Moisture Content, Moisture Transfer, and Invasion of Stored Sorghum Seeds by Fungi

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Scientific Journal Series Paper No. 6989, Institute of Agriculture, University of Minnesota. Supported in part by a grant from Cargill, Inc., Minneapolis.

Accepted for publication 9 September 1969.

ABSTRACT

Ad- and desorption moisture contents of sorghum seed exposed to relative humidities of 75, 80, and 85% were 14.9-15.8, 15.9-16.6, and 17.0-17.5%, respectively. At moisture contents of 14.5% and above, wet wt basis, invasion by storage fungi and decrease in germinability were proportional to increasing moisture content and to increasing time of storage. A temperature difference of 12-14 C in grain on opposite sides of containers in sorghum originally of 14.3% moisture resulted in rapid transfer of moisture from the warmer to the cooler portion of the grain. That portion of the grain in which the moisture accumulated became heavily invaded and decayed by storage fungi. Phytopathology 60:280-283.

In 1967, the last year for which statistics are available, 766,000,000 bu of grain sorghum (*Sorghum vulgare* Pers.) were harvested in the USA (7), and in the last decade, production of this crop has increased rapidly in this and in other countries. The magnitude of storage losses in grain sorghum is not known; however, several cases have come to my attention in which large quantities of sorghum stored for planting deteriorated to feed grade within a few months, probably as a result of invasion by storage fungi, and in which sorghum stored for feed became so heavily invaded by fungi that its value was reduced. Only a single paper (4) deals with the invasion of sorghum by storage fungi, and the work described here was undertaken to explore more fully some aspects of this problem.

MATERIALS AND METHODS.—*Sorghum.*—Samples of yellow grain sorghum of certified seed grade or of Grade No. 2 were used in all tests.

Moisture content.—This was determined by drying portions of 4 to 10 g for three days at 103 C. To determine moisture contents in equilibrium with different relative humidities, portions of about 4 g, enough to form a layer only one seed deep in the weighing cans, were exposed to relative humidities of 75, 80, and 85% in desiccators. The relative humidities were maintained by saturated solutions of NaCl, $(NH_4)_2SO_4$, and KCl, respectively (8). In addition to the saturated solution in the bottom of the desiccator, a beaker was half filled with the same solution, and a cellulose sponge was placed in the beaker so that about half the sponge projected above the rim of the beaker. This furnished additional surface for gain or loss of water vapor. The beaker was placed on the plate of the desiccator, adjacent to the samples. Every 2 or 3 days the weighing cans containing the samples were removed, covered, and weighed immediately. When there was no further gain or loss of wt in two or three successive weighings, the moisture contents were determined by oven drying.

Moisture transfer.—Glass or plastic jugs of about 4-liter (1 gal) capacity were filled with sorghum grain of about 14% moisture, placed on a desk in the laboratory, and a 60-w lamp with a reflector was put on one side, about 30 cm away, with the reflector directing the light toward the lower part of one side of the jug. The lamp was constantly lit, and maintained a temperature of 10 to 14 C higher in the grain on the warm side of the jug than in the grain on the cool side. Samples were removed periodically from the warm and cool sides, either by means of a tube inserted through the mouth of the jug or through sampling ports in the sides of the jugs. Except when samples were being taken, the mouth of the jug and the sampling ports were kept tightly closed.

Surface-disinfected kernels yielding fungi.—Fifty or 100 kernels were shaken for 1 min in 2% NaClO, rinsed in sterile water, placed on T-6 agar in petri dishes (Difco tomato juice agar, 25 g; Difco powdered agar, 15 g; NaCl, technical grade, 60 g; distilled water, 900 ml) and incubated at 27 C until the fungi grew out and could be identified, usually in 4 to 6 days. The plates were kept an additional 6-10 days and examined occasionally to detect additional fungi. This was necessary because when *Aspergillus candidus* (group species) was present along with other species of fungi it often did not appear until the plates had been incubated for about 10 days.

Germinability.—This was determined by placing 100 surface-disinfected kernels on moist paper and incubating them at 27 C for 6 days. They were examined every 2nd day, and any seed with a coleoptile or root was counted as germinated.

