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The Significance of Fungi in Cereal Grains

Postharvest diseases are responsible for some of the most severe crop production losses in the world today. Even with the tremendous advances in grain storage methods, these losses still occur, especially in underdeveloped tropical countries where high humidity predisposes stored grain to severe deterioration. In certain African countries, losses of maize in various storage facilities caused by fungi, insects, and rodents have ranged from 1 to 100%. Postharvest losses of 15–25% are reported for countries such as India, Mexico, Nigeria, Tanzania, Uganda, Venezuela, and Zambia (8). In the United States, losses initiated by fungi can range from a few mycelium-caked chunks of grain to 70% of a bin of severely blackened soybeans when heating progresses into the chemical phase. Importers frown on grain shipments that contain high percentages of foreign material, and legal activity abounds when a shipload of grain arrives at a foreign port with the grain excessively infested with insects and fungi.

The final user generally defines grain quality. For seed, a grower needs grain high in germinability and free from seed-borne disease organisms. For food, the miller/processor needs bright, sound grain free from rodent pellets, insect damage or fragments, musty odors, off colors, and mycotoxins. Feed manufacturers need grain free from fungi and mycotoxins that can affect the health of livestock.

In the absence of insects and rodents, fungi are often the sole cause of spoilage. Damage by fungi can substantially reduce quality, grade, and price of cereal grains and their products. Fungi that infest grain are ever present and, under certain conditions, will produce the undesirable quality changes that can cause concern by the final user.

C. M. Christensen at the University of Minnesota was instrumental in defining the role of fungi in stored grain (3). Many other workers also contributed to the existing information concerning the significance and control of fungi in cereal grains (9–13).

Fungus Species in Grain

More than 150 species of yeasts and filamentous fungi have been reported on cereal grains (1,3). Certain of these species known as field fungi can cause damage in the field and others known as storage fungi are capable of causing loss of quality in storage.

Field fungi invade seed before harvest and are more likely to infest developing and mature seeds of cereal plants at moisture contents of at least 22% that are in equilibrium with air at 95–100% relative humidity. Common genera often found invading seeds in the field are *Alternaria, Cladosporium, Fusarium*, and *Helminthosporium*. Genera found less often are *Curvularia, Epicoccum, Nigrospora*, and *Stemphylium* (1).

Field fungi are almost always present in seed in all grain-growing countries, even in dry climates, and are especially prevalent in seed that develop during wet weather. The presence of a field fungus in seed does not necessarily mean a loss in quality. *Alternaria*, for example, is almost always present as mycelium under the outer pericarp of wheat but causes no quality problems. This fungus will, however, cause severe kernel discoloration when swathed grain is subject to wetting, as when harvest is prevented by continuous fall rains. These fungi can cause other blights, discoloration, and mycotoxin production that reduce seed quality, and some cause diseases in the plants that grow from the infested seed. *Fusarium* spp., for example, can cause scabby grain and damping-off of seedlings of that grain when planted. *Fusarium* spp. can also produce mycotoxins in seed that can cause severe problems in hog and poultry production when used as feed.

Field fungi do not compete well under normal dry storage conditions but may grow extensively in improperly preserved corn high in moisture. This occurred when a Minnesota hog producer used corn preserved with propionic acid as feed; the corn contained areas of moldy, clumped grain (Fig. 1). Unbred gilts developed swollen vulvae and swollen mammary glands. When cultured, the grain in these clumps was found to contain almost a pure culture of what was later identified as *F. graminearum*; the only other fungus present was *Absidia* sp. Analysis revealed enough zearalenone so that the final ration contained an average concentration of 0.5–1 ppm. When the moldy material was segregated from the otherwise sound corn, the problem disappeared. Certain field fungi can grow in stored grain any time the moisture content is high. The storage duration and temperature at high moistures determine if this growth produces quality changes. Normally, most field fungi in seeds die after 6 months or a year in storage when held at moisture contents in equilibrium with relative humidities of 75–90%.

