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THE QUALITY OF WHEAT AS AFFECTED BY FARM STORAGE

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THE QUALITY OF WHEAT AS AFFECTED BY FARM STORAGE[1]

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THE PROBLEM OF PREVENTING DAMAGE IN STORAGE

STATEMENT OF PROBLEM

The farm storage of wheat presents many problems including not only those in the field of economics, but also those which relate to deterioration in quality. This bulletin is confined to a study of the quality of wheat and the methods of preventing damage while in storage. The main cause of damage in wheat is too high moisture content, which promotes mold growth, and too rapid respiration, with accompanying heating. Wheat which contains 13 per cent or less of moisture may be stored safely in any type of bin now used on farms, provided it will protect the wheat from the weather. When wheat contains 14 per cent moisture or more there is a strong possibility that it may be damaged, particularly in hot weather. Wheat may be damaged in the shock or stack by too much moisture, but this bulletin deals only with the damage which occurs in the bin.

The use of the combined harvester-thresher has magnified the storage problem. With the binder or header method of harvesting, the wheat was usually dry enough at the time of threshing to keep in good condition. There is a strong desire to start the combine before the wheat is sufficiently dry to store safely and experience with rain and hail storms has in the past justified this early start. The damp wheat may result from harvesting before the grain has dried sufficiently after kernel development, or it may be caused by dew or rain. In wet years it is almost impossible to eliminate all of the damp wheat. Past experience in the Kansas wheat belt indicates that one year out of five may have enough excess rainfall to produce damp wheat in sufficient quantity to make a serious storage problem. In wet years the presence of green weeds in the fields adds to the problem.

EXTENT OF DAMAGE

The extent of damage to wheat in farm storage is enormous as shown by data secured from large wheat growers in Kansas. Replies received from 297 such growers indicate that 60 per cent of them had suffered damage to wheat in farm storage. The average amount of damaged wheat per farm was 1,000 bushels. These reports include the year 1928 in which a large amount of damage occurred. Much of the wheat which is damaged on the farm never reaches the terminal market. (Fig. 1.)

The amount of damaged wheat, due to all causes, which arrives at terminal markets is indicated in Table I. The data were supplied by E. L. Morris of the Kansas City Office of Federal Grain Supervision.

1. Contribution No. 44 from the Department of Milling Industry and No. 63 from the Department of Agricultural Engineering.

TABLE I.—NUMBER OF CARS OF THE VARIOUS GRADES OF WHEAT RECEIVED ON THE KANSAS CITY MARKET.

GRADE.	1927-'28.	1928-'29.	1929-'30.	1930-'31.	Last half of 1931.
1	13,665	19,289	7,267	28,809	21,932
2	19,038	26,749	24,776	22,511	18,469
3	9,550	14,513	19,238	9,494	5,860
4	5,515	6,966	7,494	4,729	1,721
5	4,699	5,645	2,696	2,595	1,344
Sample	4,913	4,673	2,470	1,560	867
Total	57,380	77,835	63,941	69,698	50,193

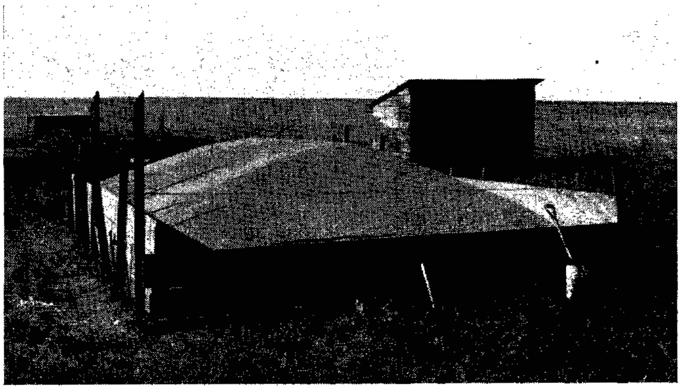

FIG. 1.—A pile of wheat with little protection. Such inadequate methods of farm storage are all too common in the Kansas wheat belt. When wheat is piled on the bare ground the possibilities of damage are even greater.

The number of cars which graded 5 and sample were about twice as great during the years 1927 and 1928 as in 1929, 1930, and 1931. The former years were wet and the latter dry during the harvest season. In about half the cases the grading down was because of damage due to too much moisture.

The percentages of cars which would be classed as milling grades, 1, 2, and 3, were as follows:

Year	Percentage of cars grading 1, 2, and 3
1927	75.4
1928	27.9
1929	80.3
1930	87.2

Thus the amount of wheat which would not class in these milling grades varies from one-eighth to one-fourth of the total. That is, in a bad year about one bushel in four, and in a good year about one bushel in eight is not suitable for milling into good flour.

QUALITY IN WHEAT IS AFFECTED BY BIOLOGICAL PROCESSES

From the milling and baking standpoint a certain amount of respiration in storage improves the quality of newly threshed wheat. Wheat ripe and dry enough to thresh undergoes a post harvest maturing process. Before this has taken place the quality is not yet satisfactory. After it has taken place the quality is at its maximum. The process continues, however, and after a while deterioration begins and the wheat may be designated as old. It finally dies when it is very poor or worthless for milling and baking. The rate at which fully developed wheat passes through these various stages depends on the moisture content and the temperature. In high-moisture wheat these transformations may take place in a few days, weeks, or months. In dry wheat the whole cycle takes many years, but in the end the wheat loses its valuable properties as a bread grain.

These changes are due to life processes in the grain of which respiration is a manifestation. Respiration seems to bring about beneficial changes in the grain after harvesting. It is a generally accepted fact that new wheat in storage improves in its milling and baking qualities up to a certain point where it remains for a considerable period, and thereafter there is a slow deterioration. Wheat with 12 per cent moisture has a better milling and baking quality when a few months old than immediately after threshing, but such wheat several years old has lost some of its quality, and continues to deteriorate until valueless. For these reasons a slight amount of heating in new wheat may actually improve its baking qualities, but, if this process is carried too far, great damage results. It is necessary to keep this in mind when interpreting the baking results obtained in some of the storage studies.

Experiments on an Old Wheat

A wheat known to be 25 years old was obtained from a farmer in the fall of 1925. This wheat had been kept in a covered tin pail hung in the loft of a granary. (Swanson, 1926.) Fortunately it had not been infested with weevil. The seed appeared to be plump, hard, and in first-class condition. There was no sign of deterioration except a small amount of bran powder and a slight odor giving the suggestion of old wheat. A germination test by the seed laboratory failed to show life in a single kernel. The wheat behaved almost as normal wheat in milling on the experimental mill, producing 70 per cent flour. The only indication of deterioration was a brittleness of the bran coat which made separation somewhat more difficult than in a normal wheat. A baking test on the flour from this old wheat gave the following results in comparison with flour from the 1925 crop.

TABLE II.—BAKING QUALITIES OF FLOUR FROM AN OLD DEAD WHEAT.

	Flour from old wheat.	*Flour from 1925 crop.*
Oven spring, cm	0.0	8.8
Loaf volume, c. c.	1,140.0	2,090.0
Color of crumb, per cent	76.0	98.0
Texture of crumb, per cent	75.0	98.0

The behavior of this flour in baking, the texture of the baked loaf, and the properties of the gluten were very similar to those observed in wheat injured in storage when the moisture is too high and excessive heating has taken place. In the latter case the aging processes have taken place in a comparatively short time and usually in connection with mold growth, but in the end the results are similar when measured by the properties of the flour.

FACTORS WHICH AFFECT THE DAMAGE TO WHEAT IN STORAGE

AMOUNT OF MOISTURE IN WHEAT AT VARIOUS STAGES OF MATURITY

The amount of moisture in immature wheat is very large. Wheat ripe enough to be cut with the binder and cured in the shock may have as much as 30 to 35 per cent moisture. This will soon be reduced to 12 per cent or less when the weather is favorable as ripening wheat dries very rapidly when the weather is hot and dry. In the summer of 1931 wheat cut at Manhattan on five successive days contained the following per cents of moisture: (1) 35.5; (2) 25.8; (3) 19.0; (4) 12.5; and (5) 9.4. That cut the first day was ripe enough to cut with the binder and cure in the shock. On the fourth day the standing wheat was dry enough to cut with the combine. Usually desiccation is slower than this.

Some fields contain patches near the edges or in low places where the wheat has too much moisture, while the main part of the field is sufficiently dry for the combine. When such patches are combined with the rest of the field, hot pockets may develop in the bin and the heating may spread to surrounding wheat, which if stored by itself would not have been damaged.

MOISTURE FROM DEW OR RAIN

Moisture from dew or rain may be both taken up and lost rapidly. In one trial at Hays, wheat cut just before a small rain contained 11 per cent moisture, while that cut soon after contained 18 per cent. In another experiment samples taken on a hot day contained 16 to 18 per cent moisture at 9 a. m. and by 4 p. m. the moisture content was 10 to 11 per cent. Whether wheat will take on moisture during the night depends on the relative humidity of the air. In some trials wheat was actually drier in the morning than the evening before, and in other trials the wheat had taken on several per cent of moisture during the night.

MOLD GROWTH AND HEATING

The processes causing damage in wheat when the moisture content is too high are usually accompanied by mold growth and heating. The liberation of heat is due to the oxidation that takes place in the respiration of the living seeds or microörganims or both. When the moisture content is low, the process takes place so slowly that the heat generated is lost by radiation, at least in such size bins as are used on farms. When the wheat is high in moisture content the process goes on much more rapidly because the high moisture promotes mold growth as well as accelerates the rate of respiration in the seed and this greatly increases the rate of heat production. Just how much heat results from the normal processes of respiration in wheat and how much from the additional respiration due to mold growth has not been determined. The probability is that the major damage results from mold growth, which in addition to producing heat also destroys the wheat tissues. Heat is also caused by weevil infestation in the grain, but this phase of the problem was not included in these studies.

RATE OF RESPIRATION

That the rate of respiration in wheat is influenced both by the moisture content and by the temperature has been shown by Bailey and Gurjar (1918). Some of their results are given in Table III. These figures show that the rate of respiration is greatly increased when the moisture content exceeds 14 per cent, and also that increasing the temperature up to 55° C. increases the rate of respiration. Thus when the process is started it is self-accelerating. No

TABLE III.—RESPIRATION OF HARD SPRING WHEAT AT DIFFERENT PERCENTAGES OF MOISTURE AND DIFFERENT TEMPERATURES.

Per cent moisture.	Mg. CO_2 respired per 24 hours per 100 gm. of dry material (37.8°C).	Temperature, degrees C.	Mg. CO_2 respired per 24 hours per 100 gm. of dry material (14.96 per cent moisture).
12	0.50	4	0.24
13	.58	25	.45
14	.68	35	1.30
15	1.13	45	6.61
16	2.72	55	31.73
17	10.73	65	15.71
		75	10.28

definite experimental evidence has come to the attention of the writers to prove that enough heat can be generated from wheat respiration alone in the absence of mold growth to cause serious damage in wheat.

RESPIRATION IN SHRIVELED AND GERMINATED WHEATS

The chief constituent oxidized in respiration is reducing sugar (Bailey and Gurjar, 1918), and more sugar is present in immature than in mature wheat (Thatcher, 1913, 1915). Sugar is also produced in the process of germination. Hence when wheat is desiccated by hot winds before it is mature[2], or if it has germinated in the shock, the respiration is greater than in sound or mature wheat. (Bailey and Gurjar, 1918.) Hence the problem in storing such wheats is not the same as with the wheats used in these experiments. (Bailey, 1917a and 1917b.)

RESPIRATION IN WHEAT PHYSIOLOGICALLY DEVELOPED BUT NOT COMPLETELY DESICCATED IN COMPARISON WITH RE-WETTED WHEAT

Sometimes the idea is expressed that in wheat not fully desiccated after complete development and, therefore, with a high moisture content, respiration is greater than in wheat developed and desiccated while standing and then subsequently wetted. Respiration studies were made on these two kinds of wheat. Some of the data obtained are given in Table IV. The wetted wheat was brought to the various moisture contents by adding water to fully developed and desiccated wheat containing 9.4 per cent moisture. These data do not indicate that respiration is different because of the natural or added moisture. This subject is treated more fully in a later paragraph.

DAMAGE FROM HEAT ALONE

That heat damage may take place in the absence of mold growth and also with very little if any respiration, has been shown by Coleman and Rothgeb (1927). The moisture content of wheat containing 11.2 per cent moisture was adjusted to 13.85, 15.13, 17.01, and 18.54 per cents, respectively, by adding water. These samples were placed in containers, sealed, and held in an incubator at 98 to 100° F. for 90 days. At the end of this time the wheat was removed and

2. The words mature and immature are used in the popularly accepted meaning. Mature means fully developed and desiccated or dry enough to store safely. Immature wheat would be that which is not completely developed and also that which contains too much natural moisture for storage.

TABLE IV.—RESPIRATION IN NOT FULLY DESICCATED WHEAT AND IN DESICCATED BUT WETTED WHEAT.

Mg. of CO_2 respired per 24 hours per 100 gm. of dry material.

Not wetted wheat.		Wetted wheat.	
Per cent of moisture.	Mg. CO_2.	Per cent of moisture.	Mg. CO_2.
35.5	1,370.0	35.5	1,806.0
25.8	379.0	25.8	354.0
19.0	35.3	22.2	85.2
12.5	4.6	19.0	45.7
9.4	2.4	14.0	1.0

allowed to become air dry. Examination of the wheat showed the following per cents of heat damage: 0.0, 0.5, 25.3 and 47.6, respectively. The dry gluten content was 9.08, 5.35, 1.16 per cent, and none. Mold growth was retarded by the limited supply of air and no aerobic respiration could take place after the initial supply of oxygen was consumed. Some of the injury may have been caused by anaerobic respiration.

Characteriatics of Hest-damaged Wheat

When heat is purposely used in conditioning wheat at the flour mill the degree of heat and the length of the heating period are carefully controlled. Heating which causes damage takes place in the wheat stack or in the storage bin before the wheat reaches the flour mill. Such wheat is variously known as "stack burnt," "bin burnt," and sometimes "skin burnt." The outward sign of such heating is a more brittle and darker red or brown bran than is normal for the variety. Heating in the stack takes place when the wheat was not sufficiently dry before being stacked, and in the bin when the wheat was threshed from the shock or harvested with the combine when the moisture content was too high.

MOLD, THE GREATEST CAUSE OF DAMAGE

Mold growth promoted by high moisture content is probably the greatest cause of damage in damp wheat. The exact conditions for mold development in damp grain have not been thoroughly studied. It is known, however, that for mold growth in wheat a favorable moisture content and temperature, as well as atmospheric oxygen, are required. Studies endeavoring to determine conditions of damage from mold growth on wheat are now in progress at this station.

INFLUENCE OF OUTDOOR TEMPERATURE

That damage to wheat depends not only on the moisture content, but also on the air temperature, has already been intimated. Bailey (1917a) examined a number of carlots of wheat which arrived at Minneapolis, Minn., in a heating condition during the unusually hot summer of 1916. No plump spring wheat containing less than 14.4 per cent moisture was found to be in a heating condition. Numerous lots of damaged, shrunken, or shriveled wheat were found to be heating when the moisture was less than 14.5 per cent. From another study by Bailey (1917b) of 20 carload lots of wheat, during a period of two summers and the intervening winter, it was concluded that wheat of ordinary plumpness containing less than 14.5 per cent of moisture is not likely to heat when stored under normal conditions in a temperate climate, while wheat containing in excess of 15.5 per cent moisture is almost certain to heat. In the cool temperature of Duluth, Minn., wheat with a moisture content of 15.5 per cent kept 333 days without developing a temperature necessitating turning. The mean outdoor temperature was 44.3° F. Wheat of 16.5 per cent moisture content heated in 49 days in the fall months.

In the cool climate of Ottawa, Canada (Saunders et al., 1921), air-dried wheat was stored for six years without loss of baking value.

INVESTIGATIONS OF FARM-STORED WHEAT

WORK WITH BINS ON FARMS

The first formally authorized study of wheat storage and shrinkage at this station was started by the Department of Milling Industry in charge of L. A. Fitz in the summer of 1916. Because of the unsettled conditions due to the World War this study was not carried very far.

In 1923 a study was undertaken on wheat shrinkage, loss, and damage in farm storage. This work was jointly conducted by the Departments of Agricultural Economics and Milling Industry. In this study observations were made on the moisture contents of wheat as it went into the bins on different farms, and when it was removed. Typical samples were subjected to milling and baking tests. The weather was very favorable for harvesting with the combine during the years 1923 and 1925, but somewhat less favorable in 1924 because of greater precipitation during harvest. The following information was obtained from this study:

1. Wheat with more than 14 to 14½ per cent moisture is very likely to heat under the temperature conditions prevailing in the Kansas wheat belt at harvest time, unless some extra care in handling is taken.
2. Wheat with as high as 15 per cent moisture was stored for two consecutive years in a barn bin with a hay loft overhead without any heating of the grain.
3. Wheat containing 16 to 17 per cent moisture showed signs of heating and caking at the end of 5 days. Baking tests made on the samples taken at this time gave good results. In fact, these samples showed an increased loaf volume in the bread with good texture and color. After 52 days, however, wheat from this bin was found to be notably damaged as shown by a decreased loaf volume and poor texture. During the five-day period the

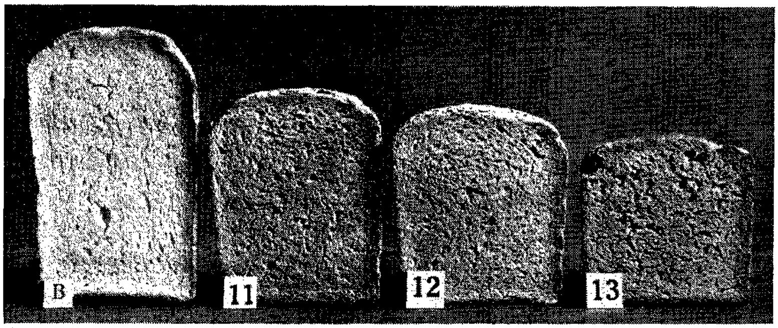

FIG. 2.—Loaves of bread from normal wheat and wheat stored at various moisture contents. (B) Normal wheat. (11) Wheat stored varying from 14 to 19 per cent moisture. (12) Wheat stored with 15 per cent moisture. (13) Wheat stored with 17 per cent moisture.

wheat had, because of high moisture and temperature conditions, undergone the post-maturing process, mentioned in the paragraph on quality, to such an extent that it would be designated as seasoned or fully matured wheat. In the 52 days this process had gone so far as to make this wheat, in effect, a very old wheat in which the gluten had been seriously injured. The serious damage which wheat undergoes when heating takes place is shown by the loaves in figure 2. The wheat from which these loaves were prepared was stored at various moisture contents in bins on farms and no turning was made.

4. Wheat with 14.2 per cent moisture content stored in a bin in contact with wheat having a moisture content of 16 per cent showed some damage from contact with the higher-moisture content wheat.

5. The temperature of the wheat in a bin is influenced by the temperature of the atmosphere. The temperature of wheat of 12 to 13% per cent moisture content run into a bin at a temperature of 102° F., was found after 5 days to be only 95° F. During this time, however, the air temperature fell to 79° F., showing that heat diffuses slowly in wheat.

6. Wheat harvested with the combine at midday was placed above wheat harvested the evening before and below that harvested the next evening. The midday wheat was from 4 to 8° C. warmer than the wheat above or below, and it took three to four weeks to establish equal temperatures. This slow diffusion of heat in wheat partly, at least, accounts for heat pockets that are sometimes found in stored wheat.

7. Wheat stored with less than 12 per cent moisture almost invariably showed an increase in weight while that stored with more than 12 per cent moisture showed a loss at the end of 4 to 5 months.

MIXING "BIN-BURNT" WHEAT WITH SOUND WHEAT

Damaged wheat that would be designated as "bin-burnt" was mixed with sound wheat in various proportions. These mixtures were then milled and the flour baked. The data obtained are given in Table V, and photographs of the loaves in figure 3. Even the smallest amount (2.5 per cent) of "bin-burnt" wheat in the mixture had an injurious effect on color and texture. The larger loaf volume in No. 3 was probably due to the presence of more sugar in the damaged wheat.

TABLE V.—EFFECT OF MIXING BIN-BURNT WHEAT WITH SOUND WHEAT UPON FLOUR ASH, LOAF VOLUME, COLOR, AND TEXTURE OF BREAD.

Loaf No. in figure 3.	Proportions of mixtures.		Ash flour.	Loaf volume.	Color.	Texture.
	Sound.	Bin-burnt.				
	Per cent.	*Per cent.*	*Per cent.*	*c. c.*	*Per cent.*	*Per cent.*
1	100.0	0.0	0.49	1,800	93	92
2	97.5	2.5	.47	1,730	91	90
3	95.0	5.0	.49	1,815	90	91
4	90.0	10.0	.52	1,645	85	88
5	85.0	15.0	.53	1,545	83	86
6	80.0	20.0	.56	1,500	80	84
7	75.0	25.0	.57	1,540	80	80
8	50.0	50.0	.69	1,175	40	40
9	25.0	75.0	.76	1,010	30	30
10	0.0	100.0	.90	1,070	20	20

LABORATORY EXPERIMENTS ON THE EFFECT OF HEAT

EARLIER WORK

Some preliminary studies on the effect of heat on wheat were conducted at the Kansas Agricultural Experiment Station in 1907-1908. (Willard and Swanson, 1911.) More extensive experiments were conducted in 1916. (Swanson, Dunton, and Fitz 1916.) This work was done on fully matured but newly threshed wheat. The object was to study the effect of heat and moisture upon those beneficial changes which take place slowly when new wheat is stored under favorable conditions. Small lots of wheat were heated in a specially constructed container in which 12 pounds of wheat could be heated quickly, uniformly, and at the exact temperature desired. Samples of wheat were heated at 45° C., 70° C., and 98° C. (113° F., 145° F., and 208.4° F.) for various lengths of time, longer periods being used for the lower temperatures than for the higher. Before heating, measured amounts of water were mixed with these lots of wheat so as to study the effect of heat in connection with varying water contents. After treatment the samples were cooled quickly, milled, and the flour baked.

