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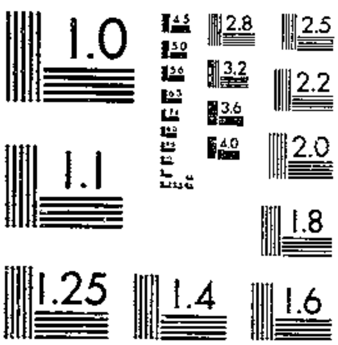

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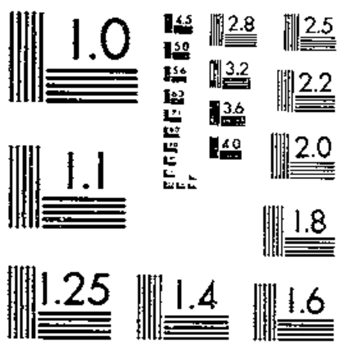

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RESPIRATION OF SORGHUM GRAINS

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RESPIRATION AND HEATING OF GRAIN

The preservation in storage or in transit of large quantities of threshed grain involves certain difficulties. The earlier investigations of Bailey (*1, 2*),[1] Bailey and Gurjar (*3, 4*), Duvel (*7*), Duvel and Duval (*8, 9*), and Shanahan, Leighty, and Boerner (*16*), have shown that corn, wheat, or rice must be fairly clean and dry when stored; otherwise injury will take place. This is particularly true if excess moisture is present.

The sorghum grain is likewise one that offers some hazard from a handling and storage standpoint. It is common for this grain to become musty and sour and to heat while stored in large bulk, especially if moisture and foreign material are present in considerable quantities.

Only comparatively recently have data been presented which indicate the reasons why grain and similar substances heat and spoil in storage. It is now rather generally agreed by plant physiologists that energy for many life processes and reactions is released in living cells in an exothermic or heat-developing reaction or a succession of reactions known collectively as respiration.

This phenomenon of respiration takes place either in the presence of air or in the absence of air. In normal, or aerobic respiration, the oxygen of the atmosphere is conducted to the cells where respiration occurs and is there involved in an oxidation process in which heat is liberated and in which water and carbon dioxide are the characteristic end products. When respiration takes place in the absence of

[1] Italic figures in parenthesis refer to "Literature cited," p. 15.

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atmospheric oxygen it is known as anaerobic respiration. Under such conditions it is thought that the oxygen of certain compounds within the plant tissue is used as the source of oxygen. Carbon dioxide, as before, is a prominent end product. Regardless of the mechanics of the respiration phenomenon, carbon dioxide and heat are generated simultaneously, and a close relationship exists between the quantity of carbon dioxide formed and the heat energy liberated.

Since the grain itself is a poor conductor of heat, it follows that the heat energy released through respiration accumulates in the mass of grain so that the increase in temperature may in time become marked.

PURPOSE OF THE INVESTIGATION[2]

Efforts to secure exact information regarding the importance of the various factors which influence the successful handling, storage, and transit of the sorghum grains under commercial conditions were not very successful because under commercial conditions it is practically impossible so to control the physical conditions of environment as to be able to isolate and weigh the importance of each factor separately.

Since it has been established that there is a close relation between the respiratory activity of grain (*2*, *3*, *4*) and its tendency to heat and spoil, recourse was had to a laboratory study of the respiration rate of different commercial classes of the sorghum grains. The study covered the influence of such factors as moisture, temperature, cracked kernels, and the general condition of the grain at the time of storage, upon the keeping qualities of these grains.

It is recognized, of course, that such a laboratory determination does not afford a simple means of computing the temperature which the grain in question would attain under commercial-storage conditions because the actual change in temperature depends not only upon the rate of respiration of the grain, but also upon such factors as the size and shape of the bin, the insulating effect of the material of which the bin is composed, the temperature of the surrounding atmosphere, and the original quality and condition of the grain itself.

But even though what will happen in farm or commercial storage under a variety of conditions can not be predicted from laboratory tests, the indications obtained from such a study are valuable, and, as was pointed out by Bailey and Gurjar (*3*, *4*), they are of the same order as those found under actual storage conditions.

METHODS USED FOR MEASURING THE RATE OF RESPIRATION

In determining the rate of respiration, the method outlined by Gurjar (*10*) and modified by Bailey (*2*), whereby the carbon dioxide evolved is absorbed in dilute barium hydroxide solution, was used.

Twenty-four-inch calcium chloride jars were used as respiration chambers. These were fitted at the bottom constriction with glass wool. The quantity of grain used varied slightly with its moisture content, 400 grams of that of lower moisture content being used, and about 325 grams when the moisture exceeded 15 per cent

The jars were sealed with paraffin of a high-melting point and placed in a constant-temperature oven. Except in the experiment in

[2] This investigation was carried out in cooperation with the Kansas and Oklahoma Agricultural Experiment Stations and is part of the general project devoted to the study of those factors which enter into the successful storage of cereal grains.

which heat was the variable factor, the temperature of the oven was maintained at 37.8° C. (100° F.).

Approximately 96 hours was chosen as the period of exposure to heat. Since it was not always possible to expose the samples exactly 96 hours, the length of time that the jars were in the oven was noted and the results were calculated uniformly to a 24-hour basis. In reporting the results the quantity of carbon dioxide respired by 100 grams of dry matter in each 24 hours was computed. To compute the calories of heat evolved, the factor found by Langworthy and Milner (*12*) may be employed: 1 gram of respired carbon dioxide equals 2.5 calories of heat.

