Effect of Moisture, Temperature, and Storage Time on Subsequent Storability of Shelled Corn[1]

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ABSTRACT

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Shelled corn of high quality was stored at 14.0, 15.5, and 18.0% moisture content (MC) for 7.0 or 7.5 months at postharvest Indianapolis temperatures (IT), starting October 15. After 2.5, 3.5, 5.5, and 7.0 or 7.5 months, aliquots were transferred to 84% rh or kept at their original moisture at 26°C for 21 days. The latter conditions were to represent transport to the southeastern United States. Mold spoilage was determined by examining kernels for visible molds, blue eye, kernel invasion, and fungal propagules. The corn was not invaded by fungi at 14.0 and 15.5% MC at IT for 7.5 months. Corn that was stored for 7.0 months at 18.0% MC was invaded by molds but was without visible mold on intact kernels. Visible mold appeared on some cracked pieces of corn. Although of high germination and free of detectable molds, corn stored for 7.5 months at 14.0 and 15.5% MC at IT developed more moldy kernels and fungi propagules after transfer to 26°C than did corn stored for 5.5 months or less. Corn stored at 18% MC for longer times at IT was more often invaded by fungi and also was more liable to spoilage at 26°C than was the corn stored for shorter periods or lower moistures at IT. To predict mold spoilage of corn during shipping to the southeastern United States, storage history (moisture, temperature, and length of previous storage) and conditions of transport should be considered.

The Midwest produces more than 90% of the dent corn in the United States. Substantial portions are shipped to the southeastern United States for domestic use and export. Published studies on changes in corn quality during shipment have been confined to changes in the official grades and increases in broken corn and foreign material (BCFM) that occur in transit (Brook et al 1976, Paulsen and Hill 1977). Corn has been reported to arrive in the Southeast with moldy portions or with portions that soon become moldy. Molds, particularly *Penicillium* spp., *Aspergillus glaucus*, and *A. flavus* are the major causes of corn deterioration. These molds discolor kernels and produce odors that lower the grade and may cause nutritive losses (Christensen and Kaufmann 1974). Interest in *Penicillium* has been heightened by the discovery that many produce mycotoxins. Because microbiological spoilage may affect domestic and overseas markets, the extent of fungal and mycotoxin contamination and related factors should be determined so that preventive measures may be taken.

The main environmental factors affecting fungal growth in storage are moisture and temperature. However, interseed atmosphere, insect activity, kernel drying temperatures, and amount of BCFM can also be important.

The main objectives of this study were to determine the significance of moisture and length of storage at Indianapolis temperatures (IT) on storability of shelled corn and to determine the effect of different lengths of Midwest storage on subsequent storage under Southeast conditions.

MATERIALS AND METHODS

Simulation of Midwest Storage Conditions (IT)

Corn (Beck 65X) from the Purdue Agronomy Farm, West Lafayette, IN, was harvested by combine on October 29, 1979, at 24% moisture content (MC). Three 22-kg lots were dried at 32° C by aeration to moistures of 18.8, 15.5, and 14.0%. After drying, samples were placed at 1.5° C for 24 hr. The corn was in relatively good physical condition: 8% of the kernels had pieces missing, and 4% had visible cracks in the pericarp. Nineteen kilograms of corn was placed in 19-L plastic containers and stored at IT, starting October 15. Temperatures were changed weekly to simulate the 30-year average temperature and were monitored with a recording tempscribe (Bacharach Ind. Instr. Co., Pittsburgh, PA) and indicating thermistors. Corn was aerated at 0.11 m^3/min per tonne (0.1 cubic foot per minute per bushel). Air was passed through a manifold and then to flow meters. Air leaving the flow meter was bubbled in deionized water, then into saturated salt and glycerol solutions to control relative humidity. The conditioned air passed through an empty jar and into the corn. An empty jar was placed between the humidifying solution and the grain to prevent draining of the salt or glycerol solution into the grain if a vacuum developed. Air exited from the corn through a dilute copper sulfate solution to prevent aerial contamination to the room and to indicate that air was flowing through the system. Saturated salt (Wink and Sears 1950) or glycerol solutions of various densities (Carr and Harris 1949) achieved relative humidities to maintain predicted equilibrium moisture contents (EMC). The EMCs of the corn were obtained from Thompson's (1967) equation. Salt solutions were checked daily for saturation, and the refractive indices of the glycerol solutions were checked weekly. Every month the corn was mixed and sampled using a Precision Divider (Dean Gamet Mfg. Co., Minneapolis, MN).

