Aeration of High Moisture Corn

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FIELD-SHELLED corn of high moisture presents handling and storage problems. While an increasing amount of corn for livestock feed is being stored wet by ensiling or chemical treatment, the load on conventional drying and handling equipment is often excessive at the peak of harvest. The heavy load may cause delays during which wet corn can go out of condition. Aeration with refrigerated or natural air has been used for temporary or extended storage of high moisture corn, and to lessen the peak load on drying equipment. It is known that high temperatures and moisture contents greatly shorten the safe storage time for corn (U.S. Department of Agriculture, 1968), but the effects of short term exposure to adverse conditions such as when drying or cooling is delayed, have not been adequately studied.

We investigated mold growth and other changes that occurred during and after delays in the start of cooling warm, moist corn and during continuous outdoor aeration of corn.

TESTS CONDUCTED

Four test lots of field-shelled corn from one field were used in aerated storage experiments for the fall harvests of 1970 and 1971. About 150 bu of corn of 21 to 22 percent moisture content were used in each lot. Storage treatments and test conditions were the same both years except that weather conditions and mechanical damage to kernels may have varied. Three lots were stored in insulated bins in a laboratory building and each bin was aerated with refrigerated air; the fourth lot was held in a similar-sized, steel bin outside and aerated with natural air (bin 4). Aeration with 0.5 cfm of air per bu was started immediately after the outdoor bin and one of the indoor refrigerated bins were filled; similar aeration was started for a second indoor bin after a 20-hr delay and for a third indoor bin after a 40-hr delay. Aeration was continuous after starting. The three refrigerated bins were cooled to and held at 35-40 F while the outdoor bin grain temperature varied with natural air conditions.

Initial samples of shelled corn from each lot were evaluated visually for mechanical damage to kernels and percentage of sound kernels. A biological stain, fast green F.C.F., was used to help detect cracks in kernels. Visual examination and screening results were as follows:

	Percent	
	1970	**1971**
Broken kernels	5.2	3.6
Kernels with large cracks	4.1	3.5
Kernels with small cracks	10.1	6.6
Sound kernels	80.6	86.3
Foreign material and fines	1.0	1.4
Moisture content	21.1	21.8

Test weight ranged from 49 to 50 lb per bu for the 1970 corn and 51 to 52 for 1971.

Probe samples were taken from two sides of the test bins at upper, middle, and lower levels (C in Fig. 1). Each probe sample was tested for moisture content, germination percentage, fat acidity, and presence of various fungi.

EQUIPMENT AND PROCEDURES

The three insulated bins in the laboratory were constructed of three concentric circular steel bins (Fig. 1). The interstice formed between the walls of the 6 and 9-ft diameter bins was filled with pour-type insulation. Corn filled the space between the 6 and 4-ft bins and received the same aeration as the test corn in the inner 4-ft bin. The fourth bin, located outside, was a 6-ft diameter bolted steel unit secured to an 8-ft square wood plenum using perforated metal to support the grain column. Probe sampling ports were at the same levels as shown in Fig. 1, but the outside bin included neither the 4-ft bin nor the outer 9-ft bin. Aeration was by a centrifugal fan with speed adjusted to supply air up through the corn at 0.5 cfm per bu.

Cold air for the three inside bins came from a walk-in refrigerator equipped with a nominal 5-ton refrigeration system. Dry-bulb temperature in the walk-in was maintained at approximately 35 F by electric reheat varied in response to a thermistor sensor in the refrigerator. Surrounding laboratory air temperatures were between 70 and 80 F most of the storage period. Final air temperature control was made at each of the individual bins by a 1/3 hp refrigeration unit and a 1,000-w electric resistance heater in the air duct at the entrance to the plenum (D and E, Fig. 1). A temperature controller varied the

