

Some Effects of Cooling Rates on Quality of High Moisture Corn

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THREE insulated, 140-bu bins were filled with field-shelled, high moisture corn four times to evaluate the effect of cooling rate on mold populations, germination percentages, and fat acidity values. In each test the three bins were cooled to 35 to 40 F in about 2, 4, and 8 days, respectively, using an upward airflow of 0.5 cfm per bu. Corn with 28 percent moisture and 90 F initial temperature was invaded by species of *Rhizopus*, *Penicillium*, and *Mucor*. In the fast-cooled bin little mold growth occurred in 12 days, but corn in the slow-cooled bin had high mold populations and was visibly discolored from mold growth on cracked or broken kernels. The same three genera of fungi were predominant in corn initially at 70 F and 26 to 27 percent moisture. Fat acidity values increased about 10 units in the slow-cooled bin, but germination was not different among bins after cooling was completed. Continued storage at 35 to 40 F allowed *Penicillium* and *Mucor* to grow as long as the moisture content remained high. Therefore, long term storage should be at a lower temperature or a lower moisture content to avoid mold damage.

When corn with 25 percent moisture was left overnight before starting the cooling process, its temperature rose from an initial 85 to 90 F to as high as 108 F. *Aspergillus flavus* was the dominant mold; *Rhizopus* and *Penicillium* also were abundant. After cooling, the more slowly cooled corn contained up to 95 ppb (parts per billion) of aflatoxin B₁; fat acidity values were as high as 37 in the slow-cooled bin as compared with 12 in the fast-cooled bin. Germination percentages were

slightly lower in the slow-cooled corn than in the fast-cooled corn.

Corn with 20 percent moisture content and 90 F initial temperature had relatively little mold growth even though cooling was delayed overnight. Extensive mold growth occurred only in the slow-cooled bin, where invasion by the *Aspergillus glaucus* group reached 40 to 50 percent. No changes in fat acidity values or germination percentages were detected during cooling or during 3 months of storage at 35 to 40 F.

INTRODUCTION

The storage life of corn and other grains is related to grain moisture content, storage temperature, and to an undetermined degree, mechanical damage to the kernels. Changes to lower grades in corn can be expected after a certain period of time at given temperatures and moisture contents. Generally, decreasing moisture content and/or storage temperature will increase allowable storage time without decreasing official grade (see reference 3).

This paper reports the effects of different cooling rates by low temperature aeration on the quality of high moisture, field-shelled corn. Corn from the 1967 and 1968 crops was cooled with a final storage temperature of 35 to 40 F at selected rates and sampled periodically. Samples were tested for moisture content, germination percentage, fat acidity value, and presence of various fungi.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

Bins and Related Equipment

The cooling rate experiments were done in the laboratory using three test bins (Fig. 1).

Each test bin (Fig. 1) consisted of three round bins arranged to form concentric cylinders: the outer one, 9 ft in diameter; the second, 6 ft and the inner, 4 ft. The interstice formed between the walls of the 6- and 9-ft bins was filled with pour-type fibrous insulation. A perforated floor was placed inside the 6-ft bin to form a plenum chamber 20 in. high. The 4-ft diameter bin was placed on the perforated floor. The 4-ft bin and the space between 4- and 6-ft bins were filled with field-shelled corn for each test. The corn between bins received the same cooling treatment as that being tested in the inner 4-ft bin. The combination of 18 in. of insulation plus the 12 in. of "buffer" corn was used to minimize external effects.

Each bin was equipped with a fan to supply a mixture of room air and refrigerated air to the plenum chamber. The cooling air was forced into the plenum chamber and then passed vertically through the corn.

The quantity of air to each bin was controlled by adjusting manual valves in the pipes supplying the refrigerated air and the room air and by regulating fan speed. Gross adjustment of air temperature for each bin was made the same way. Humidity of the air

- (A) TEST CORN
- (B) BUFFER CORN
- (C) PROBE PORTS
- (D) EVAPORATOR COIL
- (E) ELECTRIC HEATER
- (F) PLENUM CHAMBER
- (G) NOZZLE
- (H) FAN

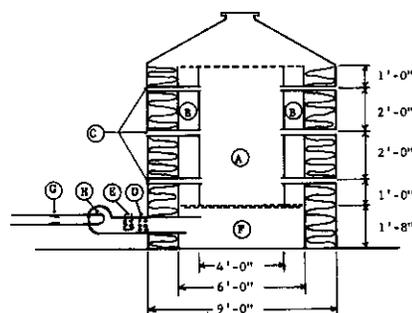


Fig. 1 Construction features of test bin

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was increased for the 1968 tests by injecting low pressure steam into the air supply lines through a manually operated needle valve. Calibrated hot-wire anemometers, located in each air supply pipe, were used for the first year to determine airflow. They were replaced the second year with standard 2-inch nozzles.