Moisture Content Determinations

Moistures were determined monthly by the official whole seed method (103° ± 1° C for 72 hr) and are on a wet weight basis.

Mold Determinations

Visual. One hundred kernels in triplicates were examined with threefold magnification for mycelia and fungal sporulation on the kernel and the germ (including blue eye). Odors were noted.

Plating. Kernels (50) were disinfected in 5% NaClO (Timesaver brand) for 1 min, rinsed twice with sterile distilled water, and placed on potato-dextrose agar containing 100 ppm Tergitol NPX and 30 ppm chlortetracycline (PDTC) and malt salt agar (6% NaCl). Fungi growing from the kernels were identified after seven days on PDTC and after 10–14 days at 22–25° C on malt salt agar.

Dilution. Twenty grams of corn was comminuted in 0.1% water agar for 1 min in a blender. Dilutions were added to duplicate plates, and cooled molten PDTC and malt salt agar were added.

Seed Germination

Triplicates of 100 disinfected kernels were plated on 1.5% water agar, and germination was determined after seven days.

Simulation of Transportation of Corn to Southeast

After 2.5, 3.5, 5.5, 7.0, or 7.5 months at Midwest conditions (IT), 520 g of corn at each of the three moistures was obtained using a Precision Divider, transferred to 26° C, and aerated at 84% rh (designated as aerated). A similar portion was transferred to 26° C in closed 0.95-L mason jars, the jars being about three-fourths full (designated as nonaerated). In the 84% rh environment, corn was

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placed on coarse metal screens in a 2.5-cm layer. The screens were placed on racks in a 95-L plastic container at 26° C. Saturated KCl solution was placed in the bottom of the container, which was lined with blotting paper. Air (0.11 m^3/min per tonne, 0.1 cubic foot per minute per bushel) was bubbled through deionized water and into the KCl solution. Tubing submerged in the salt solution had fine holes for a more even distribution of air. The corn was sampled for moisture after 1, 4, 7, 14, and 21 days. Mold deterioration was measured by visual inspection, plating, and dilution after 4, 7, 14, and 21 days. Seed germination was determined after seven and 21 days.

RESULTS

Midwest Storage Conditions (IT)

Temperatures were generally well maintained (Fig. 1). Corn temperatures below freezing obtained in this test often are not obtained in commercial bulk storage.

Corn moisture variations were usually small except when we attempted to bring the original 18.8% moisture corn to 18.0% during the test by aerating with appropriate relative humidities (Fig. 1).

Evaluation of Mold. After 7.5 months at 14.0 and 15.5% MC, the corn was essentially free of storage mold invasion, determined by plating and dilution. Kernels looked sound and had little reduction in seed germination (Table I). The 18% MC corn had no visible mold, but small amounts of *A. glaucus* (28,700/g) and *Penicillium* (7,900/g) were isolated after seven months. These colonies probably came from the fruiting heads of the fungi seen on occasional broken corn. *A. glaucus* kernel infections (7.3%) were detected after 4.5 months, whereas *Penicillium* invaded the corn in small amounts (11% infected kernels) after only seven months. Seed germination had decreased to 82%. Based on appearance and odor, 18% MC corn was "safely" stored at average IT for seven months (October 15 to May 15) and the 14.0 and 15.5% MC corn for at least 7.5 months (October 15 to May 30). However, incipient mold spoilage in the 18% MC corn was revealed by plating and by dilution.

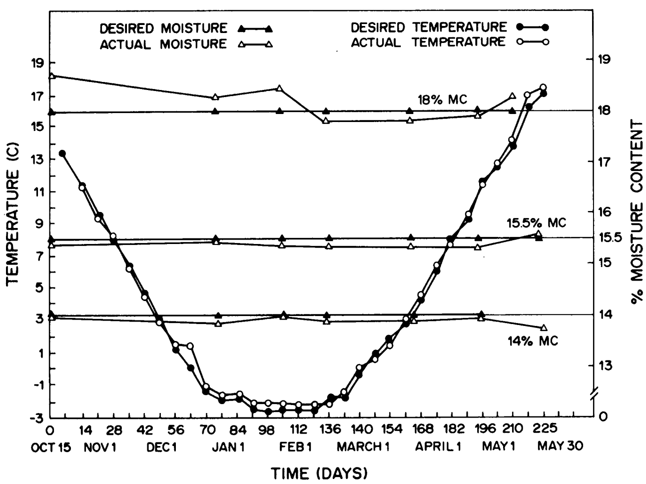

Fig. 1. Moisture content of corn stored at Indianapolis temperatures.