It was very evident from the results obtained at that time that a marked improvement in texture and loaf volume was effected by the heat treatment together with the added water, provided the temperature was not too high nor the time of treatment too long. That is, it is possible to improve the quality of new wheat by heating at certain temperatures for a definite time. Without treatment the average texture was 87 per cent and the loaf volume 1,540 c. c. After adding 5 per cent of water and heating at 45° C. for six hours, the loaf volume was increased to 1,750 c. c. and the texture was improved several per cent. With more water a similar improvement was effected in a shorter period of time. Heating at 70° C. for three hours gave a loaf volume of 1,720 c. c. and a texture of 95 per cent. Heating longer than three hours at 70° C. was harmful. No improvement was evident with heating at 98° C., and if the time exceeded 10 minutes distinctly harmful results were secured. This shows very definite limits to the use of heat. A limited amount of heating may be beneficial, but too much may cause serious damage.

These findings help to explain the better baking results obtained from slightly heated wheat, as well as the poor results from wheat following severe heating. They also offer an explanation for the relatively good texture and volume sometimes obtained from wheat which has suffered just enough damage to be graded sample grade, but not enough to injure seriously the gluten structure.

HEATING EXPERIMENTS UNDER CONTROL, 1927 AND 1928

Because of the limitations of the survey method used in 1923-1925, it was discarded in favor of experiments under laboratory controlled conditions. In 1927 and again in 1928, a field of uniform wheat was selected on the Agronomy farm at Manhattan, and harvested at four stages of maturity; namely, barely ripe enough for the binder, fairly ripe, ripe, and "dead" ripe. The first was intended to be greener than anyone would attempt to harvest with a combine, but ripe enough to start harvesting when wheat is shocked; the second, such as would be found in low places of the field when combining; the third, the earliest anyone would attempt to cut with a combine; and the fourth, fully ripe when there would be no danger of damage from too much moisture.

In 1927 the individual heads of wheat ripened very unevenly. For in-

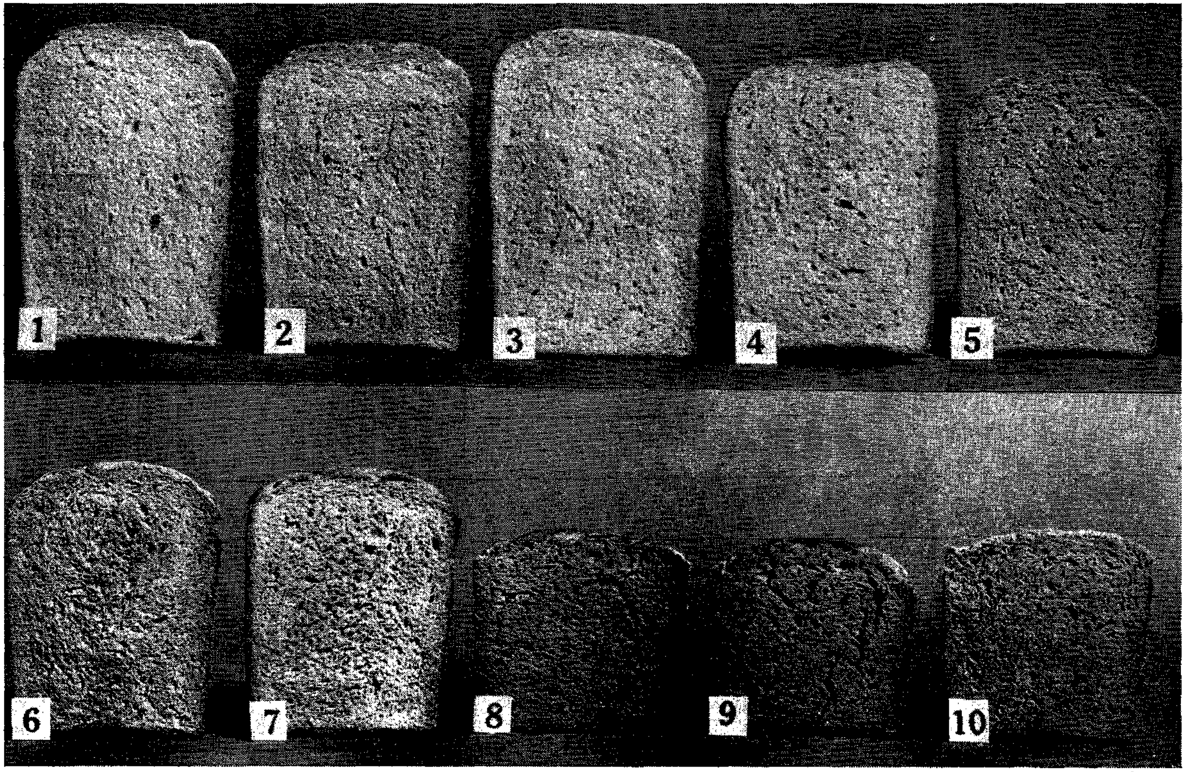

FIG. 3.—Loaves of bread showing the effect of mixing dam aged wheat with sound wheat. (Baking data in Table V.)

stance, in the third stage of cutting it was possible to find heads in all conditions of maturity, from those in the milk or dough condition to those fully ripe. For this reason it was difficult to judge the stage of ripeness and hence the results secured may not exactly represent results that would have been secured could the original plans have been adhered to more closely. Furthermore the long ripening period produced what is sometimes characterized as a weak wheat in the fourth or last stage. For this reason results on the "dead" ripe wheat were not as expected. In 1928 the wheat ripened unevenly in spots in the field. The second and third stages were cut on the same day, but in different parts of the field. The wheat was threshed immediately after cutting. The moistures in the wheats from the various cuttings are given in Table VI.

TABLE VI.—MOISTURE PERCENTAGES IN WHEAT SAMPLES CUT AT VARIOUS STAGES OF MATURITY.

	1927.	1928.
1st stage	39.6	36.0
2nd stage	22.4	30.0
3rd stage	22.2	19.4
4th stage	11.2	13.1

The wheat was used for heating experiments immediately after threshing. The general plan was to heat five-pound samples at four different temperatures, 40, 45, 50, and 55 degrees C. (104, 113, 122, and 131 degrees F.) for from one to ten periods either 12 or 24 hours each, using the shorter periods on the greener wheat. Thus the samples from the greener wheat were heated for 12, 24, 36, 48, 60, 72, 84, 96, 108, and 120 hours, respectively. The samples from the drier wheat were heated for 24, 48, 72, 96, 120, 144, 168, 192, 216, and 240 hours, respectively. Wheat from each stage of cutting was placed in each one of the four bins, and successive samples were removed at the end of the above periods. There were thus 40 samples from each stage, or 160 samples each year and each one received a treatment differing in one or more respects from each of the others.

The wheat samples were placed in gallon, flat, tin cans, such as are used for holding lubricating oil. The cans were closed with rubber stoppers through which were inserted glass tubes filled with cotton. This prevented appreciable losses of water but provided for the escape of expanding air or carbon dioxide gas and admitted little, if any, oxygen. The heating was done in four especially constructed, well-insulated wooden boxes or bins heated by electric elements under thermostatic control and the air inside the bin was kept in circulation with a small fan. It was possible to control the temperatures in all parts of each bin to within 1 degree.

Each can was weighed when placed in the bin and again when removed, and it was found that there was practically no loss of moisture. As soon as a sample was removed from the heating bin, the wheat was emptied into shallow paper boxes where cooling and drying took place rapidly, after which the wheat was milled on an Allis experimental mill. The percentages of flour obtained showed no constant variation corresponding with the stage of cutting or the amount of heating, but the heating had a marked effect on the ash content of the flour, which will be discussd later. The flours were baked by the severe method (Swanson and Working, 1928) and germination tests were made on all the heated wheat samples.

In 1928 dry wheat from Stage IV was wetted so as to have a moisture content of 20 per cent, approximating Stage III These samples, designated Stage IVB in Tables VII, VIII, and IX, were then heated in the same manner as the immature wheat.

VIABILITY OR PERCENTAGE GERMINATION OF HEATED WHEAT

Samples for viability tests were taken as soon as the heated samples were air dry. The germination tests were made by the Kansas Seed Testing Laboratory under the supervision of Prof. J. W. Zahnley. The results are given in Table VII. Before wheat is fully matured a very little heating kills the germ, but after full maturity the viability of the 1927 samples was not injured in ten days at 50° C., or in five days at 55° C. In 1928 the viability was injured by much shorter periods of heating.

TABLE VII.—VIABILITY OR PERCENTAGE GERMINATION OF WHEAT HARVESTED AT DIFFERENT STAGES OF MATURITY AND HEATED FOR VARYING LENGTHS OF TIME.

Days heated		0	½	1	1½	2	2½	3	3½	4	4½	5
1927 Crop.												
	Temperature.											
Stage I	40° C.	77	36	36	19	22	5	0	0	0	0	0
	45° C.	......	39	14	0	0	0	0	0	0	0	0
	50° C.	......	0	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage II	40° C.	84	87	87	89	74	61	39	15	2	0	0
	45° C.	......	77	23	0	1	1	0	0	0	0	0
	50° C.	......	75	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Stage III	40° C.	96	93	89	83	84	75	32	12	0	0	0
	45° C.	......	86	45	2	0	0	0	0	0	0	0
	50° C.	......	0	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Stage IV	40° C.	96	95	93	89	93	96	92	94	93	96	97
	45° C.	......	92	91	93	92	87	94	97	94	95	93
	50° C.	......	92	95	94	92	93	97	91	96	98	92
	55° C.	......	95	93	87	97	96	80	90	82	54	66
1928 Crop.												
Days heated		0	½	1	1½	2	2½	3	3½	4	4½	5
Stage I	40° C.	40	46	31	29	16	22	6	1	0	0	0
	45° C.	......	22	5	12	0	0	0	0	0	0	0
	50° C.	......	2	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Stage II	40° C.	58	40	36	32	29	7	1	0	0	0	0
	45° C.	......	43	38	21	0	0	0	0	0	0	0
	50° C.	......	18	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage III	40° C.	89	88	78	65	57	55	43	8	1	0	0
	45° C.	......	79	51	35	2	0	0	0	0	0	0
	50° C.	......	41	0	0	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0
Stage IV	40° C.	90	89	80	84	90	89	71	91	89	90	73
	45° C.	......	90	91	80	93	82	88	54	56	60	49
	50° C.	......	85	87	63	59	87	49	5	0	0	0
	55° C.	......	52	18	0	0	0	0	0	0	0	0
Stage IV B	40° C.	90	3	63	86	84	88	75	8	8	0	0
	45° C.	......	84	88	37	0	0	0	0	0	0	0
	50° C.	......	52	58	10	0	0	0	0	0	0	0
	55° C.	......	0	0	0	0	0	0	0	0	0	0

EFFECT OF HEATING ON THE MARKET GRADING FACTORS

Studies of characteristics which would affect market grading were made by Profs. J. W. Zahnley and S. C. Salmon. Their observations may be summarized as follows:

Heating at 40° C.—No visible effects were observed on wheat cut in Stage IV even after 10 days heating at 40° C. The samples from Stage III, heated 5 days or more, had a trace of odor; those heated 9 and 10 days were distinctly sour. The samples from Stage II heated 4 or more days were designated as sour and "sick wheat." The samples from Stage I began to look "sick" after 1 or 2 days heating, and after 4 or 5 days they were designated "badly heat damaged and sour.

Heating at 45° C.—The wheat samples from Stage IV, heated at 45° C., were normal, except that the one heated 10 days had a slight odor. From Stage III the samples had a suggestion of an odor after 2 days heating; after 6 days sourness appeared; and after 9 or 10 days heating the "sick" appearance was manifest. The samples from Stage II were essentially the same as from Stage III. The samples from Stage I showed some damage with the shortest period of heating. After 2 days, distinct heat damage appeared. After 3½ days the wheat was sour and badly heat damaged.

Heating at 50° C.—Samples from Stage IV were normal until after 6 days heating at 50° C., when there was present a slight odor. The samples heated 10 days had some kernels approaching "sick wheat." The samples from Stage III began to have a suggestion of an odor after 3 days heating, after 8 days there was incipient heat damage associated with "sick wheat"; and after 10 days heating the wheat had a sour odor. The samples from Stage II had some kernels approaching the "sick" condition after the shortest period of heating. After 3½ days the wheat was sour, "sick," and heat damaged. After 4½ days this condition was much intensified. Samples from Stage I showed heat damage after the shortest period of heating. After 3 days they were sour and definitely heat damaged, these conditions becoming more intensified after 4 and 5 days heating.

Heating at 55° C.—Samples from Stage IV remained normal until after 3 days heating at 55° C., when a slight odor became evident. After heating 7 to 10 days the odor was distinct, but the appearance was that of sound wheat. In the samples from Stage III there was a slight dullness of color evident for the shortest period of heating. After 6 days the samples were very dull, approaching heat damage, and this condition was intensified after 9 and 10 days heating. In samples from Stage II a slight odor appeared after ½ day heating, and manifestation of a "sick" and sour condition after 1½ days. After 3 days the wheat was definitely "sick" and heat damaged, the damage becoming more intensified after 4 and 5 days heating. In the Stage I samples the sour, "sick" condition appeared after heating ½ day. After 3 days heating the grain was sour and definitely heat damaged. A condition becoming worse after 4 and 5 days heating.

The damage done by heating wheat cut in Stage IV but wetted to 20 per cent moisture was essentially the same as the damage to wheat cut in Stage III which had approximately the same percentage of moisture.

From the above it is evident that the extent of heat damage as measured by grading is definitely related to the moisture content as well as temperature. Wheat of high moisture content is easily injured by heating, while wheat low or normal in moisture content is injured only after considerable heating. The extent of damage is more pronounced the higher the temperatures. No mold growth was evident in any of these samples and hence the damage was wholly due to heat and moisture.

EFFECT OF HEATING ON THE MILLING VALUE

The object of milling is to separate the bran coat and the germ from the endosperm and convert the latter into flour. Any condition which makes the bran coat more brittle increases the difficulties in milling, and hence lowers the milling value. The freedom of flour from bran particles is measured by the ash content. The following was observed on the ash contents of the flours from the heat-treated wheat samples discussed in preceding paragraphs. Heating increased the ash content of the flours from immature wheats; the longer the heating and the higher the temperature, the greater the increase. The flour from Stage I, 1927 samples, had a much higher ash content than the corresponding samples in 1928, the wheat in 1927 being more immature than in 1928. If the wheat is mature, such as Stage IV, it may be heated for considerable periods without notably affecting the ash content. Thus there was no increase in ash after heating the Stage IV, 1928, samples 10 days at 50° C., and at 55° C. there was only a slight increase after 3 days heating. In 1927 there was no increase in the ash content of the flour even after 10 days heating at 55° C. Hence whether heating makes the bran more brittle, making separation in milling more difficult, seems to depend on the maturity and the moisture content of the wheat. If wheat is fully matured or low in moisture content no injury to the bran will take place from moderate heating.

VOLUME AND TEXTURE OF BREAD AS AFFECTED BY HEATING WHEAT

The values obtained on the texture and volume of bread baked from wheat cut at different stages and heated for varying periods of time are presented in Tables VIII and IX, respectively. The baking tests were continued on the flours from heated wheat from each stage until the bread obtained was very poor, and it appeared useless to continue baking samples which had been heated longer. All the samples baked from Stage I, 1927 crop, including the nonheated check loaf, were poor. This wheat had not ripened enough to develop the gluten sufficiently. Better loaves were obtained from Stage I, 1928 crop. Loaves from wheat cut in the other stages showed an improvement from heating within certain limits. Wheat may be heated at 40° C. for 10 days without apparent injury even when cut at a maturity represented by Stages II and III. A short period of heating at 45° C. gave an improvement, and a longer period showed injury. In conducting the baking trials for each stage it was noticed that in many instances the loaf volume would decrease and the texture become poorer up to a certain period of heating, after which a slight improvement became evident, followed by more marked deterioration. This observation is treated further in a following paragraph. Aside from this peculiar phenomenon the results show that for the lower temperatures, more improvement was obtained with the longer heating, while with the higher temperatures there was an improvement for the shorter periods of heating, but longer periods were very injurious. The more mature the wheat the greater its ability to withstand heating.

TABLE VIII.—TEXTURE OF BREAD MADE FROM WHEAT HARVESTED AT DIFFERENT STAGES OF MATURITY AND HEATED VARYING LENGTHS OF TIME.

(Basis of 100 as perfect.)

Days heated	Temperature	0	½	1	1½	2	2½	3	3½	4	4½	5
1927 Crop.												
Stage I	40° C.	89	80	80	80	80	80	80	80	80	80	80
	45° C.	......	......	......	......	......	......	......	......	......	......	......
	50° C.	......	......	......	......	......	......	......	......	......	......	......
	55° C.	......	......	......	......	......	......	......	......	......	......	......
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage II	40° C.	89	86	89	93	99	93	91	96	95	98	98
	45° C.	......	90	96	98	97	97	92	90	90	85	89
	50° C.	......	92	95	80	80	......	......	......	......	......	......
	55° C.	......	80	75	......	......	......	......	......	......	......	......
Stage III	40° C.	89	92	90	94	94	95	95	95	97	97	99
	45° C.	......	90	94	97	97	96	92	86	80	80	94
	50° C.	......	86	80	75	......	......	......	......	......	......	......
	55° C.	......	95	75	75	......	......	......	......	......	......	......
Stage IV	40° C.	89	85	86	89	90	90	86	90	90	87	88
	45° C.	......	90	90	90	90	90	90	90	90	90	90
	50° C.	......	84	87	87	84	85	84	87	89	85	87
	55° C.	......	86	86	88	86	86	88	88	......	......	......
1928 Crop.												
Days heated		0	½	1	1½	2	2½	3	3½	4	4½	5
Stage I	40° C.	94	88	89	86	86	85	86	89	85	86	89
	45° C.	......	96	92	98	94	91	......	......	......	......	......
	50° C.	......	90	80	......	......	......	......	......	......	......	......
	55° C.	......	87	......	......	......	......	......	......	......	......	......
Stage II	40° C.	89	98	98	97	96	96	97	94	95	97	97
	45° C.	......	98	94	96	92	90	88	......	......	......	......
	50° C.	......	92	80	......	......	......	......	......	......	......	......
	55° C.	......	84	70	......	......	......	......	......	......	......	......
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage III	40° C.	98	98	98	90	90	94	84	85	88	89	83
	45° C.	......	98	83	88	86	90	83	83	......	......	......
	50° C.	......	98	86	83	......	......	......	......	......	......	......
	55° C.	......	80	70	......	......	......	......	......	......	......	......
Stage IV	40° C.	98	97	98	98	98	98	98	98	98	98	98
	45° C.	......	96	96	97	98	98	98	97	98	98	98
	50° C.	......	97	98	98	98	98	93	97	93	95	98
	55° C.	......	98	89	86	82	......	......	......	......	......	......
Stage IV B	40° C.	......	98	98	87	90	92	98	85	88	......	......
	45° C.	......	......	......	......	......	......	......	......	......	......	......
	50° C.	......	......	......	......	......	......	......	......	......	......	......
	55° C.	......	80	......	......	......	......	......	......	......	......	......

TABLE IX.—LOAF VOLUMES OBTAINED FROM WHEAT HARVESTED AT DIFFERENT STAGES OF MATURITY AND HEATED VARYING LENGTHS OF TIME.

(In cubic centimeters.)