The cold air source consisted of an 8 ft x 8 ft x 8 ft walk-in cold box equipped with a nominal 5-ton refrigeration system. The system pumped a water-ethylene glycol solution through the tubes of a shell and tube flooded evaporator and then through an air handling unit. Dry-bulb temperature in the cold air box was controlled by electric reheat, and relative humidity was regulated by the concentration of ethylene glycol in the solution.

Fine control of supply air temperature to each test bin was accomplished by placing both a 1/3-hp direct expansion refrigeration unit and a 1000-w electric resistance heater in the air duct at the entrance to the plenum (D and E, Fig. 1). The refrigeration unit ran continuously and the desired temperature was maintained by adding varying amounts of electric heat. A Honeywell R7187D temperature controller varied the heat in response to a thermistor sensor in the bin plenum chamber.

Temperatures at 80 locations in the corn were recorded periodically with a Brown 16-point recording potentiometer used in conjunction with stepping switches. Copper-constantan thermocouples were located on a one-foot square grid in a vertical plane through the center of each bin.

Six probe ports for collecting samples were provided in each bin (Fig. 1). The ports were on diametrically opposite sides of the bins, spaced vertically 1, 3, and 5 ft above the perforated floor. The ports extended through the buffer corn so that corn from only the test section was collected in the sampling probe.

The corn used for all tests was obtained from a local farmer. It was

field shelled with a combine, hauled approximately 8 miles in auger unloading trucks, and augered directly into the test bins. The bins were emptied and cleaned after each test.

Analytical Procedures

Corn samples were collected during bin loading for determinations of moisture content, fat acidity, germination, and mold counts. The same determinations were made periodically for samples of corn from each probe port of each bin.

Moisture contents were determined by drying whole corn 72 hr at 103 C in a forced draft oven, and are expressed on a wet weight basis. Two or four samples of 100 g each were tested from each of the three levels in a bin. Germination tests were made by the Kansas State Board of Agriculture's Seed Laboratory in Topeka. Fat acidity values were determined by the Department of Grain Science and Industry, Kansas State University, using AACC Method 02-01 (see reference 1), and are expressed as milligrams (mg) of KOH required to titrate the acids in 100 grams (g) of corn, dry basis.

To determine percentage of kernels invaded by various fungi, 100 kernels were surface disinfected in 2 percent NaOCl, rinsed in sterile water, and placed on agar media. Two media, Difco malt agar and Difco potato dextrose agar, were used either plain or amended, depending on the microbial populations expected. Amendments included one or more of the following: 30 parts per million (ppm) of tetracycline, 30 to 100 ppm of rose bengal, 200 ppm of Tergitol NPX (Union Carbide Corp.) and 2 to 8 percent NaCl, all materials that inhibit or select certain species of microorganisms. Most of the 1968-69 tests were based on malt agar with 4 percent NaCl and 200 ppm of Tergitol. This medium appeared best for allowing all fungi to grow from the kernels, while restricting growth of rapidly growing species. Corn was also plated without surface disinfection at the start of each test.

Dilution cultures, to measure the number of viable spores of various fungi per gram of corn, were made on some samples during the 1968-69 tests. Fifty g of corn were used for each test, with 0.15 percent agar solution as the diluent, and potato dextrose agar containing 4 percent NaCl as the culture medium. The technique was essentially the same as that used by Sauer and Christensen (1966).

RESULTS AND DISCUSSION

1967 Test I

On October 4, 1967, the three 140-bu test bins were filled with field-shelled corn containing about 28 percent moisture. Corn temperatures immediately after filling the bins were approximately 90 F. By varying airflow rates between one-half and 1 cubic foot per minute (cfm) per bushel and by varying the air temperature, we intended to cool the three bins of corn to below 40 F in 2, 4, and 10 days, respectively. However, as Fig. 2 shows, cooling rates were not precisely controlled.

For valid comparisons between bins, one given level in each of the three bins probably should be considered. For example, the areas under the time-temperature curves at the 3-ft level in each bin during the 12 days of the test (Fig. 2) can be expressed as approximately 210-, 132-, and 110-deg days (35 F base line) for the three cooling rates. The differences between cooling times (or deg days) from one level to another in the same bin, as well as from bin to bin at any given level, must be kept in mind when evaluating changes that occurred in the corn in any of these tests.

Ventilation and cooling reduced moisture 1.0 to 2.4 percent in the corn during 12 days. Corn in the fast-cooled bin lost less moisture than corn in the more slowly cooled bins. The air passing through the slower cooled bins during the first few days had more drying potential. No changes in germination percentage were detected.

