MOISTURE CONTENTS OF HARD RED WINTER WHEAT AS DETERMINED BY METERS AND BY OVEN DRYING, AND INFLUENCE OF SMALL DIFFERENCES IN MOISTURE CONTENT UPON SUBSEQUENT DETERIORATION OF THE GRAIN IN STORAGE[1]

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ABSTRACT

Samples of hard red winter wheat from commercial bins were stored in the laboratory and periodically tested. In the range between 14.0 and 15.5% moisture content, a difference of less than 1% in moisture content made a great difference in the growth of *Aspergillus restrictus,* in germ discoloration, viability, and biochemical characteristics. Moisture content as determined by any one meter on any one sample differed by as much as ±1% from moisture content determined by oven drying. The Weston meter gave consistently low readings. Extensive deterioration occurred in mixed or blended lots whose moisture content according to the Weston meter was 14.0% or below but whose moisture content by oven drying was 14.9% or above. Inaccurate measurement of moisture content may be responsible for unexpected cases of spoilage in commercially stored grain. Accurate measurement of moisture content, plus determinations of numbers and kinds of storage fungi and of other biochemical properties may aid greatly in evaluating condition and storability of grain.

Considerable work has already been done on the relation of storage fungi to development of germ damage in wheat (4,5,13,14,15) and on biochemical changes associated with quality and storability (5,8,9,11). The object of this work has been to obtain detailed information regarding the processes involved in deterioration and, subsequently, to devise a practical laboratory test or tests that would give a quick and reliable measure of grain quality and storability, such as the nomogram designed by Linko (9). The present study deals with microbiological and chemical changes associated with development of germ damage in wheat samples from commercial bulks at moisture levels of about 13 to 15.5%, the range in which deterioration may shift from minor to major importance.

Experience over the past several years with a number of moisture meters commonly used in the grain trade led to the belief that many cases of deterioration reported or encountered in commercial wheat stored below moisture levels at which storage fungi might be expected

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to grow and deterioration to take place, actually have involved errors in the measurement of moisture content. For this reason, moisture content was determined by several makes of meters as well as by oven drying.

Materials and Methods

Wheat Samples. Unless otherwise stated, all samples were of hard red winter wheat of 1960 crop and were taken shortly after they had been stored in bins, tanks, or barges at St. Louis. Approximately 1- to 2-lb. samples were taken from a bulk of 30,000 to 40,000 bu. Moisture content of the sample was determined at St. Louis with a Weston (formerly Tag-Heppenstall) meter. The remaining sample was placed in a double bag of 6-mil polyethylene and the top of the bag was folded over several times and stapled, after which the wheat was shipped to St. Paul. Immediately upon arrival the samples were tested for moisture content by meters and by oven drying, for numbers and kinds of fungi, and germ damage. The samples were then stored at room temperature, a portion in the original polyethylene bag and a portion in an 8-oz. bottle closed with a rubber stopper. Subsamples were removed at intervals and tested as above. In December 1961, after approximately 14 months of storage, the remaining portion of each sample was sent to Kansas State University where it was tested for germination, sedimentation value, glutamic acid decarboxylase activity, and fat acidity.

Moisture Content. Moisture content was determined by Motomco, Radson, Steinlite, and Weston meters, as well as by the 2-stage air-oven procedure (1).

Microflora. Fifty kernels were shaken in 2% sodium hypochlorite for 1 minute, rinsed in sterile water, cultured on malt agar containing 10% sodium chloride, and incubated at room temperature until the fungi could be identified.

Germ Damage. Pericarps covering the embryo were removed from 100 kernels under a stereoscopic microscope (magnification 10×); the color of the embryo was rated with the unaided eye. The presence of fungus sporophores on the germ, and of mites or mite damage and insects or insect damage was also recorded.

Germination. Germination percentage was determined according to Linko and Sogn (12).

Sedimentation Value. Fifteen grams of wheat were milled with the Brabender Quadrumat Pilot Mill, from which the sifter portion had been removed. The meal obtained was sieved and analyzed for the sedimentation value (11).

Glutamic Acid Decarboxylase Activity. Glutamatic acid decarboxylase activity (GADA) was determined as outlined by Linko (10), using Sandstedt & Blish pressuremeters filled with ethyl lactate (EL) colored with crystal violet. Carbon dioxide evolution during 30 minutes at 30°C. by 30 g. of ground wheat (2 minutes with a Waring Blendor) from 15 ml. of 0.1*M* glutamic acid in 0.067*M* phosphate buffer of pH 5.8 was recorded and the reading, in mm. EL plus 100, was taken as a measure of GADA.