Days heated	Temperature.	0	½	1	1½	2	2½	3	3½	4	4½	5
1927 Crop.												
Stage I	40° C	1750	1650	1690	1660	1630	1575	1630	1620	1620	1585	1605
	45° C	......	......	......	......	......	......	......	......	......	......	......
	50° C	......	......	......	......	......	......	......	......	......	......	......
	55° C	......	......	......	......	......	......	......	......	......	......	......
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage II	40° C	1690	1750	1880	1960	1880	1955	1870	2070	2030	2155	2095
	45° C	......	1740	2005	2085	2085	2000	1775	1715	1740	1520	1695
	50° C	......	1965	2120	1460	1315	......	......	......	......	......	......
	55° C	......	1490	1350	......	......	......	......	......	......	......	......
Stage III	40° C	1570	1840	1875	1880	1920	1950	1930	1955	2025	2030	2135
	45° C	......	1960	2030	2150	2130	2070	1850	1570	1525	1510	1560
	50° C	......	1620	1400	1415	......	1360	......	......	......	......	......
	55° C	......	1990	1325	1345	......	......	......	......	......	......	......
Stage IV	40° C	1630	1660	1775	1805	1980	1865	1880	1865	1825	1785	1880
	45° C	......	1760	1640	1610	1690	1630	1670	1600	1630	1620	1580
	50° C	......	1730	1680	1690	1785	1750	1810	1660	1820	1910	1690
	55° C	......	1700	1755	1720	1760	1750	1700	1785	......	......	......
1928 Crop.												
Days heated		0	½	1	1½	2	2½	3	3½	4	4½	5
Stage I	40° C	1835	1710	1720	1690	1660	1585	1575	1710	1530	1680	1695
	45° C	......	2055	1930	1820	1995	1800	......	......	......	......	......
	50° C	......	1820	1450	......	......	......	......	......	......	......	......
	55° C	......	1690	......	......	......	......	......	......	......	......	......
Stage II	40° C	1910	2075	2100	2075	2080	2045	2050	1980	2045	2120	2100
	45° C	......	2150	2015	2130	1890	1830	1685	......	......	......	......
	50° C	......	1935	1530	......	......	......	......	......	......	......	......
	55° C	......	1485	1320	......	......	......	......	......	......	......	......
Days heated		0	1	2	3	4	5	6	7	8	9	10
Stage III	40° C	2085	2120	2010	1800	1840	2000	1580	1595	1675	1650	1560
	45° C	......	2160	1625	1755	1705	1840	1620	1610	......	......	......
	50° C	......	2125	1680	1600	......	......	......	......	......	......	......
	55° C	......	1500	1205	......	......	......	......	......	......	......	......
Stage IV	40° C	2100	1990	1970	2015	2125	2010	2050	2080	2050	2140	2155
	45° C	......	1880	1900	1960	2010	1900	2060	1900	2060	2000	2065
	50° C	......	1975	2110	2000	2055	2050	1870	2020	1810	1900	1715
	55° C	......	2030	1760	1670	1540	......	......	......	......	......	......
Stage IV B	40° C	......	2065	1995	1590	1670	1735	1990	1545	1650	......	......
	45° C	......	1530	......	......	......	......	......	......	......	......	......
	50° C	......	......	......	......	......	......	......	......	......	......	......
	55° C	......	......	......	......	......	......	......	......	......	......	......

The heating of artificially wetted wheat cut in Stage IV seemed to be more injurious than the heating of wheat cut in Stage III which had about the same moisture content. The color score of the bread was lowered proportionately to the impairment in the volume and texture.

The possible improvements in volume and texture which may result from heating new wheat at 40° C. and at 45° C. are shown in figures 4 and 5,

FIG. 4.—Loaves of bread showing the improvement made by heating (at 40° C.) wheat which was cut when it had 22 per cent moisture. The numbers on loaves indicate the days heated.

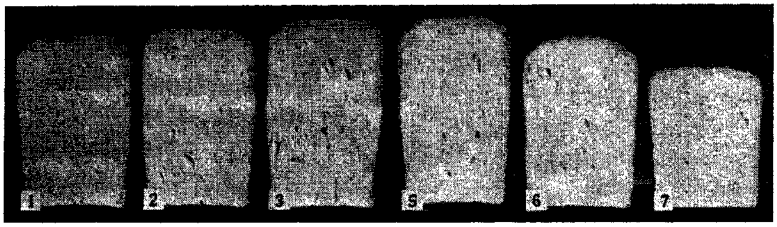

FIG. 5.—Loaves of bread showing the improvement made by heating wheat (at 45° C.) up to and including 5 days, and then the deterioration from heating thereafter. The numbers on the loaves indicate the days heated.

respectively. These loaves were made from Stage III, crop of 1927. More than 5 days heating at 45° C. produced injury. These results help to explain the fairly good volume and texture obtained in later experiments from wheat which had suffered a limited amount of heating in the bin.

OVERMIXING DOUGH FROM HEAT-DAMAGED WHEAT

The phenomena mentioned in a preceding paragraph relative to better volume and texture obtained from some of the longer heated wheats seemed worthy of further investigation. It was noted that better volume and texture could be obtained from heated flours by longer or more severe mixing. Apparently, heating weakens the gluten in such a way that with normal mixing proper dough development cannot be obtained, but with longer mixing the gluten particles seem to recombine. To test out this possibility, samples of flour were used which were beyond the point where very poor bread had been obtained. The dough was mixed much longer than had been the practice with the other doughs. Some of the results obtained are given in Table X, and illustrated in figure 6. The loaves in figure 6 were either from wheat originally higher in moisture content, or the heating had been at a higher temperature than for the loaves shown in figures 4 and 5. Loaf No. 4 illustrates the type of loaf obtained from all these flours by ordinary mixing. In the case of No. 4, however, no amount of mixing would produce a good loaf since the injury to the wheat had gone too far. These loaves, particularly 5 and 6, had as good texture and volume as is obtained from flour of sound wheat.

TABLE X.—VOLUME AND TEXTURE OF BREAD OBTAINED BY SEVERELY MIXING DOUGH FROM HEAT-DAMAGED WHEAT.

Loaves on fig. 6.	Stage of cutting.	Days heated.	Heating temperature, degrees C.	Minutes mixed.	Overmixed dough.		Best loaf by ordinary mixing	
					Volume, c. c.	Texture, per cent.	Volume, c. c.	Texture, per cent(a).
1	II	3½	45	8	1,980	97	1,685	88
2	II	5	45	12	1,760	92	1,685	88
3	II	1½	50	12	1,805	94	1,530	80
4	II	5	50	15	1,270	60	1,530	80
5	III	10	45	13	2,080	97	1,610	83
6	III	4	50	20	2,020	97	1,600	83

(a) Loaves not shown in figure 6.

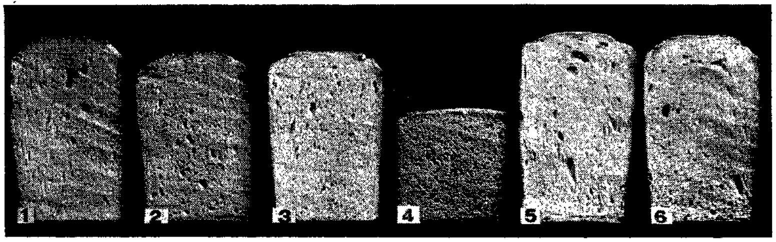

FIG. 6.—Loaves of bread produced by long mixing of flour from wheat heated to such an extent that good bread could not be obtained by ordinary mixing. (Baking data in Table X.)

SUMMARY OF HEATING EXPERIMENTS

The data presented on artificial heating may be summarized as follows:

1. Carefully controlled use of heat on new wheat may bring about an improvement in baking qualities, but if the degree of temperature is too high or if the period of heating is too long, marked damage may result, such damage being proportional to the moisture content of the wheat.
2. When heating takes place under uncontrolled conditions, such as happen when wheat is cut immature, threshed, and stored with too much moisture, serious damage may result.
3. Mature wheat has greater viability than immature wheat, and heating is less injurious to the viability of mature wheat.

RESPIRATION IN WHEAT

It has already been shown (Table IV) that the rate of respiration is greater in immature wheat of high moisture content than in mature wheat of low moisture content, and also that the rate of respiration in mature wheat is related to the moisture content and the temperature. Further discussion and data relative to respiration are given in the following paragraphs.

DEVELOPMENT OF THE WHEAT KERNEL

The formation of the wheat kernel involves an intense biological activity. Within the space of a few weeks the kernel grows from a mere speck to the fully formed wheat grain. When the kernel emerges it is soft, and the inside is filled with a thick milky fluid. This gradually hardens and becomes the endosperm in the ripe kernel. During the process of kernel formation, materials are transferred from the leaves and stems and used to build the starch and protein of the kernel. This process goes on until complete ripeness, but at a decreasing rate. The final stage is primarily one of desiccation, which must proceed to a certain extent before gluten can be obtained from the endosperm. Parallel with desiccation the protein undergoes such changes that when water is added to the sifted wheat flour, gluten will form. Biological activity decreases as maturity is approached, and when the kernel is fully ripe and air dry, it becomes dormant or in a state of minimum activity. When wheat is cut a little on the green side there is still considerable biological activity which may have an important effect on its quality.

RESPIRATION AS A SOURCE OF HEAT

The normal sound wheat kernel is a living organism and all living organisms respire, a process accompanied by the production of carbon dioxide and the liberation of energy in the form of heat. In a dry dormant seed the vital activities go on at the minimum rate. The addition of water or increase of temperature stimulates this activity. More activity means a greater rate of heat production. When enough moisture is present the temperature will be perceptibly raised, and this in turn will stimulate the rate of respiration thereby liberating more heat. This acceleration of vital activity and elevation of temperature may continue until checked by the injurious effect of the high temperature. Hence when wheat starts heating the rate may soon increase to such an extent as to cause rapid and severe damage. As has already been pointed out, molds usually develop at the same time and the respiration of the molds is an added source of heat, perhaps even greater than that of the respiration of the wheat. Whether respiration of wheat in the absence of mold growth can produce enough heating to cause serious damage has not been determined.

SWEATING IN WHEAT

Wheat after harvesting undergoes what may be called a post-ripening process. Flour milled from new wheat has not the same quality as when milled after that same wheat has aged for some weeks or months. When wheat is cut with the harvester, shocked, and stacked, part of this process takes place before threshing. One manifestation of such changes is commonly known as sweating and may take place in the stack or in the bin. Sweating is simply another name for a very active respiration in which water, also a product of this process, becomes evident. If the wheat is fairly dry and the humidity low the formation of water goes on very slowly and is either evaporated as fast as formed or absorbed by the dry kernels, hence is not observed under very dry conditions. If the grain is more moist and the atmosphere sufficiently humid there will be enough moisture produced to be observed easily.

DETERMINING THE RATE OF RESPIRATION

The rate of respiration in wheat cut and threshed at different stages of ripeness, and subjected to various temperatures was determined on samples from the crop of 1928.[3] The moisture contents of the wheat used for respiration experiments were as follows: Stage I, 36.3 per cent; Stage II, 30; Stage III, 19.4 Stage IV, 13.1. One of the bins used in the wheat-heating experiments was used as a respiration chamber. Duplicate samples of the grain were placed in calcium chloride towers inside of the bin and the temperature was held at 45° C. The rate of carbon dioxide evolution was determined by first sweeping out these towers at certain intervals with CO_2

3. Respiration data from other experiments have also been given in Tables III and IV.

free air and then collecting the CO_2 from the towers for a definite period. The CO_2 was absorbed in standard $Ba(OH)_2$ held in Brady-Meyer tubes and the excess $Ba(OH)_2$ titrated with standard sulphuric acid.

Readings were made at 6 a.m. and 6 p.m., or as near that time as possible. The values recorded in figure 7 are milligrams of CO_2 respired per hour from 100 grams of dry material.

RESPIRATION IN RELATION TO MATURITY

The respiration values obtained were somewhat irregular. In figure 7 are curves showing the relation of maturity to rate of respiration. Respiration was highest in wheat cut in Stage I, slower in Stages II and III, and slowest in Stage IV. In wheat cut in Stages I, II, and III the respiration decreased as incubation progressed, the decrease being most marked for Stage I. No molding was evident in these samples. Wheat from Stage IV exhibited a low and even rate of respiration. In such wheat the biological activity is at a minimum. Sufficient water was added to wheat cut in Stage IV to bring the moisture content to 21 per cent, approximating the wheat cut in Stage III, and the rate of respiration determined. This wetted wheat respired somewhat faster than the wheat from Stage III, possibly because of a slightly higher moisture content. It appears that an equal amount of water added artificially has the same effect on respiration as moisture due to immaturity, disproving the conception that moisture due to immaturity is more likely to cause heating. The moisture in immature wheat is usually less apparent to the senses than is water added artificially or by rain, and hence the latter may be thought to be more abundant.

From this study it may be concluded: (1) Respiration is more rapid in less mature wheat. (2) The rate of respiration, temperature being constant, depends on the moisture content. (3) Moisture added artificially seems to have as marked an effect on the rate of respiration as moisture due to immaturity.

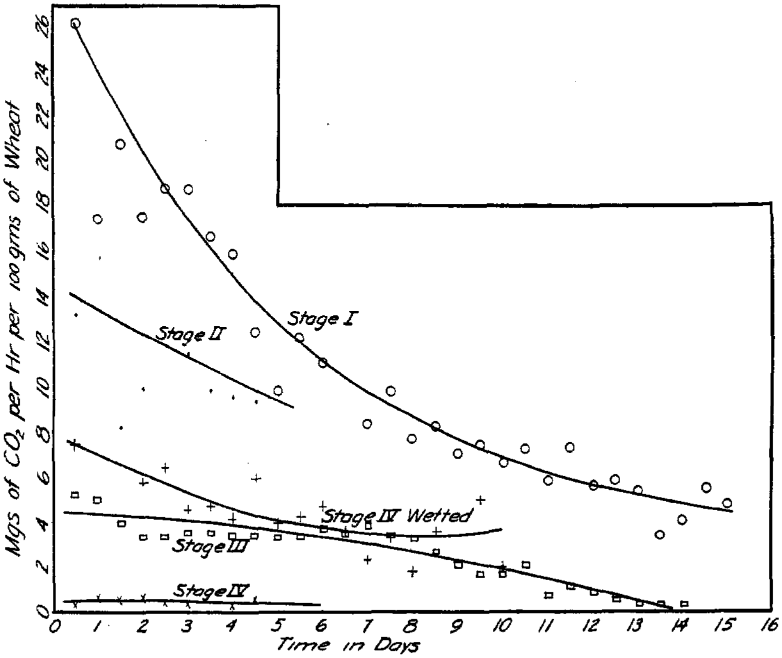

FIG. 7.—Graphs showing rate of respiration as affected by stage of maturity.

COMPARING BIN TYPES, FORT HAYS STATION, 1929

PURPOSE OF THE STUDY

The object of this work was to compare different types of bins as to their effectiveness in preventing damage to damp wheat and to study different methods of ventilation in common farm bins.

Since the survey method used in 1923-'25 is limited by a lack of control of the time of handling the wheat, it was decided to conduct the storage experiments at the Fort Hays branch of the Agricultural Experiment Station, located in the center of the Kansas wheat belt. The analytical, milling, and baking studies were performed in the laboratories of the Department of Milling Industry, Manhattan, Kan.[4]

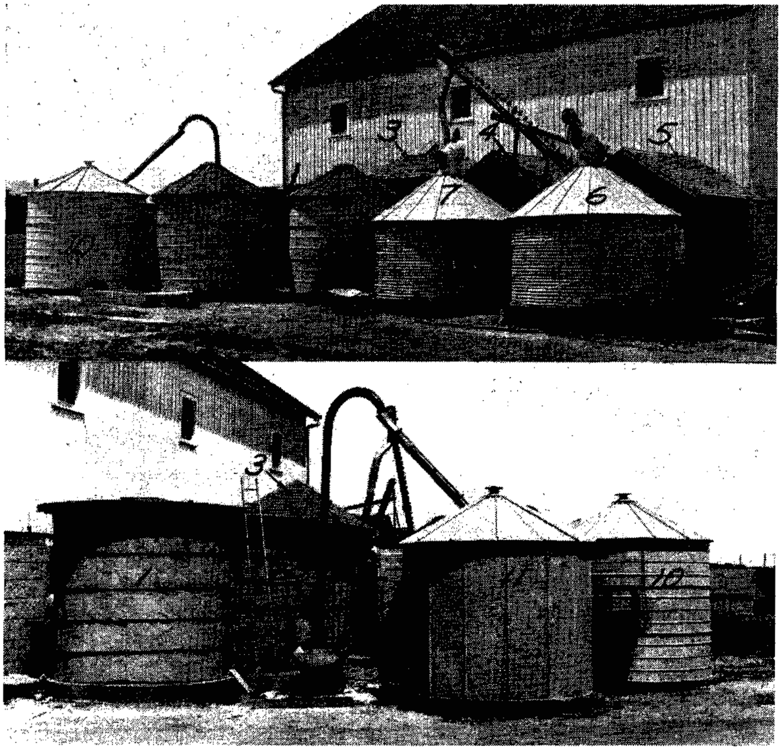

FIG. 8.—Bins used in the wheat storage experiments, summer, 1929.

BINS USED

Eleven grain bins of approximately 500 bushels capacity each, were erected on the grounds of the Fort Hays station. Figure 8 shows these bins as viewed from two directions. A brief description of each follows:

Bin 1.—Concrete stave, similar to silo construction, placed on concrete foundation and floor; outside surface waterproofed.

4. A report of the work done in 1929 was published in Cereal Chemistry, Vol. 7, pp. 428-448. Abstract of that work is made in these pages.

Bin 2.—Same as No. 1, except that both outside and inside surfaces of wall were waterproofed.

Bin 3.—Square, constructed of concrete boards, making a wall 5" thick filled with horizontal air spaces; foundation and floor made of concrete.

Bin 4.—Wooden bin with lumber both inside and outside of 2 x 6" studs. Inside walls and roof lined with ½" celotex.

Bin 5.—Wooden bin similar in construction to No. 4, but with the celotex omitted.

Bins 6 and 7.—Circular steel bins with perforated side walls and large central ventilating flue with suction cupola on top. These two bins were set on wooden floors.

Bins 8 and 9.—Circular steel bins with tight side walls, metal floor and roof.

Bin 10.—Circular steel bin with tight side walls, steel floor and roof, small central ventilator of steel.

Bin 11.—Circular steel bin with slight ventilation in the side walls; steel floor and roof.

It should be noted that the construction of bins Nos. 6 and 7 provided ventilation through the floors, walls, and large central ventilating flues; bins Nos. 10 and 11 had slight ventilation, while in the others no particular provision for ventilation was made in the bin construction. In several of these bins an attempt was made to assist ventilation by means of perforated metal tubes, and flues made of a combination of wood and screen wire.

These bins were erected in two groups. Bins Nos. 1, 2, 9, 10, and 11 made up one group so arranged that wheat could be transferred from one bin to another by means of a blower elevator. Bins Nos. 3, 4, 5, 6, 7, and 8 composed the second group which were arranged to be filled by a tubular farm elevator (John Deere small grain elevator) and the wheat was moved by a drag line conveyor from the different bins to the elevator.

DATA TAKEN

1. Temperature Studies.—In each bin from three to six thermometers of the electrical resistance type were installed and so arranged that the temperature of the wheat could be read from central points. Temperatures were read three times each day at the beginning, but later it was found that once a day was sufficient. Temperatures outside the bins were also recorded. (Table XI.)

2. Moisture Studies.—A Brown-Duvel moisture determining apparatus was installed at the Fort Hays station in order to be able to take samples for moisture determination and secure the results promptly. After the rush of harvest was over this apparatus was shipped back to Manhattan and the moisture tests made there.

Moisture determinations were made on the standing grain to determine when to start harvesting. After windrowing some of the wheat, samples were also taken to note how rapidly the grain dried out and to determine when to begin picking up and threshing. As each load of grain was delivered to the bins a composite sample was taken for moisture content. Whenever it was necessary to move the wheat because of high temperature, moisture determinations were made from various parts of the bins. In those bins which did not heat and were not moved, samples for moisture determination were taken by a grain probe. Final samples for moisture content were taken when the wheat was removed from the bins about October 1.

3. Milling Samples.—A number of samples were taken of the wheat going into each bin and placed in cotton sacks and buried in the bins. As the wheat was moved, these sacks were moved and were thus subjected to the same heating and moisture conditions as the rest of the wheat. At the end of the experiment additional samples of wheat were taken from the bins for milling and baking tests. A few check samples taken at time of binning were stored in the laboratory.

TABLE XI.—METEOROLOGICAL DATA, DURING PERIOD OF WHEAT STORAGE EXPERIMENT, JULY 1 TO SEPTEMBER 30, 1929.

(Fort Hays Agricultural Experiment Station.)

DAY OF MONTH.	Rainfall. Inches per day.			Relative humidity. Per cent of saturation, average of 3 readings.			Wind velocity. Average miles per hour at noon.			Temperature. Noon temperature in sun at bins, degrees C.		
	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.	July.	Aug.	Sept.
1	......	......	......	48	32	42	24	12	15	32	44	38
2	......	......	......	39	45	35	18	11	12	30	47	34
3	......	T	0.09	26	52	51	10	17	23	34	32	20
4	......	......	.03	24	41	71	18	13	22	35	45	28
5	......	......	.08	49	47	67	8	14	18	33	27	25
6	0.12	0.32	.04	50	76	60	8	21	6	35	28	24
7	......	.01	.47	72	70	74	9	14	11	25	24	21
8	.12	.01	.38	72	89	69	22	12	9	25	24	26
9	.12	.47	.85	69	86	56	23	14	8	21	32	24
10	......	1.48	......	80	85	55	8	10	12	27	26	28
11	3.20	.01	T	61	62	54	17	4	7	36	32	30
12	......	......	.68	52	59	67	20	4	10	40	38	27
13	......	......	......	49	43	52	23	5	12	40	33	30
14	......	......	......	47	45	51	12	8	14	42	31	27
15	......	......	......	55	46	45	10	14	12	44	35	26
16	......	......	......	74	38	62	14	7	......	37	40	31
17	.13	......	......	64	39	43	9	17	......	35	35	21
18	1.47	......	......	69	63	63	14	12	......	33	36	19
19	.05	......	T	59	51	77	10	12	......	31	34	18
20	......	......	......	65	29	80	9	13	......	40	47	17
21	......	......	......	59	33	38	16	10	......	35	40	26
22	......	T	......	56	45	36	14	15	......	38	37	25
23	.11	......	......	69	40	48	11	14	......	36	39	27
24	1.79	......	......	84	39	52	10	8	......	24	40	28
25	.03	......	......	59	50	50	8	17	......	35	......	26
26	......	.07	.93	56	86	49	10	15	......	36	22	25
27	......	.47	T	51	70	......	14	7	......	37	38	26
28	T	......	.03	53	77	......	15	5	......	31	32	......
29	......	......	......	61	66	......	10	6	......	37	30	......
30	......	......	......	63	36	......	7	4	......	43	30	......
31	......	......	......	31	42	......	10	15	......	43	36	......

