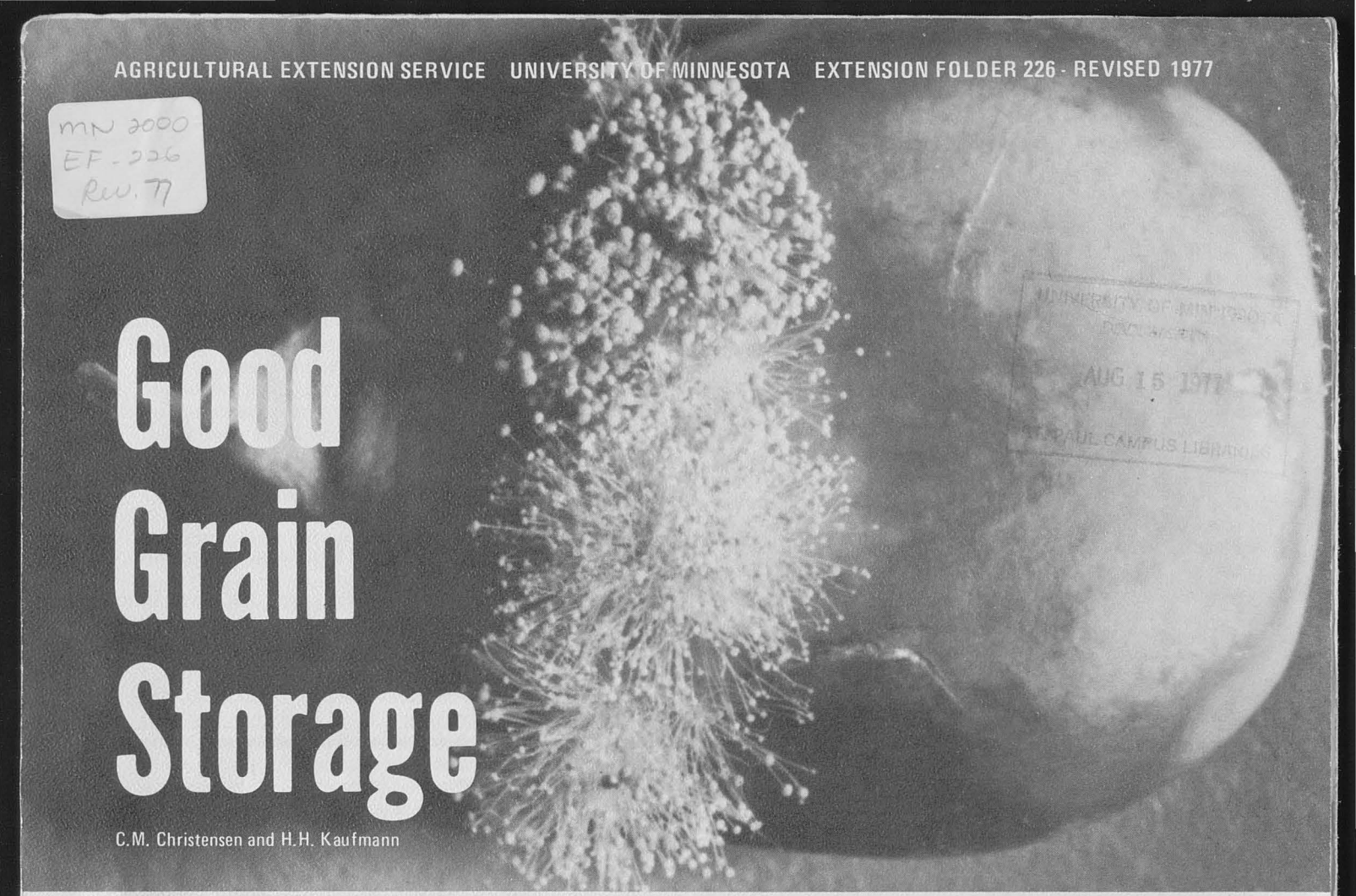
AGRICULTURAL EXTENSION SERVICE UNIVERSITY OF MINNESOTA EXTENSION FOLDER 226 - REVISED 1977



Good Grain Storage

C.M. Christensen and H.H. Kaufmann

Aspergillus flavus growing from the germ of a damaged corn kernel. This corn was not outwardly moldy, but when kernels were placed on agar, the fungus grew out from the interior.