SOURCE OF MATERIAL

Lots of nine of the more common commercial classes of sorghum grains were obtained as material for study. Bulk lots of these classes were thoroughly cleaned to remove cracked kernels, unsound kernels, and foreign material. The classes chosen were darso, feterita, freed sorgo, yellow milo, brown kaoliang, red kafir, white kafir, shrock kafir, and shallu.[3] The lots of all of these classes except brown kaoliang and freed sorgo were grown at the United States Department of Agriculture Dry Land Field Station at Woodward, Okla., in 1926. The brown kaoliang and the freed sorgo were grown at the Fort Hays Branch Experiment Station at Hays, Kans., in the same year. Yellow milo and white kafir represent the commercially important classes of sorghum grain; the other classes are those which are gradually becoming commercially important.

As a matter of interest, chemical composition and physical characteristics of these nine classes are given in Table 1.

TABLE 1.—*Chemical composition and physical characteristics of the samples of nine sorghums*

CHEMICAL COMPOSITION[a]

(Water-free basis)

Classes	Crude protein	Ash	Ether extract	Crude fiber	Nitrogen-free extract	Hydrogen-ion concentration
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*pH*
Yellow milo	12.98	1.34	4.77	1.94	78.97	6.61
White kafir	10.08	1.44	4.04	2.05	82.39	6.72
Brown kaoliang	15.73	1.64	6.10	1.71	74.62	6.68
Darso	9.33	1.27	4.19	1.71	83.50	6.66
Feterita	14.52	1.28	5.10	2.04	77.06	6.54
Freed sorgo	14.47	1.78	5.06	1.65	77.04	6.68
Red kafir	11.25	1.43	5.40	1.81	80.11	6.52
Shallu	10.28	1.40	4.54	2.29	81.49	6.51
Shrock kafir	9.72	1.33	5.92	2.26	80.77	6.48

[a] The chemical methods used in this investigation are contained in the following publication: AMERICAN ASSOCIATION OF CEREAL CHEMISTS. METHODS FOR THE ANALYSIS OF CEREALS AND CEREAL PRODUCTS. COMPILED BY THE COMMITTEE ON METHODS OF ANALYSIS. 176 p. Lancaster, Pa. Lancaster Press, Inc. 1928.

[3] The names used are the designations of commercial classes and not of sorghum varieties. White kafir is a commercial class including all kafir varieties with white kernels. Dawn kafir was the variety used in this study.

TABLE 1.—*Chemical composition and physical characteristics of the sample of nine sorghums*.—Continued

PHYSICAL CHARACTERISTICS

	Moisture	Test weight per bushel	Weight per 1,000 kernels	Germination	Average volume of 1,000 kernels
	Per cent	*Pounds*	*Grams*	*Per cent*	*C. c.*
Yellow milo	11.1	59.0	37.8	91.5	28.75
White kafir	10.3	57.0	23.9	95.5	18.75
Brown kaoliang	9.3	56.5	21.3	89.5	16.25
Darso	10.5	59.0	24.7	96.5	19.25
Feterita	10.0	55.5	41.5	81.5	32.50
Freed sorgo	10.6	60.3	25.2	97.0	19.00
Red kafir	10.9	60.0	24.0	92.5	18.00
Shallu	11.8	60.4	25.4	98.5	19.25
Shrock kafir	10.1	58.5	23.7	98.5	18.50

HYGROSCOPIC MOISTURE IN SORGHUM GRAINS

The sorghum grains, like all other cereal grains, are hygroscopic. They lose moisture to the atmosphere, or gain moisture from it, until the hygroscopic moisture of the grain is in equilibrium with the humidity of the air.

There is a direct relation between respiration and relative humidity inasmuch as when the moisture content of plant tissues increases there is a corresponding increase in the rate of respiration. Data relating to the moisture content of the sorghum grain when in equilibrium with atmospheres of different relative humidities are also important because they indicate whether a shrinkage or increase in weight will take place in grain if stored in a wet or dry environment. Such data also point out to those who wish to store wet or damp grain what the possibilities are that such grain may be conditioned naturally without recourse to artificial drying.

Data concerning the moisture content of sorghum grain when in equilibrium with atmospheres of different relative humidities were not found in the literature. Experiments were undertaken to secure this information. The nine classes of sorghum grain named above were used for this purpose.

Approximately 20 grams of each of these classes were spread in shallow aluminum boxes which were suspended in 10-inch desiccators over aqueous solutions of sulphuric acid. Seven such desiccators were used, and the vapor pressure of the sulphuric solutions were so adjusted (according to Wilson's (*17*) tables) that the resulting relative humidities of the atmospheres in the desiccators at 25° to 28° C. were 15, 30, 45, 50, 75, 90, and 100 per cent. The grain remained in the desiccators for four weeks, or until no further change in weight took place in 48 hours. At the end of this period the grain was removed from the desiccators, and the percentage of moisture was determined in a vacuum oven operated at 99° to 100° at a pressure of 4 inches, drying the material to a constant weight. This usually took about 96 hours. The specific gravities of the sulphuric acid solutions were determined as the grain was removed from the desiccators. The humidity data reported, therefore, are on the basis of conditions prevailing at the close of the experiment. The moisture data given are the percentages of moisture absorbed by the moisturefree grain and will be found in Table 2, as well as represented graphically in Figure 1.