4. Meteorological Data.—Information on wind velocity and direction, rainfall, humidity, and temperature was available from the office of Dry-land Agriculture located on the Fort Hays station. These data are found in Table XI.

5. Judging the Grain.—At the end of the storage period, half-pound portions of the milling samples were sent to O. F. Phillips, chairman of the Board of Review, Federal Grain Division, Chicago. These samples were sent in cloth sacks which permitted the escape of odors before the grain was judged.

6. Rancidity and Germination Tests.—The samples used for judging the grain were tested for rancidity by Dr. D. A. Coleman, Bureau of Agricultural Economics, United States Department of Agriculture, Washington, D. C. They were also tested for viability by the seed laboratory of the Bureau of Plant Industry, United States Department of Agriculture.

THE HARVEST

The harvest began on June 28 when wheat which had been windrowed was "picked up" and threshed. The weather was hot and windy, drying the grain very rapidly. Grain which contained 18 per cent moisture in the morning was down to 14 per cent by afternoon. For these reasons very little damp wheat was secured from that which was windrowed. Another combine was started on a field of standing grain which was still green in the low places. Some high moisture wheat was secured from this field. The threshing was not satisfactory because the machine could not handle both the green wheat on the low land and the ripe dry wheat on the higher land in a satisfactory manner. Three bins of this mixture of green and ripe wheat were secured and proved to be the most difficult to store without damage.

Figure 9 shows the John Deere tubular type of elevator being used to fill the bins.

MOVING THE GRAIN

In order to prevent loss by damage in storage, the wheat was moved whenever it reached a temperature of 45° C. (113° F.). Just what constitutes a dangerous temperature has not been definitely determined and may vary

FIG. 9.—Filling the bins with damp wheat by use of the John Deere tubular grain elevator, summer, 1929.

widely under different conditions. It required more power to move wheat with the blower elevator than with the cup or tubular type, but the former seemed more effective in cooling.

OBERVATIONS ON THE WHEAT IN DIFFERENT BINS

Bins Nos. 1, 4, and 5 were filled with wheat so dry that there was no danger of damage and the grain was not moved. The wheat in bin No. 3 was very warm when stored and it was thought best to move it although the temperature never reached 45° C. Wheat in bins Nos. 6 and 7 was not moved although it had a moisture content considered unsafe for storage.

A more detailed discussion of bins Nos. 2, 4, 6, and 11 will be given because the course of events in these were of more significance. A preliminary report of this experiment has already been published (Fenton and Swanson, 1930).

Bin No. 2, Concrete Stave.—This bin was filled with the dampest wheat secured during the harvest. It consisted of a mixture of grain from low areas that was too green to thresh properly and very dry grain from the higher parts of the field. The entire bin averaged 16.2 per cent moisture, and one load contained as high as 18.6 per cent moisture. This wheat with an initial temperature of 40° C. (104° F.) began to heat almost immediately. In 5 days it had reached 50° C. (122° F.) in one part of the bin. The entire contents of the bin would undoubtedly have been a total loss if left undisturbed. The grain had caked so hard that it would stand up vertically in the bin and the odor resembled that of fermenting silage. The wheat, within 8 inches of the outside wall was cooler and much wetter than that nearer the inside. The wet wheat near the outside must have resulted from condensation since no rain had fallen during the period, and hence no moisture could have been added from the outside. It is possible that the moisture produced in the center, where the temperature was higher and respiration very rapid, was condensed nearer the walls where the temperature was lower.

This wheat was moved by a blower elevator into a steel bin and then returned to bin No. 2. The moving cooled the grain to 32° C. from which point the temperature gradually rose to 48° C. 20 days later. This wheat was moved five more times during the summer and occupied successively, bins Nos. 11, 8, 3, 10, 11 for varying lengths of time. By the six transfers the moisture content had been lowered to 14 per cent. A graphic story of the temperature changes in this bin of wheat is told by the curves in figure 10. Plotted along with the wheat temperature is also a curve showing the daily noon temperature near the bins. The data recorded at the time of grading, the moisture content, germination percentages, test weight, and chemical and baking tests are given in Table XII.

Nine of the wheat samples graded "no damage"; five graded "slightly sour odor"; and the remainder "odor indeterminate."

All the wheat was dead with the exception of three samples, and in these the germination was very low. The rancidity values were also high in all samples, the highest being in the samples taken when the wheat was moved to the elevator. The least rancidity was in two of the four samples taken when the wheat was moved the second time. The question might be raised as to the relative damage of the wheat in the sacks compared with the loose wheat in the bin. The rancidity measurements indicate slightly less damage, while the baking tests show more damage to the grain in the sacks. It is doubtful if the wheat in the sacks was as effectively cooled as the wheat which passed through the blower elevator. Measured by the baking test every sample from this bin had suffered damage, but those taken at the second moving had suffered least.

Bin No. 4, Wooden, Celotex-lined.—The results secured in this bin were comparable to those obtained in a farm bin under favorable moisture conditions. The moisture content of representative loads of wheat were 16.4, 15.4, 14.4, 13.6, and 12.2 per cent, or scarcely enough to create a storage problem. The wheat went into the bin at an average temperature of 35° c. (95° F.). It never rose above this and hence was not moved. The wheat appeared to be in perfect condition when taken from the bin on October 1. A study of figure 11 will show how uniform the temperatures remained throughout the storage period. The data relative to other tests made on the samples we presented in Table XIII.

All the samples from this bin graded "no damage" and, except for one sample, the rancidity was low indicating no damage. The baking results also did not indicate any damage. Sample 14801 containing 15.4 per cent moisture at the time of binning gave zero germination and the highest rancidity. Sample 14802 also had low germination. In the other samples the germination approximated that of grain from bins in which the wheat kept best. For some reason the germination was comparatively low even in the samples in which no damage could be detected by the other tests.

Bin No. 6, Ventilated Steel.—The first wheat threshed from windrowed wheat was stored in this bin. It averaged 16 per cent moisture, including one load containing 18 per cent. The initial temperature of this wheat was 34° C. (93.2° F.) which gradually declined to about 20° C. (68° F.) when it was removed, September 28, though it was not necessary to move this wheat on account of heat. At the end of the storage period this wheat still contained 16 per cent moisture, a rather high moisture content not to be accompanied by heating. The temperature curves are plotted in figure 12 and other data are given in Table XIV. It may be that being threshed from "windrowed" wheat accounts in part for the results obtained in this bin.

TABLE XII.—DATA FROM BIN NO. 2, CONCRETE STAVE.

Wheat combined July 3 from low land. Average moisture content 16.2 per cent; maximum, 18.6 per cent.

Serial No.	DESCRIPTION OF SAMPLES.	Moisture.	Germination.	Rancidity (a).	Protein.	Test weight at lab.	Flour yield.	Flour ash.	Loaf volume.	Texture of bread.
		Per cent.	*Per cent.*		*Per cent.*	*Lbs.*	*Per cent.*	*Per cent.*	*c. c.*	*Per cent.*
14795	Placed at center near bottom. Graded slightly sour odor	17.0	0.0	26.03	13.8	53.4	68.3	0.71	1,430	88
14796	Placed 3 feet from bottom away from ventilators. Graded slightly sour odor	18.6	.0	29.75	13.2	53.6	68.0	.69	1,435	88
14797	Placed at center, near top. Graded slightly sour odor	17.6	.0	24.76	14.9	54.1	66.5	.73	1,455	88
	Wheat moved July 8, no samples.									
	Wheat moved July 29. Average moisture 16.2 per cent; maximum moisture 16.7 per cent.									
14824	Taken near door, bottom. Graded no damage	15.6	4.0	26.45	15.0	53.3	71.8	0.59	1,810	94
14825	Taken near top, wheat caked. Graded no damage	16.0	1.5	15.76	14.3	54.8	71.0	.61	1,680	92
14826	Taken near center, wheat caked. Graded no damage	15.6	.0	30.76	14.2	55.0	71.3	.62	1,690	92
14827	Taken at center near bottom. Graded slightly sour	16.7	.0	14.83	13.95	54.4	67.8	.63	1,620	89
	Wheat moved August 5. Average moisture 14.5 per cent; maximum 15.2 per cent.									
14840	Taken near center at top, caked, hot. Graded no damage	15.2	0.0	29.40	13.6	55.3	70.3	0.63	1,670	88
14841	Taken near bottom center, caked, hot. Graded odor indeterminate	15.0	.0	19.19	14.3	55.7	71.0	.63	1,780	94
	Wheat moved August 13. Average moisture 14.3 per cent; maximum 14.5 per cent.									
14836	Taken near bottom center, 47° C. Graded no damage	14.4	0.0	32.36	14.0	56.2	71.3	0.68	1,590	90
14837	Taken near bottom center, 47° C. Odor indeterminate	14.4	.5	26.17	14.4	56.2	70.3	.62	1,770	94

TABLE XII.—CONCLUDED.

Serial No.	DESCRIPTION OF SAMPLES.	Moisture.	Germination.	Rancidity (*a*).	Protein.	Test weight at lab.	Flour yield.	Flour ash.	Loaf volume.	Texture of bread.
	Wheat moved August 24. Average moisture 14.3 per cent; maximum 15.4 per cent.									
		Per cent.	*Per cent.*		*Per cent.*	*Lbs.*	*Per cent.*	*Per cent.*	*c. c.*	*Per cent.*
14842	Top center 45° C. Graded no damage	14.3	0.0	26.12	14.0	56.1	69.3	0.65	1,650	90
14843	Bottom center 45° C. Graded odor indeterminate	14.4	.0	34.0	14.0	55.9	72.3	.67	1,590	88
	Wheat moved to elevator September 28. Average moisture 14.0 per cent; maximum 14.2 per cent.									
14866	Near top, little musty. Graded no damage	14.2	0.0	33.79	14.0	55.3	70.0	0.66	1,600	85
14867	Center, little musty. Graded slightly sour odor	14.0	.0	32.90	14.2	56.1	70.0	.66	1,640	90
14868	Center, little musty, graded no damage	13.9	.0	32.35	14.0	55.7	71.3	.66	1,540	85
14869	Bottom, little musty, graded no damage	14.1	.0	32.90	14.0	55.8	70.3	.65	1,570	85

(*a*) The figures for rancidity are the milligrams of potassium hydroxide neutralized per gram of fat. Winter wheat in sound condition does not usually give a figure much over 8.

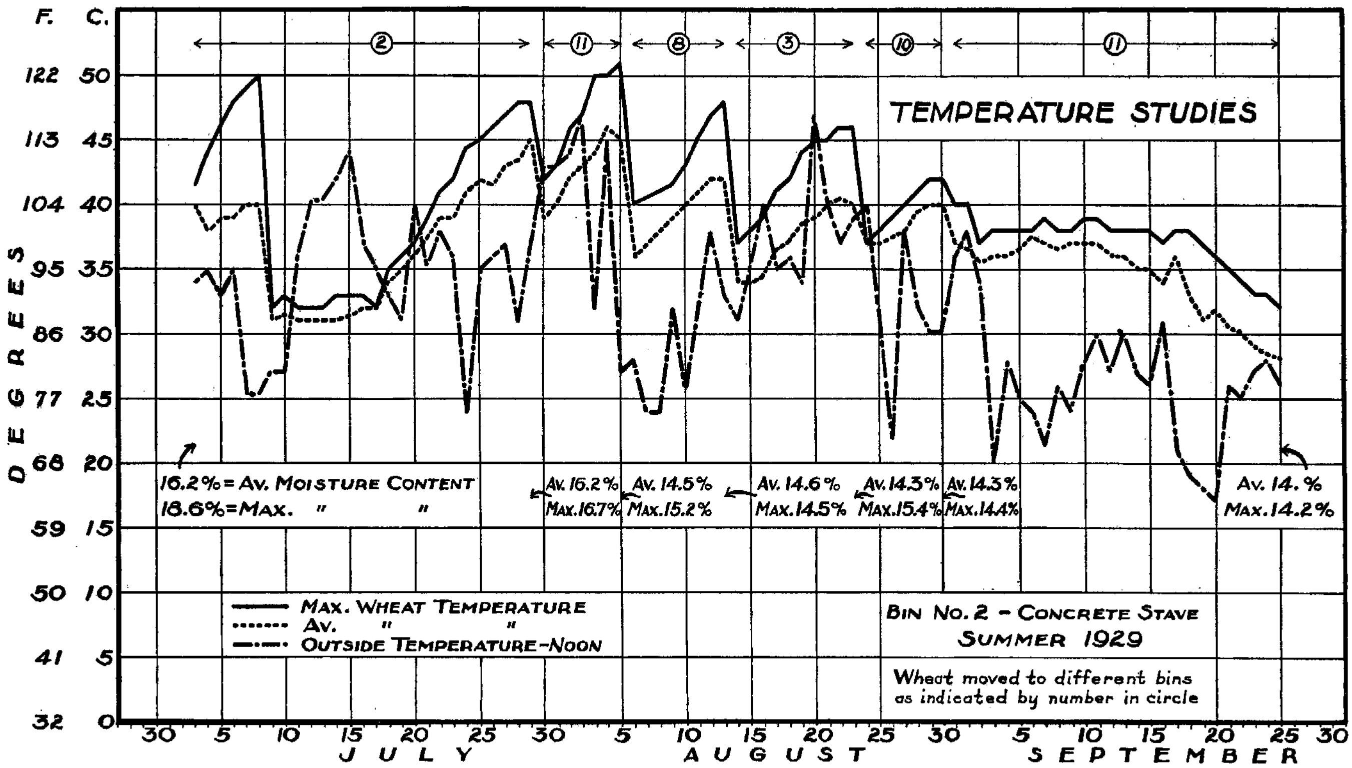

FIG. 10.—Temperature studies, bin No. 2, summer, 1929.

TABLE XIII.—DATA FROM BIN NO. 4, WOODEN, DOUBLE WALLS, INSULATED WITH CELOTEX.

Wheat windrowed June 26, threshed June 28. Average moisture content, 14.4 per cent; maximum, 16.4 per cent.

Serial No.	DESCRIPTION OF SAMPLES.	Moisture.	Germination.	Rancidity (a).	Protein.	Test weight at lab.	Flour yield.	Flour ash.	Loaf volume.	Texture of bread.
		Per cent.	Per cent.		Per cent.	Lbs.	Per cent.	Per cent.	c. c.	Per cent.
14801	Placed at center near bottom	15.4	0.0	20.16	11.0	56.5	70.5	0.60	1,675	93
14802	Placed at center near middle	13.6	0.5	11.15	10.9	58.2	69.8	.58	1,690	91
14803	Placed at center near top. All graded, no damage	12.2	22.5	8.18	11.0	58.9	69.8	.58	1,860	97
	Wheat moved to elevator September 28.									
14852	Taken near top center	13.1	34.5	8.06	11.1	58.5	68.3	0.58	1,580	90
14853	Taken near bottom center. Both graded no damage	14.3	26.0	8.66	10.8	58.8	70.0	.56	1,620	90

(a) See footnote Table XII.

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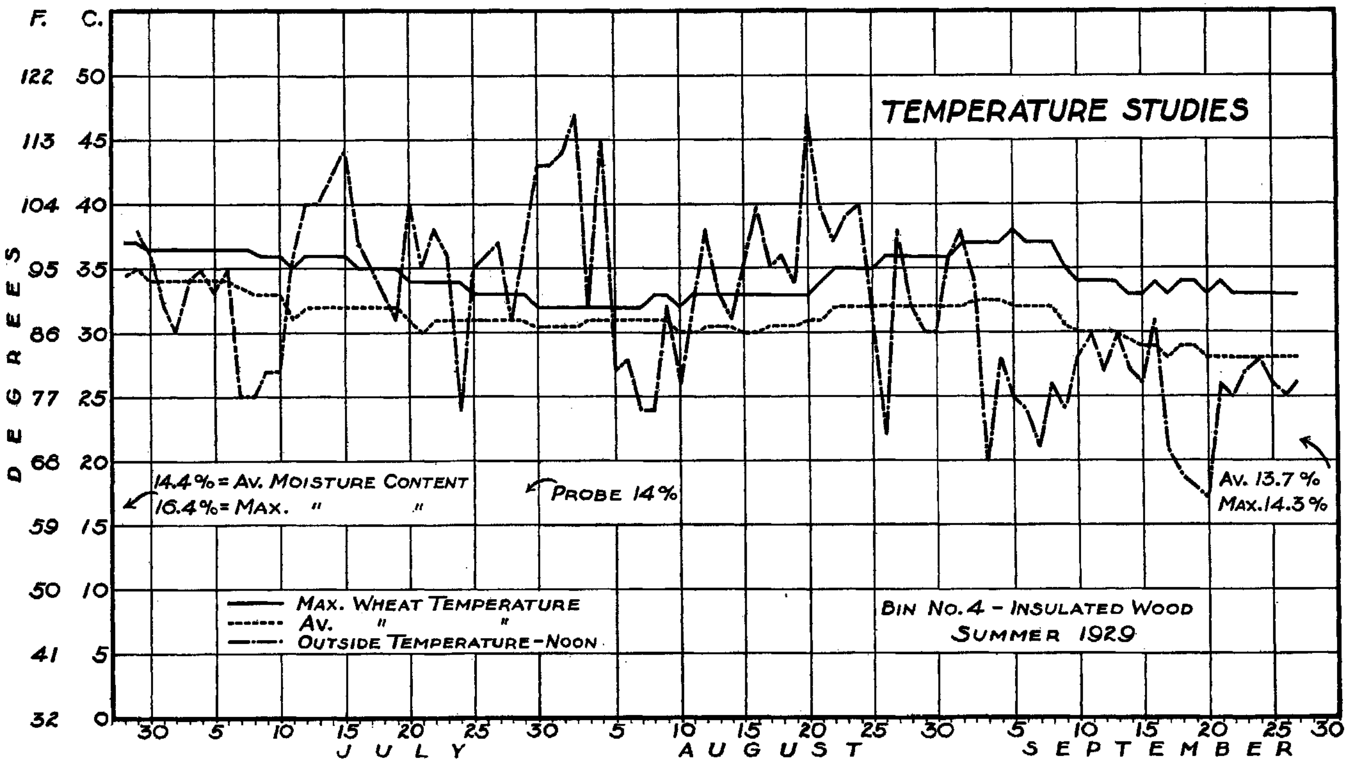

FIG. 11.—Temperature studies, bin No. 4, summer, 1929.

TABLE XIV.—DATA FROM BIN NO. 6, STEEL, SUCTION VENTILATOR AT TOP; DRUM IN CENTER FROM TOP TO BOTTOM; PERFORATED WALLS; MAXIMUM AMOUNT OF NATURAL VENTILATION.

Wheat windrowed June 26, almost ripe. Average moisture content 16 per cent; maximum 18 per cent.

Serial No.	DESCRIPTION OF SAMPLES.	Moisture.	Germination.	Rancidity (*a*).	Protein.	Test weight at lab.	Flour yield.	Flour ash.	Loaf volume.	Texture of bread.
		Per cent.	*Per cent.*		*Per cent.*	*Lbs.*	*Per cent.*	*Per cent.*	*c. c.*	*Per cent.*
14806	Check, not placed in bin, no damage	15.8	73.0	5.40	11.5	57.9	70.8	0.55	1,865	97
14807	Placed near bottom 12 inches from wall, no damage	....	58.5	7.23	13.3	55.7	68.8	.59	1,980	96
14808	Placed near center, no damage	14.6	24.0	5.73	11.0	59.0	70.0	.56	1,680	92
14809	Placed near center toward top. Graded slightly sour odor	18.0	23.5	14.82	11.9	55.4	69.8	.59	1,645	91
14810	Placed near top. Graded slightly sour odor	15.2	5.0	16.38	11.7	55.8	69.8	.60	1,630	90
14811	Placed almost on top, no damage	....	69.5	7.09	11.6	58.0	69.0	.53	1,720	92
14812	Threshed from dried wheat but having 26 per cent moisture when windrowed June 26, no damage. Not stored in the bin	10.2	31.0	6.27	12.8	54.8	68.0	.57	1,840	95
	Samples taken when grain was moved to elevator September 28.									
14856	Taken near top	12.2	23.5	6.98	10.9	58.2	68.0	0.56	1,690	92
14857	Taken near center where 18 per cent moisture wheat was put	16.2	2.5	16.88	11.5	56.4	70.8	.59	1,710	90
14858	Taken near center	15.3	19.5	12.40	11.5	57.2	70.0	.54	1,690	92
14859	Taken near ventilator. (All samples graded no damage)	16.0	6.5	13.54	11.7	55.8	69.3	.58	1,780	92

(*a*) See footnote Table XII.

