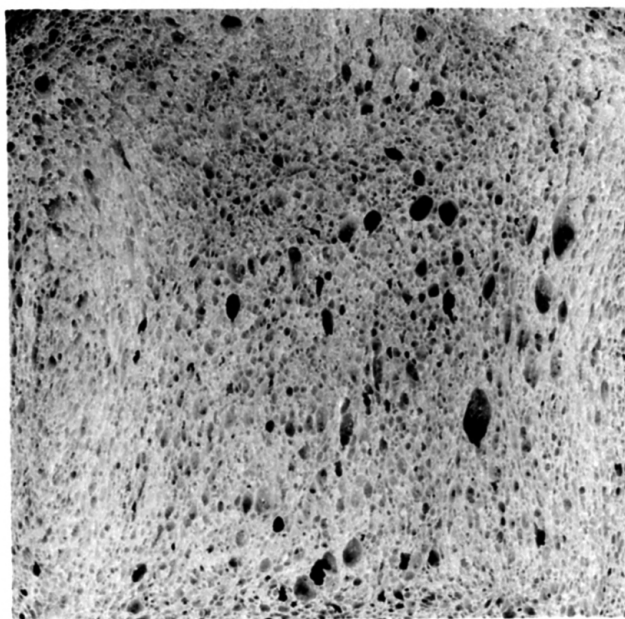
Plate XII



Symmetry of form of loaf.

Several grain of crumb types, as described by Blish (1928) are illustrated in Plates XIII to XVI. The highest value for grain of crumb, 10 points in a total of 100, is given to those loaves having a grain similar to type 5, illustrated in Plate XIII.

Plate XIII

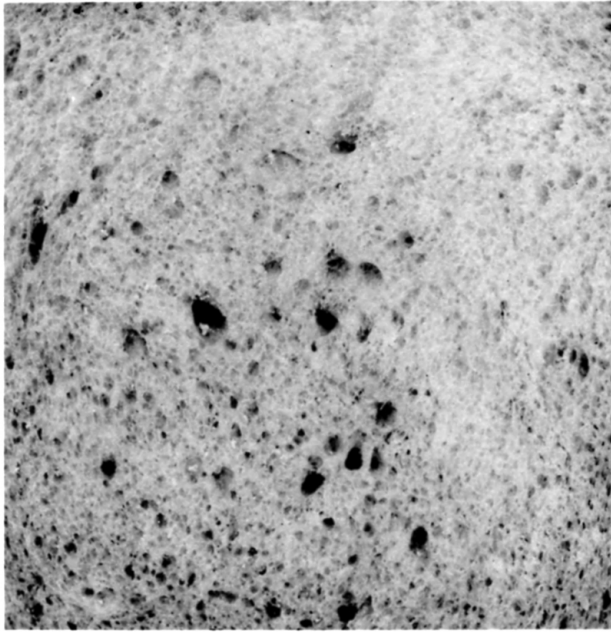


5

Grain of crumb of loaf.