Stored grain and seed are subject to invasion by another group of fungi collectively called storage fungi because seed is invaded after harvest during storage. These are predominantly species of *Aspergillus* and *Penicillium*, including *A. restrictus, A. glaucus, A. candidus, A. flavus*, and *A. ochraceus* and *P. brevicompactum, P. cyclopium*, and *P. viridicatum*. *Aspergillus* spp. will grow starting at 65% relative humidity and are common initiators of grain deterioration in storage and transit. *Penicillium* spp. require more moisture (over 80% relative humidity), can grow at lower temperatures, and are usually found in severely deteriorated grain. Table 1 shows the minimum equilibrium relative humidities at which some storage fungi can grow. Other genera of fungi that invade stored grain are *Absidia, Chaetomium, Mucor, Paecilomyces, Rhizopus*, and *Scopulariopsis*.

For the most part, the classification of field fungi and storage fungi is accurate,

Paper No. 14,792, Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul, MN 55108.

but exceptions exist. Under the corn-growing conditions in the southern United States, the common storage fungus *A. flavus* can invade unharvested corn and produce aflatoxin (5). In one case on a farm near Princeton, Minnesota, *A. flavus* was found in high-moisture corn (22–29%) stored in stave silos. During January of 1980, dairy cattle that consumed this high-moisture corn had a sudden production loss and suffered from loose bowels. This continued as long as the high-moisture corn was fed to the lactating herd. Examination of the corn in the silo revealed that *A. flavus* was growing on the surface layer and produced heat that caused the temperature to reach 27–30 C. The grain temperature below the surface had reached 49 C. Corn infested with *A. flavus* in the surface layer was fed daily to the cattle; when this layer was removed, another batch of toxic feed was produced in time for the next feeding. The situation was resolved by unloading all the heating corn and removing enough of the remaining sound corn at a fast enough rate (3.8 cm per day) so that the temperature on the surface did not exceed 24 C. Adequate removal rates are essential to prevent heating on the surface of corn preserved in this manner. The presence of hot corn in a stave silo, however, does not always mean that *A. flavus* is present, as other fungi and bacteria can be the cause of heating (9).