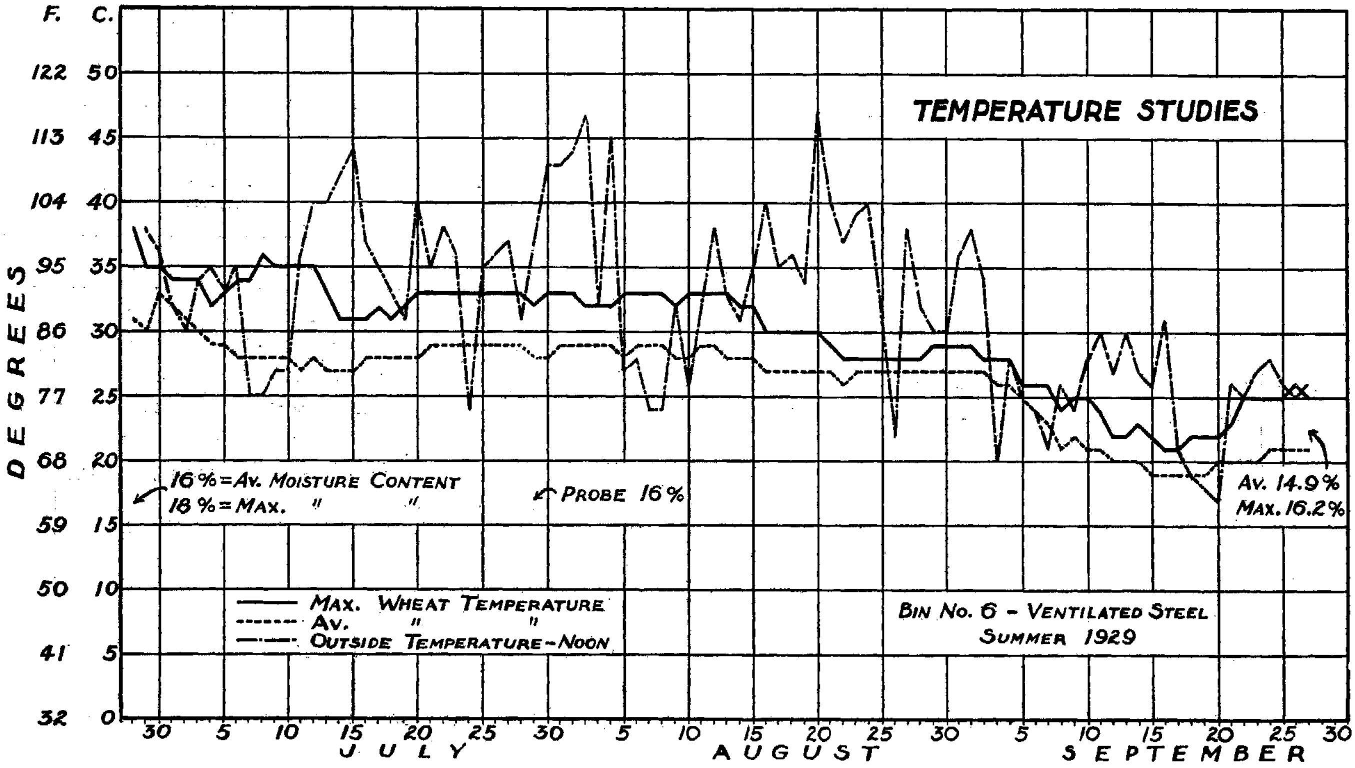

Fig. 12.—Temperature studies, bin No. 6, summer, 1929.

TABLE XV.—DATA FROM BIN NO. 11, STEEL WITH TIGHT WALL. ONE SIDE OF BIN FILLED WITH SCREEN VENTILATORS.

Wheat combined July 1. Average moisture content 15.6 per cent; maximum 16.3 per cent.

Serial No.	DESCRIPTION OF SAMPLES.	Moisture.	Germination.	Rancidity (a).	Protein.	Test weight at lab.	Flour yield.	Flour ash.	Loaf volume.	Texture of bread.
		Per cent.	*Per cent.*		*Per cent.*	*Lbs.*	*Per cent.*	*Per cent.*	*c. c.*	*Per cent.*
14817	Placed at bottom center. Graded slightly sour odor	16.3	0.0	26.76	14.7	53.9	68.5	0.61	1,730	94
14818	Placed at bottom center. Graded no damage	16.0	.0	33.50	14.8	54.2	70.0	.63	1,800	95
14819	Placed at center. Graded no damage	15.8	.0	26.45	14.8	53.4	70.8	.63	1,685	91
14820	Placed at center. Graded slightly sour odor	16.0	.0	30.33	15.3	55.7	68.8	.62	1,720	92
14821	Placed at center near top. Graded no damage	14.0	8.0	10.63	14.7	55.0	69.8	.56	1,835	97
14822	Placed at center near top. Graded no damage	14.8	12.0	9.0	14.6	55.9	69.8	.57	1,885	97
	Wheat moved July 20.									
14823	Composite sample	....	4.0	20.78	15.1	54.6	72.3	0.60	1,710	91
	Wheat moved August 5.									
14838	Taken from top center, hot. Graded no damage	14.2	0.0	21.48	13.9	55.0	70.7	0.66	1,660	90
14839	Taken from bottom center, hot caked. Graded no damage	15.4	70.5	9.26	13.2	56.8	70.3	.55	1,840	97
	Wheat moved August 23.									
15029	Bottom center caked. Graded slightly sour odor	....	0.5	28.35	14.2	55.9	70.0	0.62	1,680	90
15030	Top center caked. Graded no damage	....	1.5	15.30	14.0	56.1	70.5	.57	1,810	94
	Wheat moved to elevator September 28.									
14850	Taken from top. Graded no damage	15.1	0.0	19.57	13.8	54.9	67.8	0.60	1,830	94
14851	Taken from bottom. Graded no damage	14.4	.0	15.44	13.6	55.7	67.8	.58	1,635	90

(*a*) See footnote Table XII.

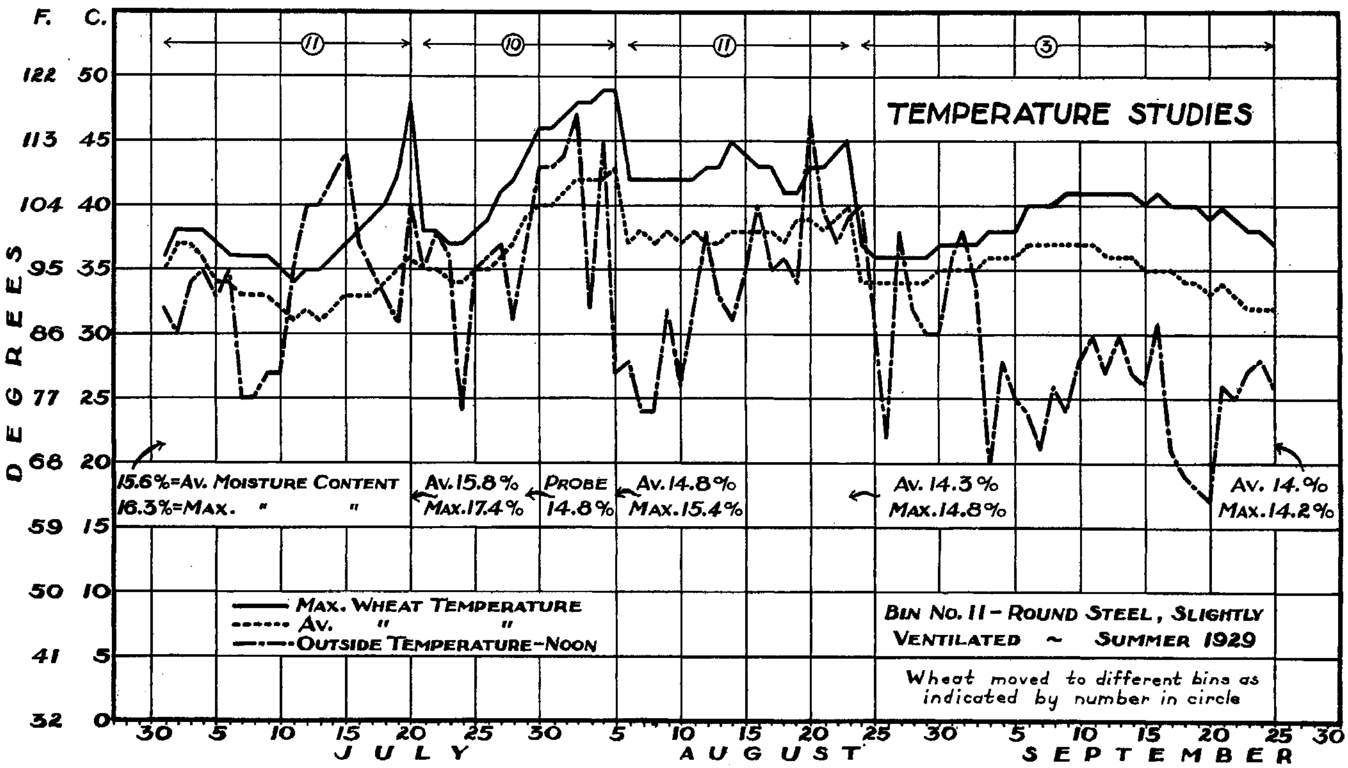

FIG. 13.—Temperature studies, bin No. 11, summer, 1929.

No spoiled wheat was found in any part of the bin and the grain appeared to be in perfect condition. Two of the samples taken at the time of binning and stored with the wheat graded "slightly sour odor." These two had 15.2 and 18 per cent of moisture, respectively, when placed in the bin. These two also gave high rancidity values and were low in baking tests. The rest graded "no damage." Germination was comparatively high except for three samples, two of which were taken when the wheat was last moved. It was noted that the moisture content in three of the samples taken when the wheat was last moved was high, yet on the whole the wheat kept very well. No sample showed any great damage in the baking test, though those with fairly high rancidity gave smaller loaf volumes.

Bin No. 11, Steel with Tight Wall.—This bin was filled with damp wheat made up of green and ripe kernels similar to that placed in bin No. 2. The average moisture content was 15.6. The temperature declined until about the middle of July when high external temperature seemed to start heating, and the temperature rose rapidly until the wheat was moved on July 20. At this time the grain was in bad condition and would have been seriously damaged if left undisturbed. This bin of wheat was moved three times occupying successively bins Nos. 11, 10, 11, and 3. The temperature changes are recorded in figure 13, and in Table XV are given the data from the other tests.

Ten of the thirteen samples from this bin graded no damage. The other three graded slightly sour odor. The germination test showed that the wheat was dead in most of the samples, and rancidity was high except in three samples. In these two respects the wheat was similar to that in bin No. 2, but the baking results indicated less damage, showing that less deterioration had taken place as compared with bin No. 2. The wheat in bin No. 11 was binned at a somewhat lower temperature, and the bin had some wall ventilation which No. 2 did not have.

Baking Tests.—Typical loaves from several bins are shown in figure 14. These are from the small sacks of wheat placed in the bin at harvest time. No. 2 shows serious damage: the others may be said to show little or no damage as measured by volume and texture. The data for these baking tests are given in Table XVI.

TABLE XVI.—DATA FROM LOAVES SHOWN IN FIGURE 14.

Serial No.	Bin No.	Moisture in wheat when binned.	Loaf volume, c. c.	Texture.
		Per cent.		*Per cent.*
14797	2	17.6	1,455	88
14798	3	10.2	1,745	93
14801	4	15.4	1,675	93
14804	5	13.2	1,695	93
14807	6	15.2	1,670	93

VENTILATION FLUES

Several types of ventilation flues were tried in bins of damp wheat. One type, which has been sold in considerable numbers in Kansas, consists of a perforated steel tube 3 inches in diameter with a smaller pasteboard tube inside. Another kind was made by nailing 1- by 2-inch strips vertically and lengthwise in the center on each side of a 1- by 5-inch board. This "wooden cross" was then covered with fly-screen wire, thus providing four channels for air when placed vertically in the wheat. (Fig. 15.) These ventilators were

FIG. 14.—Typical loaves of bread from several bins. The loaf numbers correspond to bin numbers.

placed vertically in the bin when filling with wheat and allowed to extend above the wheat in the bin. Flues of this type were of no value as far as could be observed. The same was true of the small central ventilator furnished with several of the steel bins. Around these small central flues there was always an area of wetter grain than anywhere else in the bin. Ventilators of the type under discussion provide for an inlet of air and condensation of moisture, but there is not enough movement of air to carry away the moisture. Unless ventilators effect a movement of air sufficient to remove moisture or cool the wheat they do more harm than good. Enough oxygen is admitted to promote mold growth, and when such a bin was left undisturbed for a time this damp wheat became badly molded.

Central ventilators in connection with perforated walls, such as were used in bins Nos. 6 and 7, effect a movement of air which carries away moisture and also helps to cool the wheat.

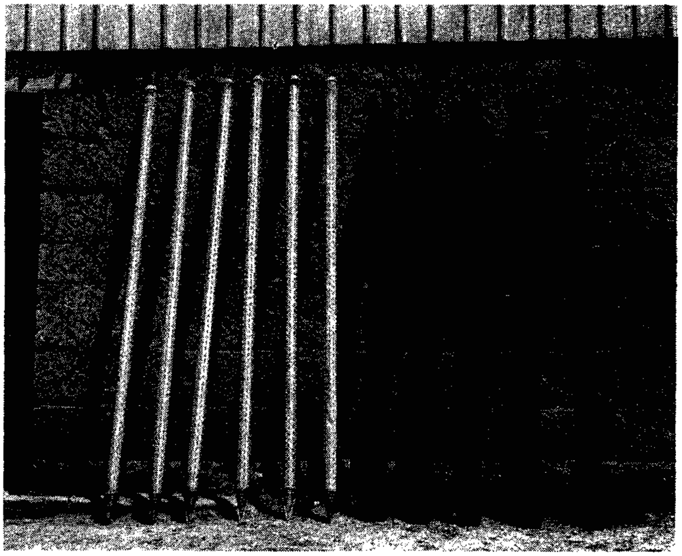

FIG. 15.—Two types of ventilation flues that were tested.

EFFECTIVENESS OF MOVING WHEAT

Moving wheat to prevent damage seems to be fairly effective. If the wheat is caked, the moving breaks up this condition and permits better air circulation. Hot pockets are broken up and redistributed. Moldy spots and damp areas are mixed with the drier wheat and the harmful effects minimized. The weather conditions have an influence upon the results obtained, since the cooling effect depends upon the difference in temperature between the outside air and the wheat. As a result of 16 comparisons it appears that moving of wheat will lower the temperature two-thirds of the difference between the wheat and the outside air tempemtures. Wheat transferred on a hot day was lowered only 2 degrees in temperature.

The drying effect of moving is more difficult to measure. Moisture determinations showed considerable variation and insufficient samples were taken to obtain an extensive record of moisture content. The wheat is undoubtedly dried somewhat by each transfer, but no definite relation could be established between moisture reduction and the number of transfers. Moving the grain six times in bin No. 2 reduced the moisture slightly over 2 per cent. The degree of saturation of the atmosphere is probably of primary importance in this connection, but the relatively low humidities existing in the Kansas wheat belt during the harvest season make it fairly certain that any movement, especially with a blower elevator, would reduce the moisture content.

EFFECT OF TYPE OF BIN ON HEATING OF WHEAT

It is impossible to make any definite comparisons of the different bins because the wheat was not uniform in moisture content or other characteristics. It is true that the wheat in the ventilated steel bin No. 6 with a relatively high moisture content did not heat; however, this wheat was windrowed while that in the steel and concrete bins was combined and contained a larger percentage of green kernels. The wheat stored in the wooden bins was comparatively dry. The data indicate that wheat stored in tight-walled bins heats more quickly than that in the ventilated types.

CONCLUSIONS FROM THE 1929 STORAGE EXPERIMENTS

1. Any wheat stored with a moisture content of 15 per cent or higher is likely to be damaged because of heating. Such damage lowers the market grade, seriously impairs the viability, and lowers the milling and baking value.
2. Wheat stored in tight-walled bins seems more likely to heat than when stored in ventilated bins.
3. It is possible to prevent severe damage to damp wheat by moving it as soon as it starts heating. This moving will be effective in proportion as it cools the wheat and removes moisture.
4. The power cost of moving wheat is very small, amounting to from 8 to 15 cents for 500 bushels.
5. Hot weather influences heating of wheat in steel bins more than in bins better insulated.
6. When the outside temperature is low and the bin is filled with hot wheat there is a decided condensation of moisture on the wheat near the outside walls, especially in the steel and concrete stave bins. This causes the outside 6 or 8 inches of wheat to mold more rapidly.
7. In this experiment the wheat stored in wooden bins was not damp enough to create a storage problem.
8. No definite comparisons can be made of the merits of different types of bins because the wheat was not uniform in quality or moisture content in all bins.
9. Insulation may be a valuable asset in preventing the heating of wheat in hot weather.
10. Ventilation appears to be an important factor in preventing heating of wheat in storage. This ventilation, however, must facilitate air movements sufficient to cool the wheat and remove moisture. Ventilators which do not accomplish this do more harm than good.

COMPARING TYPES OF VENTILATION, FORT HAYS STATION, 1930

PURPOSE OF THE STUDY

The work in 1929 indicated that the material of which the bin was constructed was probably of less importance than the type of ventilation. The work in 1930 was an attempt to determine the best methods of ventilation and the effect of ventilation upon the removal of moisture, cooling, and the prevention of damage.

GENERAL DESCRIPTION OF THE EXPERIMENT

Wheat was stored in five bins of 1,000-bushel capacity, each bin representing a different type of ventilation. The wheat stored was combined before it

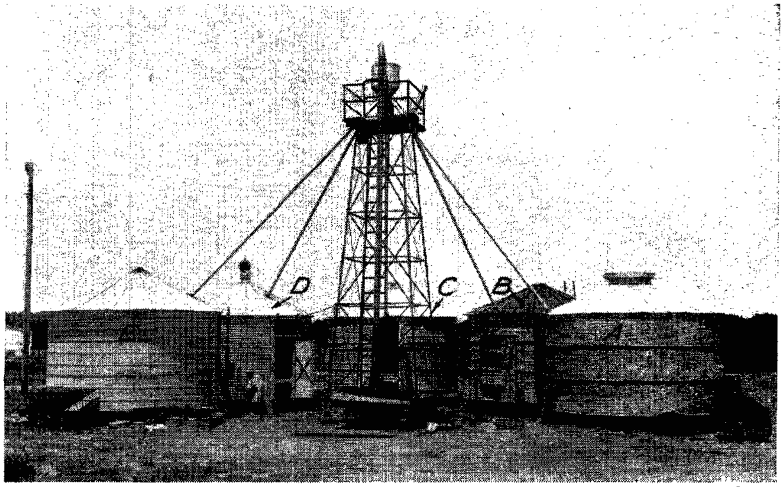

FIG. 16.—The bin arrangement used in the 1930 storage experiments. A blower elevator raised the grain to the top of the tower where a dividing mechanism distributed it equally among the five bins.

was entirely ripe, and contained enough moisture to create a difficult storage problem. Each load of wheat was divided equally among the five bins, thus providing wheat of similar quality and condition in each bin. The elevator, dividing mechanism, and arrangement of bins are shown in figure 16. Frequent samples of the wheat were taken as described later to give accurate data on moisture content, quality, and condition of wheat. Daily temperature readings were taken at six representative points in each bin by electrical resistance thermometers.

An attempt was made to prevent excessive heating of the wheat in four bins by moving the grain. In the fifth bin the grain was purposely left undisturbed during the period of the test. The bins were filled during the last few days in June and emptied on November 3 and 4.

BINS USED IN THE EXPERIMENT

The bins were furnished by the steel bin manufacturers. Each bin was selected to represent a different kind of ventilation. No attempt was made to force air through the wheat artificially. The following brief description of the bins may be followed more easily by referring to figure 17 which shows the type of ventilation in each of the five bins.

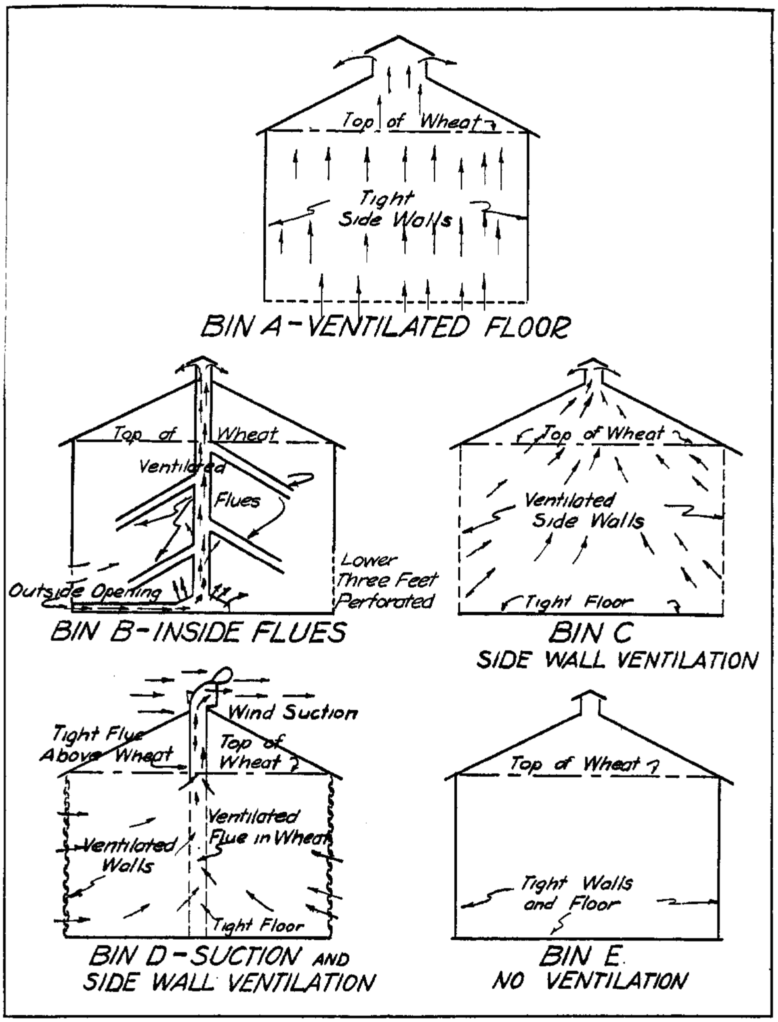

FIG. 17.—Different types of ventilation used in the 1930 storage experiments.