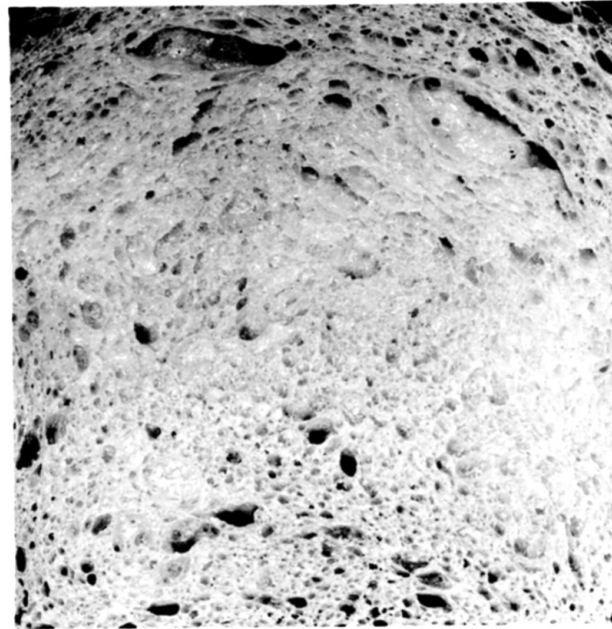
Plate XIV

Figure 1



6

Figure 2

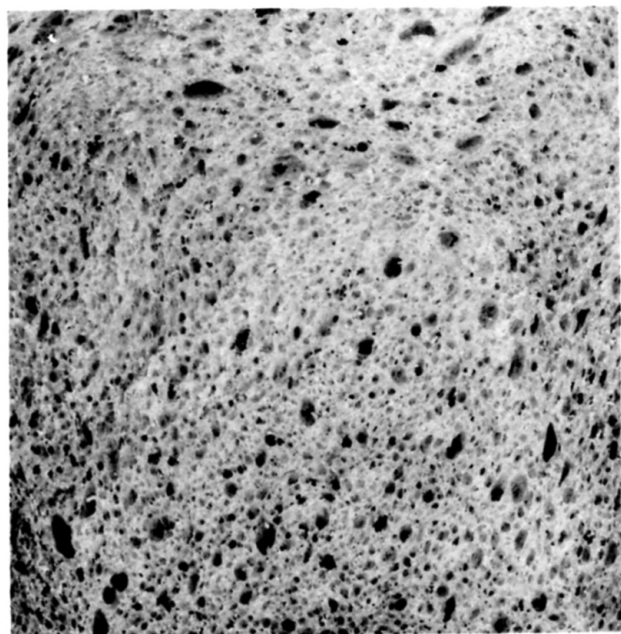


7

Grain of crumb of loaf.

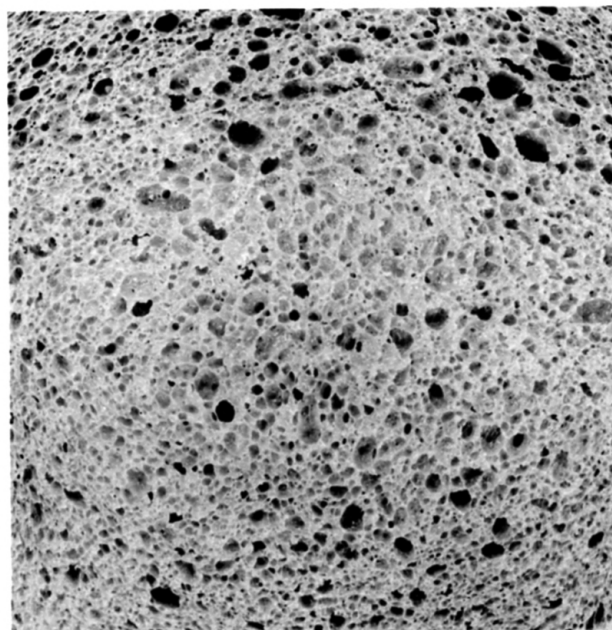
Plate XV

Figure 1



4

Figure 2



3

Grain of crumb of loaf.