From Table 2 it can be seen that the average percentage of hygroscopic moisture in the nine classes of sorghum grains studied ranged from 6.65 per cent at 13.8 per cent relative humidity (25° C.) to 28.04 per cent at 100 per cent relative humidity. It is evident, therefore, that the sorghum grains undergo considerable change in moisture content when exposed to different humidities, providing the conditions of exposure are such that the movement of water vapor can take place.

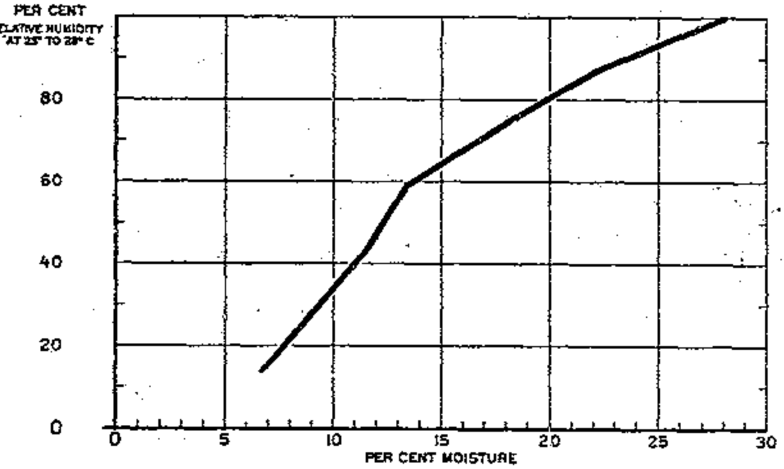

FIG. 1.—Hygroscopic moisture of sorghum grains (average of nine classes) exposed to atmospheres of different relative humidities at 25 to 28° C.

TABLE 2.—*Hygroscopic moisture of nine classes of sorghum grain exposed to atmospheres of different relative humidities at 25° to 28° C.*

Relative humidity of atmosphere at 25° to 28° C.	Average hygroscopic moisture of—									Average hygroscopic moisture of 9 classes
	Yellow milo	White kafir	Brown kaoliang	Darso	Feterita	Freed sorgo	Red kafir	Shallu	Shrock kafir	
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
13.8	6.54	6.78	6.57	6.82	6.69	6.45	6.53	6.69	6.79	6.65
31.0	9.57	9.59	9.39	9.34	9.64	9.22	9.55	9.79	9.45	9.50
43.0	11.74	11.36	11.30	11.45	11.37	11.19	11.80	11.77	11.45	11.49
59.0	13.48	13.41	13.02	13.56	13.41	13.06	13.69	13.66	13.53	13.42
76.0	17.95	18.95	18.08	18.92	17.82	17.52	18.60	18.85	19.04	18.41
87.0	22.00	22.15	21.50	22.25	22.39	21.97	21.99	22.28	22.73	22.07
100.0	27.34	28.71	28.19	28.49	27.03	28.30	28.22	27.45	28.60	28.04

The hygroscopicity of the sorghum grain likewise is not greatly different from that of other cereal grains. The only outstanding differences to be noted are found at atmospheres of relative humidity of 75 per cent and over. These comparative data are given in Table 3.

TABLE 3.—*Hygroscopic moisture of cereal grains exposed to atmospheres of different relative humidities at 25° to 28° C.*

Relative humidity of atmosphere at 25° to 28° C.	Average hygroscopic moisture of—							
	Barley	Buckwheat	Corn	Sorghum grain	Oats	Rice	Rye	Wheat
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
15	6.45	7.17	7.09	6.95	6.03	7.27	7.49	7.03
30	9.24	9.99	9.25	9.42	8.76	9.92	9.58	9.34
45	11.16	12.18	11.39	11.90	10.60	12.00	11.72	10.99
60	13.74	14.52	14.52	15.00	13.40	14.38	13.94	13.81
75	16.88	17.01	16.79	18.25	16.05	16.86	17.41	17.30
90	24.17	23.63	23.12	24.98	22.05	22.15	25.92	24.82
100	30.65	32.47	31.22	28.03	31.71	30.85	33.51	34.38

RELATION BETWEEN MOISTURE CONTENT OF SORGHUM GRAINS AND RESPIRATORY RATE

In the preceding section it was shown that sorghum grain is hygroscopic; that it absorbs or loses moisture, depending upon the humidity of the surrounding atmosphere. The influence of these moisture changes on the respiratory activity of this grain will now be discussed.