RESULTS AND DISCUSSION.—*Equilibrium moisture contents.*—Usually equilibrium moisture contents were attained within 12 days. With additional storage time, the wt did not remain absolutely constant, but fluctuated slightly from one weighing period to the next. Presumably, this resulted from changes in relative humidity within the desiccators due to temperature changes in the room. When the samples were absorbing moisture, the highest wt attained was used in calculating the moisture content, and when they were desorbing moisture, the lowest wt attained was used in calculating moisture content (Table 1).

Whether the seeds were sound or heavily invaded by storage fungi made no difference in the equilibrium moisture contents. Four commercial lots, all of which had moderate amounts of broken kernels and fine material, had the same equilibrium moisture contents as the

TABLE 1. Adsorption and desorption equilibrium moisture contents of sorghum seed exposed to relative humidities of 75, 80, and 85% at 25 C

Relative humidity	Ad- or de-sorption	Original condition and % moisture of sample	Moisture content after storage for 12-14 days[a]	
			Avg	Range
%			%	%
75	Adsorption	Sound, 11.9%	14.9[a]	14.83-14.87
		Moldy, 9.0%	15.0	14.96-14.99
		Four commercial lots, 10.0-13.0%	15.0	14.86-15.15
		Oven-dried, 0.0%	13.7	13.62-13.69
	Desorption	Sound, 17.3%	15.7	15.72-15.74
		Sound, 20.3%	15.8	15.83-15.88
		Moldy, 17.4%	15.6	15.63-15.67
80	Adsorption	Sound, 11.0%	15.9	15.89-15.91
	Desorption	Sound, 20.0%	16.6	16.55-16.57
85	Adsorption	Sound, 11.0%	17.0	17.00-17.06
	Desorption	Sound, 20.0%	17.5	17.51-17.58

[a] Each figure is an avg of three replicate samples, and is calculated on wet wt basis.

sample of certified seed grade. At all of the relative humidities, equilibrium moisture contents of the non-oven-dried samples adsorbing moisture were from 0.5 to 0.9% below those of the samples that were desorbing moisture. These are smaller differences than those Hubbard et al. (2) reported for wheat and corn, but about the same as those reported by Tuite & Foster (5) for corn. Samples that were oven dried to zero moisture, then exposed to 75% relative humidity, had an adsorption moisture content of 13.7%, about 1.3% below that of the samples that were not oven dried, and 2.0% below that of the samples that were desorbing moisture to reach an equilibrium with 75% relative humidity. Tuite & Foster (5) reported differences almost as large as this in samples of corn exposed to a relative humidity of 80% after having been dried at different temperatures. Whether sorghum seed that has adsorbed moisture at 75% relative humidity and has a moisture content of 14.8-15.0% (or lower, if it previously has been kiln dried), and sorghum seed that has desorbed moisture and has a moisture content of 15.6-15.8%, are equally susceptible to invasion and damage by fungi is not known. This might make a great difference in deterioration risk in storage.

The equilibrium moisture contents for sorghum seed reported here are slightly higher than those reported by López & Christensen (4). Their samples were several cm deep, and only the top surface of the samples was exposed to the air in the desiccators. Their samples were still increasing in wt after 7 months, and it is likely that their figures for equilibrium moisture contents were low.

Relation of moisture content and length of storage period at 22-25 C to changes in fungus flora and to loss

TABLE 2. Relation of moisture content and length of storage period of sorghum seed kept at 22-25 C to germinability of the seed and to fungi isolated from surface disinfected kernels[a]

Days stored	Moisture content		Germination	Surface-disinfected kernels yielding[a]			
	Initial	At test period		*Alternaria*	*Aspergillus glaucus*	*Aspergillus candidus*	*Penicillium* spp.
	% wet wt		%	%	%	%	%
0	11.0		95	98	0	0	0
69	13.5	13.6	99	96	0	0	0
	14.5	14.6	97	98	0	0	0
	15.5	15.5	93	84	32	0	0
	16.5	16.3	75	91	44	0	0
	17.5	17.3	59	71	61	0	0
105	16.5	16.3	58	34	94	0	0
	17.5	17.4	37	6	93	24	3
146	13.5	13.5	99	63	0	0	0
	14.5	14.4	93	20	10	0	0
	15.5	15.4	38	10	88	0	0
	16.5	16.6	38	2	97	2	0
	17.5	17.6	29	0	96	62	4[b]
216	13.5	13.5	97	14	0	0	0
	14.5	14.4	82	1	42	0	0
	15.5	15.4	7	0	100	0	0

[a] Each figure is an avg of two to three replicates.
[b] Plus *A. versicolor* from 12%.