Plate XVI

Figure 1

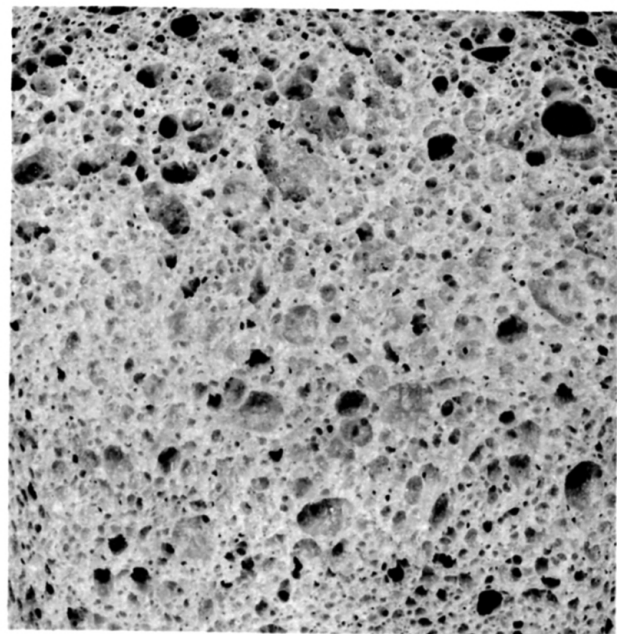
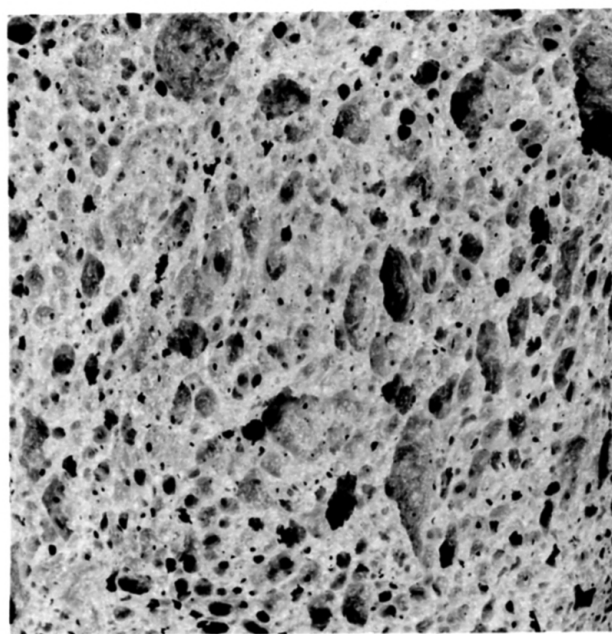


Figure 2



Grain of crumb of loaf.

Loaves with grain of crumb similar to types 6 and 7 shown in Figures 1 and 2 of Plate XIV are considered less desirable and are assigned 8 points. Loaves with grain of crumb similar to types 4 and 3, as shown in Figures 1 and 2 of Plate XV, are still less desirable and are given values of 7 and 6, respectively. Loaves with grain of crumb similar to types 2 and 1 as shown in Figures 1 and 2 of Plate XVI are poor and are given the low scores of 5 and 4, respectively.

Quartile studies of the relation of "time" to symmetry of form and grain of loaf show a tendency for the long "time" varieties to have more desirable symmetry of form and grain of crumb than the shorter "time" varieties. The quartiles are as follows:

Quartile	No. varieties	Ave. "time", minutes	Modal classes	
			Symmetry of form	Grain of crumb
I	18	134	G (good-)	6+ (good-)
II	17	100	G (good-)	7- (good-)
III	17	74	H (fair+)	6 (fair+)
IV	17	52	H (fair+)	4 (fair)

As neither the "time test" nor the baking test is by itself an adequate measure of quality, one cannot draw the conclusion from these data that one or the other test is not reliable. Lack of agreement between the results of these 2 tests may be due as much to variations in the baking test as in the "time test". While it is not claimed that the "time

test" is a more consistent index of quality than the baking test, results reported in this thesis and those of other investigators show that the "time test" does have an important place in wheat quality testing, especially in plant breeding.

SUMMARY AND CONCLUSIONS

The present investigation was undertaken to bring together and summarize data on the wheat meal fermentation time of varieties and hybrid strains of wheat obtained previous to and since the investigation was begun in the fall of 1936. From these data an attempt has been made to arrive at a conclusion as to the value of the wheat meal fermentation time test to the plant breeder in selecting high quality strains of wheat early in the breeding program.

The methods used in obtaining the data on the crops previous to 1936 are those described by Cutler and Worzella (1933). For the crops of 1936 and 1937 a modified procedure, found desirable in work with hard wheats, has been used.