Three genera of fungi, *Rhizopus*, *Penicillium*, and *Mucor*, accounted for

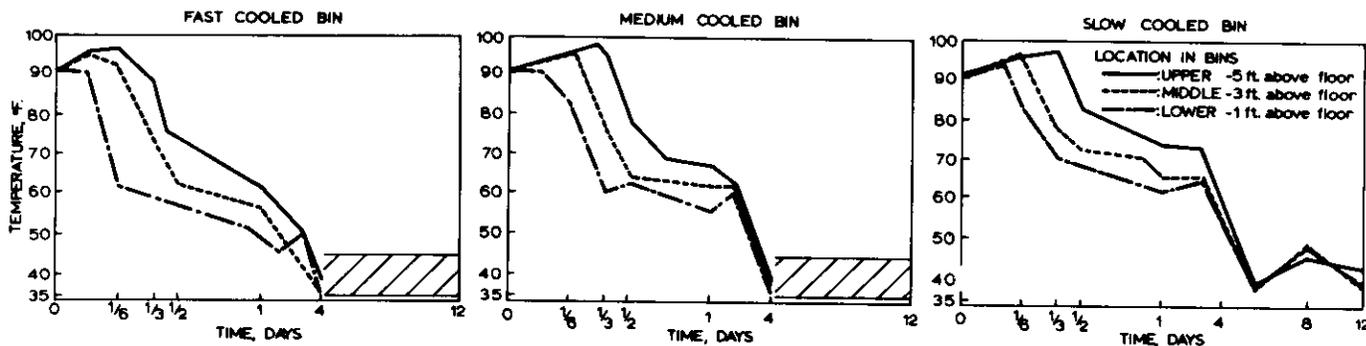


Fig. 2 Test 1, 1967. Temperatures in corn cooled at three different rates

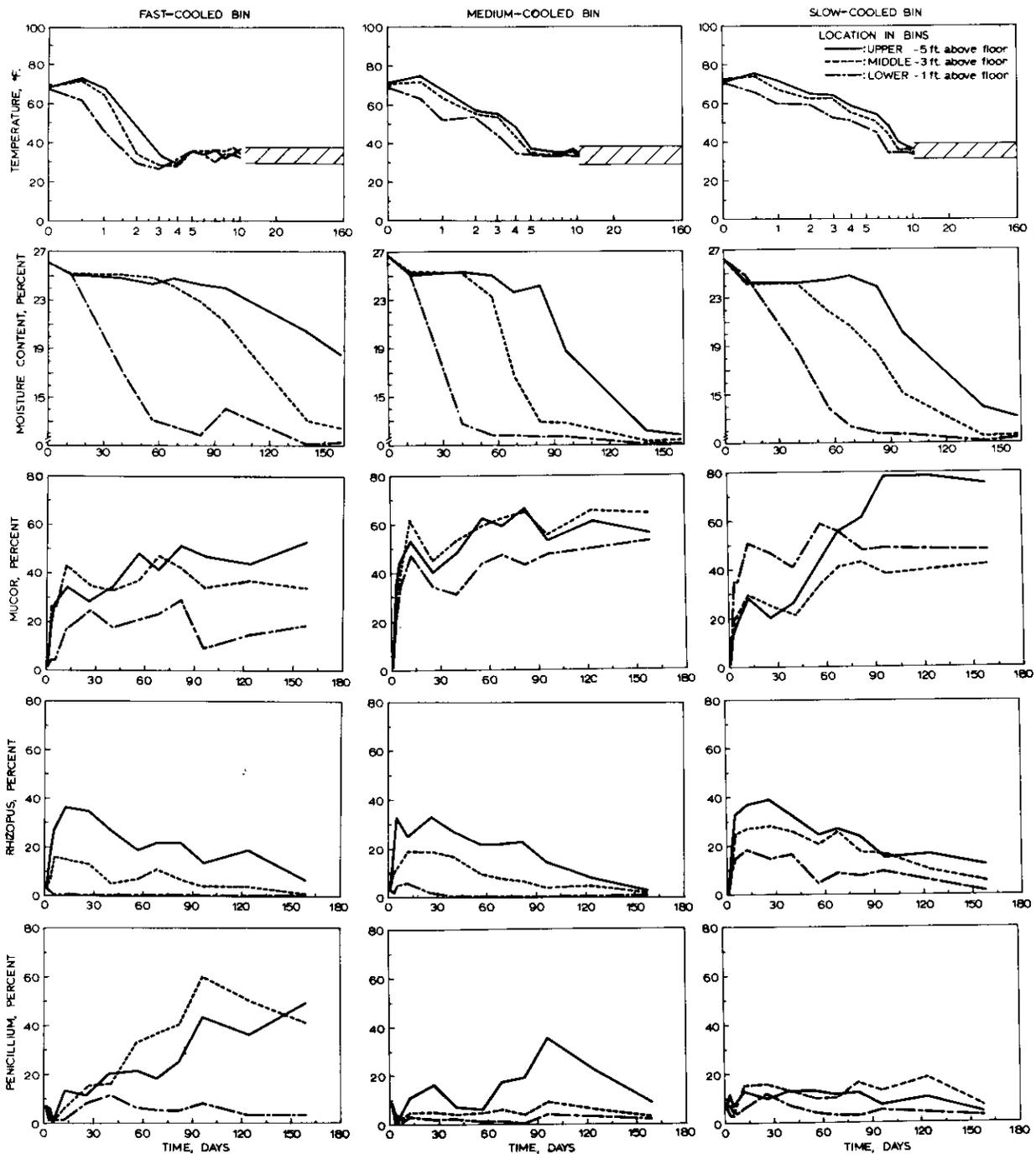


Fig. 3 Test 2, 1967. Temperature, moisture content and percentage of surface-disinfected kernels yielding MUCOR, RHIZOPUS and PENICILLIUM in corn cooled at three different rates

most of the detectable mold growth. *Rhizopus* and *Mucor* were present in less than 1 percent of the surface-disinfected kernels at the beginning of the tests; *Penicillium* was in about 3 percent of the kernels.

Rhizopus grew rapidly the first 3 days while the corn was warm, but did not increase thereafter when the grain was cool. Percentages of surface-disinfected kernels yielding *Rhizopus* ranged from 1 percent in the lower part of the fast-cooled bin to 20 percent in the upper part of the slow-cooled bin.

Mucor was tolerant of low temperatures and invaded 5 to 15 percent of

the kernels. Cooling rate and percentage of kernels invaded by *Mucor* seemed to be unrelated.

Invasion by *Penicillium* at the end of 12 days ranged from 4 percent in the lower part of the fast-cooled bin to 27 percent in the upper part of the slow-cooled bin. Other points in the bins were intermediate, reflecting differences in cooling rate.

Corn in the slow-cooled bin and in the top of the medium-cooled bin was slightly discolored by mold growth on the many broken kernels and along cracks. Because of the high percentage of cracked and broken kernels, mold

growth made the corn appear somewhat dirty. The slow-cooled corn tended to hang or stick together when removed from the bin at the end of the 12-day test.

1967 Test 2

On November 8, 1967, the three test bins were filled with field-shelled corn at 26 to 27 percent moisture. Corn temperatures were approximately 70 F. Air to cool the corn was supplied at 0.5 cfm per bu, and air temperatures were controlled so that the average corn temperatures in the three bins reached 35 F in approximately 2, 5, and 8 days, respectively.