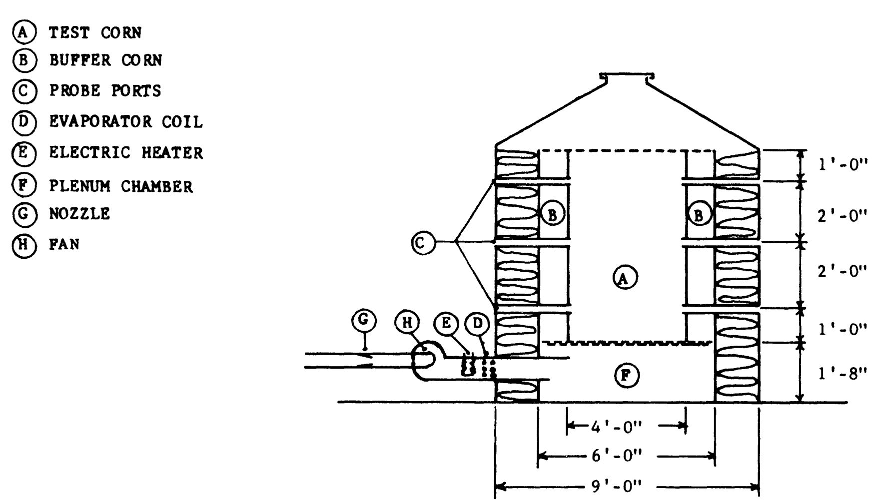

FIG. 1 Construction features of test bin.

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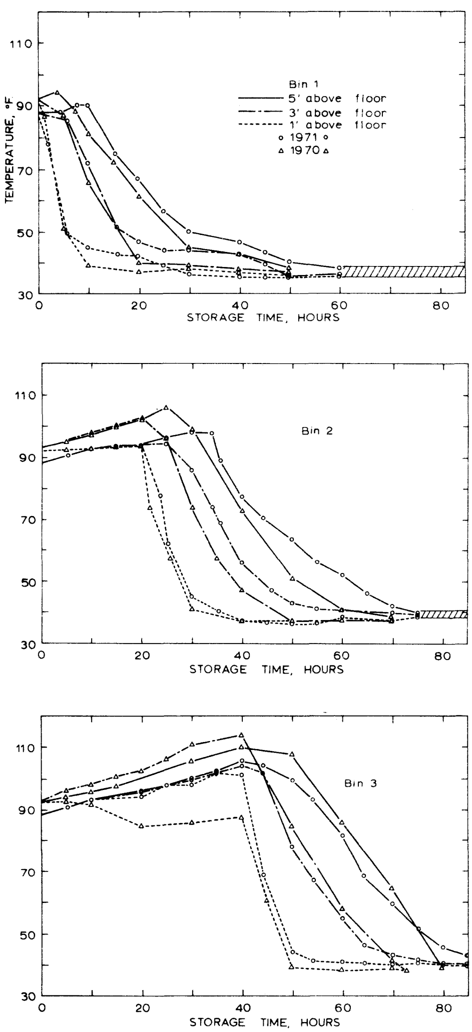

FIG. 2 Temperatures in corn at top = 5 ft., middle = 3 ft., bottom = 1 ft. above the floor during the first 80 hours of storage in three bins for 1970 and 1971.

TABLE 1. PERCENTAGES OF KERNELS INVADED BY *ASPERGILLUS FLAVUS* AND *A. NIGER* AFTER ONE WEEK OF STORAGE WITH AND WITHOUT COOLING DELAYS

Bin	Location in bin*	1970		1971	
		A. flavus	*A. niger*	*A. flavus*	*A. niger*
Bin 1	Top	1	0	1	0
cooled immediately	Middle	1	1	0	1
to 35 - 40 F	Bottom	1	0	0	1
Bin 2	Top	74	49	10	14
cooling delayed	Middle	58	29	6	6
20 hr	Bottom	17	6	1	2
Bin 3	Top	95	73	37	24
cooling delayed	Middle	80	41	28	27
40 hr	Bottom	87	44	9	17

*Top = 5 ft, middle = 3 ft, bottom = 1 ft above floor in 6 ft of grain.