In the earlier use of the "time test", results were often obtained which indicated great variability of this test when applied to the same samples. Realizing that in a reliable test of wheat quality variability in the results obtained must not be too wide, several factors influencing "time" were studied.

Studies were made on the influence of certain factors on "time" in an attempt to learn the reason for variability

of results. It was found that comparable results may be obtained over a period of several weeks after harvest, i.e. aging seems not to affect "time" of samples tested.

The results obtained with flour are greatly different from those obtained with the wheat meal of the same wheats. Correlation of the "time" readings recorded for the meal and flour of 18 wheat varieties grown in the wheat breeding nursery in 1937 was determined, $r = .165 \text{ \& } .162$. Thus, since flour and not meal is used in bread making, the value of the "time test", as an accurate test for baking value, may be lessened by "time testing" wheat meal in place of flour.

Polshenke (1931) stated that gas-producing power of whole meal doughs is very uniform in comparison with flour doughs. The time that it took for the doughballs to float from the time of submergence was recorded on all those varieties from the wheat breeding nursery tested for "time" in 1937. The time that each doughball took to float was considered to be an indication of the rate of gas production. There was considerable variation in the rate of gas production in the different wheat varieties. The flour doughballs of the 18 varieties grown in the 1937 wheat breeding nursery also showed considerable variation in gas production.

The effect of protease enzymes on the "time" was found to be an important factor. The protease enzymes, pepsin, trypsin and papain were used in this study. These three enzymes in general had no effect on the "time" of soft red winter wheats but markedly reduced the "time" of hard wheats and semi-hard wheats. By adding sufficient quantities of protease enzyme to the meal during the mixing of the dough-ball the "time" of the long "time" hard wheat varieties was reduced to the range of soft red winter wheat varieties. The protease activator cystiene-monohydrochloride was used on the varieties Tenmarq (hard), Kawvale (semi-hard), and Clarkan (soft). "Time" of the hard and semi-hard wheat varieties was significantly lowered, presumably due to an activation of latent proteases naturally occurring in the hard wheat varieties. This activator had only a small effect on the soft red winter variety Clarkan. Protease inhibiting agents, KBrO_3 and Cebione (Vitamin C) lengthened the "time" of hard wheat varieties markedly. Large amounts of the inhibiting agent KBrO_3 were required to lengthen materially the "time" of the soft wheat variety Clarkan, while small quantities of Cebione greatly lengthened the "time" of this variety.

The results obtained in this study of the influence of protease enzymes on "time" suggest that one of the main

causes that soft wheat varieties have short "time" and most hard wheats have long "time" when whole meal is used is that there seems to be a high proteolytic enzyme content in the bran layer of the soft wheats and only latent enzymes or a low content in the hard wheats.

Data obtained from the nitrogen fixation plots at the agronomy farm at Manhattan indicate that soil conditions may play an important role in influencing "time". Studies of varieties grown in southern and central sections of the hard red winter wheat region in 1934, and on varieties grown in cooperative variety tests on farms in Kansas, show that climate also may play an important role in influencing "time".

It has been found that a given variety will have "time" readings in different seasons that are comparable, i.e., the test is consistent. Fifty-four varieties grown in the cereal breeding nursery in 1936 and 1937 were "time tested", using the same technic. The "time" readings in the two seasons were highly correlated, $r = .840 \pm .028$.

"Time" of different market classes of wheat differs from each other. A few varieties were found that do not have the typical "time" characteristic of their market class, but the average "time" of varieties in a given market class has a definite rank in relation to other

classes. The following market classes of wheat are named in order of average "time": (1) hard red spring, (2) hard red winter, (3) soft red winter, and (4) white wheat.

The exact meaning of "time" is not fully understood. Until more extensive investigations of the possibilities of the "time test" are made, one can not be certain that a long "time" indicates high quality wheat for bread-making, and vice versa. In these studies "time" is considered to be a useful indication of variety type.