That the grade of agricultural grains and seeds influences price is obvious to everyone dealing with grain marketing. Less obvious to many of those who buy, sell, handle, store, and ship grain is that molds or fungi are a major cause of reduction in quality. Also, given the right circumstances, in a short time molds can convert premium quality grain into Sample Grade or worse. Most of this spoilage is preventable.

To some extent, spoilage hazards in stored grains increase with the amount stored in any given lot, but even small amounts of grain may suffer the same degree of spoilage for the same reasons and from the same processes as grain in tanks or warehouses holding thousands of tons. Also grain that has been kept in seemingly good condition through the winter may suddenly undergo severe spoilage in the spring; and grain kept in commercial storage for as long as a year without obvious damage may, during transport by barge or ship, undergo fairly extensive spoilage within a few weeks. The reasons for this are discussed in this publication.

QUALITY

Quality in grain means different things to different users. Grain that would be of very low quality if marketed may be satisfactory for feed on the farm where it was produced. Special characteristics may be required for special uses as in corn for starch production or barley for malting. Characteristics specified by the Official United States Standards for different grades of wheat, corn, and soybeans are given in tables 1, 2, and 3.

Note that in corn, for example, relatively small increases in broken corn and foreign material and in damaged kernels results in lowering of grade. (In corn, "foreign material" is, by definition, anything that will pass through a 12/64 inch round hole sieve.) Up to 3.9 percent of broken kernels and foreign material is permitted in Grade No. 2, but if it has 4.0 percent broken corn and foreign material, the corn is Grade No. 3, regardless of its other characteristics. And corn with 0.5 percent "heat damaged" kernels (kernels dark brown to black, mostly discolored by molds, not heat) will be of Grade No. 3 regardless of other characteristics. Both "damaged" and "heat damaged" kernels are mainly a product of the growth of storage fungi. The presence of these types of damage in grain in commercial channels is evidence that somewhere during its storage life the grain was fairly heavily invaded by storage fungi or molds.

FIELD FUNGI

Seeds borne more or less exposed, as are those of the cultivated cereal plants such as wheat, oats, barley, rye, rice, sorghum, the millets, and corn, may be invaded in the field before harvest by many kinds of fungi. Some fungus invasion in the field, in fact, is just about universal. We

Table 1. Grades and grade requirements for all classes of wheat, except mixed wheat.

Grade	Minimum test weight per bushel		Maximum limits of—						
								Wheat of other classes[3]	
	Hard Red Spr. Wheat or White or Club Wheat	All other classes and sub-classes	Heat-damaged kernels	Damaged kernels (total)[1]	Foreign material	Shrunken and broken kernels	Defects (total)[2]	Con-trasting classes	Wheat of other classes (total)[4]
	pounds	pounds	percent	percent	percent	percent	percent	percent	percent
U.S. No. 1	58.0	60.0	0.2	2.0	0.5	3.0	3.0	1.0	3.0
U.S. No. 2	57.0	58.0	0.2	4.0	1.0	5.0	5.0	2.0	5.0
U.S. No. 3	55.0	56.0	0.5	7.0	2.0	8.0	8.0	3.0	10.0
U.S. No. 4	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0

U.S. Sample grade U.S. Sample grade shall be wheat which:

(1) Does not meet the **requirements** for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

(2) Contains a quantity of smut so great that one or more of the grade **requirements** cannot be determined accurately; or

(3) Contains 8 or more stones, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* ssp.), 3 or more castor beans (*Ricinus communis*), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substances, or 2 or more rodent pellets, bird droppings, or an equivalent quantity of other animal filth per 1,000 grams of wheat; or

(4) Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor; or

(5) Is heating or otherwise of distinctly low quality.