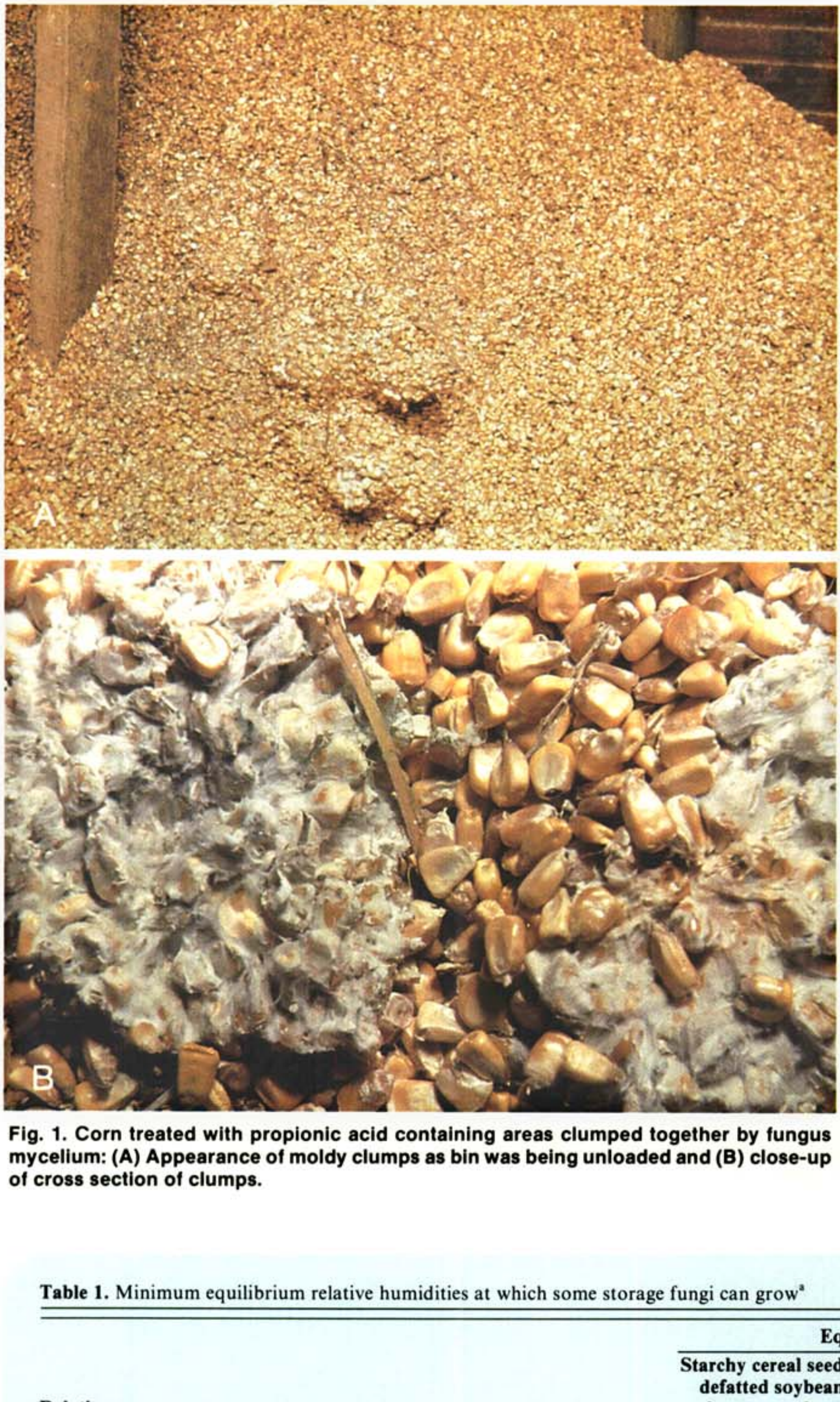

Fig. 1. Corn treated with propionic acid containing areas clumped together by fungus mycelium: (A) Appearance of moldy clumps as bin was being unloaded and (B) close-up of cross section of clumps.

Fusarium, a common field fungus, can continue to decay grain in storage if the moisture content is high enough, and certain species of *Penicillium* are found as field fungi while others occur as storage fungi (2,6).

Storage Fungi Effects on Grain

The major effects of storage fungi on grain are decrease in germination, discoloration, heating and mustiness, dry matter loss, mycotoxin production, and nutritional changes. The importance of these effects, however, depends on the grain's final use. Depending on severity, infestation by fungi can affect grain quality and can completely destroy the usefulness of grain.

When conditions are right for growth, storage fungi invade the seed embryos preferentially and sometimes almost exclusively (4). The storage fungi usually kill the embryo before any discoloration is evident. When germ discoloration is obvious, the seeds are not likely to

Table 1. Minimum equilibrium relative humidities at which some storage fungi can grow[a]

		Equilibrium moisture content[b]		
Relative humidity (%)	Fungi	Starchy cereal seeds,[c] defatted soybean and cottonseed meal, alfalfa pellets, most feeds	Soybeans	Sunflower and safflower seeds, peanuts, copra
65–70	*Aspergillus halophilicus*	13.0–14.0	12.0–13.0	5.0–6.0
70–75	*A. restrictus, A. glaucus, Wallemia sebi*	14.0–15.0	13.0–14.0	6.0–7.0
75–80	*A. candidus, A. ochraceus*, plus the above	14.5–16.0	14.0–15.0	7.0–8.0
80–85	*A. flavus, Penicillium*, plus the above	16.0–18.0	15.0–17.0	8.0–10.0
85–90	*Penicillium*, plus the above	18.0–20.0	17.0–19.0	10.0–12.0

[a] Adapted from Christensen and Sauer (4).
[b] Percentage wet weight (figures are approximations; in practice, variations up to ± 1.0% can be expected).
[c] Barley, maize, millet, oats, rice, rye, sorghum, triticale, and wheat.

germinate. Some strains of *A. restrictus* and *A. candidus* kill the germs very quickly, so keeping seed stocks well below the moisture contents that would permit these fungi to grow is important.

Both field and storage fungi can discolor seeds, and when invasion discolors the germ or endosperm, the grain is classified as damaged. Damaged kernels lower the grade of grain in market channels, which can result in considerable financial loss.