In order to determine the "time" of a large number of varieties grown each year, wheat samples from several sources were obtained in 1931, 1934, 1935, 1936, and 1937. "Time" data determined on the varieties from the cooperative wheat variety tests on farms in Kansas show that the test in general separated strong, semi-strong, and weak wheats. Certain exceptions were noted. Turkey and Kanred, two hard wheat varieties of accepted high quality did not always differ enough in "time" from the varieties Blackhull and Early Blackhull, two hard wheat varieties having questionable quality and lower strength than Turkey and Kanred, to distinguish quality differences by use of the "time test" alone. Even though grown under a wide range of climatic and soil conditions, the varieties Tenmarq and Cheyenne consistently gave long "time", while Turkey,

Kanred, Blackhull, Early Blackhull, Quivira, and Kawvale had medium "time". The soft wheats, Clarkan, Harvest Queen, Michigan Wonder, and Fulcaster had low "time" readings. Chiefkan, a hard wheat, also had low "time".

Data obtained on varieties of wheat grown in plots at the branch experiment stations and regional experimental fields show that Oro, Cheyenne, Kanred x Hard Federation (Ks. 2672), and Tenmarq, have long "time", while Turkey, Quivira, Blackhull, Early Blackhull, other strains of Kanred x Hard Federation, and Nebraska Turkey sel., C.I. 10016, have medium to low "time" readings, for hard red winter wheats.

Varieties from the wheat variety plots at the agronomy farm, Manhattan, gave "time" readings comparable to the same varieties grown in the cooperative wheat variety tests in Kansas and on the branch stations and regional experimental fields. Nebraska Turkey sel., C.I. 10094, and Nebraska No. 60 grown in these plots have long "time" and medium short "time", respectively. Kharkov is intermediate in "time". Several hybrid wheats are included in the farm plots that have long "time", namely, Kanred x Marquis, and three selections of Oro x Tenmarq.

A large number of varieties, pedigree selections, and advanced hybrids grown in the cereal breeding nursery have

been tested. The varieties Tenmarq, Cheyenne, Oro, Kanocks, Lin Calel, and Danne selections C24-10 and C7H10 were found to have long "time". Turkey, Kanred, Blackhull, Early Blackhull, Quivira, Minturki, Kawvale, and Iobred have medium "time". Superhard Blackhull, Kanhull, Chiefkan, Danne selection H68B, Nebraska No. 28, and Mutant (Akron No. 7) are hard winter wheat varieties having short "time". The soft red winter varieties tested all have comparatively short "time". Among the pedigree selections tested, selections of Tenmarq and a few of Turkey have very long "time". Certain other selections of Turkey and Quivira have medium to short "time". Certain selections of Kanred x Marquis, Kanred x Hard Federation, Quivira x Tenmarq, Early Blackhull x Tenmarq, and Tenmarq x Kawvale consistently gave long "time". Strains of medium "time" were found in Kawvale x Tenmarq, Kanred x Kawvale, Kanred x Hard Federation, Quivira x (Kanred x Marquis), Quivira x Tenmarq, Kanred x Quivira, and Early Blackhull x Tenmarq. A selection of the Martin x Tenmarq back-cross had medium "time". Strains of short "time" were found in selections of Honor x Kanred, Kanred x Nebraska No. 28, Kanred x Hard Federation, Early Blackhull x Tenmarq, Tenmarq x Kawvale, Harvest Queen x Kawvale, and Fulcaster No. 4 x Tenmarq.

Since the "time" of varieties, selections, and advanced hybrids remains in a given range from year to year, the greatest value of the "time" test probably lies in its use to the plant breeder.