Bin A had tight outside walls, a screen bottom, and a large ventilator on the roof. This bin was built especially for this test. The ventilation is provided by an upward movement of air through the wheat.

Bin B was a special bin having inside ventilation flues. A large central flue made of perforated sheet steel extended from the floor upward into a small cupola on the roof. The bottom of this flue was connected by a small horizontal pipe to the outside air through the door of the bin. In this way free circulation of air was promoted in this vertical flue. From this central flue were a number of smaller flues extending outward to within about 1 foot of the side walls.

Bin C had small perforations in the side walls, a tight metal floor, and a small cupola on the roof.

Bin D was constructed with perforated side walls and a vertical flue 10 inches in diameter on the top of which was a revolving suction cupola. This bin was similar to bins Nos. 6 and 7 used in 1929.

Bin E contained no ventilation system. It was of the type commonly sold throughout the wheat belt and may be described as a steel bin with tight walls and floor.

The transfer bin, a bin similar to bin E, was provided into which the wheat was transferred whenever heating occurred. It was then moved back to the original bin.

METHOD OF HANDLING THE WHEAT

A blower type of elevator was used to move the grain. This elevator was driven by a 7½ h. p. electric motor mounted on a frame with the blower. This outfit would raise the grain 30 feet, which was ample to permit separa-

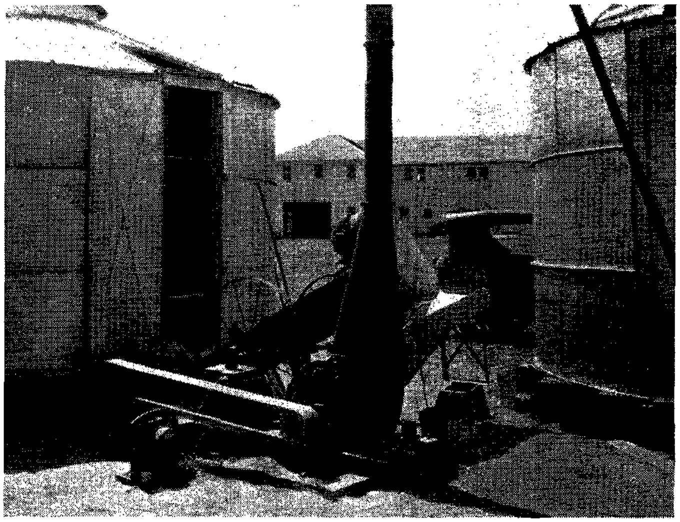

FIG. 18.—Transferring wheat from one bin to another for purposes of cooling and drying.

tion of the grain into five equal streams, one running into each bin. In moving the wheat the grain was allowed to fall through a hole in the bin floor into an auger-type conveyor beneath the bin. This conveyor carried the wheat to the hopper of the blower elevator from which it was blown into the transfer bin. The method of returning the wheat was similar. With these devices wheat could be moved very rapidly, but considerable breaking of the grain occurred, particularly toward the end of the experiment when the grain became dry. The mechanical equipment for moving the grain is shown in figure 18.

SAMPLES TAKEN DURING THE EXPERIMENT

Samples of wheat were taken for two purposes:

1. To determine its moisture content.
2. To determine its quality by milling and baking tests and by market grading.

Samples for Moisture Determination.—A sample was taken from each load of wheat as it was delivered to the bins. A cupful was taken from several parts of the load as it was being emptied into the hopper. This sample was divided by a Boerner sample divider until a quantity was secured small enough to fill a pint fruit jar. The jar was tightly closed and the moisture determinations made as soon as possible. Samples for moisture content were also taken each time the grain was moved, at which time an attempt was made to secure composite representative samples from each of three parts of the bin—top, center, and bottom.

Samples for Milling, Baking, and Other Tests.—Samples were taken of the wheat as it left the trucks and these were composited as follows: Loads 1-15; 16-26; 27-37; 38-47, and 48-68. Each of these large composite samples was divided into six subsamples of 8 to 10 pounds each and placed in cloth sacks. Five of the six samples from each group of loads were buried in the bins along with the wheat from which the samples were taken, thus five sacks were buried in each bin. When the wheat was transferred these samples were moved with the wheat and returned to the position formerly occupied. The sixth sample of each lot was placed in good storage conditions and was used as a control for the samples in the bin.

Each time the wheat was moved three samples of wheat were taken, one near the top, one near the center, and one near the bottom. These samples were placed in sacks and stored where rapid drying would take place. Three samples were also taken from each bin, except bin B, at the end of the experiment; eight samples were taken from bin B.

THE CONDITION OF THE WHEAT USED IN THE EXPERIMENT

The wheat was purchased from six different farmers living in the vicinity of Hays. They were asked to start the harvesting machines a day or two earlier than they would normally have done, in order to supply damp wheat. The moisture analysis showed that the wheat contained more moisture than it appeared to have from casual observation. The wheat as indicated below was much damper than that commonly stored in farm bins:

	Average moisture
Loads 1-15	17.75 per cent
Loads 16-26	18.40 per cent
Loads 27-37	17.88 per cent
Loads 38-47	16.00 per cent
Loads 48-68	17.75 per cent
Average	17.50 per cent

This wheat graded No. 2 and No. 3 with from 3 to 5 per cent damage after it had dried out under ideal storage conditions.

WHEAT AND WEATHER TEMPERATURE

The weather was very hot during the summer of 1930. The temperature of the wheat when placed in the bins was high and due to the high moisture content it very soon began to heat in all the bins. Moving the wheat proved to be rather ineffective in cooling it sufficiently.

Figure 19 indicates the changes in temperature of the wheat during the entire storage period. These curves show the gradual rise in temperature as the wheat heated, the abrupt drop in temperature due to moving the wheat, the maximum and minimum temperatures during heating and cooling, and the gradual decline in temperature after all heating ceased. After the wheat had been moved the first time it always heated more rapidly than before. The aeration accomplished by the transfer furnished oxygen for the respiration of both wheat and mold and, hence, increased the rate of rise in temperature. The results secured from each bin will be discussed in detail.

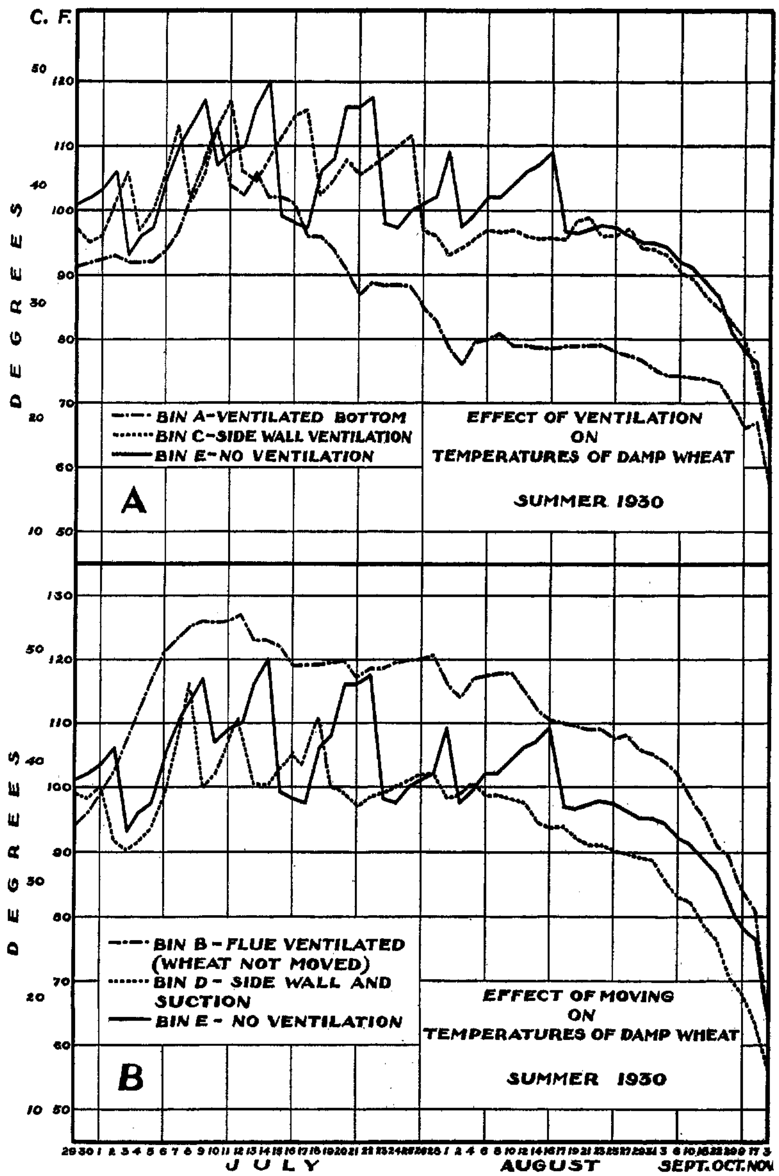

FIG. 19.—Effect of ventilation (A) and moving (B) on temperatures of damp wheat, summer, 1930.

OBSERVATIONS ON THE TEMPERATURE CHANGES AND ON THE CONDITION OF THE WHEAT IN THE DIFFERENT BINS

Bin A, Bottom Ventilation.—In bin A the effect of the bottom ventilation was very noticeable from the beginning in that the grain in the lower part of the bin did not become hot. There were hot places in the upper half and the wheat was moved on the sixth day after the bin was filled. The average temperature of this wheat was low because of the cool part near the bottom. The grain was moved three times although the third moving was probably un-

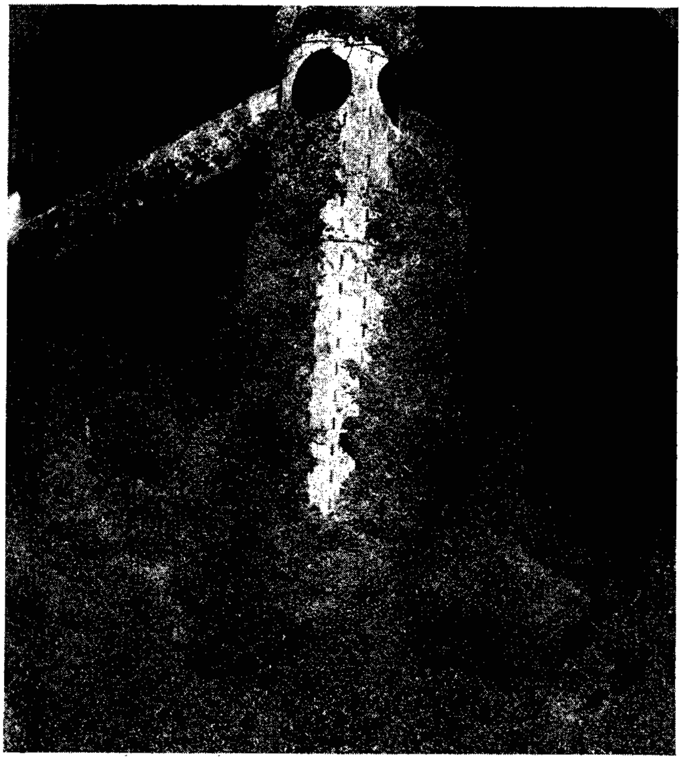

FIG. 20.—Wheat sticking on a central ventilating flue, showing that such a flue is ineffective in preventing damage to a bin of damp wheat.

necessary since the wheat was in good condition at this time and the temperature was falling. After the third transfer the temperature continued to move downward to the end of the storage period in November.

At the first two transfers the wheat was uniformly caked and somewhat musty except near the walls, top, and bottom. The caking was much less at the third transfer. At the final moving the wheat appeared dry and in fairly good condition considering the original quality.

Bin B, Special Flue Ventilation.—The wheat in this bin was not moved during the entire storage period, the manufacturer of the bin requesting that the wheat be left undisturbed. The temperatures increased rapidly and remained high during most of the storage period. The maximum temperature recorded in this bin was 131° F. (55° C.), while the average of the six thermometers was between 120° F. and 130° F. (48.9-54.4° C.) during most of the storage period, The flue ventilation system seemed to be of no value in cooling or drying the wheat and did not prevent damage.

Since no transfers of the grain were made, no observations could be taken during the storage period. When the wheat was removed it was moldy and caked so that it would stand vertically from top to bottom, and was extremely dusty. The wheat was so badly damaged that it was unfit for anything but very poor hog feed. Figure 20 shows the damaged wheat caked on the central flue when the wheat was removed from the bin.

Bin C, Side-wall Ventilation.—The wheat in this bin was moved 5 days from the beginning of the storage period, at, which time the temperature was 115°F. (46.1° C.) and the moving cooled it to about 98° C. (36.7° F.), from which point it rapidly rose to 122° F. (50° C.) in 4 days. The side-wall ventlla-tion was ineffective in preventing heating of this grain. The wheat in this bin was moved five times. After the fifth transfer, on July 26, no further heating occurred. The wheat was caked considerably throughout the bin at each of the transfers, but less so near the top and next to the wall. At the third, fourth, and fifth transfers the wheat was still damp and somewhat moldy.

Bin D, Side-wall Ventilation with Suction Cupola.—The temperature changes in this bin were similar to those in bin C., although the maximum did not quite reach 120° F. (48.9° C.). The first transfer was on the third day and the wheat was moved four times to prevent excessive heating, but after July 19 no serious heating occurred. The caking and molding were not uniformly distributed, being noticeable near the central flue and in a few places near the walls. At the last moving the wheat would run freely, but was dusty.

Bin E, Tight-walled Bin, No Ventilation.—The temperatures recorded in this bin were the highest of those in which the grain was moved. The first transfer was on the fourth day and it was necessary to transfer the wheat six times to prevent excessive heating. The heating continued nearly a month after the ventilated bins had stopped heating.

The wheat was found to be caked and somewhat moldy at several of the transfers. The mold was worst near the small central flue. At the last transfer there was less caking and apparently no additional mold, the wheat appearing dry but dusty at the end of the experiment.

THE EFFECT OF VENTILATION ON THE TEMPERATURE OF WHEAT IN STORAGE

Due to high moisture content of the wheat and the extreme heat of the summer the ventilation was not adequate in any bin to prevent heating. Some damage occurred in all of the bins. However, the temperature records shown graphically in figure 21 indicate in a striking manner the effect of ventilation on the temperature of the wheat. In bin A, for example, the thermometer near the ventilated bottom averaged nearly 14° F. (7.8° C.) cooler than the one most distant from the bottom. Also, in bins C and D the thermometers near the ventilated side-walls show much lower temperatures than those near the center of the bin. The ventilated bins averaged lower in temperature than the unventilated ones in spite of the fact that the wheat was transferred less frequently.

It is also noticeable that the two bins, A and D, that had the best ventila-tion, cooled down more rapidly when the fall weather came on. Probably if the summer heat had been less intense the effect of the ventilation upon wheat temperatures might have been more noticeable.

The persistent appearance of moldy spots near the wall in bin C and near the walls and central flue in bins D and E indicate that a limited supply of air is conducive to more excessive molding. To prevent this it is necessary to provide sufficient ventilation to remove the excess moisture.

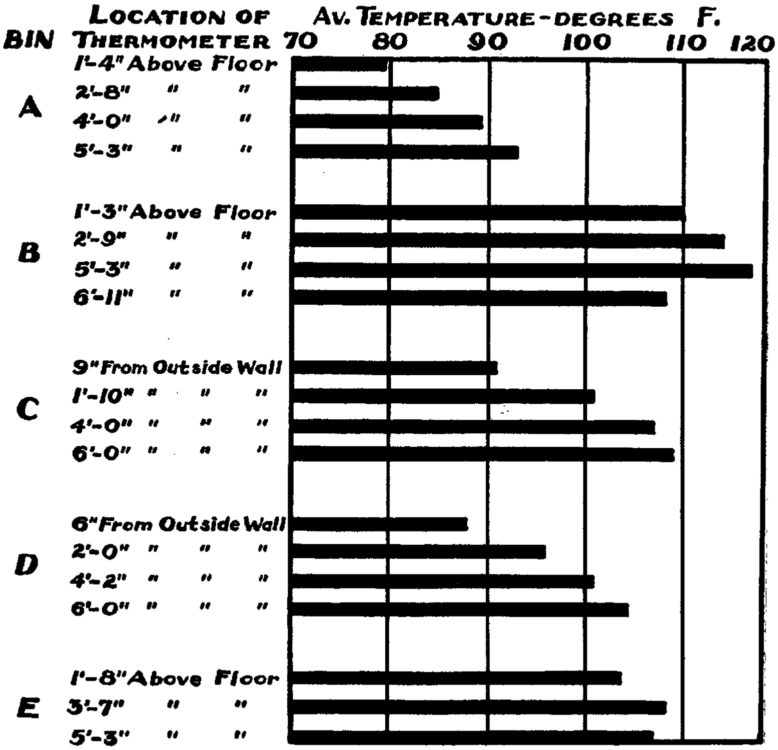

FIG. 21.—Graphic illustration of the effect of ventilation upon the temperature of the wheat in the storage bins.

THE EFFECT OF VENTILATION ON THE MOISTURE CONTENT OF THE WHEAT

At the end of the storage period, November 1, the following average per cents of moisture were found in the wheat in the different bins: A, 12.2; B, 13.8; C, 12.0; D, 11.6; and E, 12.0. The data as to moisture contents at the time of the various transfers are found in Table XVII.

The ventilation did not have so apparent an effect upon moisture content as upon temperature of the grain. About 5.5 per cent of moisture on the average was removed from the grain during the storage period. In bin A three transfers of the wheat removed about 2.52 per cent of moisture, leaving about 3 per cent to be removed by the ventilation. In the tight-walled bin E, which theoretically had no ventilation, six transfers removed only about 3 per cent moisture, so that the remaining 2.5 per cent must have evaporated even though there was no special provision for ventilation. In bin B, left undisturbed throughout the storage period, 3.7 per cent moisture was lost from the grain even though it was not moved.

TABLE XVII.—EFFECT UPON THE MOISTURE CONTENT OF MOVING WHEAT WITH BLOWER ELEVATOR.

DATE.	Bin.	Weather conditions.		Moisture content of grain.		Changes in moisture content.	
		Maximum temperature.	Lowest relative humidity.	Before moving.	After moving.	Decrease.	Increase.
				Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
7- 1-30	D	100	30	17.63	17.33	0.30	....
7- 2-30	E	102	32	17.27	16.96	.31	....
7- 3-30	C	98	36	17.03	16.51	.52	....
7- 4-30	A	105	24	16.73	16.50	.23	....
7- 7-30	C	105	28	17.10	16.06	1.04	....
7- 8-30	D	100	30	16.00	15.70	.30	....
7- 9-30	E	102	30	16.00	15.75	.25	....
7-10-30	A	101	28	16.13	16.00	.13	....
7-11-30	C	108	28	16.20	15.33	.87	....
7-12-30	D	103	30	15.06	14.82	.24	....
7-14-30	E	90	32	15.60	15.02	.58	....
7-16-30	A	105	25	15.30	14.52	.78	....
7-17-30	C	110	18	13.86	14.05	....	0.19
7-18-30	D	112	17	14.46	13.77	.69	....
7-22-30	E	110	56	14.53	14.55	....	.02
7-25-30	C	102	31	14.20	13.97	.23	....
8- 1-30	E	100	32	14.00	13.80	.20	....
8-16-30	E	113	17	13.50	13.37	.13	....

EFFECT OF STORAGE ON THE GRADING OF THE WHEAT

At the close of the experiment, half-pound portions of all samples of wheat taken during the experiment were submitted to O. F. Phillips, chairman of the Board of Review, Federal Grain Supervision, Chicago, to be graded. The results of this examination are given in Tables XVIII and XIX.

TABLE XVIII.—GRADING DATA ON SAMPLES STORED IN BINS IN SACKS AND THOSE TAKEN AT THE VARIOUS TRANSFERS.