Fat Acidity. Fat acidity was determined as described by Bautista and Linko (2).

Results and Discussion

Data obtained on the wheat samples as received are summarized in Table I, in order of increasing moisture content as determined by oven drying. The oven drying generally gave higher moisture values

TABLE I

MOISTURE CONTENTS AND GERM COLOR OF, AND FUNGI ISOLATED FROM, SAMPLES OF HARD RED WINTER WHEAT WHEN RECEIVED

Sample	Moisture Content						Brown Germs	Surface-Disinfected Kernels Yielding	
	By Meters					By Oven			
	Motomco	Radson	Steinlite	Weston, St. Louis	Weston, St. Paul			Field Fungi	Storage Fungi
	%	%	%	%	%	%	%	%	%
1	....	13.1	13.38	12.4	12.02	13.0	0	86	10
2	....	13.8	13.03	....	13.37	14.0	0	100	2
3	....	14.2	14.39	13.72	13.17	14.1	0	98	0
4	....	14.0	14.50	13.60	13.40	14.1	0	94	8
5	....	13.8	14.46	13.61	13.50	14.2	0	100	0
6	....	14.35	13.63	....	13.75	14.3	0	100	0
7	....	14.00	13.46	13.63	13.81	14.3	1	100	0
8	14.58	14.55	13.92	14.19	13.50	14.8	0	76	44
9	14.92	14.5	15.00	14.00	13.52	15.1	0	76	36
10	....	14.65	14.30	14.00	13.95	15.2	7	90	26
11	15.34	14.8	15.24	14.4	14.10	15.4	5	50	66
12	15.60	15.5	15.35	14.6	14.83	15.6	4.5	17	90
13	....	15.40	14.97	15.1	15.61	15.6	0	98	18
14	....	15.5	15.40	15.0	14.88	15.7	0	..	..

than those obtained by the Weston moisture meter, in some cases (Nos. 9, 10, 11, and 12) 1% or more. Within a moisture content range of 13 to 15%, an increase of less than 1% may greatly increase the growth of *Aspergillus restrictus* and the development of germ discoloration typical of germ-damaged wheat, as shown by Table II. All of the samples possessing a moisture content of 14.3% or less, as determined by oven drying, yielded field fungi from 86 to 100% of the surface-disinfected kernels, whereas storage fungi grew only on

TABLE II

INFLUENCE OF MOISTURE CONTENT UPON INCREASE OF STORAGE FUNGI AND BROWN GERMS IN SAMPLES OF HARD RED WINTER WHEAT STORED 16 MONTHS AT ROOM TEMPERATURE

Moisture Content (Oven)	No. of Samples	Brown Germs	Surface-Disinfected Kernels Yielding		Colonies	
			A. restrictus	Other spp. of *A. glaucus*	*A. restrictus*	Other spp. of *A. glaucus*
%		%	%	%	*thou-sands/g*	*thou-sands/g*
13.0–13.8	2	0	8	0	0	0
14.1–14.5	4	3	75	1	161	0.4
14.8–15.1	2	24	47	48	195	30
15.2–15.6	2	100	64	94	1920	442

1 to 10% of the kernels. When moisture content was 14.8% or above the relative number of kernels yielding field fungi decreased, and the number of those yielding storage fungi increased; the only excep-

TABLE III

INFLUENCE OF MOISTURE CONTENT UPON INCREASE IN STORAGE FUNGI AND BROWN GERMS IN SAMPLES OF HARD RED WINTER WHEAT STORED 8 TO 14 MONTHS AT ROOM TEMPERATURE

Sample No. and Container	Storage Time	Moisture Content	Brown Germs	Surface-Disinfected Kernels Yielding		Colonies	
				Aspergillus restrictus	Other spp. of *A. glaucus*	*A. restrictus*	Other spp. of *A. glaucus*
	months	%	%			*thou-sands/g*	*thou-sands/g*
		(13.0)[a]					
1 Bag	9	12.5	0	2	14	3.5	0
	14	12.3	0	0	2	0	0
		(14.0)					
2 Bag	9	13.6	0	0	0	0	0
	14	13.2	0	14	0	0	0
		(14.1)					
3 Bottle	10	14.2	3(?)	6	2	14	1.5[b]
	14	14.1	3	76	0	25	0
		(14.1)					
4 Bottle	10	14.2	2	18	0	5.5	1
	14	13.8	3	72	0	120	0
		(14.2)					
5 Bottle	10	14.2	1	32	2	1	0
	14	13.8	2	78	4	180	0[c]
		(14.3)					
6 Bottle	10	14.4	4	48	2	185	18
	14	14.2	5	76	0	330	0
		(14.3)					
7 Bag	9	13.4	1	0	4	0	0
		(14.8)					
8 Bottle	8	15.3	5	6	32	6	43
	14	14.7	20	60	22	210	10