Mustiness can be detected by odor and may develop while grain is relatively sound by other measurements. Usually, at least some mold is visible on the kernels by the time musty or moldy odors are detected. The webbing produced by mycelial growth can cake the grain. This type of caking is commonly found in the top surface of grain in storage and is brought about by moisture migration that brings the surface grain to a moisture content at which fungi will grow. Grain in this area of the bin is often severely damaged (Fig. 2). This deteriorating grain commonly generates heat that raises temperatures to as high as 60 C, which can cause problems in unloading when moldy chunks plug unloading chutes. If mixed with good grain, this deteriorating grain increases the amount of damaged kernels, potentially decreasing the grade.

Areas of grain within a grain bulk, most commonly in a spoutline (the grain located directly under the fill spout and which usually contains a large amount of fine material), can be at a moisture content that supports the growth of fungi. Heat can accumulate to the point where a large portion of grain or an entire bin of grain is blackened (Fig. 3). Temperatures of up to 99 C have been recorded. Heating may be so severe that grain bursts into flame when exposed to a sufficient amount of air. Most of the time, however, heating never reaches the point where combustion is manifested by flame or glowing. Fire insurance companies are not willing to cover losses from such blackening, and policies indicate that flame or glowing must be present before any loss is justified as insurable. Settlements vary in such cases, even when fire has occurred. This is because the two sides involved often disagree as to how much grain damage was caused directly by the fire and how much was caused by the deterioration that occurred before the fire. Obviously, losses to the grain owner can be considerable. Cases are documented where 10,000–90,000 bu have been blackened by this heating process. In one very severe case, much of the bin structure was destroyed during the process of removing the severely damaged grain. This is not a profitable practice, especially when much of this loss could have been prevented by such good grain management practices as providing adequate aeration, screening the grain to eliminate the fine material in