TABLE I
Seed Germination of Corn Stored at Indianapolis Temperatures at Various Moistures and Transferred for 21 Days to Aerated and Nonaerated Conditions at 26°C

Moisture Content (%)	Previous Storage (months)	Percent Seed Germination[a] Aerated[b] 0 Days	7 Days	21 Days	Nonaerated[c] 0 Days	7 Days	21 Days
14.0	2.5	98	95	73	98	96	94
	3.5	95	93	73	95	93	92
	5.5	95	92	78	95	90	87
	7.5	98	95	78	98	95	95
15.5	2.5	94	86	76	94	92	91
	3.5	94	86	73	94	89	92
	5.5	95	86	69	95	91	93
	7.5	95	94	70	95	93	94
18.0	2.5	91	80	69	91	84	70
	3.5	92	75	53	92	75	59
	5.5	93	76	50	93	85	60
	7.0	82	73	47	82	81	48

[a] Average of three replicates.
[b] 84% rh.
[c] Equilibrium relative humidity of corn.

Southeast Storage Conditions

Aerated Condition: Moisture and Mold Evaluations. The environment of 84% rh and 26° C was used to simulate conditions that might occur in the southeastern United States, when cold grain contacts warm air, or when moisture migration occurs. Increase in moisture may be small and/or may be restricted to small portions of the grain bulk but could cause serious mold spoilage.

The moistures of the corn transferred to 84% rh and 26° C are shown in Fig. 2. The 14.0 and 15.5% moisture corn rapidly increased in moisture, reaching equilibrium in about 14 days. Eighteen percent corn decreased 1.3%, and EMC seemed to have been reached by 21 days.

The 14.0% MC corn (16.5% after one week) had little blue eye, but 24% of the kernels were visibly molded after 21 days (Fig. 3). This corn was not invaded by molds after seven days, but *A. glaucus* invaded almost all the kernels by 14 days (Fig. 4). Storage molds, as detected visually (Fig. 3) and by dilution (Fig. 5), were more prevalent on the corn previously stored for 7.5 and 5.5 months at IT than on the corn stored for less time. Length of previous storage caused little difference in kernel infections (Fig. 4). Reduction in seed germination was minimal.

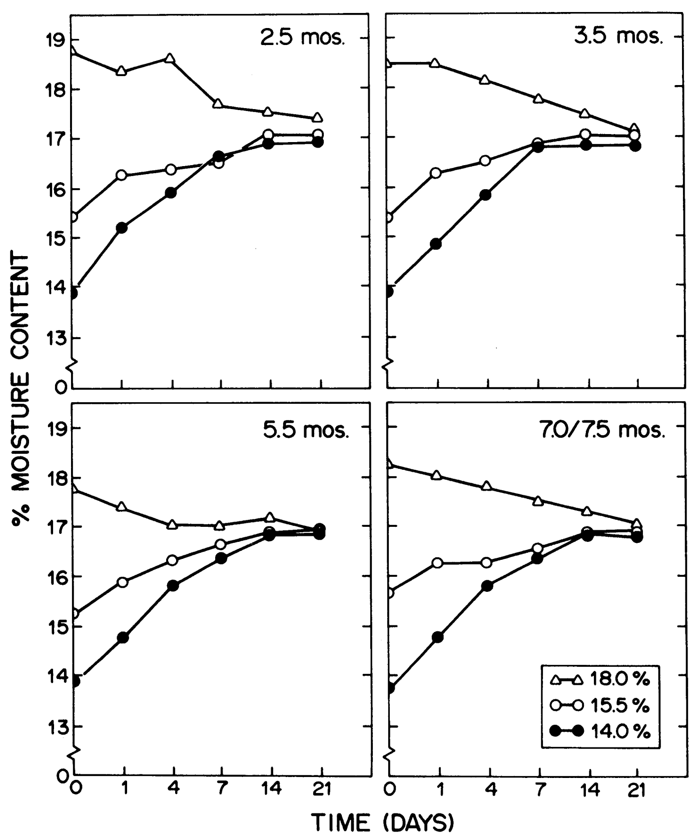

Fig. 2. Moisture content of corn stored for 2.5, 3.5, 5.5, and 7.0 or 7.5 months at Indianapolis temperatures and transferred to 26° C at 84% rh for 21 days.