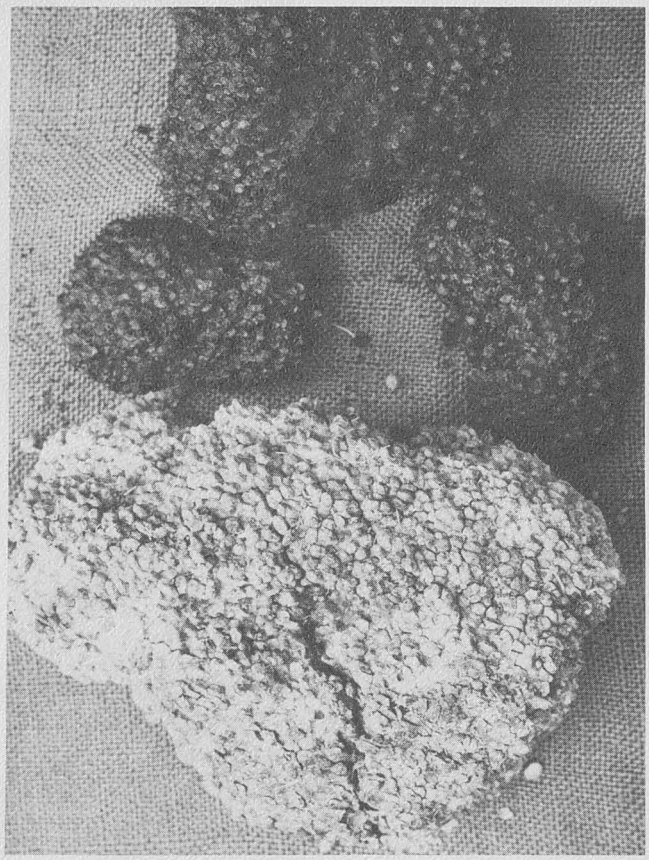
[1]Includes heat-damaged kernels.

[2]Defects (total include damaged kernels (total, foreign material, and shrunken and broken kernels. The sum of these three factors may not exceed the limit for defects.

[3]Unclassed wheat of any grade may contain not more than 10 percent of wheat of other classes.

[4]Includes contrasting classes.

Soybeans damaged by storage molds. The dark soybeans at the top are typically bin burned. At the bottom are heavily caked soybeans.



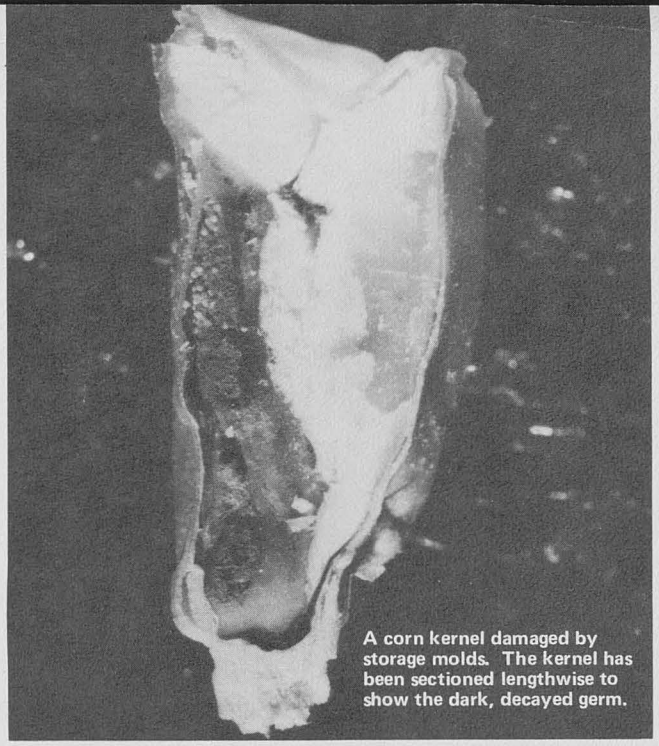
never have found a sample of freshly harvested wheat even from irrigated and dry land farming areas that did not have moderately abundant mycelium of the fungus *Alternaria* under the pericarps. A light invasion by *Alternaria* or by other field fungi is not detectable to the unaided eye, and it has no effect on processing quality. Heavier invasions result in various kinds of blemishes, blights, and discolorations that may reduce the quality of the grain for some uses, including for foods and feeds. Some of these field fungi produce toxic compounds (discussed later) that, if present in sufficient quantity, make the grain unfit for consumption. All of these field fungi require a high moisture content in the seed to grow, and normally they do not continue to grow after harvest. The damage that they do is done by harvest time. An exception is high moisture ear corn stored in cribs and in which some of the field fungi may continue to grow.