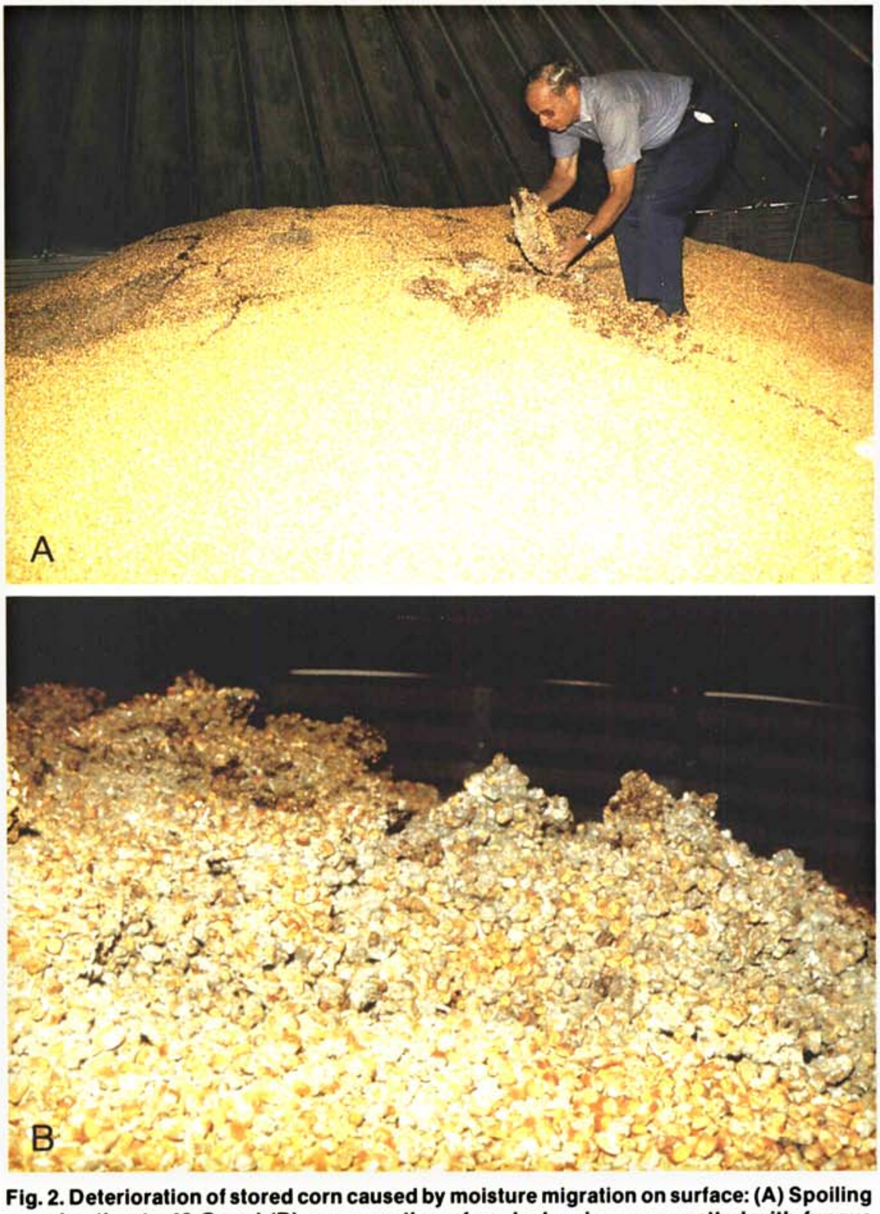

Fig. 2. Deterioration of stored corn caused by moisture migration on surface: (A) Spoiling corn heating to 43 C and (B) cross section of peak showing corn matted with fungus mycelium.

R. A. Meronuck

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the spoutline, and installing and using temperature-detecting devices.

Many nutritive changes in grain have been shown to occur during storage (7), and some are associated with the presence of fungi. Grain undergoing severe deterioration obviously loses test weight because energy components are being metabolized.

What Are We Doing to Improve Grain Storage Methods?

Educational programs have increased awareness of the importance of using good grain storage practices. Catastrophic losses of grain due to severe infestation of insects and/or fungi have in some cases signaled the need for more prudent use of these practices.

In Minnesota, we have a very active extension program in grain storage management. Extension specialists in the departments of agricultural engineering, entomology, and plant pathology have held numerous meetings in the state solely on the subject of grain storage management. Publications on the significance of insects, rodents, and fungi are used in these programs. Videotapes on grain storage mold and insect prevention have been produced and shown in many high school classes, county meetings, and short courses and on public television. Other videotapes are being produced on aeration management and the economics of good storage practices. Publications on drying, aeration management, and grain storage structural design are used to promote methods that prevent infestation by fungi and insects. These educational efforts are showing results. Producer requests for mycotoxin analysis have resulted in intelligent decisions in altering rations containing mycotoxins. Large poultry and hog producers are taking more care in keeping moldy grain out of their rations. Preservatives such as propionic acid and ammonia have been used successfully on grain for feeding operations.

This educational contact has resulted in the installation of new drying and aeration equipment. Drying techniques that have been adopted include "dryeration," in which grain is dried in a high-speed dryer, transferred hot to a dryeration bin, allowed to temper for 4–6 hours, then cooled slowly. Another technique is low-temperature drying, in which high-volume ambient air is used to dry corn at moisture contents of 22% and lower (for Minnesota temperatures). Another result has been the installation of temperature-detecting equipment in new and existing bins. This equipment ranges from a single thermistor to a series of thermocouples that are monitored manually or automatically. Fungus analysis is used to determine the storage history and future storability of a given lot of grain. Consulting firms are offering grain-monitoring services that include recommendations on the control of fungi and insects. Research programs have been the ultimate source of information for these efforts.

Investigators in many states and other countries are involved in the various aspects of grain storage/mycotoxin research. A regional research project (NC-151) has been organized to bring these various investigators together so that the information can be integrated. The project includes participants from industry so that benefits can be derived not only from academic research but also from industry research and experience. The investigators have produced a vast amount of useful information. Special projects involve moisture content analysis, grain breakage testers, grain grades, insects, fungi, resistance to fungus infection, grain transit, fumigation, and mycotoxin analysis, just to mention a few. These projects have improved existing testing procedures and promoted greater uniformity in test results and ultimately will improve the quality of grain throughout the world.