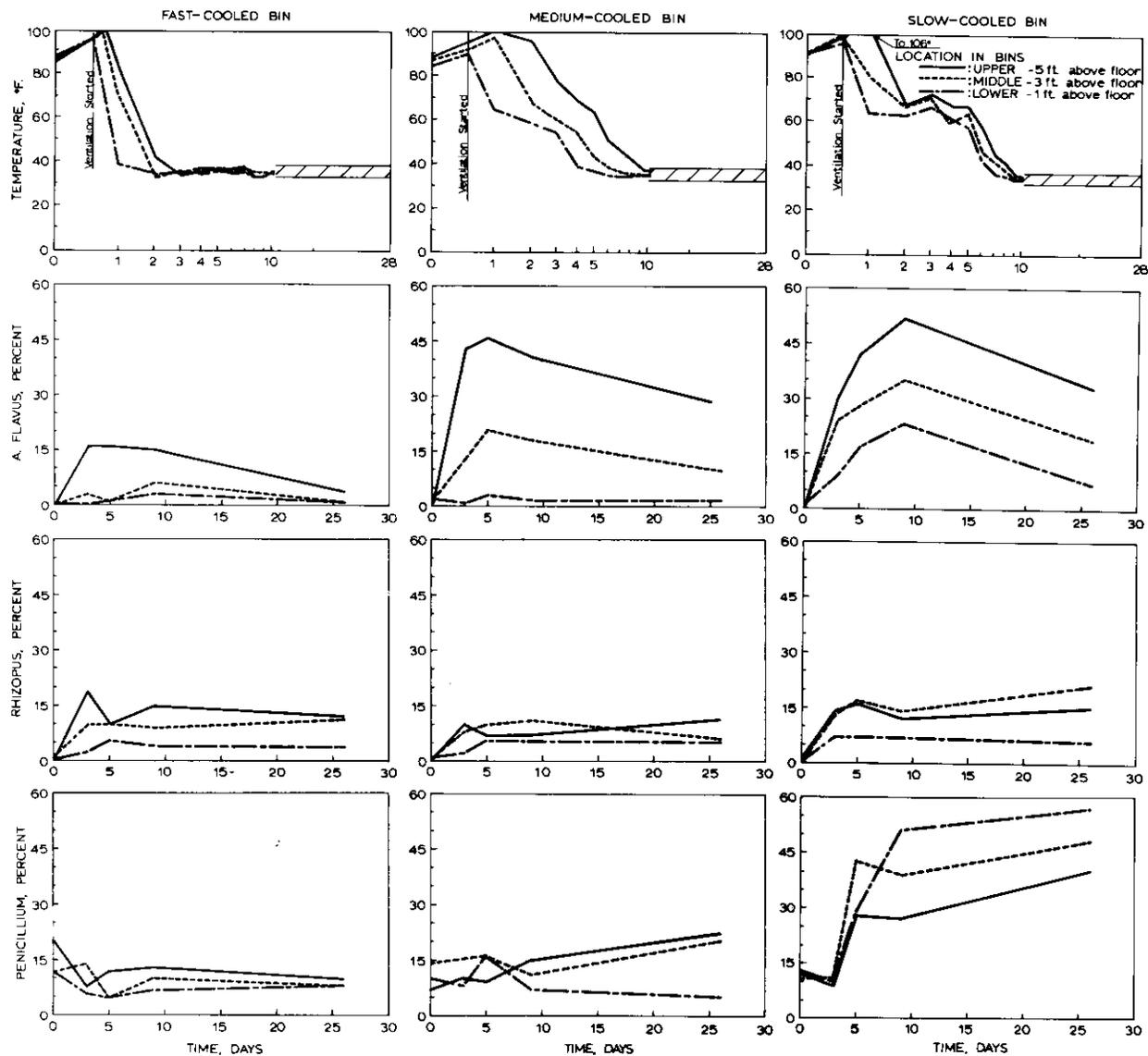


Fig. 4 Test 1, 1968. Temperature and percentage of surface-disinfected kernels yielding *ASPERGILLUS FLAVUS*, *RHIZOPUS*, and *PENICILLIUM* in corn cooled at three different rates

Fig. 3 shows temperature gradients in each bin during cooling. The maximum temperature differences between the lower 1 ft and the upper 1 ft of the grain during cooling was about 25 to 30 F, 10 to 15 F, and 5 to 10 F, respectively, for the fast-, medium-, and slow-cooled bins.

Corn cooled the fastest, dried the slowest, and lost the least moisture—from 0.8 to 1.0 percent—during cooling, compared with from 1.4 to 2.0 percent for corn cooled slowest. A drying front gradually moved up through each bin (Fig. 3). The corn had reached 23 percent moisture content and a drying front was clearly established in all bins after about 18 days at the 1-ft level, 50-80 days at the 3-ft level, and 85-110 days at the 5-ft level.

Rhizopus, *Penicillium*, and *Mucor* were the principal fungi in this corn, the same as in the earlier tests with corn of higher moisture content and higher

initial temperature (Fig. 3). Fungal growth was restricted only in grain cooled the fastest; i.e., the bottoms of the two fast-cooled bins.

As in the previous test, *Rhizopus* reached the highest levels in the corn that remained warm the longest. After the corn was cool, *Rhizopus* apparently could neither grow nor survive.

Mucor also grew quickly while the corn was warm, but continued to grow as the temperature dropped. The only samples that had less than 40 percent of the kernels invaded by *Mucor* were those from the bottom of the fast-cooled bin; there, 30 percent was the highest. The percentage of kernels containing *Mucor* remained high, 40-70 percent in most samples throughout the 5 months of storage.

Penicillium did not appear to grow rapidly at first, but rather increased slowly throughout the storage period in grain that remained high in moisture

content. *Penicillium* reached its highest levels in the fast-cooled bin after about 3 months, demonstrating its ability to grow at low temperatures. Corn in this bin was about 1 percent higher in moisture and remained high longer than corn in the other two bins; the higher moisture content may account for the greater amount of *Penicillium* in the fast-cooled bin.

Germination percentage decreased significantly only in the top of the slow-cooled bin, where, after 5 months, it was 19 percentage points lower than the average.

Fat acidity values after cooling averaged 32 for the fast-cooled bin, 38 for the medium-cooled bin, and 43 for the slow-cooled bin. The values did not change much during storage except that in the fast-cooled bin the average reached 54. That increase was attributed to the higher moisture content

and greater growth of *Penicillium* in this bin.