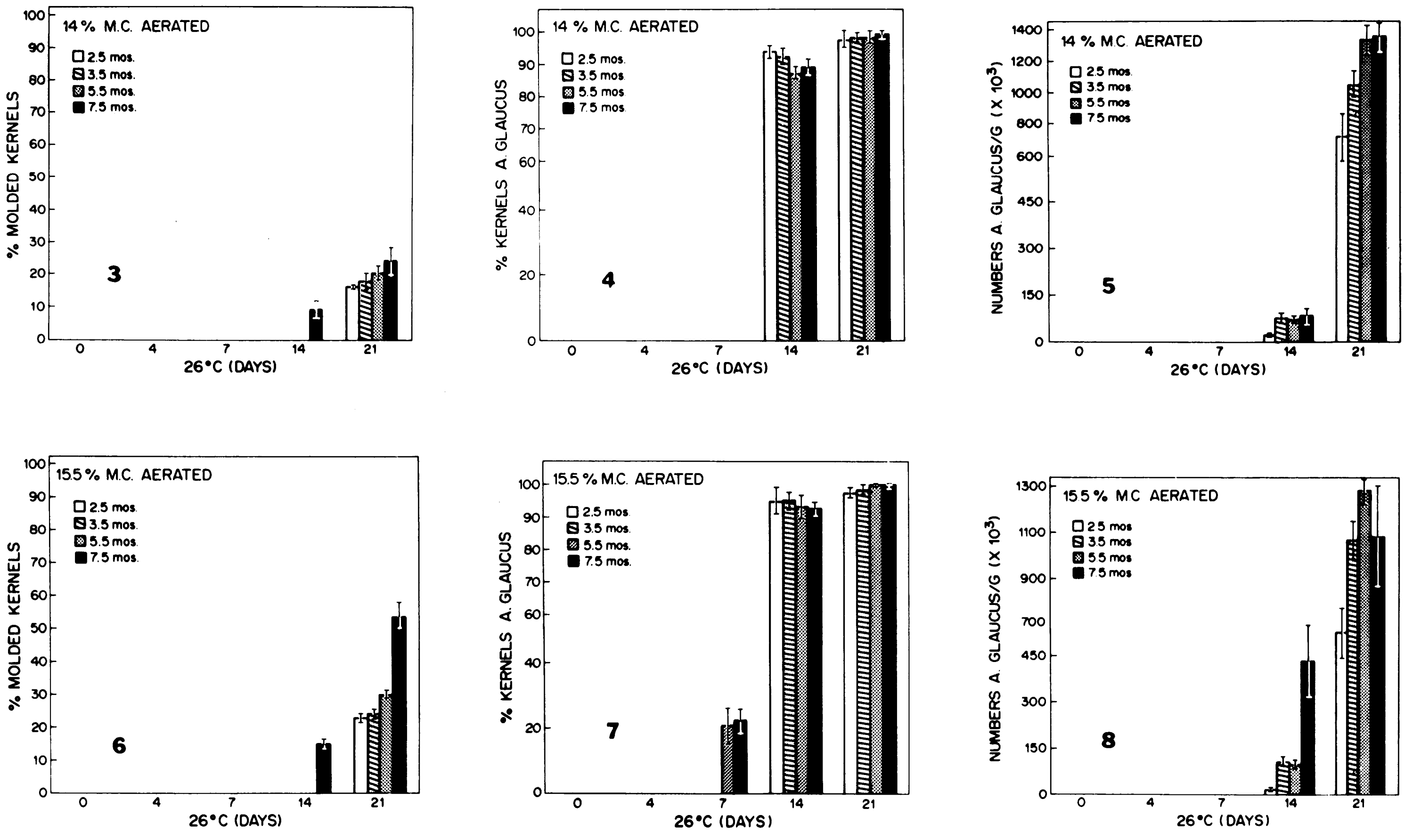

Fig. 3–8. Corn stored at 14.0 and 15.5% moisture content (M.C.) for 2.5–7.0 months at Indianapolis temperatures and transferred to 84% rh and 26° C for 21 days. Standard error of the mean is indicated by bars.