Serial No.	ORIGIN OF SAMPLES.	Per cent of moisture.	Odor.	Per cent of damage.	Grade.	Per cent broken.
	Bin A.					
15982	Loads 1-15 buried 18″ from bottom....	17.75	O. K......	3.0	No. 2........	....
15983	Loads 16-26 buried 3′ from bottom....	18.40	Musty.....	8.5	No. 5........	....
15984	Loads 27-37 buried center of bin......	17.88	Musty.....	15.0	No. 5........	....
15985	Loads 38-47 buried 3′ from top........	16.00	Musty.....	9.0	No. 5........	....
15986	Loads 48-68 buried 18″ from top......	17.75	Musty.....	17.0	Sample grade	....
15987	First transfer, July 4, near top........	16.70	O. K......	12.0	No. 5........	....
15988	First transfer, July 4, near middle.....	16.30	Musty.....	10.0	No. 5........	....
15989	First transfer, July 4, near bottom.....	17.30	O. K......	3.8	No. 2........	....
15990	Second transfer, July 10, near top.....	16.30	Musty.....	23.0	Sample grade	....
15991	Second transfer, July 10, near middle..	16.20	O. K......	11.0	No. 5........	....
15992	Second transfer, July 10, near bottom..	15.90	O. K......	8.0	No. 4........	....
15993	Third transfer, July 16, near top......	15.60	Musty.....	40.0	Sample grade	....
15994	Third transfer, July 16, near middle...	15.40	O. K......	13.0	No. 5........	....
15995	Third transfer, July 16, near bottom...	14.90	Musty.....	16.0	Sample grade	....
15996	When moving, Nov. 3, first half.......	12.20	Musty.....	30.0	Sample grade	....
15997	When moving, Nov. 3, center.........	12.30	Musty.....	18.0	Sample grade	....
15998	When moving, Nov. 3, second half....	12.10	Musty....	20.0	Sample grade	....
	Bin B.					
15999	Loads 1-15 buried 18″ from bottom....	17.75	Musty.....	100.0	Sample grd.(*a*)	....
16000	Loads 16-26 buried 3′ from bottom....	18.40	Musty.....	100.0	Sample grd.(*a*)	....
16001	Loads 27-37 buried center of bin......	17.88	Musty.....	100.0	Sample grd.(*a*)	....
16002	Loads 38-47 buried 3′ from top........	16.00	Musty.....	100.0	Sample grd.(*a*)	....
16003	Loads 48-68 buried 18″ from top......	17.75	Musty.....	100.0	Sample grd.(*a*)	....
16004	First out, Nov. 3....................	12.10	Very musty	60.0	Sample grade	....
16005	Moldy wheat near radial ventilators, Nov. 3........................	15.00	Very musty	100.0	Sample grade	....
16006	Moldy pocket, Nov. 3.................	14.20	Very musty	100.0	Sample grade	....
16006*a*	Nonmoldy portion, best appearing, Nov. 3..........................	13.40	Musty.....	100.0	Sample grade	....
16006*b*	Bad portion, Nov. 3.................	20.00	Very musty	100.0	Sample grade	....
16006*c*	First composite, Nov. 3.............	13.80	Musty.....	95.0	Sample grade	....
16006*d*	After moving, Nov. 3................	14.10	Musty.....	96.0	Sample grade	....
16006*e*	Second composite, Nov. 3...........	13.60	Musty.....	80.0	Sample grade	....
	Bin C.					
16007	Loads 1-15 buried 18″ from bottom....	17.75	Musty.....	55.0	Sample grade	....
16008	Loads 16-26 buried 3′...............	18.40	Musty.....	38.0	Sample grade	....
16009	Loads 27-37 buried center of bin......	17.88	Musty.....	70.0	Sample grade	....
16010	Loads 38-47 buried 3′ from top........	16.00	Musty.....	39.0	Sample grade	....
16011	Loads 48-68 buried 18″ from top......	17.75	Musty.....	32.0	Sample grade	....
16012	First transfer, July 3, near top.......	17.10	O. K......	7.0	No. 3........	....
16013	First transfer, July 3, near middle.....	16.80	Musty.....	34.0	Sample grade	....
16014	First transfer, July 3, near bottom.....	17.20	Musty.....	32.0	Sample grade	....
16015	Second transfer, July 7, near top......	16.90	Musty.....	20.0	Sample grade	....
16016	Second transfer, July 7, near middle...	18.90	Musty.....	9.0	No. 5........	....
16017	Second transfer, July 7, near bottom...	17.20	Musty.....	10.0	No. 5........	....
16018	Third transfer, July 11, near top......	16.10	Musty.....	40.0	Sample grade	....
16019	Third transfer, July 11, near middle...	16.40	Musty.....	42.0	Sample grade	....
16020	Third transfer, July 11, near bottom...	16.10	Musty.....	44.0	Sample grade	....
16021	Fourth transfer, July 17, top..........	14.30	Musty.....	35.0	Sample grade	....
16022	Fourth transfer, July 17, near middle..	13.50	Musty.....	40.0	Sample grade	....
16023	Fourth transfer, July 17, near bottom..	13.80	Musty.....	33.0	Sample grade	....
16024	Fifth transfer, July 25, near top.......	14.20	Musty.....	35.0	Sample grade	7.0
16025	Fifth transfer, July 25, near middle....	14.30	Musty.....	37.0	Sample grade	9.0
16026	Fifth transfer, July 25, near bottom....	14.10	Musty.....	49.0	Sample grade	6.5
16027	Taken at last moving, Nov. 4, from first part.........................	12.00	Musty.....	55.0	Sample grade	8.0
16028	Taken at last moving, Nov. 4, from center............................	12.10	Musty.....	56.0	Sample grade	9.0
16029	Taken at last moving, Nov. 4, from second part.......................	12.00	Musty.....	58.0	Sample grade	11.0

TABLE XVIII—CONCLUDED.

Serial No.	ORIGIN OF SAMPLES.	Per cent of moisture.	Odor.	Per cent of damage.	Grade.	Per cent broken.
	Bin D.					
16030	Loads 1-15 buried 18″ from bottom....	17.75	O. K.......	7.0	No. 3........	....
16031	Loads 16-26 buried 3′ from bottom....	18.40	O. K.......	5.5	No. 3........	....
16032	Loads 27-37 buried center of bin......	17.88	....	....	....	....
16033	Loads 38-47 buried 3′ from top........	16.00	O. K.......	6.0	No. 3........	....
16034	Loads 48-68 buried 18″ from top......	17.75	....	....	....	....
16035	First transfer, July 1, near top........	18.20	O. K.......	4.0	No. 2........	....
16036	First transfer, July 1, near middle.....	17.80	Musty.....	10.0	No. 5........	....
16037	First transfer, July 1, near bottom.....	16.90	O. K.......	4.7	No. 3........	....
16038	Second transfer, July 8, near top......	16.00	Musty.....	19.0	Sample grade	....
16039	Second transfer, July 8, near middle...	16.00	O. K.......	15.0	No. 5........	....
16040	Second transfer, July 8, near bottom...	16.00	O. K.......	8.0	No. 4........	....
16041	Third transfer, July 12, near top......	15.40	Musty.....	12.0	No. 5........	....
16042	Third transfer, July 12, near middle...	15.70	Musty.....	38.0	Sample grade	....
16043	Third transfer, July 12, near bottom...	14.10	O. K.......	6.0	No. 3........	....
16044	Fourth transfer, July 18, near top.....	15.10	O. K.......	8.0	No. 4........	....
16045	Fourth transfer, July 18, near middle..	14.30	O. K.......	9.0	No. 4........	....
16046	Fourth transfer, July 18, from bottom,	14.00	O. K.......	6.0	No. 3........	....
16047	Before last moving, Nov. 4, first part..	11.20	O. K.......	9.0	No. 4........	....
16048	After last moving, Nov. 4, center......	11.90	O. K.......	11.0	Sample grade	12.0
16049	Before last moving, Nov. 4, second part.	11.70	O. K.......	15.0	No. 5........	....
	Bin E.					
16050	Loads 1-15 buried 18″ from bottom....	17.75	O. K.......	3.5	No. 2........	....
16051	Loads 16-26 buried 3′ from bottom....	18.40	Musty.....	16.0	Sample grade	....
16052	Loads 27-37 buried center of bin......	17.88	Musty.....	25.0	Sample grade	....
16053	Loads 38-47 buried 3′ from top........	16.00	Musty.....	12.0	No. 5........	....
16054	Loads 48-68 buried 18″ from top......	17.75	....	....	....	....
16055	First transfer, July 2, near top........	18.20	O. K.......	5.0	No. 3........	....
16056	First transfer, July 2, near middle.....	16.00	O. K.......	6.0	No. 3........	....
16057	First transfer, July 2, near bottom.....	17.60	O. K.......	7.0	No. 3........	....
16058	Second transfer, July 9, near top......	16.00	O. K.......	13.0	No. 5........	....
16059	Second transfer, July 9, near middle...	16.40	Musty.....	44.0	Sample grade	....
16060	Second transfer, July 9, near bottom...	15.60	Musty.....	75.0	Sample grade	....
16061	Third transfer, July 14, near top......	15.60	Musty.....	38.0	Sample grade	....
16062	Third transfer, July 14, near middle...	16.10	Musty.....	30.0	Sample grade	....
16063	Third transfer, July 14, near bottom...	15.10	....	....	....	....
16064	Fourth transfer, July 22, near top.....	14.60	Musty.....	42.0	Sample grade	....
16065	Fourth transfer, July 22, near middle..	14.70	Musty.....	43.0	Sample grade	5.0
16066	Fourth transfer, July 22, near bottom..	14.30	O. K.......	15.0	No. 5........	5.8
16067	Fifth transfer, Aug. 1, near top........	13.90	O. K.......	18.0	Sample grade	....
16068	Fifth transfer, Aug. 1, near middle.....	14.10	O. K.......	20.0	Sample grade	6.0
16069	Fifth transfer, Aug. 1, near bottom....	14.00	Musty.....	40.0	Sample grade	....
16070	Sixth transfer, Aug. 16, near top......	13.50	Musty.....	41.0	Sample grade	11.0
16071	Sixth transfer, Aug. 16, near middle...	13.40	Musty.....	48.0	Sample grade	13.5
16072	Sixth transfer, Aug. 16, near bottom...	13.60	O. K.......	45.0	Sample grade	10.0
16073	Before last moving, Nov. 4, first part..	11.80	Musty.....	47.0	Sample grade	11.0
16074	After last moving, Nov. 4, center......	11.90	Musty.....	48.0	Sample grade	11.5
16075	Before last moving, Nov. 4, second part.	12.40	Musty.....	50.0	Sample grade	9.5

(*a*) Approximately all heat damaged.

TABLE XIX.—PERCENTAGE MOISTURE DAMAGE AND GRADE OF SAMPLES TAKEN AT THE TIME OF BINNING AND STORED UNDER IDEAL STORAGE CONDITIONS.

Serial No.	ORIGIN OF SAMPLE.	Moisture.		Odor.	Per cent damage.	Grade.
		Original.	Final.			
16076	Loads 1-15	17.75	12.3	O. K.	4.0	No. 2
16077	Loads 16-26	18.40	12.3	O. K.	3.2	No. 2
16078	Loads 27-37	17.88	12.3	O. K.	4.0	No. 2
16079	Loads 38-47	16.00	12.3	O. K.	3.5	No. 2
16080	Loads 48-68	17.75	12.3	O. K.	5.5	No. 3

EXTENT OF DAMAGE TO THE WHEAT IN BINS

A summary of the data presented in Table XVIII concerning odor, percentage of damage, and grade of the samples is presented in Table XX. This summary shows clearly that the wheat on the whole was badly damaged and that none of the bins was capable of handling the very damp wheat under the conditions of the extreme heat of the 1930 season. The wheat used, however, was not very good as shown by the fact that it graded No. 2 and 3, with 4 to 5 per cent damage even when stored under ideal conditions.

TABLE XX.—NUMERICAL SUMMARY OF THE AMOUNT OF DAMAGE IN THE DIFFERENT BINS.

Bin.	Number of transfers.	Total number of samples.	Odor.			Grade.					
			O. K.	Musty.	Very musty.	1.	2.	3.	4.	5.	Sample.
A	3	17	6	11	0	0	2	0	1	7	7
B	0	13	0	9	4	0	0	0	0	0	13
C	5	23	1	22	0	0	0	1	0	2	20
D	4	18	14	4	0	0	1	6	4	4	3
E	6	24	9	15	0	0	1	3	0	3	17

The amount of damage increased in the bins as the period of heating was prolonged. The wheat in bin E, which continued to heat until the middle of August and had to be transferred six times, showed more damage than that in those bins in which the heating ceased earlier. The wheat in bin B, which was not moved and was allowed to heat to the limit, showed 100 per cent damage. Bins A and D contained less damaged wheat than any of the other bins and also kept the temperature lower. The wheat in bin D showed slightly less damage than that in bin A, although it heated for a longer period and was transferred once more than bin A. It is probably unfair to draw an absolute comparison among these bins because the wheat was not transferred at the same time. Since the wheat in bin A showed the least serious heating it was always the last one to be moved, and this might account for the slightly greater damage in this bin than in bin D.

The fact that the samples of wheat taken during the last transfer graded more damage than those samples in sacks buried in the bins indicates that the blower was responsible for a part of the damage. The cracking of the wheat was very noticeable during the last transfers when the grain was drier.

DAMAGE MEASURED BY MILLING TESTS

The various wheat samples taken during the experiment were milled on the experimental mill. To determine as far as possible the effect of storage on the milling properties, the flour was weighed separately as break, tailings, and middlings flours, and the percentages of each calculated. The percentage total flour was calculated on the basis of the amount of wheat milled. As ash or mineral matter is a measure of cleanness of separation of endosperm from bran, the ash content of the break, tailings, and middlings flours were determined separately. A study of the figures obtained showed that the differences among the samples from the same bin were not significant and, hence, only the averages of the samples from each bin are presented in Table XXI.

TABLE XXI.—PERCENTAGES OF FLOUR AND ASH.

Bin.	Flour percentage.				Ash percentage.		
	Break.	Tailings.	Middlings.	Total.	Break.	Tailings.	Middlings.
A	15.8	5.0	46.9	67.7	0.73	0.65	0.53
B	15.6	5.4	45.7	66.7	.96	.83	.74
C	16.9	4.9	46.6	68.4	.75	.65	.53
D	15.7	4.8	47.7	68.2	.74	.67	.53
E	17.1	5.2	45.7	68.0	.75	.67	.55
Check samples	13.3	5.2	50.9	69.4	.70	.65	.49

The figures in Table XXI do not show any essential differences among the bins A, C, D, and E. However, when the results are compared with the check samples, it becomes evident that the wheat in all the bins had suffered some damage in its milling characteristics. Less break flow, more middlings, and more total flour were obtained from the check samples than from any of the wheats from the bins, and this greater extraction was obtained with a lower ash content.

The wheat in bin B had a much more brittle bran which increased the ash content of the flour above that of the other bins. This shows the harm to the milling value of wheat which may follow by adding "bin burnt" wheat. The "bin burnt" bran pulverizes more easily and as a result more bran is introduced into the flour causing a darker color. As long as the ash content and color are used in evaluating flour, mixing "bin burnt" wheat with sound wheat will cause harm proportional to the damaged wheat added.

DAMAGE MEASURED BY BAKING TESTS

The flours from all the samples recorded in Table XVIII were baked by the standard fermentation method. The average of the results obtained from each set of five samples buried in the bins at the time of filling, the averages from each set of the three samples taken at each transfer, and the averages from the five check samples are given in Table XXII.

All the samples showed some deterioration as compared with the average of the check samples stored in the laboratory. The least damage to the baking qualities was in the samples from bins D and E. In both bins A and C there was an improvement in the baking qualities of the samples taken at the third transfer as compared with those taken at the first transfer. In bin A, however, the quality obtained from the final samples is as good as that at the third transfer, but in bin C there was a marked deterioration in the samples taken at

TABLE XXII.—AVERAGE BAKING RESULTS OF 1930 TESTS.

SAMPLES WHICH WERE AVERAGED.	Time in bins.	Loaf volume, c. c.	Color, per cent.	Texture, per cent.
Bin A.				
Samples buried in wheat at time of filling	....	1,430	95	90
First transfer	5 days	1,335	94	87
Second transfer	11 days	1,450	95	92
Third transfer	17 days	1,520	96	96
Last moving	4 months	1,520	96	97
Grand average	....	1,450	95	93
Bin B.				
No results. Flour would not make dough.				
Bin C.				
Samples buried in wheat at time of filling	....	1,486	95	95
First transfer	4 days	1,450	95	89
Second transfer	8 days	1,470	96	91
Third transfer	12 days	1,540	96	95
Fourth transfer	18 days	1,395	93	91
Fifth transfer	26 days	1,360	93	90
Last moving	4 months	1,340	90	88
Grand average	....	1,440	94	91
Bin D.				
Samples buried in wheat at time of filling	....	1,550	98	95
First transfer	2 days	1,560	98	96
Second transfer	9 days	1,580	98	96
Third transfer	13 days	1,530	98	95
Fourth transfer	19 days	1,575	98	92
Last moving	4 months	1,540	98	94
Grand average	....	1,560	98	94
Bin E.				
Samples buried in wheat at time of filling	....	1,540	94	96
First transfer	3 days	1,590	97	97
Second transfer	10 days	1,525	97	97
Third transfer	15 days	1,540	96	97
Fourth transfer	23 days	1,460	94	95
Fifth transfer	33 days	1,480	96	95
Sixth transfer	48 days	1,525	97	95
Last moving	4 months	1,515	97	98
Grand average	....	1,520	96	96
Average of samples taken at time of filling and stored in laboratory	....	1,550	98	98

the fourth, fifth, and last transfers. If the comparison is made on the basis of the samples obtained at the last moving after 4 months of storage, then the best results were obtained from bins A and E, followed by Bin D. Not considering bin B, the poorest results were obtained from bin C. The comparatively poor showing of bin A probably is due to the fact that the wheat in this bin was always the last to be moved and since it took a whole day to move the contents of a bin, the wheat was left undisturbed three days longer each time in bin A.

In figure 22 are given photographs of loaves from the samples taken from bin E. The numbers on the loaves correspond to the last two digits of the serial numbers given in Table XVIII. That no more damage had happened to the factors which affect volume and texture was surprising. The heating and molding evidently had done no damage to the gluten that could be measured by this type of baking test.

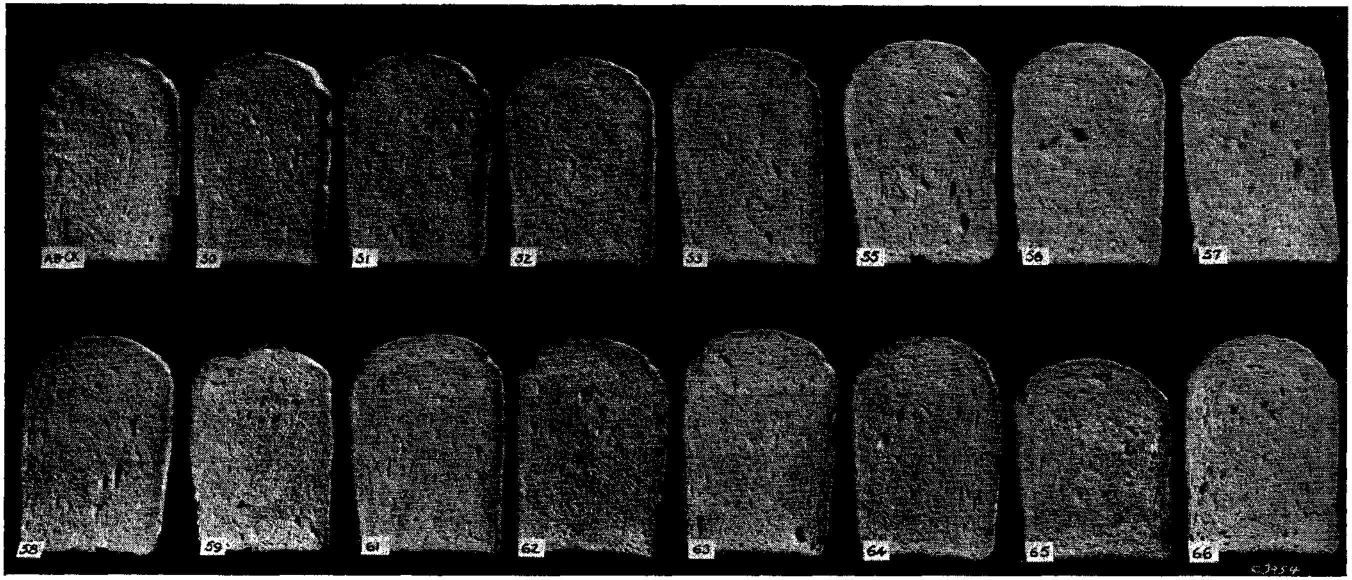

FIG. 22.—Loaves of bread made from samples of wheat from bin E. (AB-CK is a check loaf from standard flour.)

GENERAL SUMMARY OF THE 1930 TESTS

1. Wheat with a moisture content of 17.5 per cent is too damp for safe storage in any ordinary type of bin in hot weather.
2. Cooling wheat by transferring it from one bin to another is not very effective when the weather is extremely hot.
3. Ventilation is very valuable in lowering the temperature in damp wheat in storage.
4. The ventilated bottom proved to be the most effective method used to lower the temperature during the summer of 1930.
5. The bin with ventilated side walls, a flue in the center with a suction cupola on top, was also effective in cooling the wheat.
6. The ventilation flues of perforated metal are of little value in cooling the grain; in fact, they may promote molding.
7. The blower type of elevator cracks much of the grain if the moisture content is below 15 per cent.
8. The wheat in all the bins was damaged from the standpoint of milling.
9. The factors which influence loaf volume and texture were not damaged so much as some other quality factors, except in bin B.

MECHANICAL METHODS OF VENTILATION, FORT HAYS STATION, 1931

PURPOSE OF THE STUDY

The results of two previous seasons' work had demonstrated the value of ventilation in preventing damage to damp wheat in storage. It had also been shown that when the moisture content was too high and the weather hot no system of natural ventilation would solve the storage problem. During the 1931 season it was decided to try mechanical methods of ventilation and to compare these methods with the natural ventilation which had shown the greatest promise in the previous years.