1968 Test 1

On September 25, 1968, between 4:00 and 6:00 p.m., the three bins were filled with field-shelled corn with a moisture content of approximately 25 percent. Ventilation with an airflow rate of 0.5 cfm per bushel was started at 8:00 a.m. the next morning. Corn temperatures were about 85 to 90 F when the bins were filled, but increased to as high as 108 F. before the corn was cooled.

It was planned to cool the corn to 35 to 40 F in 2, 4, and 8 days, which was accomplished in the fast- and slow-cooled bins. In the medium-cooled bin, however, an accumulation of fine material near the bottom diverted much of the air through the surrounding buffer corn so that the test was not cooled as quickly as planned (Fig. 4).

Corn 1 ft above the bin floors lost 1.1 to 2.2 percent moisture during the first 8 days, while corn 5 ft above the floor, the last to cool, lost 1.8 to 2.4 percent. When the experiment ended after 26 days, a drying front was established in corn at the 1-ft level. Average reduction in moisture content throughout the bins was 1.8 percent in the fast-cooled bin and 3.1 percent in the slow-cooled bin.

The overnight delay in starting ventilation allowed rapid growth of fungi, especially in the upper parts of the bins. Restricted airflow in the medium-cooled bin resulted in higher temperatures and more mold growth than was expected in the top portion of the bin (Fig. 4).

Within 3 days *Aspergillus flavus* (group species) and *Rhizopus* had invaded corn in all three bins to a considerable degree, except in bottom portions of the two fast-cooled bins. Those two fungi, and particularly *A. flavus*, thrive under conditions of high moisture and moderate to high temperatures. *A. flavus* was the dominant species (Fig. 4), and its prevalence correlated well with the cooling rate. The longer the corn remained warm, the higher the percentage of kernels invaded by *A. flavus*. Dilution cultures the fifth day of the tests showed *A. flavus* spore counts ranging up to 1 million per g in the corn cooled the slowest. The percentage of surface disinfected kernels yielding *A. flavus* gradually declined after the grain cooled, indicating that the fungus was not growing and that the mycelium inside the kernels could not survive at the low temperature and high moisture that prevailed.

Rhizopus grew more in the top and middle portions of the bins than in the bottoms, but the counts were not much

different from bin to bin or between the top and middle of the bins. *Rhizopus* growth was considerably less in this test than in the 1967 tests. The relative scarcity of *Rhizopus* and *Mucor* may have resulted from a lower initial population, or from the slightly lower moisture content, which might have been more favorable for *A. flavus* than for *Rhizopus* and *Mucor*.

Penicillium did not develop in the fast-cooled bin and grew only slightly in the medium-cooled bin. In the slow-cooled bin, 40 to 57 percent of the kernels yielded *Penicillium* after 26 days of storage. We cannot explain this, or why the population was higher in the bottom of the bin than in the top. Moisture content during the first week averaged only 0.6 of 1 percent higher in the slow-cooled bin than in the medium-cooled bin, but was highest in the fast-cooled bin. Therefore, the differences in *Penicillium* cannot clearly be attributed to differences in temperature or moisture. However, the high populations of *Penicillium* and *A. flavus* in the slow-cooled bin emphasize that an 8-day cooling period is unsatisfactory for corn with 25 percent moisture content and 85 F initial temperature.

After the corn had cooled, samples were analyzed by the University's Grain Science and Industry Department for aflatoxin, using thin-layer chromatography. None was detected in the fast-cooled bin or in the bottom or middle of the medium-cooled bin. Samples from the slow-cooled bin and from the 5-ft level of the medium-cooled bin contained from 16 to 95 ppb of aflatoxin B₁. The aflatoxin accumulated within a few days of harvest and the corn was not artificially inoculated with *Aspergillus flavus*.

Increases in fat acidity reflected differences in cooling rates (Table 1) and differences in mold growth. Corn in the slow-cooled bins and in upper parts

TABLE 1. FAT ACIDITY VALUES* IN 25 PERCENT MOISTURE CORN WHEN COOLED TO 35-40 F AT THREE DIFFERENT RATES (1968 TEST 1)

Days stored	Location in bin		
	Bottom 1 ft above floor	Middle 3 ft above floor	Top 5 ft above floor
Fast cooling rate			
9	12	11	12
26	14	16	16
Medium cooling rate			
9	11	13	23
26	17	24	26
Slow cooling rate			
9	20	28	37
26	26	32	41

* Expressed as mg of KOH required to titrate the acids in 100 g of grain, dry matter basis.

of bins had higher fat acidity values.

Changes in germination were less sensitive indicators of treatment differences than were degrees of invasion by *Aspergillus flavus* and increases in fat acidity; however, all showed the same general trend (Table 2). Germination percentages were lower in the corn cooled slowly than in the corn cooled rapidly.