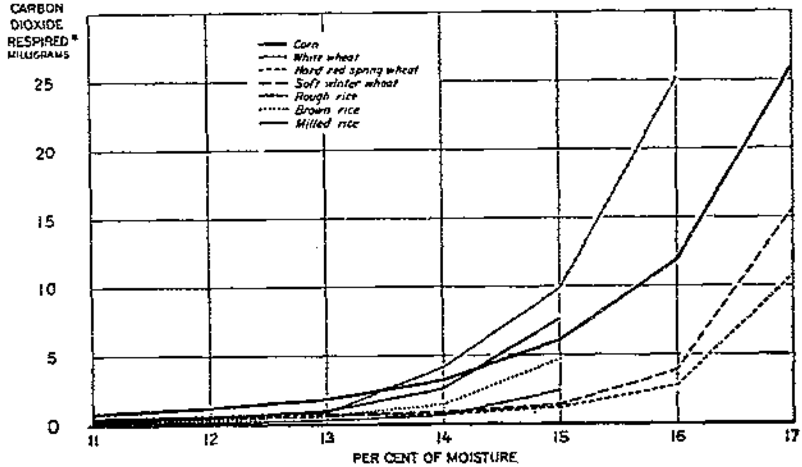

FIG. 2.—Rate of respiration related to the moisture content of cereal grains. Milligrams of carbon dioxide respired per 100 grams of dry matter in each 24 hours

As early as 1894, Lund (*13*) observed that an increase in the moisture content of seeds and tubers increased their rate of respiration. This observation has been repeatedly confirmed. Kolkwitz (*11*) reported that barley kernels which contain 10 to 11 per cent of moisture respired very feebly, whereas when the kernels were moistened the intensity of respiration increased tremendously. Qvam (*14*) likewise has made similar observations.

Duvel (*6*), in studying the vitality of seeds, noted an increased respiration with an increase in the moisture content of the seed.

Bailey (*2*), and Bailey and Gurjar (*3*, *4*), found that by increasing the moisture content of wheat, corn, and rice, the intensity of respiration was greatly accelerated. A summary of their data is shown graphically in Figure 2.

Shanahan, Leighty, and Boerner (*16*), as well as Duvel and Duval (*8*, *9*), have given evidence to show an increased respiratory activity with an increase in the moisture content of corn in storage or in transit.

In the determination of the relation of moisture to respiration in stored sorghum grain, classes yellow milo, red kafir, white kafir, shrock kafir, feterita, freed sorgo, kaoliang, and shallu were used. Weighed portions of each class were brought to different moisture contents by the addition of water. To prevent incipient fermentation, these samples were placed in air-tight containers in an ice box. They were given frequent agitation for four days to insure uniform distribution of water throughout the kernels.

The percentages of moisture obtained varied from approximately 10 to 16.5 per cent. These limits were chosen because it is within

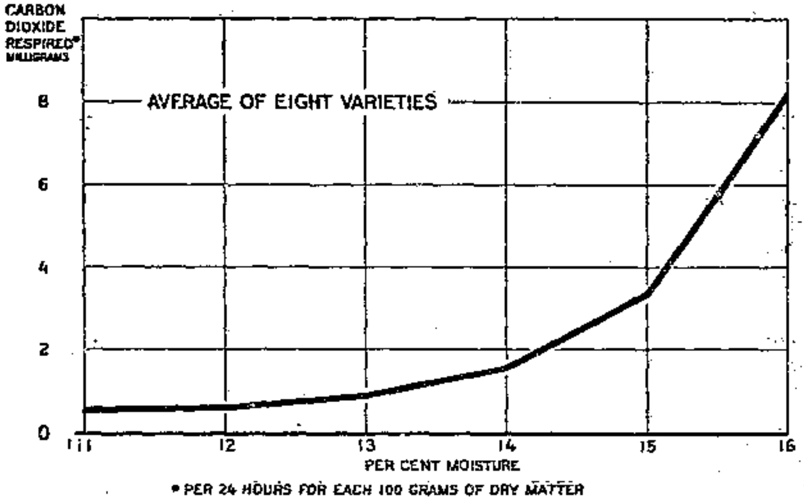

FIG. 3.—Average rate of respiration and moisture content of eight classes of sorghum grain: Eight classes were studied as the ninth sample became infested with weevil

this moisture range that the moisture content of most samples of sorghum grain lies on arrival at market and because respiration reaches a sufficiently high rate in that range to raise the temperature of bulk grain to a point at which damage takes place.

When the grain was ready to work, weighed quantities were placed in the jars already described, and the jars were sealed with paraffin. At the time of sealing, a representative sample was drawn for moisture determination. In all instances the jars were maintained at a temperature of 37.8° C. (100° F.) for approximately 96 hours; the exact time was noted as the respiration jars were removed from the constant-temperature oven.

The quantity of carbon dioxide respired per 24 hours by each 100 grams of dry matter by each of these eight classes is given in Table 4, and the mean average respiratory rate is shown graphically in Figure 3.

TABLE 4.—*Average rate of respiration of 8 classes of grain sorghums of given moisture content*

Moisture content	Carbon dioxide respired per 24 hours for each 100 grams of dry matter of—								
	Yellow milo	White kafir	Kaoliang	Feterita	Freed sorgo	Red kafir	Shallu	Shrock kafir	Average
Per cent	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*
11	0.53	0.67	0.53	1.00	0.50	0.36	0.25	0.45	0.54
12	.70	.80	.62	1.10	.54	.46	.35	.52	.64
13	1.00	1.12	.83	1.58	.71	.72	.53	.71	.90
14	1.56	1.72	1.25	3.00	1.51	1.40	.87	1.31	1.58
15	3.27	3.52	2.23	5.80	3.98	3.11	1.80	3.17	3.36
16	7.58	8.23	4.80	11.80	11.05	8.59	5.30	8.60	8.24

