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Needed: Research on Storage Molds in Grains, Seeds, and Their Products

"Damage by storage fungi is a major cause of reduction in quality, grade, and price of cereal grains and their products. Where insects and rodents are controlled, fungi are often the sole cause of spoilage, and even when insects are present the fungi associated with them may contribute greatly to the damage, and if the insects are killed the spoilage by fungi may continue. These storage fungi are ever-present, their habits and characteristics are well known, and the conditions that permit or promote their growth have been established within fairly precise limits. Prevention of damage by storage fungi is by maintenance of conditions that keep them from growing. The principles and practices of good grain storage are known, and where these principles and practices are followed, storage losses are minimal, even in regions and environments of high storage risk."—From the chapter on microflora in the revised edition of *Storage of Cereal Grains and Their Products*, to be published in 1981.

In my considered judgment, problems posed by storage molds throughout the world are important enough to deserve somewhat more than the essentially zero research effort now devoted to them. There has been no long-continued work on the problem other than that carried on in the Department of Plant Pathology at the University of Minnesota for nearly 40 years.

The Problem of "Sick" Wheat

The work was begun in the early 1940s in collaboration with cereal chemists in the then Department of Agricultural Biochemistry, who suspected that molds might be involved in the respiration of moist stored grains—a novel idea at the time. The work received a sharp impetus in 1952, when men in charge of the Grain Division of Cargill, Inc., a multinational grain merchandizing firm with headquarters in Minneapolis, Minnesota, brought to us the problem of "sick" or germ-damaged wheat, which had been causing the grain merchandizing and grain milling industries a good deal of grief for 20 years or more and the cause of which was a mystery.

To promote the study of this and other problems suspected to be mold-related, Cargill, Inc., established a fellowship in plant pathology, and an official project was set up "to study the nature, cause, and control of microbiological deterioration of stored grains," a deliberately general description that gave us considerable leeway to shift from one point of attack to another as different problems arose. This project was continued up to the time of my retirement in 1974 and, after a fashion and unofficially, until I left St. Paul in July 1980.

0191-2917/80/12106704/$03.00/0

Collaborative Research for Mutual Benefit

In 1952, Cargill, Inc., also established their own grain research laboratory, with H. H. Kaufmann as director, to study some of the more practical and applied aspects of grain storage, handling, and transport. Collaboration between their laboratory and ours and among Kaufmann and others in their laboratory and me was close and continuous until the time I left St. Paul.

This association was mutually beneficial. We in the Department of Plant Pathology had entrée to the practical problems encountered in the storage, handling, and transport of grain by a large and progressive firm and access to its warehouses, its bins, and even its record books. They, in turn, had available our accumulated and growing background of knowledge about storage fungi and, in the person of the current Cargill fellow, research talent that could be directed toward and devoted to the development of information to aid in the solution of problems important to them. Throughout this long and productive association there was never any pressure brought to bear on us by the people of Cargill, Inc., to attack or avoid any specific problem. Nor was there ever so much as a suggestion of limitation concerning publication. Cargill, Inc., had—and still has—a large and flourishing research division of its own, so they were accustomed to research and to the sometimes peculiar ways of research men.

About the same time, in 1952, Kurth Malting Corporation of Milwaukee, Wisconsin, also established a fellowship in plant pathology, for the study of microflora of barley, including storage fungi, which sometimes caused trouble. This fellowship was later taken over by the Malting Barley Improvement Association, so it could serve the entire malting industry, and was continued until the late 1960s. Kurth Malting Corporation also had a research laboratory and were accustomed to the role of research in solving problems.

The project on storage fungi had constant moral support and occasional financial support from the experiment station and for a brief time received some welcome financial support from the USDA.

I do not have the records available, but I believe that throughout the life of the project on storage molds approximately 20 graduate students from half a dozen countries received all or part of their financial support and earned M.S. or Ph.D. degrees, or both, in work on storage molds. Our joint and several efforts, including those of the men at Cargill, Inc., resulted in the publication of about 150 research papers, one book, and chapters in several other books.

Why No Other Projects?