TABLE 2. PERCENTAGES OF KERNELS INVADED BY *PENICILLIUM* AND *ASPERGILLUS* AFTER 4 WEEKS WITH CONTINUOUS OUTDOOR AERATION AT 0.5 CFM PER BU

Location in bin*	*Penicillium* spp.	*A. flavus*	*A. niger*	*A. ochraceus*	*A. glaucus*
			1970		
Top	97	58	32	13	12
Middle	97	51	36	16	5
Bottom	82	16	7	6	5
			1971		
Top	41	17	13	5	5
Middle	40	8	7	5	3
Bottom	1	2	1	0	1

*Top = 5 ft, middle = 3 ft, bottom = 1 ft above floor in 6 ft of grain.

heat in response to a thermistor sensor in the plenum chamber under the bin.

Temperatures in the three refrigerated bins were recorded periodically from thermocouples located on a 1-ft square grid in a vertical plane through the center of the bins. Corn temperatures in the outside bin were measured at 24 points.

Moisture contents, expressed on a wet weight basis, were determined by drying whole corn samples 72 hrs at 103 C in a forced draft oven.

Fat acidity values were determined by AACC Method 02-04 (American Ass'n. of Cereal Chemists 1962), and expressed as milligrams of KOH required to titrate the acids in 100 grams of corn, dry basis.

Percentage of kernels invaded by various fungi was determined by washing 100 kernels in 2 percent NaOCl 1 min, rinsing in distilled water, and placing on malt agar (Difco) containing 4 percent NaCl and 200 ppm Tergitol NPX (Union Carbide Corp.). Seeds were incubated at 25 C until fungi could be identified and counted.

Germination percentage was determined by placing 200 kernels between wet paper towels in aluminum foil folders. Kernels that sprouted within 7 days were considered germinated.

RESULTS

Corn Temperatures

Temperature increased in warm moist corn during delays between harvest and start of aeration and during aeration in locations farthest from the air supply (Fig. 2). Even though initial temperatures and moisture contents were nearly identical for the two test years, temperature increased 50 percent more in 1970 than in 1971 in the refrigerated air bins. Both years the temperatures increased linearly in the upper parts of the bins before aeration was started. Approximate rates of temperature rise were 0.5 F per hour for the 1970 tests and 0.35 F per hour for 1971.

The temperature increases correlated well with mold invasion after one week (Table 1) and also with mechanical damage to kernels during harvest. In 1970 there was greater temperature rise, greater mold activity and greater mechanical damage than in 1971. All three factors were interrelated.

Corn temperature ranges for the tests with the outside bin are shown in Figs. 3 and 4, and reflect daily fluctuation in outside air temperature.

In 1970 tests were started on September 8 and in 1971, on September 28. This difference in time caused average corn temperature during the early weeks of the tests to be higher in 1970 than 1971.

Normal mean monthly temperatures at Manhattan, Kansas (Kansas Agricultural Experiment Station 1972) and the mean temperatures recorded during our outside tests were as follows:

	Normal	1970	1971
September	70.6	69.0	70.8
October	59.1	54.3	61.8
November	43.3	41.7	42.4
December	33.6	36.1	34.9

Average of mean weekly dry and wet bulb temperatures for the first 4 weeks and 12 weeks of aeration (beginning Sept. 8, 1970 and Sept. 28, 1971) were as follows (2, 4):

	1970		1971	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb
4 weeks	64.5	59.7	63.8	56.0
12 weeks	50.8	47.8	50.0	44.0

Evaporative cooling will result in lower grain temperatures when aerating wet corn with dry air than with moist air of the same dry bulb temperature.

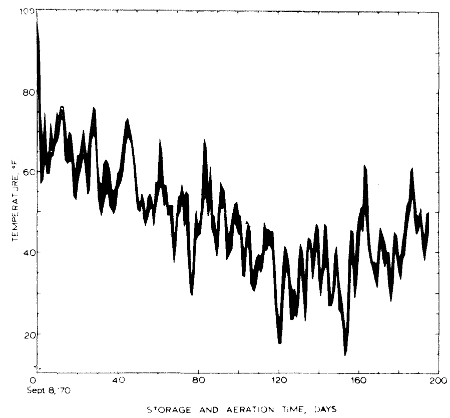

FIG. 3 Corn temperatures in the outdoor bin with continuous aeration, 1970 grain.