TABLE 2. GERMINATION PERCENTAGES OF 25 PERCENT MOISTURE CORN WHEN COOLED TO 35-40 F AT THREE DIFFERENT RATES (1968 TEST 1)

Days stored	Location in bin		
	Bottom 1 ft above floor	Middle 3 ft above floor	Top 5 ft above floor
Fast cooling rate			
0	83	81	85
9	86	83	83
26	84	81	79
Medium cooling rate			
0	82	87	84
9	82	84	82
26	81	79	81
Slow cooling rate			
0	84	83	84
9	77	75	74
26	77	69	72

This test was concluded after 26 days.

1968 Test 2

On October 30, 1968, field-shelled corn was loaded into the bins. As with Test 1, ventilation was started 15 hr after the bins were filled. Initial temperature was about 90 F and increased only slightly before cooling began (Fig. 5). The bins were cooled in 2, 4, and 8 days, with an airflow of 0.5 cfm per bushel.

Initial moisture content of this corn ranged from 19.2 to 22.0 percent. Corn in the fast-cooled bin averaged 19.7 percent; that in the medium-cooled, 20.0 percent; and that in the slow-cooled, 20.4 percent. Moisture reduction during the first 8 days ranged from 1.3 to 1.8 percent (Fig. 5). A drying zone gradually moved up through the bins. Corn in all bins had reached 17.5 percent moisture and had clearly defined drying fronts after about 18 days at the 1-ft level, about 42 days at the 3-ft level, and about 57 days at the 5-ft level.

Since airflow was upward during the 97-day test, the corn in the first foot above the floor had the highest airflow per accumulated bushel, equivalent to 3.0 cfm per bu. Total moisture reduction at the lower level was from 5.7 to 7.2 percent and averaged 6.6 percent. The 3-ft level had an airflow rate of 1.0 cfm per accumulated bu, and total