Any plant pathology department of stature in the United States probably could list a dozen or more projects that have functioned continuously for 40 years or longer and which have ground out more research—and more research men and women—than the one I have described on storage molds. So what justifies this account? Simply that, so far as I am aware, our project on storage fungi on stored grains and their products was the only one of its kind, anywhere. The project never achieved bandwagon status, or if it did, nobody else climbed on. Why?

A major portion of agricultural effort throughout the world is devoted to the production of grains and seeds—for human food, for animal feed, and for industrial processing. Hundreds of plant pathologists in many countries throughout the world spend a large part of their

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working time on problems directly related to increasing production of grains and seeds. So do other members of the production teams—plant breeders, agronomists, soil scientists, pest control experts, extension specialists. In a given state or region or country, a continuing, year-by-year increase in yield of a given crop by as much as 2% is justifiably pointed to with pride, especially at appropriations time.

Very few plant pathologists and certainly none of the other experts mentioned spend any of their time on problems related to preservation of the grains and seeds once these have been harvested. I do not know of any university or experiment station projects in this field or on this subject anywhere in the United States. The USDA Grain Marketing Research Laboratory at Manhattan, Kansas, has one man assigned to mold-related storage problems, including mycotoxins. None of the four USDA regional laboratories—those great modern research factories—devotes any effort to the study of deterioration of stored grains and seeds by fungi.

In Great Britain, the Pest Infestation Control Laboratory and the Tropical Products Institute pay relatively little attention to storage molds; in their lists of published papers on stored products problems I would estimate that fewer than 1 in 100 deals with fungi. The justly famous International Center for Corn and Wheat Improvement (CIMMYT)—with headquarters at El Batan, near Mexico City, with satellite stations around the world, and dedicated to increasing the food supply in developing countries—has never had a staff member assigned to work on mold-related postharvest problems in grains and seeds. This in spite of the fact that in recent years, according to presumably accurate reports from my former students, there have been heavy losses from mold spoilage in corn stored in government warehouses in Mexico, some not too far from CIMMYT headquarters, and similar losses have occurred in corn and other food grains in other countries where CIMMYT operates. For example, the 1972–1973 report of the director of the Institute of Agriculture and Training, University of Ife, Nigeria, stated: "Storage insects and molds destroy or ruin at least a third of the food grain stored every year." Losses of that magnitude evidently are common in tropical countries but are passed over without comment by those who concentrate on production.

Would it not be desirable to at least try to find out what happens to the increased production after harvest? Food is not food until it is eaten. The FAO operates in many countries where one would suspect heavy losses from storage molds might occur but has no work under way on fungi in stored grains and seeds. Incidentally, the project "to study the nature, cause, and control of microbiological deterioration of stored grains" evidently was not considered economically justifiable, since it was terminated when I retired.

Figures on Economic Losses Needed But Hard to Come By

The situation is somewhat anomalous: A private firm, profit motivated, not only contributed rather generous support to work on storage molds for many years but also established its own laboratory to work on related problems. They must have found this investment in research worthwhile, or they would not have continued it. Yet no university or experiment station or no privately or publicly supported institution dedicated to increasing the food supply, anywhere in the world, has established so much as a project on postharvest pathology of grains and seeds.

Evidently the approximately 150 research papers, the book, and the numerous summary and review articles on the subject in scientific, technical, and farm journals in several countries have not sufficed to convince those who control funds for research of the need for such work, or even of the need to determine whether problems in postharvest pathology of grains and seeds exist. Obviously, a promoter is needed, but for the promoter to be effective it would be highly desirable to have some hard figures on economic losses caused by fungi in stored grains and seeds and their products. For various reasons such figures are hard to come by.

For one thing, once harvested, grains or seeds are hidden away out of sight in dark bins or tanks or warehouses—and in most cases also out of mind—until they are loaded out weeks, months, or even years later. If fields of growing wheat or rice or corn are wiped out by disease, the loss is obvious to everyone. If the losses in a number of fields are severe, county agricultural agents are alerted and report the problem to crops departments at the experiment station, editors of country newspapers view with alarm, radio and TV broadcasts publicize the news, extension specialists of various persuasions visit the area and come up with loss estimates, growers' associations demand help, legislators get together with experiment station directors and department heads, strategy is planned, research proposals are drafted, money is appropriated, and in a surprisingly short time research on the problem is under way. This is all as it should be and is part of what makes agricultural research in the United States so responsive to new production problems. More subtle but still important losses from disease or other causes can be authenticated by yield plots in farmers' fields, data from which help establish objectively the importance of the problem and the need for research.