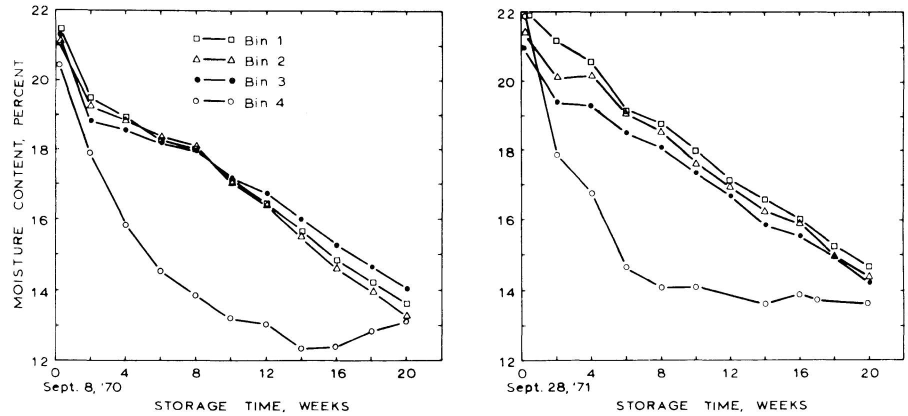

FIG. 5 Average moisture contents of corn in four storage bins, 1970-71 and 1971-72.

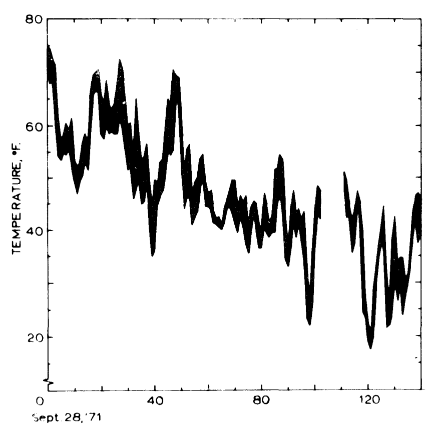

FIG. 4 Corn temperatures in the outdoor bin with continuous aeration, 1971 grain.

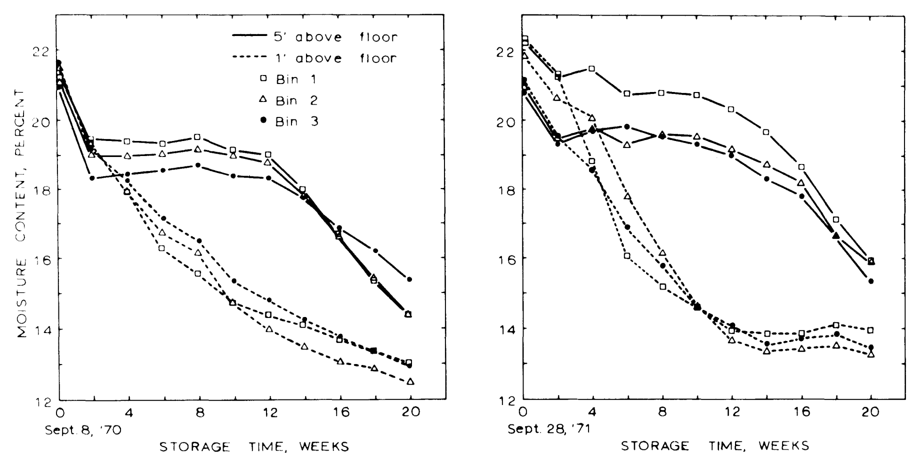

FIG. 6 Moisture contents of corn at 5 ft and 1 ft above the floor in the three refrigerated bins in 1970 and 1971.

During the first 4 weeks of our tests, dry bulb temperatures were essentially the same in 1970 and 1971. However, wet bulb temperatures and grain temperatures in the upper half of the outdoor bin averaged about 4 deg higher in 1970 than in 1971.

Moisture Content Reduction

Decreases in corn moisture content were similar in both years (Fig. 5). The average rate of moisture reduction in refrigerated air bins was 0.32 to 0.34 percent per week in 1970 and 0.34 to 0.36 percent in 1971. The rate of drying in the outside bin was about the same for the first 10 weeks but slowed down the last 10 weeks. In 1970, the moisture reduction in the corn outside averaged 0.72 percent per week and in 1971, 0.80 percent per week during the first 10 weeks.