BINS USED

Bins A, C, D, and E (1,000-bushel, steel) from the 1930 experiments were used; bin A, having the bottom ventilation, and bin D, the perforated side walls and the central flue with suction cupola, were used exactly as in the

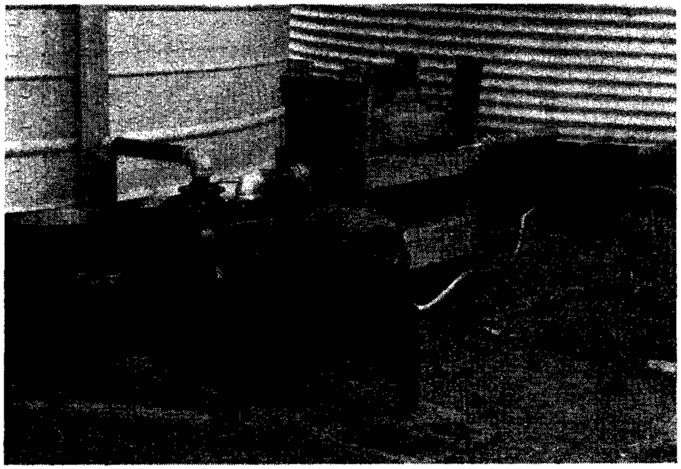

FIG. 23.—Apparatus used to draw air out of bin C in the 1931 storage experiments.

previous season. Bin C was the same as in 1930 except that air was drawn out by suction. To provide this suction an electric motor and air pump were used. The air was drawn out at four points about midway between the floor and the top of the bin and midway between the center and the side walls. (Fig. 23.) Bin E, with tight bottom and side walls, had an forced from the bottom emerging from five perforated nipples placed near the floor, one at the center and four in a circle about one-third the distance from the walls. (Fig. 24.)

AMOUNT OF FORCED VENTILATION

The amount of air forced in or out of bins C and E was measured by gas meters. From bin C the air was drawn out at a rate to provide six changes of air per hour, and into bin E the air was forced so as to provide eight changes per hour. It was assumed that the air space in the wheat was one-third of the total volume. The blower and suction apparatus were operated continuously through the months of July and August. By September 1 it was apparent that no heating was likely to occur in any of the bins, and the motors were stopped on that date.

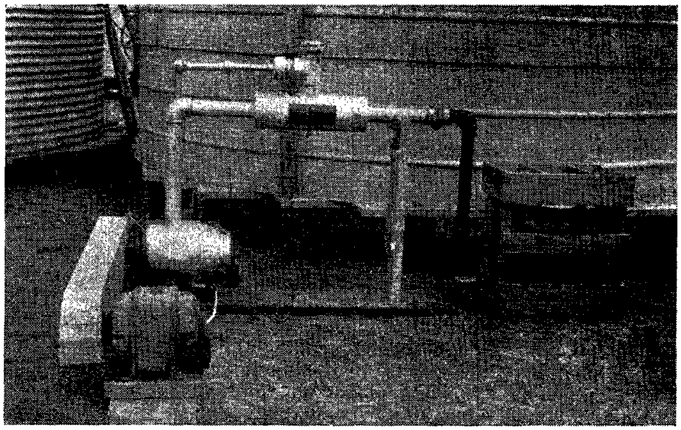

FIG. 24.—The blower used to force air through the wheat in bin E. The air was measured by a standard No. 3 gas meter.

MOISTURE CONDITION OF THE WHEAT AND SAMPLING

The wheat was harvested from the fields of the Fort Hays Agricultural Experiment Station. The cutting started June 29, 1931. Each load of wheat was elevated to the top of a steel tower, and by means of a divider one-fourth was allowed to run through conveyors into each bin. (Fig. 25.)

A representative sample of wheat was taken from each load for moisture determination by removing handfuls continuously as it was being unloaded. The large sample thus secured was then subdivided by means of a Boerner sample divider and the ultimate sample placed in a Mason jar and sealed. The moisture determination was made on a Tag-Heppenstal tester which had been calibrated against the Brawn-Duvel apparatus. On dry wheat it was possible to make this determination at once. When unripe kernels, or those in the dough stage were present, it was necessary to keep the wheat in Mason jars for 24 hours before the determinations were made.

The average moisture content of the wheat was 12.26 per cent. Most of the wheat had 10 to 11 per cent moisture. Nineteen of the 68 loads, or 22.8 per cent of the total, averaged 17.23 per cent moisture, a value too high for safe storage, but these loads were the last to be put in the bins. The other four-fifths averaged 10.8 per cent moisture content or about 2 per cent below the normal or average moisture content of wheat. This unusual dryness of nearly four-fifths of the wheat helped to prevent damage in the portions of the wheat which were high in moisture. At the time the bins were filled large representative samples were taken as described in the 1930 experiment and from these five sacks of 5,000 grams each were filled. Five such samples were taken and one of the corresponding sacks from each sample was buried near the center radially in each bin in that portion of the wheat from which the samples came. The fifth sack from each sample was stored in the laboratory.

TEMPERATURE STUDIES

Daily readings of the temperature at eight points in each bin were taken and the curves shown in figure 26 represent the daily averages throughout the storage period. Since no heating occurred in any of the bins there were no

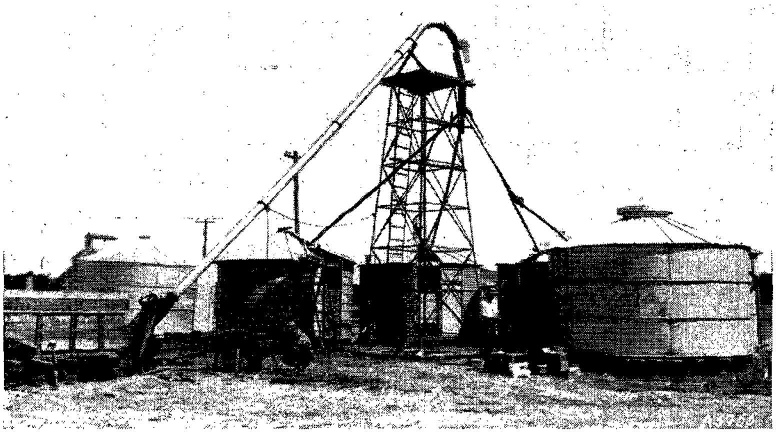

FIG. 25.—The blower-type elevator and dividing mechanism used to fill the bins during the summer of 1931.

outstanding changes in temperature. The effectiveness of the different methods of ventilation are clearly shown by the quickness with which the different bins reacted to changes in the external temperature. The bins were filled during a period of intense heat and the average initial temperature of the wheat in the bins was between 95° F. (35° C.) and 100° F. (37.8° C.) Immediately after filling, the weather turned cool and the temperature of the wheat declined rapidly. The temperature in bin E, having forced draft ventilation, dropped much more rapidly than in any other bin, falling from 95° (35° C.) to 73° F. (22.8° C.) within 10 days. Throughout the storage period, bin E with forced ventilation showed quicker response to outside temperature changes than did any other bin. Bin A with ventilated bottom remained cooler, for the most part, than the other bins. The rapid cooling of the bins soon after filling probably accounts for, at least in part, the absence of damage in that portion of the wheat stored with a high moisture content.

CONDITION OF THE WHEAT AT THE CLOSE OF TEE STORAGE PERIOD

The experiment ended October 30, 1931, when the wheat was moved from the bins. At this time samples for the determination of moisture content and for milling and baking tests were taken from several points in each of the four bins. The sacks buried in the wheat were collected and weighed as soon as removed. The moisture contents of the wheat samples taken at the close of the experiment are given in Table XXIII.

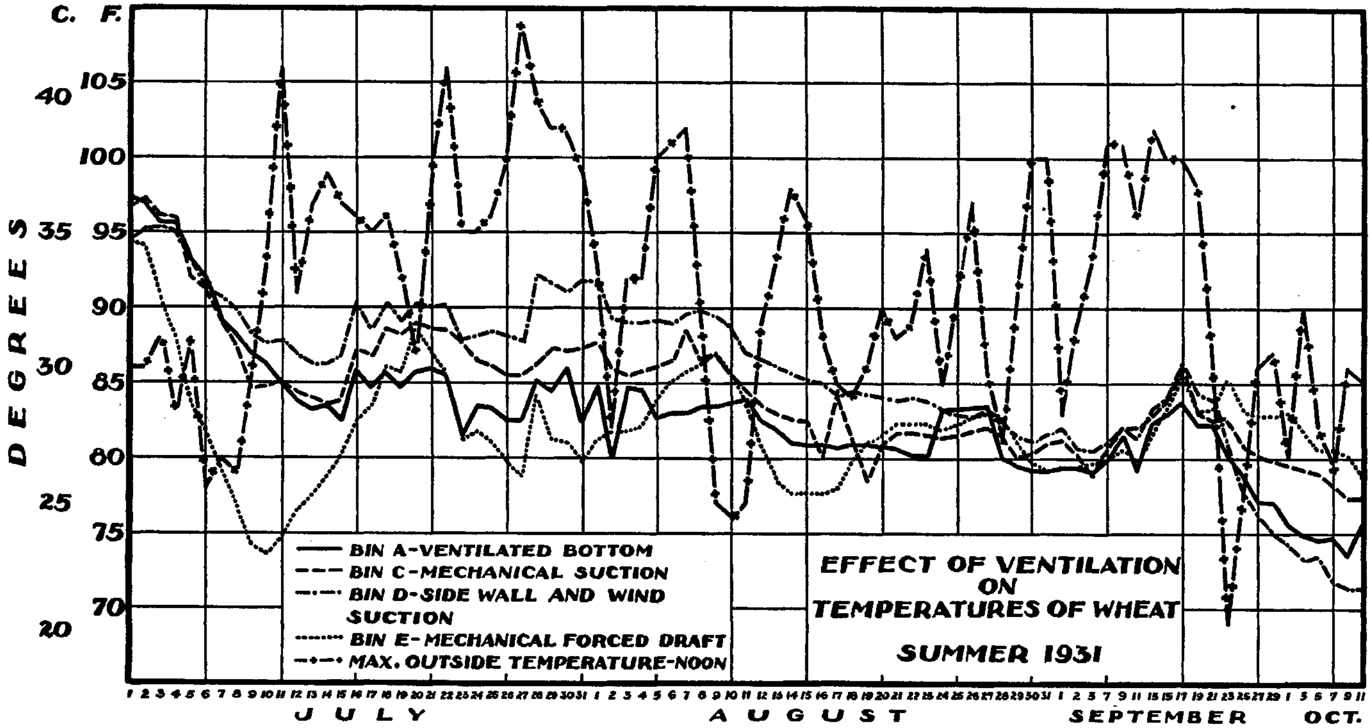

Fig. 26.—Effect of ventilation on temperatures of wheat, summer, 1931.

TABLE XXIII.—MOISTURE PERCENTAGES IN THE WHEAT FROM THE DIFFERENT BINS AT THE CLOSE OF THE EXPERIMENT.

PLACE OF SAMPLING.	Bins.			
	A.	C.	D.	E.
Near top	12.6	11.9	13.0	13.8
Near top	12.1	10.7	11.0	13.3
Upper center	12.6	11.2	11.5	12.3
Middle	11.9	10.8	10.8	11.8
Lower center	10.9	10.3	10.6	10.1
Lower center	10.4	10.4	10.0	9.9
Lower center	10.8	....	10.3	....

The moisture content of the wheat in all the bins was highest near the top, varying from 11.9 to 13.8 per cent. As the original average moisture content of the wheat on top was 17.23 per cent this wheat had undergone considerable drying. Apparently some drying had taken place even in the wheat of lower moisture content, as it averaged 10.8 per cent when put in the bins.

No moldy pockets of wheat were observed in any of the bins except one small mass in bin D, caused by a leak through the roof during a rain. The wheat in all the bins was in good condition. The wheat in bin A was, on the whole, better than that in bin D. No differences could be observed between bins C and E as the wheat in both was excellent, and somewhat better than that in bin A. The losses in weight of the wheat in sacks as taken from the bins are given in Table XXIV. The largest loss in weight from any sack stored in the bins was 150 grams or 5 per cent. Two sacks showed a small gain. Apparently the drying of the wheat in the sacks was not equal to that of the wheat loose in the bin.

TABLE XXIV.—LOSSES IN WEIGHTS OF THE WHEAT IN SACKS AT TIME OF REMOVAL FROM BINS, OCTOBER 30, 1931.

In grams.

PLACE OF SAMPLING.	Bins.				Stored in laboratory.
	A.	C.	D.	E.	
Near top	65	150	45	105	215
Upper center	70	130	140	65	160
Middle	70	5	5	20	20
Lower center	5	40	5	40	20
Near bottom	80	35	(*a*) 90	25	50

(*a*) Sack slightly torn.

GRADING THE WHEAT AT CLOSE OF THE EXPERIMENT

At the close of the experiment, half-pound quantities were taken from the sacks buried in the bins, and from the milling samples taken near top, center, and bottom of the bins when the wheat was moved, and sent to O. F. Phillips in Chicago for grading. Grading data are embodied in Table XXV. Only three samples graded sample grade, and in two of these the damage resulted from a leak in the roof. Most samples graded No. 1, and those that graded No. 2 did so on account of test weight.

TABLE XXV.—GRADING AND BAKING DATA ON WHEAT FROM STORAGE EXPERIMENTS, 1931.

Includes check samples.

Bin.	Description.	Location in bin.	Per cent damaged.	Odor.	Test weight.	Grade.	Per cent absorption.	Proof time.	Volume.	Texture, per cent.
A	From sacks buried in wheat at harvest	Near top	Trace	O. K.	59.7	2	56.8	45	1,470	93
		Upper center	1.3	O. K.	59.4	2	56.8	42	1,545	96
		Near middle	Trace	O. K.	60.9	1	54.8	42	1,460	93
		Lower center	Trace	O. K.	61.0	1	52.8	42	1,580	95
		Near bottom	Trace	O. K.	60.7	1	54.8	35	1,540	95
	Taken from bin at close of experiment	Near top	1.6	Slightly sour	58.0	Sample	54.8	27	1,600	96
		Middle	Trace	O. K.	61.2	1	54.8	38	1,590	96
		Near bottom	Trace	O. K.	61.2	1	....	....	....	....
C	From sacks buried in wheat at harvest	Near top	1.2	O. K.	59.3	2	54.8	36	1,525	93
		Upper center	2.0	O. K.	59.4	2	56.8	35	1,550	95
		Near middle	1.3	O. K.	60.7	1	56.8	45	1,435	93
		Lower center	Trace	O. K.	61.1	1	54.8	40	1,515	95
		Near bottom	Trace	O. K.	60.7	1	56.8	42	1,555	96
	Taken from bin at close of experiment	Near top	1.5	O. K.	59.3	2	56.8	31	1,520	93
		Middle	Trace	O. K.	60.9	1	58.8	33	1,460	93
		Near bottom	Trace	O. K.	60.9	1	....	....	....	....
D	From sacks buried in wheat at harvest	Near top	7.0	Very musty	58.0	Sample	54.8	37	1,400	90
		Upper center	Trace	O. K.	59.2	2	56.8	33	1,505	93
		Near middle	Trace	O. K.	60.8	1	56.8	38	1,450	93
		Lower center	Trace	O. K.	61.1	1	56.8	43	1,510	95
		Near bottom	Trace	O. K.	60.5	1	58.8	37	1,440	94
	Taken from bin at close of experiment	Near top	30.0	Very musty	57.8	Sample	54.8	37	1,410	90
		Middle	Trace	O. K.	60.6	1	58.8	37	1,480	93
		Near bottom	Trace	O. K.	60.6	1	....	....	....	....

TABLE XXV.—CONCLUDED.

Bin.	DESCRIPTION.	Location in bin.	Per cent damaged.	Odor.	Test weight.	Grade.	Per cent absorption.	Proof time.	Volume.	Texture, per cent.
E	From sacks buried in wheat at harvest	Near top	1.5	O. K.	60.4	1	56.8	37	1,490	95
		Upper center	1.0	O. K.	59.5	2	58.8	42	1,435	93
		Middle	Trace	O. K.	61.0	1	56.0	47	1,430	93
		Lower center	Trace	O. K.	61.0	1	56.0	42	1,445	93
		Near bottom	Trace	O. K.	60.5	1	57.6	40	1,460	94
	Taken from bin at close of experiment	Near top	2.6	O. K.	58.4	2	56.8	35	1,530	96
		Near middle	2.8	O. K.	59.0	2	56.8	35	1,430	90
		Near bottom	1.2	O. K.	60.5	....	....	....	....	....
	Check samples stored in the laboratory	Near top	1.0	O. K.	60.2	1	60.8	32	1,400	93
		Upper center	Trace	O. K.	59.6	2	60.8	30	1,500	96
		Middle	Trace	O. K.	60.6	1	58.8	33	1,340	90
		Lower center	Trace	O. K.	60.6	1	56.8	35	1,340	90
		Near bottom	Trace	O. K.	60.1	1	58.8	32	1,400	90

BAKING RESULTS

After it was found that no damage to the stored wheat had occurred it was decided to use a baking method which would measure the effect of the widely varying moisture contents of the grains upon baking characteristics. As previously pointed out relatively high moisture content should promote those post-harvest maturing processes which are so essential for the best-quality flours. The average moisture content of the grain in the lower four-fifths of each bin was 10.8 per cent, while that in the upper fifth contained 17.23 per cent when stored. The results of the baking tests are given in Table XXV and typical loaves are shown in figure 27. Loaves 42 and 43 are from wheat which had high moisture content when binned and hence had matured. Loaves 39 and 69 are from wheat that was too dry to bring about the maturing processes. If molding or heating had taken place in the high-moisture wheats, loaves 42 and 43 would have been poorer than 39 and 69. Only one of the samples stored In the laboratory, hence with a constant very low moisture content but otherwise under ideal storage conditions, gave a loaf volume and texture equal to the best of those from the bins.

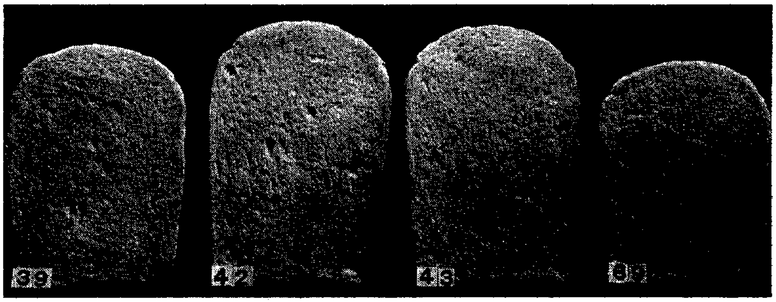

FIG. 27.—Loaves of bread from storage samples, 1931.

39—Bin A, stored in sack near middle at time of binning.
42—Bin A, taken from near top at end of storage.
43—Bin A, taken from near middle and bottom at end of storage.
69—Stored in laboratory representing wheat placed at bottom of bins.

SUMMARY OF THE 1931 EXPERIMENTS

1. Only about 22 per cent of the total wheat put in the bins was damp enough to constitute a storage problem. Most of this wheat was placed on top of unusually dry wheat.
2. No strata or pockets of damaged wheat were found in any of the bins.
3. No dangerous temperatures developed in any of the bins.
4. Forced ventilation was more effective in cooling the wheat than natural ventilation.
5. The evidence comparing suction of air with forcing of air was too limited, but indications were that forcing was more effective than suction.
6. The temperature of wheat stored in the ventilated bins approximated the outside air temperatures more closely than that stored in unventilated bins.

GENERAL SUMMARY

Damage to the quality of combined wheat results from storing with a sufficient moisture content to cause heating which is usually accompanied by molding. Too much moisture in wheat may result from combining too early, from immature wheat in low spots in the field, or from rain or dew. Excessive heating is more likely to take place if the temperature of the wheat is abnormally high when it is placed in the bin. Continued hot weather soon after storing will also promote heating of the wheat. Heat diffuses slowly in wheat, hence, hot pockets may develop from loads of high-moisture or high-temperature wheat. Small amounts of damp wheat are less likely to be damaged if mixed and stored with dry wheat.

The heating of wheat high in moisture content results from the accelerated natural respiration in the wheat and from the respiration of molds. The rate of respiration depends upon the moisture content and the temperature. In normally dry wheat it is slow, but it increases many fold as the moisture is increased regardless of whether the high moisture is due to immaturity or to water added by rain. Heating alone may damage wheat, but the greatest injury usually results when heating is accompanied by mold growth. Whether enough heat may result from new wheat respiration alone to do damage has not been determined.

Natural respiration in normally dry wheat brings about an improvement in the baking value of the flour, and this process may be hastened by heat and moisture under carefully controlled conditions. However, if the moisture content is too high with the resultant heating and molding, a lowering of the milling and baking value takes place. The accompanying odors and appearance of the wheat also lower the market grades and, hence, the selling value. Too high moisture content has caused injury to from 10 to 25 per cent of the total Kansas wheat crop during the past five years.

The type of material used in bin construction is of less importance in preventing damage than the type of ventilation used in the bin. If ventilation is to be effective it must cause enough air movement to cool the wheat and remove excess moisture. A type of ventilator which does not accomplish this promotes damage rather than prevents it, because it tends to condense moisture and brings in enough oxygen to support mold growth. Of the natural methods of ventilation tried, that which permits the passing of air upward through a perforated floor has given the best results. Another effective method of natural ventilation was by means of perforated side walls and a large perforated central flue with a suction cupola on top. Forced ventilation probably can be made more effective than natural ventilation, but its limitations have not been fully worked out.

Heating wheat may be cooled and lowered in moisture content by transferring from one bin to another. In very hot weather the amount of cooling may be very little while the amount of moisture removed is dependent upon the relative humidity of the air.

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Note: P. 67-69 are indexes of illustrations and tables which are omitted as redundant material to reduce file size.

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Bin A and the transfer bin by Black-Sivalls and Bryson Manufacturing Company, Kansas City, Mo.; Bin B by Columbian Steel Bin Manufacturers Association, Kansas City, Mo.; Bin B by Butler Manufacturing Company, Kansas City, Mo.; Bin D by Martin Steel Products Company, Mansfield, Ohio; and Bin E by Eaton Metal Products Company, Omaha, Neb.

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