Data obtained on early generation hybrids, F_2 to F_7 , grown in wheat breeding nurseries at Manhattan in 1931, 1935, 1936, and 1937 are presented. These data clearly show the value of the "time test" in plant breeding. The results of testing these early generation hybrids show that the "time test" is probably most useful in studying the progeny of two varieties differing widely in "time". In the segregating generations of such crosses, for example Early Blackhull x Tenmarq, only those lines having "time" in the same range as that of the parent having the most desirable quality, should be selected. In such crosses the plant breeder can be relatively sure as to the inherent quality of the strains selected, as any strain having "time" in the range of the poor quality parent would in all likelihood have the quality of the poor quality parent and vice versa. A few lines having "time" exceeding the limits of either parent, probably due to transgressive segregation, were obtained in most of the crosses tested. These lines probably have different quality than either parent. Most segregates tested in crosses between parents of good to

excellent bread making quality, such as Kanred x Hard Federation, (Ks. 2672) and Tenmarq, each having approximately the same "time", or such as Kanred and Tenmarq, having different "time" readings, would have good quality gluten, except possibly for the segregates having "time" readings transgressing the limits of the parents, particularly on the low side. The "time test" probably has much less value in testing the progeny of crosses between two varieties having approximately the same "time", but of distinctly different baking quality, such as Kanred x Blackhull or Marquillo x Tenmarq.

The "time test" was used in a study of samples representing the official grain grades of the United States, Canada, and Argentina. In general, the "time test" was found to delineate the various market classes, although the grades within a class did not always correspond to the quality ratings as given by the "time test". "Time tests" of the Official Standard Wheats of Argentina for the crop seasons of 1935-36 and 1936-37 show that the test separated the hard, semi-hard, and soft texture classes in each of the three major wheat growing zones in Argentina. Hard wheats have longer "time" than semi-hard wheats and semi-hard wheats have longer "time" than soft wheats. A few spring wheat varieties grown in the prairie provinces of Canada

were "time tested". These Canadian spring wheats have long "time", verifying their known high strength and excellent baking qualities. The variety Garnet is an exception, having long "time" but inferior baking quality.

Eight prize winning samples from the Kansas State Fair at Hutchinson in 1937 were tested for "time". Three of these samples had long "time", while the others had medium to short "time". The three long "time" samples were probably the high quality Tenmarq variety, while the five short "time" samples were probably the variety Chiefkan, which is considered by many cereal chemists and millers to be of inferior quality. Thus, the "time test" has potential value at wheat shows in helping to place in the prize winning classes only varieties of good quality, by aiding in the recognition of and placing emphasis on such varieties.

A group of export samples from the ports of Galveston and New York City were tested for "time". The test showed that occasional samples, though of a high grade and protein content, had shorter "time" than typical of the market class represented by the sample, indicating weaker gluten. The "time test" may prove useful as a rapid means of determining the probable gluten strength of export shipments of wheat.

A large number of farmers' samples submitted for planting in the initial Kansas Crop Testing plot at Junction City

in 1937 were "time tested". The results of this study showed that the "time test" is a great help to the cerealist in identifying unknown samples, and in verifying the name given to the sample. "Time testing" varieties in the plot aided in placing before the cooperating farmers the need of growing varieties desired by the grain trade, the miller, and the baker.

Correlations of the "time test" have been made with other tests of wheat quality; namely, (1) the protein test, (2) dough development curves, and (3) the baking test. In 3 years, using more than 100 strains each year, no significant correlations were obtained between the "time test" and percentage of protein in the wheat. Preliminary studies of the "time" of varieties of which recording dough mixer curves are available indicate significant correlation between the "time" and the curve type, i. e., long "time" wheats usually have curves of desirable type and vice versa. Limited studies of correlation between the "time test" and the loaf characteristics indicated only low correlation between "time" and the total bread score used, $r = .4025 \pm .0750$, and between "time" and loaf volume, $r = .2067 \pm .0808$. A tendency for long "time" varieties to have more desirable symmetry of form in the loaf and more desirable grain of crumb was noted. If "time" and loaf characteristics do not always show close correlation, this may be due as much to variations in the baking test as in the "time test".

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