More important than the average moisture content was the moisture content of the corn in the upper layers that was the last to dry. For the refrigerated air bins, 18 to 20 weeks were required for the upper corn to dry to below 16 percent (Fig. 6). The lower 1-ft layers of corn in each of the three bins dried to 14 percent in 12 to 15 weeks.

Moisture content of the corn in the upper and lower layers in the outside bin are shown in Fig. 7. The upper layer was down to 14 percent in 12 weeks the first year and down to 15 percent in 12 weeks the second year.

Mold Development and Associated Changes

Essentially no mold growth occurred either year in the bin which was cooled immediately. *Aspergillus flavus* and *A. niger* were the principal storage fungi that grew in the bins with delayed cooling both in 1970 and 1971, but the amount of invasion was much greater in 1970. Temperature increased more during delays in cooling in 1970 (Fig. 2). Mold growth in the outdoor bin (bin 4) was greater in 1970 than in 1971 (Table 2). Corn temperatures in the outdoor bin (Figs. 3 and 4) were about 10 deg higher the first two weeks of 1970 than in 1971. Mold invasion was generally more extensive in the top portions of the bins (Tables 1 and 2), reflecting the slower cooling and/or drying farther from the aeration source.

Initial condition of the corn in 1971 was somewhat different than in 1970. Thirteen of 800 kernels in 1970 had been invaded by *A. flavus,* three by *A. niger;* in 1971 the figures were 0 and 2,

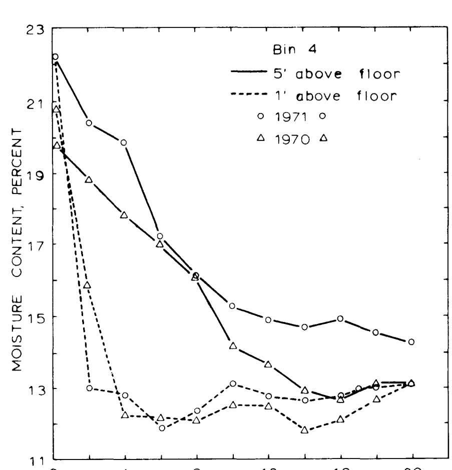

FIG. 7 Moisture contents of corn at 5 ft. and 1 ft. above the floor in the outdoor bin, 1970 and 1971.

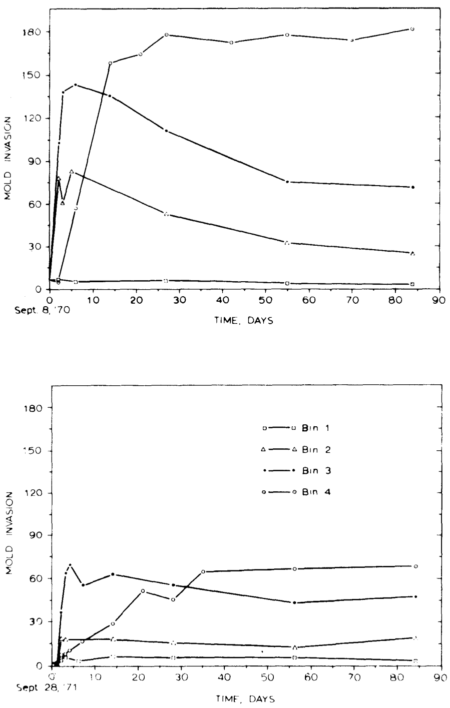

FIG. 8 Average percentage of corn kernels invaded by *Penicillium* spp. plus percentages invaded by various *Aspergillus* species in four bins in 1970 and 1971.

TABLE 3. PERCENTAGES OF KERNELS INVADED BY INDICATED FUNGI AT HARVEST AND AFTER 28 DAYS. FIGURES ARE AVERAGES OF 2 SAMPLES FROM EACH OF THREE LEVELS IN BINS.