(Continued)

TABLE III (Continued)

Sample No. and Container	Storage Time	Moisture Content	Brown Germs	Surface-Disinfected Kernels Yielding		Colonies	
				Aspergillus restrictus	Other spp. of *A. glaucus*	*A. restrictus*	Other spp. of *A. glaucus*
	months	%	%			*thousands/g*	*thousands/g*
		(15.1)					
9 Bottle	8	15.2	13	33	17	75	32
	14	14.9	28	34	74	480	50
Bag	8	14.6	11	45	22	114	11
	14	14.3	20	66	94	203	1
		(15.2)					
10 Bottle	8	15.1	7	16	21	70	18
	14	15.1	27	0	18	0	15[d]
Bag	14	13.3	0	20	16	0.5	7.5
		(15.4)					
11 Bottle	14	15.5	100	70	96	2160	60
Bag	8	15.2	47	18	81	8900	20
	14	14.6	76	62	82	1500	15
		(15.6)					
12 Bottle	8	15.9	64	3	17	0	270
	14	15.9	100	58	92	1680	825
Bag	8	15.3	57	20	83	3600	115
	14	14.7	84	66	82	2135	95
		(15.6)					
13 Bottle	9	15.7	39	54	43	200	5
	14	15.5	100	54	78	610	15
Bag	9	15.4	15	46	38	575	35
	14	15.1	100	60	36	1000	8.5
		(15.7)					
14 Bottle	14	15.6	100	26	56	660	20

[a] Parentheses indicate original content.
[b] 100,000 yeasts per g.
[c] 20,000 yeasts per g.
[d] Yeasts present.

tion, No. 13, had been harvested shortly before it was tested, and when stored in the laboratory, storage fungi developed on it within a few weeks.

Data obtained after storing the wheat in the laboratory for 8 to 14 months are summarized in Tables III and IV. *Aspergillus restrictus* and percentage of brown embryos increased slightly to moderately in samples of moisture content between 14.0 and 14.3% (Nos. 3, 4, 5, and 6), and more rapidly at or above 14.8% moisture. Sample No. 10, of 15.2% original moisture content, obviously had lost some moisture during storage in the polyethylene bag, and thus remained essentially free of storage fungi, as well as of germ damage. Similarly, fat acidity remained low, and germination percentage and GADA relatively high compared with the other samples originally high in moisture. When

TABLE IV

INFLUENCE OF MOISTURE CONTENT UPON VIABILITY, GERM COLOR, AND BIOCHEMICAL CHARACTERISTICS OF HARD RED WINTER WHEAT STORED 14 MONTHS AT ROOM TEMPERATURE

SAMPLE NO. AND CONTAINER	MOISTURE CONTENT		GERMINATION	BROWN GERMS	SEDIMENTATION VALUE	FAT ACIDITY	GADA
	Original	Final					
	%	%	%		*ml*		
1 Bag	13.0	12.3	89	0	31	23.78	233
2 Bag	14.0	13.2	74	0	31	27.10	142
3 Bottle	14.1	14.1	7	3	29	21.10	132
4 Bottle	14.1	13.8	18	3	30	26.41	146
5 Bottle	14.2	13.8	22	2	29	24.78	132
6 Bottle	14.3	14.2	1	5	29	31.42	141
8 Bottle	14.8	14.7	0	20	25	26.70	154
9 Bottle	15.1	14.9	0	28	24	30.96	147
Bag		14.3	1	20	23	28.40	135
10 Bottle	15.2	15.1	0	27	22	30.42	156
Bag		13.3	65	0	22	22.70	173
11 Bottle	15.4	15.5	0	100	23	37.80	146
Bag		14.6	0	76	23	38.43	144
12 Bottle	15.6	15.9	0	100	25	42.20	139
Bag		14.7	0	84	24	42.80	147
13 Bottle	15.6	15.5	0	100	25	32.99	176
Bag		15.1	0	100	23	32.03	157
14 Bottle	15.7	15.6	0	100	26	39.10	140

moisture content approached or exceeded 15.5%, viability was totally lost in 14 months and nearly 100% of the embryos were discolored. The fat acidity of such samples ranged from 32.99 to 42.80, and GADA sedimentation values decreased in comparison with sound samples. No field fungi were isolated from any samples stored 8 to 9 months at or above 14.8% moisture content; loss of viability of field fungi has been observed repeatedly in our tests in the past of samples of wheat stored for more than a few months at moisture contents of 13 to 15%. The samples stored in tightly stoppered bottles at moisture contents above 14% developed a sour odor, and an unidentified yeast was isolated in rather large numbers from some of them.