It is not possible to establish disease-loss plots in bins of grain. Once filled partially or to capacity, many bins, especially those in large elevator complexes, cannot be entered easily or at all or can be entered only at some risk. Moreover, elevator superintendents traditionally object to outsiders poking around in their bins. Flat or Quonset-type bins of any size can be entered for sampling, but access to grain in some cylindrical or silo-type bins, even small ones, is difficult. If the bins can be entered after they are filled, samples can be taken from the surface and as far down as a probe will reach. A vacuum probe is available that removes samples of just about any size from any portion of any grain bulk. Laboratory examination of such samples will detect early stages of deterioration long before it becomes of economic significance. Such sampling and testing constitute one of the important elements in good grain storage. They are useful in determining condition of the grain, in predicting continued storability, and in preventing spoilage, but they do not give us much information on loss.

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What Happens to Moldy Grain?

Molding of grains causes weight loss, but we do not know how much molding causes how much loss. It should not be difficult to determine weight loss of samples drawn from the bulk, using the device for determining bushel weight in grain inspection or something similar. Modern terminal elevators have electronic scales that measure very accurately the weight of incoming and outgoing grain, but when a million bushels of grain pass through the elevator every day, measuring any weight loss from molding is not possible. It might be possible, though, to do this with bulks held undisturbed in a given bin for some time, especially where condition problems due to molding have developed.

Loss of quality in an identity-preserved lot of grain is easy to measure and sometimes can be equated with economic or dollar loss. If, for example, a given quantity of Grade No. 2 corn is loaded into a bin or barge or ship, undergoes some mold spoilage, and is loaded out as Grade No. 5, the monetary loss would be about 40¢ a bushel. If, however, the grain is stored on the farm where it was grown and used there for feed, it is not graded and probably not even examined very closely as it comes out of the bin. If some has been damaged by molds, it may or may not be less wholesome than sound corn. If the animals to which the grain is fed accept it, it is considered to be satisfactory. Unless the animals consuming it become obviously ill or show decreased weight gain or milk production (both of which can result from many things other than unwholesome moldy feed), there is no measurable financial loss. Mold-damaged corn sold to a country or terminal elevator is discounted in price and the farmer who produced it suffers a direct financial loss, but at the elevator the damaged corn will be mixed with sound corn and so brought up to Grade No. 2, in which 5% damaged kernels are permitted.

At times, spoilage by fungi progresses to total decay, usually accompanied by heating, occasionally to the point of combustion. Such totally spoiled grain may be disposed of by dumping, although, surprisingly enough, some is salvaged and blended with sound grain to be used for feed or is sold at a minimal price to be spread on farm fields as soil conditioner and fertilizer. In my experience, total losses are rare. If combustion in the spoiling grain mass is provable, part or all of the financial loss may be recovered from insurance, but if only bin-burning is involved, the loss is not recoverable. Some elevators and grain storage firms have been bankrupted by a single catastrophic loss of that sort, and in those cases the losses are very definitely measurable.

The situation with wheat is somewhat different, because most wheat is used for food. The "sick" or germ-damaged wheat mentioned previously was an important problem from the early 1930s until the late 1950s because much wheat at that time was stored for a year or longer at moisture contents that permitted invasion of the germs by *Aspergillus restrictus* and *A. glaucus*. The fungus-damaged germs turned dark brown to black. They also became somewhat friable, so that when the grain was milled some of the germ tissue ended up as black specks in the flour, and being high in fatty acids, as is characteristic of high oil content tissues decayed by some storage fungi, they contributed a bitter flavor to the flour. Wheat with more than a very small percentage of damaged germs was not acceptable for milling. Large quantities of wheat that were bought and stored for milling came out of storage fit only for feed. There were some heavy financial losses, but no loss figures were ever published—grain merchandizing firms are not likely to publicize such data. Once the cause of the damage became known and the moisture content limit for all numerical grades of all classes of wheat was lowered to 13.5%, the problem disappeared. In recent years, sick wheat has not been of any commercial importance, but with much wheat now in longtime storage, it may appear again.