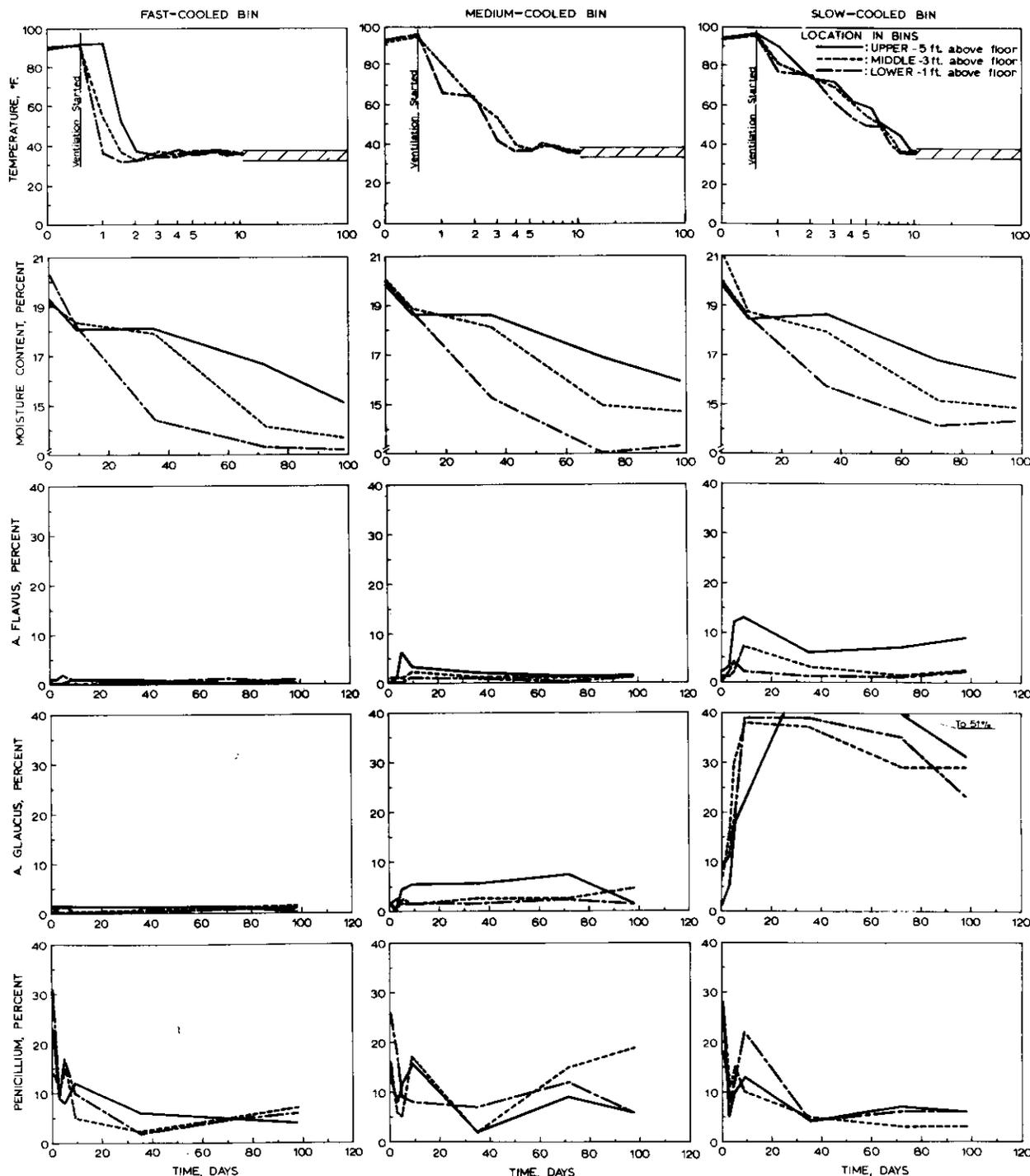


Fig. 5 Test 2, 1968. Temperature, moisture content, and percentage of surface-disinfected kernels yielding *ASPERGILLUS FLAVUS*, *A. GLAUCUS*, and *PENICILLIUM* in corn cooled at three different rates

moisture reduction was from 5.4 to 6.4 percent with an average of 5.8 percent. The 5-ft level had an airflow rate of 0.6 cfm per accumulated bu, and total moisture reduction was from 3.8 to 4.2 percent, with an average of 4.0 percent in the 97 days.

Aspergillus flavus failed to develop significantly in most of this corn, even though cooling was delayed overnight and initial temperature was about 90 F. Highest kernel invasion was 13 percent in the upper part of the slow-cooled bin (Fig. 5).

The dominant storage mold in this test, and the one that best reflected differences in cooling rate, was *Aspergillus glaucus* (group species). It invaded about 5 percent of the kernels in the upper part of the medium-cooled bin and up to 51 percent of the kernels in the slow-cooled bin. Percentage of kernels yielding *A. glaucus* gradually declined after about 1 month of storage.

Percentage of kernels yielding *Penicillium* was erratic and, as in previous tests, not clearly related to cooling rate. Several species of *Penicillium* were ob-

served, but no attempt was made to identify or to separate them. Some of the apparent fluctuations may have resulted from different species being present at different times. Some species may have been dying while others were increasing.

Fat acidity and germination percentages did not seem to change during the 3 months of storage. Although visual observations and test data indicated that the quality of the corn remained quite high, we think the 8-day cooling rate should be considered inadequate

because so much mold invaded the corn.

SUMMARY AND CONCLUSIONS

Mold growth in corn during cooling was similar in both 1967 tests. Initial moisture content was high (26 to 28 percent) in both tests, but the initial temperature was much lower in the second test. Nevertheless, in both tests the corn in the fast-cooled bin had little mold growth, the slow-cooled had high mold populations, and the medium-cooled was intermediate. Even in the fast-cooled bin there was a moderate amount of mold growth in the upper part of the bin in both tests. Corn with 26 to 28 percent moisture content and 70 to 90 F initial temperature probably should be cooled to 35 to 40 F within 2 days. A 4-day cooling period may not cause measureable loss in quality, but does allow an undesirable amount of mold growth, especially in the portion of the bin farthest from the

source of cooling air. Cooling times longer than 4 days should be avoided when initial grain temperatures are above 70 F.

Extensive growth of *Penicillium* in some of the corn held several months indicated that 35 to 40 F is not cold enough for extended storage of high-moisture corn. Such corn should be stored at lower temperatures or dried to a lower moisture content.

The importance of mechanical damage to corn was observed throughout the tests. Growth of storage molds was visible on broken surfaces and cracks long before it was visible on sound kernels.

Corn used for the first 1968 test was lower in moisture than corn in either of the 1967 tests. However, the overnight delay in cooling 25 percent moisture corn in 1968 allowed extensive mold growth and an increase in temperature. High temperatures permitted rapid growth of *Aspergillus flavus* and

some aflatoxin production in the corn cooled more slowly.

The results of an overnight cooling delay emphasize the importance of starting the cooling process immediately after harvest. Even within each bin, cooling was always delayed in the top portion, and the slow cooling was accompanied by more mold growth.

Biological activity was much slower in the 20 percent moisture corn (1968 Test No. 2) than in the 25 to 28 percent moisture corn used in the previous tests. Temperatures increased only slightly when cooling was delayed, and little mold growth occurred except in the corn cooled most slowly.

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