The rates of respiration of the classes of sorghum grain studied were much alike, except for feterita and shallu. The difference in activity of feterita may be explained in three ways. Records show that this sample of feterita was exposed to some weathering before threshing; in fact, evidence of sprouting was present. Sprouted seed has been shown by Bailey (*2*) and by Bailey and Gurjar (*3, 4*) to be considerably more active than normal seed. The fact that feterita is an early maturing variety and is soft and chalky in texture may also contribute to its greater activity. Soft and starchy wheats respire more rapidly than do hard vitreous wheats containing the same percentage of moisture, and a similar relation may obtain with feterita, as this variety is much less vitreous than are the other varieties in the lot studied. It also has been suggested by Bailey (*2*) in his discussion of data by Reed and Holland (*15*), that the respiratory activity of early-maturing varieties of grain may possibly be greater than that of later-maturing varieties. Shallu, on the other hand, is just the opposite in characteristics. It is a late-maturing variety. In fact, it matures the latest of the eight studied. Shallu likewise is vitreous. By the same reasoning used before (as to kernel texture and lateness of maturity), the low respiration rate of shallu may possibly be explained.

The acceleration of respiration with increasing moisture content was calculated according to the formula $\frac{K_m - K_{m-1}}{K_{m-1}}$. In this formula, K_m represents the rate of respiration at a given percentage of moisture (m), and K_m–1 the rate when the sample contained 1 per cent less moisture ($m-1$). The values thus obtained represent the fractional increase in respiratory rate associated with unit intervals in moisture content.

These values, based on the average respiratory rates for the eight classes included in this part of the study, are shown in Table 5, together with comparable data for corn, rice, and wheat.

TABLE 5.—*Acceleration of rate of respiration of sorghum, corn, rice, and wheat with increasing moisture content*

Grain	Acceleration of rate of respiration [1] in grain with—						
	11 to 12 per cent moisture	12 to 13 per cent moisture	13 to 14 per cent moisture	14 to 15 per cent moisture	15 to 16 per cent moisture	16 to 17 per cent moisture	17 to 18 per cent moisture
Sorghum	0.13	0.43	0.74	1.14	1.45		
Corn [3]	.56	.60	.75	.89	.97	1.19	1.24
Rice [4]		.50	.97	1.60	1.99		
Wheat [2]		.16	.17	.66	1.41	3.02	

[1] See formula p. 8.
[2] BAILEY, C. H. (2).
[3] BAILEY, C. H., and GURJAR, A. M. (3).
[4] BAILEY, C. H., and GURJAR, A. M. (4).

It appears that the relative acceleration in rate of respiration with increasing moisture content is fairly uniform. There is no sharp break in the curve; the acceleration increases uniformly as the moisture content increases.

This phenomenon differs from that found by Bailey (*2*) and Bailey and Gurjar (*3*) with wheat or corn and for some distance is similar to the curve shown by Bailey and Gurjar (*4*) for the acceleration in respiration rate for paddy rice.

The reasons for the marked acceleration in respiratory activity such as results from comparatively small increases in the moisture content of the kernel are still incompetely known.

Respiration can scarcely proceed unless the substances involved in this reaction move, chiefly by diffusion, to the seat of respiration. When the kernels are dry, very little diffusion can take place, as the hygroscopic water in the kernel is held by the organic colloids within the kernel in a state of high tension. It has been shown that by the addition of moisture to the kernel this pressure becomes lessened. This being the case, diffusion of sugars, mineral salts, gases, etc., to the seat of respiration must be progressively enhanced by each successive addition of water. This result manifests itself as increased oxidation and increased heat in the bulk of grain.

INFLUENCE OF TEMPERATURE UPON THE RATE OF RESPIRATION

The carefully controlled laboratory experiments of Bailey (*2*) and Bailey and Gurjar (*3, 4*), as well as the observations of Bailey (*1*), Boerner (*5*), Duvel (*7*), Duvel and Duval (*8, 9*), upon commercial lots of corn and wheat have all shown that as grain begins to heat the rise in temperature per unit of time becomes greater as the temperature of the bulk grain becomes higher.

According to Bailey and Gurjar (*3*) the most rapid change in respiratory rate of stored wheat was between 35° and 55° C.

In connection with the other respiration studies with the sorghum grains a comparison of the respiration rate of yellow milo, a common commercial class of grain sorghum, was determined at two different temperatures. As before, six portions of this grain were brought to different moisture contents in the manner before described. In this study the moisture contents of the six portions varied from 10.98 to 15.83 per cent. One set of samples was held at 37.8° C. and the other set at 27.8°. The data from these tests are given in Table 6.

TABLE 6.—*Respiration of yellow milo at 27.8° and 37.8° C.*

Moisture content	Carbon dioxide respired per 24 hours for each 100 grams of dry matter at—		Rate at 37.8° C. / Rate at 27.8° C.	Moisture content	Carbon dioxide respired per 24 hours for each 100 grams of dry matter at—		Rate at 37.8° C. / Rate at 27.8° C.
	27.8° C.	37.8° C.			27.8 °C.	37.8° C.	
Per cent	*Mgm.*	*Mgm.*		*Per cent*	*Mgm.*	*Mgm.*	
10.98	0.23	0.43	1.87	13.85	.62	1.25	2.02
11.62	.33	.62	1.88	14.95	1.50	2.90	1.93
13.05	.44	.85	1.93	15.83	3.02	5.95	1.97

It can be clearly seen that temperature has a decided influence on the respiratory rate of yellow milo, as the rate at 27.8° C. was just about half of that rate at 37.8°. This difference in respiratory rate also was fairly uniform throughout the range of percentages of moisture used.