Two mixes or blends were made of samples of different moisture contents and stored for 16 months. In both mixes, samples were chosen which, when combined in approximately equal portions, yielded a blend whose moisture content as determined by the Weston meter was 13.9 to 14.0%. The moisture content as determined by oven drying was 14.7% in mix No. 1, and 14.9% in mix No. 2. After 16 months, 39% of the kernels in mix No. 1 had brown germs, and dilution cultures of the grain yielded 55,000 colonies of *A. restrictus* per g. In mix No. 2, after 16 months, 52% of the kernels had brown germs, and dilution cultures yielded 355,000 colonies of *A. restrictus* per g. Had the moisture content of these mixes actually been 14%, as the Weston

meter erroneously indicated that it was, no great increase in storage fungi or in percentage of brown germs should have occurred, as shown by samples 2, 3, 4, and 5 in Table III. If mixes such as these were made by an elevator operator he would have no basis, from moisture determinations made by the Weston meter (if his meter were no more accurate than the ones used on these samples at St. Louis and at St. Paul) to suspect that the grain was of high storage risk.

There are additional hazards in such mixes. It is well established that when grains of different moisture contents are mixed together the theoretical or arithmetic average moisture content is not attained (7). If to this is added an underestimation of moisture content by as much as 1%, and if the average moisture content aimed at is 14.0% or just below, it is not at all surprising that spoilage may develop. Still another factor may add to the storage hazard of such blends: the moister portion of the mix may have had a moisture content of over 15% for several weeks to several months, may already be heavily invaded by storage fungi, and may be on the verge of developing moderate to heavy germ damage. This is not evident to men in charge of stored grain, but may be obvious if the grain is tested for storage fungi in the laboratory.

Much work has been done to evaluate the accuracy of different methods of determining moisture content of grains (3,6,16). In grain trading it is essential that the buyer, seller, and grain inspection office agree closely on the moisture content of a given sample of grain, and this agreement probably is more important in trading operations than is a high degree of accuracy (16). However, if the grain is to be stored for some months to a year or more it is essential that the moisture content be known accurately. This is especially true of lots whose moisture content is between 14 and 15%, and of lots that are to be mixed to achieve a moisture content of 14% or just below.

On the basis of data obtained on the samples when received (Table I), the condition of the grain and its probable risk of developing significant amounts of damage in storage were estimated. Samples 1 through 7 had moisture contents, as determined by oven drying, of 13.0 to 14.3%, no brown germs (1% in No. 7, which was thought to be a stray bad seed, since none of the other germs of the 100 kernels examined had the slightest trace of discoloration or of storage fungi), yielded field fungi from 86 to 100% of the surface-disinfected kernels, and storage fungi from 0 to 10%. The storability of these samples was judged to be excellent; it was suggested, however, that samples be drawn again, within 3 months, from those lots whose moisture content was over 14%, and tested to determine their condition. As stored in

the laboratory, several of these samples developed 1 to 4% brown germs in 10 months, and 2 to 5% brown germs in 14 months (Table III).

Samples 8 through 14 had moisture contents of 14.8 to 15.7% as determined by oven drying when they were received, several already had an appreciable number of brown germs, plus an additional number of germs which were off-color and on which storage fungi could be seen when the germs were examined microscopically, and 18 to 90% of the surface-disinfected kernels yielded storage fungi. These lots were considered to be of high storage risk, in which the percentage of brown germs probably would increase. As shown in Table III the prediction was essentially accurate.

Neither of the two methods of storage in the laboratory—in double plastic bags or in tightly stoppered bottles—was completely satisfactory. Some of the samples in the plastic bags lost moisture slowly, and in the range of moisture content between 14 and 15% a loss of even a fraction of 1% may reduce the growth of storage fungi. Those stored at moisture contents of 14% and above in tightly stoppered bottles developed a sour odor characteristic of certain types of anaerobic fermentation. As stated above, considerable numbers of a yeast were isolated from some of these. This yeast, not as yet identified, has not previously been isolated in our work on microflora of stored grains, although it may be commonly present on such grains.

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