Effects on Germination

At or near the lower limit of moisture that storage fungi need to invade seeds, they invade the germs preferentially and, at times, almost exclusively. The germs may be invaded to the point of decay, with no outward evidence of molding, even under microscopic examination, and with little or no invasion of the endosperm tissues immediately adjacent to the embryo. The first effect of this invasion is weakening of the embryo, followed by death and then discoloration. In other words, both germination vigor and percentage may be drastically reduced when embryos are invaded by storage fungi, without this being evident to bare-eye inspection. (In this invasion and killing of living tissues of the embryos, storage fungi are very definitely functioning as parasites.)

Malting barley must have a high and uniform germination percentage, but it is bought on a basis of visual inspection. If a country elevator mixes into a carload lot of malting barley some of last year's barley, the germs of which have been invaded and weakened or killed by storage molds (and this has been known to happen!), the buyer for a malting firm may accept and pay for it as malting barley. The maltster finds it unsatisfactory, however, and it is sold as feed barley. The maltster is not likely to know that the irregular or low germination percentage of the barley was due to storage molds, and even if he did, a loss of that sort would be almost impossible to document as specifically caused by storage molds.

Some insects that feed on stored products, such as the granary and rice weevils, the larvae and pupae of which develop within the infested kernels, are closely associated with *A. restrictus* and *A. glaucus*. The insects carry with them inoculum of these fungi and provide moisture for the fungi to grow, so that if the insects are developing in a mass of grain, so are the associated fungi. Even if the insects are killed by fumigation, the damage by fungi may continue. The same is true of some grain-infesting mites, and some secondary stored-products insects subsist mainly or solely on moldy grain. Yet if insects are present, the damage is usually ascribed totally to them. If the problem is entomological/plant pathological, perhaps it should receive entomological/plant pathological study. It has received some but could do with more.

Misconception About Mycotoxins

Since about 1965, aflatoxins—and mycotoxins in general—have received a good deal of publicity. It is a common misconception that mycotoxins are likely to be produced by storage fungi growing in moist stored grains. That is possible, of course, but unlikely; I have not heard of a single recorded case of mycotoxins developing in stored grain known to have been free from mycotoxins when stored. One of the requirements of toxin formation by fungi is that the toxin-producing fungus be present in practically pure culture wherever it is growing, and this requirement is seldom met when fungi invade stored grains. Lightly or even heavily molded grains, feeds, or feed ingredients may or may not be less wholesome than their sound counterparts, but the mere presence of large numbers of spores or other propagules of a potential toxin-producing fungus in a given sample of feed is not evidence that toxins are present or the feed is in any way unwholesome.

Any animal in any barn or feedlot inevitably consumes a variety of molds every day. So do we, sometimes with gusto, as with mold-ripened cheeses or such spices as black and red pepper. Yet in recent court cases, the presence in a feed sample of spores of *A. flavus* or other potential toxin-producing fungus has been accepted as evidence that the feed was responsible for illness or death in the animals that consumed it, and on the basis of such evidence the plaintiffs have been awarded large monetary judgments. Some lawsuits of this kind have involved well over a million dollars, and such suits are becoming more frequent. This puts the feed manufacturers in an exceedingly tough spot, because they have no effective defense. All feeds contain a variety of molds; if they did not, they would acquire a varied mold population as soon as they were exposed to the air on the farm or feedlot where they are used. Whether losses such as these are attributable to storage molds probably is of little moment, but the situation demands some serious attention by mycotoxicologists and storage mold experts.

A Way to Establish Need for Research

Whether storage molds will receive any attention probably is up to those now active in postharvest pathology. One way to establish need for such research would be to develop solid data on economic losses caused by these fungi in stored grains and seeds and their products, from harvest on to the final consumer or processor.

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