RESPIRATION OF HEAT-DAMAGED SORGHUM GRAINS

Two samples of heat-damaged sorghums (one of white kafir and the other of white kafir and yellow milo mixed in about equal proportions) were obtained from box cars in Kansas City. In the sample of white kafir 17.7 per cent of the grains were discolored by heat of fermentation, and in the other sample 25.2 per cent of the grains were discolored by heat of fermentation.

Portions of each of these samples were brought to different percentages of moisture by the addition of water, and their rate of respiration was ascertained. The data relating to these samples are given in Tables 7 and 8; comparison of these data with those shown for normal sorghum grain indicates that heat-damaged sorghum grains respire at a considerably higher rate than do normal sorghum grains.

TABLE 7.—*Rate of respiration of heat-damaged sorghum grain*

Sample of white kafir, 17.7 per cent of kernels heat damaged		Sample of white kafir and yellow milo mixed, 25.2 per cent of kernels heat damaged	
Moisture	Carbon dioxide respired per 24 hours for each 100 grams of dry matter	Moisture	Carbon dioxide respired per 24 hours for each 100 grams of dry matter
Per cent	*Mgm.*	*Per cent*	*Mgm.*
12.82	0.57	11.04	2.54
13.81	.86	11.59	3.20
14.84	3.69	12.73	3.86
15.70	17.09	13.85	5.30
17.19	24.09	15.08	7.78

TABLE 8.—*Respiration of heat-damaged samples of sorghum grains as compared with that of samples of sound sorghums*

Moisture content	Carbon dioxide respired per 24 hours for each 100 grams of dry matter		
	Sound sorghums	Heat-damaged white kafir [1]	Heat-damaged white kafir [2] and yellow milo mixed
Per cent	*Mgms.*	*Mgms.*	*Mgms.*
12	0.63	0.80	3.42
13	.90	1.08	4.38
14	1.57	2.40	5.80
15	3.36	16.90	7.78
16	8.24	23.20	----------

[1] 17.7 per cent heat damaged. [2] 25.2 per cent heat damaged.

RESPIRATION OF CRACKED SORGHUM GRAINS

It has been observed by others that the storage of grain which contains a considerable quantity of cracked kernels or finely divided material is more hazardous than is the storage of clean whole grain under similar conditions. Thus, Bailey (*2*) found in his studies of the respiration of shelled corn that "there is evidently a greater hazard in handling corn containing an appreciable quantity of cracked corn than in handling sound clean grain under similar conditions."

Sorghum grains on the average contain more cracked grain than do any other cereal grains marketed. As a rule the cracked grain to be found in a carload of this cereal amounts to 6 to 8 per cent. Frequently it is present to the extent of 35 or 40 per cent.

As a means of determining the influence of cracked kernels upon the keeping qualities of the sorghum grains, whole kernels of Freed sorgo were broken and the cracked material was separated so that bulk lots were obtained, one of which would and the other of which would not pass through an $\frac{8}{64}$-inch sieve.

Moisture was added to small lots of these two sizes of cracked kernels in the amounts before described. When the material was in condition to work, the two series of samples were held at 37.8° C. for approximately 96 hours. The quantities of carbon dioxide respired by these cracked kernels per unit of time and material at even percentages of moisture are given in Table 9, with the rate of respiration of sound and whole Freed sorgo for comparison.

TABLE 9.—*Respiration of whole and cracked Freed sorgo grains*

Moisture content	Carbon dioxide respired in 24 hours for each 100 grams of dry matter			Moisture content	Carbon dioxide respired in 24 hours for each 100 grams of dry matter		
	Sound material	Cracked material not passing through an $\frac{8}{64}$-inch triangular sieve	Cracked material passing through an $\frac{8}{64}$-inch triangular sieve		Sound material	Cracked material not passing through an $\frac{8}{64}$-inch triangular sieve	Cracked material passing through an $\frac{8}{64}$-inch triangular sieve
Per cent	*Mgm.*	*Mgm.*	*Mgm.*	*Per cent*	*Mgm.*	*Mgm.*	*Mgm.*
11	0.50	0.38	0.37	14	1.51	1.60	1.30
12	.54	.48	.48	15	3.98	4.80	4.55
13	.71	.80	.69	16	11.05	18.30	18.27

It is evident from these data that the rate of respiration of the cracked kernels in both series is greater at the highest moisture content than is the rate of respiration of the whole kernels. On the other hand, there does not seem to be a very great difference in the respiratory rate of those portions of cracked kernels which passed through an $\frac{8}{64}$-inch triangular sieve and the activity of those which did not pass through such a sieve. If there is any difference, the smaller portions were less active. This may be due to a smaller proportion of germ material in the smaller pieces of kernels. The acceleration of the rate of respiration was determined for material of each size tested and is shown in Table 10.