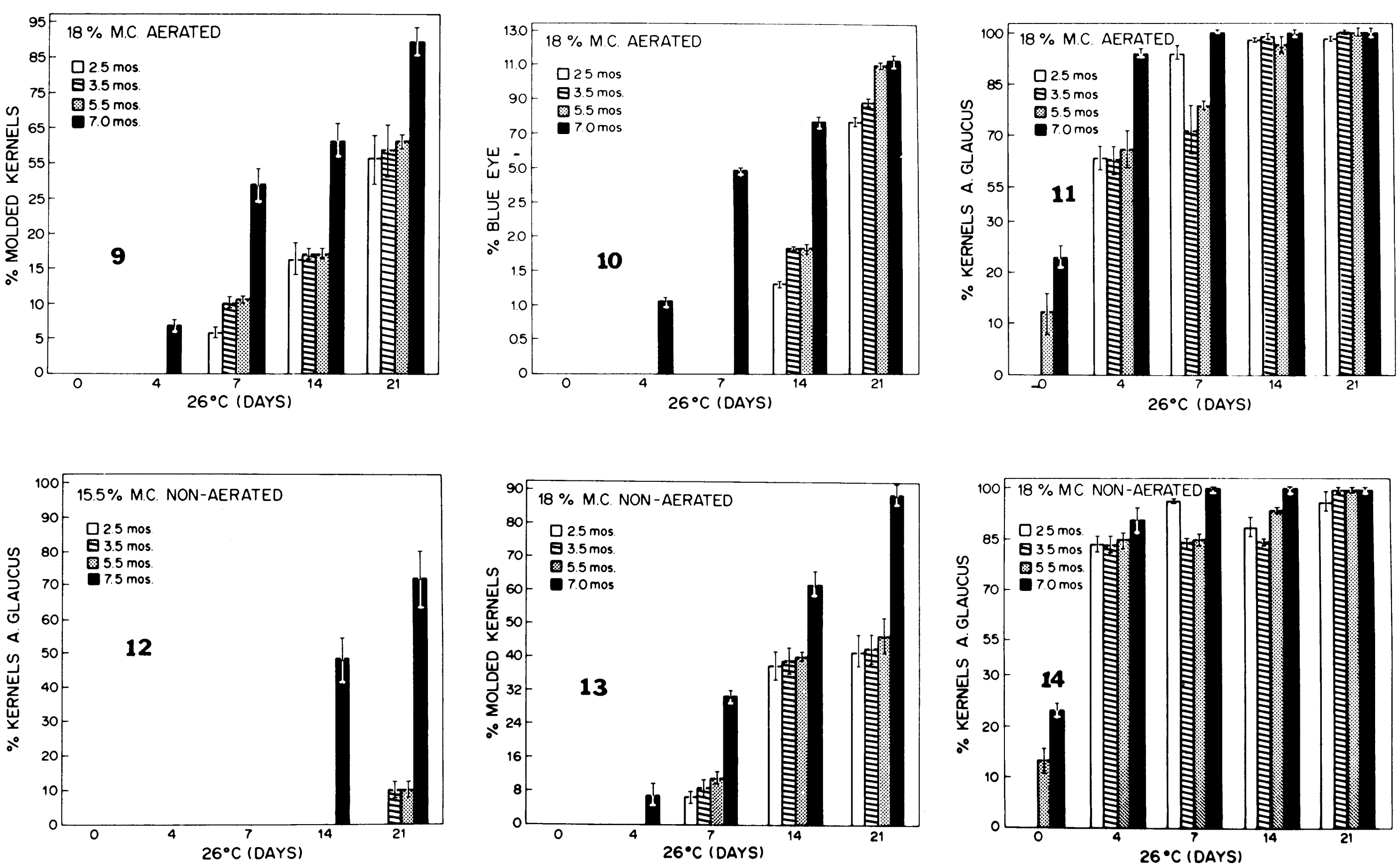

Fig. 9–14. Corn stored at 15.5 and 18% moisture content (M.C.) for 2.5–7 months at Indianapolis temperatures and transferred to 84% rh and 26° C for 21 days. Standard error of the mean is indicated by bars.