TABLE 3. Effect of differences in temperature upon shifts in moisture in sorghum seed stored in 1-gal (about 4-liter) containers in the laboratory, and the relation of such shift to invasion of the seed by storage fungi and to loss of germinability

Container	Days stored	Temp	Moisture content	Surface-disinfected kernels yielding			Germination
				Alternaria	*Aspergillus glaucus*	*Aspergillus candidus*	
no.			*% wet wt*	%	%	%	%
1	0	25[a]	14.4	98	0	0	95
	31	34	12.5	86	0	0	96
		25	17.4	52	56	0	91
	46	38	11.3	82	0	0	98
		24	17.2	46	68	0	87
	77	32	12.9	28	0	0	97
		27	17.6	40	54	0	84
	108	36	11.8	2	6	0	91
		24	19.1	6	40	14	58
2	0	25	14.0	75	4	0	59
	105	36	9.4	32	16	0	57
		24	16.7	48	70	6	12
3	0	24	14.0	75	4	0	59
	105	38	10.6	24	14	0	39
		26	15.3	22	88	0	4

[a] Temp of the grain at or near the place where the sample was taken on the warm or cool side, respectively.

of germinability.—In the samples stored at 13.5% moisture the percentage of surface-disinfected kernels yielding *Aspergillus* spp. did not increase, and after 216 days the seeds germinated 97%. At moisture contents of 14.5% and above, increasing invasion by storage fungi and loss of germinability of the seed were proportional to increasing moisture content and to increasing time of storage. After 146 days, the samples with 15.5% moisture were invaded more by storage fungi and had a much lower germination percentage than those with 14.5% moisture (Table 2). The Official Grain Standards of the United States (6) specify a maximum moisture content of 14.0% for Grade No. 2 and 15.0% for Grade No. 3 for all classes of grain sorghum. The results of the present tests indicate that these specifications are reasonable.

Influence of temperature differences upon moisture transfer.—Transfer of moisture from the warmer to the cooler portions of the samples was relatively rapid (Table 3). In container no. 1, samples were withdrawn after 3 and 6 days and tested for moisture content. After 3 days, the moisture content of the grain on the cool side of the jug was 1.4% higher than that of the grain on the cool side; after 6 days the difference was 2.0%.

After 140 days of storage, the grain on the cool side of container no. 1 was caked together with mycelium from the wall to about 2 cm in from the wall. Some of these kernels were removed and scattered, without any prior treatment, on several kinds of agar media. The principal fungi that developed on the kernels and on the agar media were *A. candidus, A. glaucus* (group species), and *Penicillium.* I estimated that 10-15% of the grain in the container was caked together and decayed.

Transfer of moisture from one portion of grain to another in bins, resulting from temperature differences, has long been recognized, although its possible importance in loss of quality has not been emphasized. Holman (1) reported such transfer in soybeans stored in Illinois. Soybeans stored in November 1942, with an average moisture content of 12-13%, had by February 1943 a moisture content of 16-17% in the center of the upper surface of the bulk. By February 1944, after 15 months of storage, the moisture content of the beans in the center of the upper surface of the bulk ranged from 20-24%. Johnson (3) calculated that in a large bin of corn with 14.5% moisture, a temperature differential of about 22 C between the interior and the surface of the bulk would result, in 20 days, in sufficient transfer of moisture to raise the moisture content of a layer 6 inches (about 15 cm) deep on the surface of the bulk to 20%. It seems probable that such transfer of moisture from the warmer to the cooler portions of grain stored in bulk may be much more important in initiating deteriorative processes than is recognized by many practical grain men.

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