TABLE 10.—*Acceleration of rate of respiration of whole and cracked freed sorgo with increasing moisture content*

Character of material	Acceleration in rate of respiration in grain with—				
	11 to 12 per cent moisture	12 to 13 per cent moisture	13 to 14 per cent moisture	14 to 15 per cent moisture	15 to 18 per cent moisture
Whole	0.08	0.31	1.13	1.64	1.78
Not passing through an $\frac{8}{64}$-inch triangular sieve	.29	.67	1.00	2.00	2.81
Passing through an $\frac{8}{64}$-inch triangular sieve	.30	.44	.88	1.50	3.02

It would follow, therefore, that when varying quantities of cracked material are present in whole kernels, the cracked sorghums would accelerate the respiration of the bulk grain under excessive-moisture conditions.

RESPIRATION OF COMMERCIAL SAMPLES OF SORGHUM GRAINS

In connection with these studies, several samples of white kafir were taken from farm granaries by Roy Bainer of the Kansas Agricultural Experiment Station during the fall of 1926.

Among other tests the respiratory rate of each of these samples was ascertained. The results are given in Table 11. As compared with the results shown in Table 4, which were obtained on samples of sorghum grain moistened in the laboratory, there is a higher respiratory rate in the naturally damp sorghum grain, especially at the higher moisture contents. Thus, another factor, that of the length of time during which a lot of sorghum grains has been stored in a moist condition, enters into consideration when the importance of these factors which contribute to the safe storage of the sorghum grains is being judged.

TABLE 11.—*Respiration of white kafir collected from 10 farm granaries and incubated at 37.8° C. (100° F.) for 96 hours*

Laboratory No.	Moisture	Carbon dioxide respired in 24 hours for each 100 grams of dry matter	Laboratory No.	Moisture	Carbon dioxide respired in 24 hours for each 100 grams of dry matter
	Per cent	*Mgm.*		*Per cent*	*Mgm.*
B227	13.22	0.65	B228	14.76	3.80
B226	13.27	.47	B221	14.78	3.92
B223	13.30	.56	B229	15.70	6.22
B224	13.57	.65	B225	17.33	16.32
B222	14.58	2.95	B230	18.04	23.97

LABORATORY STORAGE EXPERIMENTS

In the preceding pages it has been shown that, providing the sample is sound, heat and moisture largely determine the rate of respiration of the eight classes of sorghum grain included in this part of the study. It was shown that at between 13 and 14 per cent of moisture the respiratory rate of these varieties was high and that as the moisture content was increased up to 16 per cent very large increases in activity took place.

An experiment was planned to determine on a small scale what the physical condition of each of a number of classes would be if stored under conditions similar in character to those obtaining in the respiration studies. Accordingly, 1,500-gram portions of each of the nine classes of sorghum grain and one commercial lot of yellow milo were moistened as before described so that there were four lots of each kind, containing 14, 16, 18, and 20 per cent of moisture, respectively. The exact moisture content of the samples will be found by consulting Table 12. These 1,500-gram portions were placed in sealed containers to maintain the moisture content and to create anaerobic conditions, and these containers were held in an air thermostat at a temperature ranging from 100° to 102° F. (38° to 39° C.) for seven weeks.

Tests of the physical condition of the grain were made before it was inserted in the thermostat, and each sample was sound in all respects. At the end of the storage period the containers were opened and the moisture content, test weight per bushel, odor, color, percentage of damaged kernels, and germination of the grain were determined. These findings are shown in Table 12.

TABLE 12.—*Physical characteristics of 10 lots of sorghum grains after storage for seven weeks at 100° to 102° F.*

Variety	Moisture	Test weight per bushel	Odor	Color	Heat-damaged kernels	Germination
	Per cent	*Pounds*				
Yellow milo	14.6	57.8	Normal	Normal	None	59.5 per cent.
	15.6	56.5	Slightly sour	1 shade off	do	None.
	17.8	55.1	Sour	2 shades off	Skin burnt	Do.
	20.0	54.6	Very sour	3 shades off	1.7 per cent	Do.
White kafir	14.6	56.1	Slightly sour	Normal	None	Do.
	15.2	55.6	Sour	1 shade off	do	Do.
	17.7	55.0	do	2 shades off	do	Do.
	19.5	53.8	Very sour	3 shades off	1.3 per cent	Do.
Brown kaoliang	14.3	55.1	Slightly sour	Normal	None	2 per cent.
	16.3	54.2	Sour	do	do	None.
	18.0	53.2	do	1 shade off	Skin burnt	Do.
	20.0	52.2	Very sour	2 shades off	2.2 per cent	Do.
Darso	14.3	58.0	Normal	Normal	None	0.5 per cent.
	16.1	57.4	Slightly sour	do	do	None.
	18.0	56.0	Sour	1 shade off	do	Do.
	19.5	55.5	Very sour	2 shades off	3.2 per cent	Do.
Feterita	14.8	54.7	Normal	Normal	None	Do.
	15.9	54.4	Sour	1 shade off	do	Do.
	17.6	53.8	do	2 shades off	Skin burnt	Do.
	19.9	52.6	Very sour	3 shades off	3.7 per cent	Do.
Freed sorgo	13.1	59.6	Normal	Normal	None	Do.
	15.4	58.7	Slightly sour	do	do	Do.
	17.5	57.8	Sour	1 shade off	do	Do.
	19.8	56.9	Very sour	2 shades off	Skin burnt	Do.
Red kafir	14.3	59.1	Slightly sour	Normal	None	Do.
	15.3	58.5	Sour	1 shade off	do	Do.
	17.1	56.9	do	2 shades off	do	Do.
	19.6	56.2	Very sour	3 shades off	1.3 per cent	Do.