When aerated at 84% rh, corn of 15.5% moisture had more visible molds (Fig. 6) and was more rapidly invaded by *A. glaucus* (Fig. 7) than the 14.0% moisture corn. Also evident was the enhanced vulnerability to mold invasion of the 15.5% moisture corn stored for 7.5 months as compared to that of corn stored for shorter periods. This was reflected by numbers of moldy kernels (Fig. 6) and propagules (Fig. 8). More kernels were infected with *A. glaucus* in the 5.5- and 7.5-month samples than in the 2.5- and 3.5-month samples after seven days at 84% rh, but the differences disappeared after 14 and 21 days (Fig. 7). Loss in seed germination was about the same for 14.0% MC corn with no differences in the corn of different storage ages.

After seven months intact corn stored at 18% MC appeared sound but was invaded by small amounts of *A. glaucus* and *Penicillium*. It was rapidly invaded by storage molds when transferred to environments of 84% rh, even when the corn dried slightly while coming into EMC (Fig. 2). This rapid invasion and sporulation by *A. glaucus* and *Penicillium* was reflected by molded kernels (Fig. 9) and blue eye (Fig. 10). Blue eye, caused by either *A. glaucus* or *Penicillium* spp., is important in grading corn. Loss in grade because of blue eye damage occurred by 14 days and was at the maximum allowable level of damaged kernels for grade no. 2 after seven days. The 18% moisture corn stored for the longest time (seven months at IT) spoiled faster than the corn stored for 5.5 months or less, manifested by moldy kernels (Fig. 9), blue eye (Fig. 10), and *A. glaucus* kernel infection (Fig. 11). Corn stored seven months had slightly higher percentages of kernels invaded by *A. glaucus* and *Penicillium* than the other samples, before storage at 84% rh. Seed germination at 84% rh was significantly lower in 18% moisture corn (Table I) than in 15.5 and 14.0% moisture corn.

Nonaerated Condition: Moisture and Mold Evaluations. Corn stored in jars at 26° C did not change in moisture and probably reflects the more common condition of transported grain. As expected because of the lower moistures, 14.0 and 15.5% MC corn had less mold growth than the aerated corn. Blue eye and visible molds were not observed in 14.0 and 15.5% MC corn, and the 14.0% MC corn had no mold invasion after 21 days. About half of the kernels at 15.5% MC were invaded by *A. glaucus* after 14 days and three-fourths by 21 days, but only in corn that was previously stored for 7.5 months at IT (Fig. 12). Ten percent or less of the kernels was invaded after 21 days for the corn stored for 5.5 months or less at IT. Seed germination remained over 90%.

The 18% MC corn transferred to aerated (84% rh) and nonaerated conditions had significant differences in the amount of mold growth but similar declines in grade quality because of the length of previous storage. Longer storage (seven months) at IT shortened the time for the 18% MC corn to spoil, as reflected by greater amounts of moldy kernels (Fig. 13), kernel infections (Fig. 14), and number of propagules of *Penicillium* (Fig. 15). Also noticeable was an erratic but higher *Penicillium* infection and number of propagules after 14 and 21 days in nonaerated compared to aerated samples. Significant loss in seed germination was associated with extensive mold invasion (Table I).

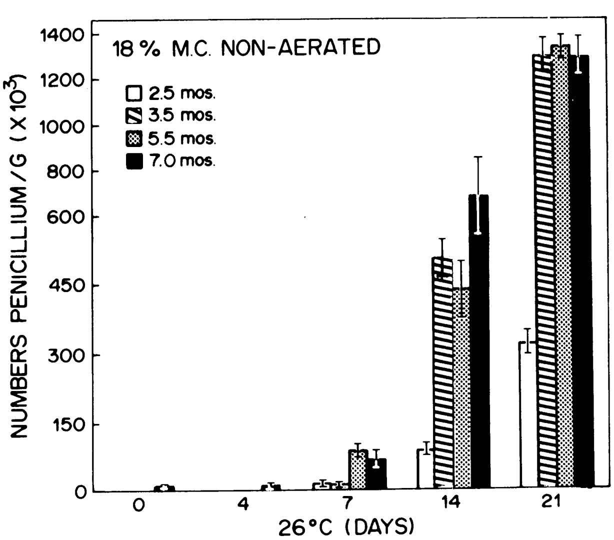

Fig. 15. Numbers of *Penicillium* per gram of 18.0% moisture corn (M.C.) stored for 2.5 to 7.0 months at Indianapolis temperatures and transferred to 26° C for 21 days. Standard error of the mean is indicated by bars.