Fungi	Days	1970 Bin 1	1970 Bin 2	1970 Bin 3	1970 Bin 4	1971 Bin 1	1971 Bin 2	1971 Bin 3	1971 Bin 4
*Fusarium**	0	79	80	80	73	27	24	27	29
	28	73	59	42	42	37	39	33	86
Cephalosporium	0	—	—	—	—	30	35	37	35
	28	—	—	—	—	32	23	20	5
Alternaria	0	5	5	4	4	2	2	1	1
	28	2	5	3	3	25	29	17	45
Cladosporium	0	5	3	1	2	1	1	2	1
	28	2	1	1	2	8	1	0	23
Mucor	0	0	0	1	1	0	0	0	0
	28	0	1	0	0	1	0	1	0
Nigrospora	0	2	2	1	1	2	3	4	2
	28	1	1	1	1	10	2	1	2
Penicillium	0	4	6	7	4	2	1	1	1
	28	5	3	2	92	3	6	5	23
A. flavus	0	3	1	1	1	0	0	0	0
	28	1	35	76	42	1	4	28	10
A. glaucus	0	1	0	0	1	0	0	0	0
	28	0	1	1	7	0	2	3	2
A. niger	0	1	1	1	1	1	0	1	0
	28	0	15	33	25	1	4	19	7
A. ochraceus	0	0	0	0	0	0	0	0	0
	28	0	0	1	12	0	0	0	3

*Mainly *F. moniliforme*. Data for 1970 include *Cephalosporium*.

respectively. Mechanical damage was 19 percent in 1970, 13 percent in 1971.

Table 3 illustrates the variety of fungi found in the corn initially and 28 days later. The *Aspergillus and Penicillium* species were the principal fungi which grew in all of the corn, so average percentages of those species were totaled and plotted (Fig. 8) for each sampling time. Maximum invasion in the delayed cooling bins (2 and 3) occurred the first few days, while invasion in bin 4 was slower, but continued longer.

Selected samples taken after five months storage were submitted to a Market Quality Research Division laboratory where aflatoxin assays were completed with these results:

	Aflatoxin in 1970 corn B_1 (ppb)	Aflatoxin in 1971 corn B_1 (ppb)
Bin 1	none	—
Bin 2		
Surface	10 to 50	10
Top layer	10	none
Bin 3		
Surface	34 to 80	7 to 10
Top layer	10 to 14	—
Middle layer	0 to 61	none
Outside		
Surface	10 to 40	2 to 4
Top layer	10 to 34	3 to 5
Middle layer	0 to 11	—

Germination of corn from the outdoor bin decreased to 76 percent in 1970 while it was above 90 percent for all other bins. In 1971, percentages in all bins remained essentially unchanged during storage.

Fat acidity did not consistently reflect either the extensive microbiological changes or the heating that occurred during the first few days either year.

DISCUSSION

Storage conditions the first few days are critical in regard to mold invasion. As shown by the weather data and in Figs. 3 and 4, temperatures are more favorable in October than in September for natural air cooling. September average temperatures of about 70 F, coupled with grain of high moisture content, are ideal for mold growth.

Delays in aeration increased mold invasion and amount of deterioration in grain quality. Aeration as an adjunct to drying, or to maintain quality during short-term storage, should be started immediately after harvest.

Mold invasion and heating were greater in 1970 corn than in the 1971 corn, even though initial moisture and temperature were nearly the same. This was true in the delay cooled bins, and also in the outdoor bin. The 1970 corn had somewhat more mechanical damage and much more mold invasion initially than the 1971 corn, both factors which contribute to greater deterioration. A possible third factor is that a different variety of corn was used each year. No information is available regarding varietal differences in susceptibility to storage mold invasion.

Mold developed in the upper half of all bins, except No. 1, to an extent that grain quality was impaired. While all of the test corn graded No. 2 at the end of the 5-month tests, it is possible that grade changes would occur in long-term storage due to these initial mold invasions.

Weather from October through December was satisfactory for reducing the corn moisture content to 14-15 percent in 120 days with continuous aeration with outdoor air; however, mold invasion was high during the first four weeks of 1970. Higher aeration airflow rates would reduce the drying time and possibly reduce the mold activity during the early weeks of storage.

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