TABLE 12.—*Physical characteristics of 10 lots of sorghum grains after storage for seven weeks at 100° to 102° F.*—Continued

Variety	Moisture	Test weight per bushel	Odor	Color	Heat-damaged kernels	Germination
	Per cent	*Pounds*				
Shallu	13.7	59.8	Slightly musty	Normal	None	31 per cent.
	16.1	58.5	Musty	1 shade off	do	None.
	18.2	57.2	Sour	2 shades off	Skin burnt	Do.
	20.3	56.3	Very sour	3 shades off	1.5 per cent	Do.
Shrock kafir	14.1	57.6	Normal	Normal	None	2 per cent.
	15.9	57.1	Slightly sour	do	do	None.
	18.0	55.6	Sour	1 shade off	Skin burnt	Do.
	19.9	55.3	Very sour	2 shades off	1.5 per cent	Do.
Milo (field)	14.6	56.0	Slightly sour	Normal	None	Do.
	15.6	55.5	Sour	1 shade off	do	Do.
	17.6	55.2	do	2 shades off	Moldy	Do.
	19.4	54.0	Very sour	3 shades off	1.8 per cent	Do.

It can be readily seen from the results given in Table 12 that the physical condition of the stored sorghum grains became increasingly bad as the moisture content of the grain increased, as would be expected. There was a progressive drop in test weight per bushel as the moisture content increased. With a moisture content of slightly over 14 per cent, brown kaoliang and red kafir and white kafir and field milo had a slight odor. The other classes developed no odor at a moisture content of approximately 14 per cent. At 16 per cent of moisture and over all samples had an increasingly bad odor.

At a moisture content ranging between 15 and 16 per cent, white kafir, red kafir, yellow milo, and feterita were slightly off color. When more moisture than this was present, the kernels of all classes were off color.

Heat damage did not occur in any of the classes tested until a moisture content of between 19 and 20 per cent was reached. The vitality of all classes, except yellow milo and shallu, was practically destroyed when stored for seven weeks with a moisture content of between 14 and 15 per cent and in a constant temperature of 100° to 102° F., as shown by poor germination at the end of this storage period. Yellow milo stored with a moisture content of 14.6 per cent had a germination of 59.5 per cent at the end of the seven weeks in storage, and shallu with 13.7 per cent moisture had 31 per cent of germination at that time.

SUMMARY

Laboratory experiments were made under controlled conditions to determine the relationship between the factors that enter into the keeping qualities of the grain sorghum.

These studies showed that the hygroscopic moisture of sorghum grain when in equilibrium, at 25° to 28° C., with atmospheres of different relative humidities, was similar to that of the other cereal grains, the exception being that at relative humidities of 75 or greater, the other cereal grains, such as corn, barley, buckwheat, oats, wheat, and rye, contained more moisture than did the sorghum grain.

The relationship between hygroscopic moisture and relative humidity is so similar in all the classes studied that no class difference can be shown. The average hygroscopic moisture of the nine classes

of sorghum grains studied varied from 6.65 per cent at 13.8 per cent relative humidity, to 28.04 per cent at 100 per cent relative humidity (25° to 28° C.).

There is a clear-cut relationship between the hygroscopic moisture of the sorghum grains and their respiratory rate, as the moisture content of whole sorghum grain largely determines the rate of respiration when stored under uniform laboratory conditions.

Acceleration of the respiratory rate with an increase in the moisture content is gradual, and there is no sharp break in the curve. If the moisture content is between 13 and 14 per cent the acceleration is rapid, and it increases in intensity as the moisture content increases. In this respect the respiratory activity of the sorghum grain is similar in character to that of rice. On the other hand, it is distinctly different from that of wheat, in which there is a sharp break in the respiration curve at 14 per cent of moisture.

At high moisture contents cracked and broken sorghum kernels respire more vigorously than do normal whole kernels. Accordingly an increased risk is involved in storing and transporting sorghum grains that contain appreciable quantities of broken kernels. Furthermore, as whole sorghum grains seem to be no more hygroscopic than are other cereal grains and inasmuch as whole sorghum grains do not exhibit more respiratory activity than other cereal grains, it would seem reasonable to attribute the chief responsibility for the greater storage difficulties of the sorghum grains, as compared with other cereal grains, to the high percentage of cracked kernels usually present in commercial lots of sorghum grains.

The period of dampness, that is, the length of time that excess moisture has been present in the grain, bears a direct relation to the rate of heating, for naturally damp grain of the same moisture content respired somewhat more vigorously than did grain freshly dampened in the laboratory.

By increasing the temperature from 27.8° C. to 37.8° C. the rate of respiration of yellow milo was nearly doubled.

Heat-damaged sorghums likewise respire more vigorously than do sound kernels. Grain which has been exposed to incipient heating develops a condition which makes it unsafe for storage, as it seems to go out of condition more rapidly than does sound grain under the same conditions.

Storage tests made under laboratory conditions bear out in a general way the findings of the respiration studies; namely, that if the temperature is sufficiently high (100° F. or more) sorghum grains that contain over 14 per cent of moisture will go out of condition.

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