DISCUSSION

Corn with little physical damage and little BCFM was stored at 14.0 and 15.5% MC for 7.5 months (October 15 to May 30) at IT without detectable mold growth and with little reduction in seed germination. When transferred to 26° C for 21 days, corn of both moistures was free from visible molds, but the 15.5% moisture corn was invaded by *A. glaucus* (No. 2 grade corn is most commonly marketed and has a maximum allowable moisture of 15.5% MC.)

These results from the nonaerated portion of our tests should not suggest that 15.5% moisture corn may be readily shipped from the Midwest to the Southeast for 21 days without loss in grade or appreciable mold growth. The corn used was high quality, germinated over 90%, had little physical damage, practically no BCFM, and moistures were maintained. These factors would not be equaled in commercial shipments of no. 2 corn. Also, corn stored for more than 7.5 months probably would be more vulnerable to fungal attack. We found that substantially more growth of *A. glaucus* occurred in the 15.5% corn at 26° C when previously stored for 7.5 months at IT than in corn stored for shorter periods. The vulnerability to mold spoilage of corn at 15.5% MC would probably be compounded by the increased invasion of kernels that would occur during summertime storage in the Midwest. As a consequence, shipment of corn with such a history would be hazardous. At 18.0% moisture, the negative effect of storage time was more obvious. The 18.0% moisture corn stored for seven months, however, had greater percentages of kernels invaded by *A. glaucus* and *Penicillium* before storage at 26° C than the other samples.

Aspergillus glaucus is considered nonmycotoxigenic but can cause musty grain, kernel discoloration, blue eye, and consequent loss in grade (Christensen and Kaufmann 1974). *Penicillium* spp. are of major concern in the Midwest because several species grow at low temperatures and moderately low relative humidity (Mislivec and Tuite 1970), and some are mycotoxigenic.

Seed germination was not as sensitive as mold activity in indicating deleterious effects caused by prior storage. However, decreases in germination of 18% moisture corn indicated an inverse relationship between infection and seed germinability, similar to earlier findings (Christensen and Kaufmann 1974).

The considerable increase in moisture when 14.0 and 15.5% MC corn was transferred to 26° C and 84% rh permitted abundant mold growth. An increase in moisture of corn when shipped to Southeast conditions may be caused by condensation (Aldis and Foster 1977, Wade and Christensen 1977), moisture migration, or a high ambient relative humidity.

When transferred to 84% rh, the corn stored at IT was "predisposed," as was the nonaerated corn. Corn stored longer at IT did not store well subsequently. Corn at 14.0% MC had no detectable mold growth after 7.5 months at IT but was much more susceptible to *A. glaucus* than corn stored for 5.5 months or less. Sorger-Domenigg et al (1955) reported that previous storage circumstances influenced subsequent loss in quality of wheat even when subsequently stored at moistures at which fungi do not grow. The corn at 15.5% MC, although not invaded by *A. glaucus* at IT after 7.5 months, deteriorated faster than 14.0% MC corn when transferred to 26° C and 84% rh. This may be due to an incipient but undetected mold invasion in 15.5% moisture corn after 7.5 months and/or to the seeds becoming more vulnerable to fungi.

What appears significant is that corn at 14–18% moisture, although showing no visible mold on intact kernels after 7–7.5 months, was more liable to spoilage than the corn stored for shorter periods. A loss in grade occurred, as judged by blue eye damage after two weeks in 18% moisture corn. Thus moisture and length of previous storage had a profound effect on spoilage of corn when it was subjected to temperatures and humidities suitable for molds and to conditions encountered in barge and possibly rail transport to the southeastern United States from the Midwest. The real decline in potential storability apparently was after 5.5 months. Additional storage at IT probably would further increase mold vulnerability.

With information on the environment of grain during transport from the midwestern to the southern United States, recommendations or predictions of safe storage may be possible, based on time of transport, condition, and age of grain. Other factors to consider would be BCFM and its distribution, grain temperature, the relative humidity and temperature of the air when loaded, insect infestation, and blending history. Consideration of such factors would decrease the hazards of interregional transport.

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