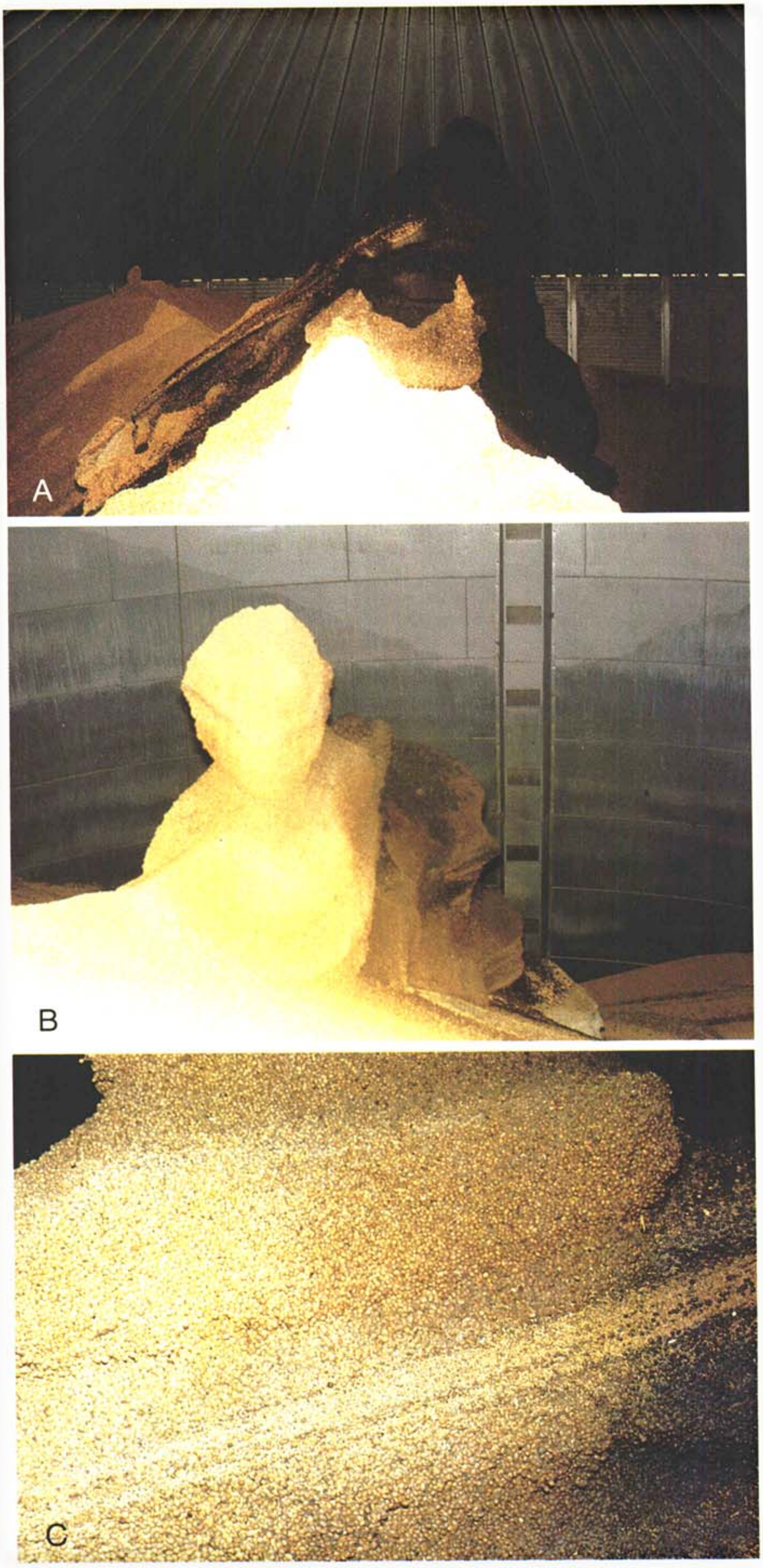

Fig. 3. Severely blackened (A) corn and (B) soybeans caused by spontaneous heating initiated by fungi. (C) This heating is commonly associated with layers of material in a bin spoutline.

Grain storage research and educational programs must continue so that we can protect one of our most precious commodities, our stored grain. This work is very important in underdeveloped countries as well as in our own. The Green Revolution has helped in the production of cereal grains. Now we need to do all we can to preserve these valuable stores of grain.

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