STORAGE FUNGI

Stored grains and seeds are subject to invasion and damage by another group of fungi, collectively called storage fungi or storage molds. These storage molds are few in number of species but widely distributed and ever-present. With one exception, discussed later, they do not invade grain or other seeds to any significant degree or extent before harvest. But if grains or seeds of any kind are stored under conditions that permit these fungi to grow, they inevitably grow. The damage that they cause includes loss of germinability, which is important in seeds to be used for planting, malting, or production of edible sprouts; discoloration of the germ or of the entire kernel (''sick'' wheat, ''damaged'' or ''heat damaged'' kernels of corn,

Table 2. Grades and grade requirements for corn.

Grade	Minimum test wt per bushel	Maximum limits of— Moisture	Broken corn and foreign material	Damaged Kernels Total	Heat-damaged kernels
	pounds	percent	percent	percent	percent
U.S. No. 1	56.0	14.0	2.0	3.0	0.1
U.S. No. 2	54.0	15.5	3.0	5.0	.2
U.S. No. 3	52.0	17.5	4.0	7.0	.5
U.S. No. 4	49.0	20.0	5.0	10.0	1.0
U.S. No. 5	46.0	23.0	7.0	15.0	3.0
U.S. Sample grade	U.S. Sample grade shall be corn which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; or which contains stones; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.				



A corn kernel damaged by storage molds. The kernel has been sectioned lengthwise to show the dark, decayed germ.

Table 3. Grades and grade requirements for soybeans.

Grade	Minimum test wt. per bushel	Maximum limits of— Moisture	Splits	Damaged kernels Total	Heat damaged	Foreign material	Brown, black and or bicolored soybeans in yellow or green soybeans
	pounds	percent	percent	percent	percent	percent	percent
U.S. No. 1	56.0	13.0	10.0	2.0	0.2	1.0	1.0
U.S. No. 2	54.0	14.0	20.0	3.0	0.5	2.0	2.0
U.S. No. 3[1]	52.0	16.0	30.0	5.0	1.0	3.0	5.0
U.S. No. 4[2]	49.0	18.0	40.0	8.0	3.0	5.0	10.0
U.S. Sample grade	U.S. Sample grade shall be soybeans which do not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 4, inclusive; or which are musty, sour, or heating; or which have any commercially objectionable foreign odor; or which contain stones; or which are otherwise of distinctly low quality.						

[1]Soybeans which are purple mottled or stained shall be graded not higher than U.S. No. 3.
[2]Soybeans which are materially weathered shall be graded not higher than U.S. No. 4.

and other kinds of seeds); mustiness, caking, heating, and total spoilage. Germinability is not a factor in grade, but all of the other changes listed reduce the grade and therefore the price of the grain. All of these quality degrading changes are caused by storage molds, and only by storage molds. At one time it was widely believed that heating in moist grain was a product of the respiration of the grains themselves, which is not true, and even that grain had an "urge to heat and germinate in the spring," which is nonsense.

We now know precisely the conditions that must prevail in stored grains of different kinds to permit one or another of the storage fungi to grow enough to cause damage. We also know the combinations of moisture content and temperature that must be maintained to prevent damaging growth of storage molds during a given storage period. We also have techniques to make sure that grain of high quality when it goes into storage will be kept of high quality until it is used or sold, and techniques to monitor quality and evaluate future storage risk at any time during the storage life of the grain.

CONDITIONS THAT MAKE FOR DAMAGE IN STORED GRAINS

The major factors that determine whether grain during storage will be sufficiently invaded by storage fungi to develop commercially important damage are: moisture content of the grain, temperature of the grain, the amount of cracked and broken kernels and foreign material, the degree to which the grain already has been invaded by storage fungi before it arrives at a given storage site, and the length of time it is stored. All of these factors interact with one another, and all of them are measurable.

Moisture content—Moisture contents of some of the common grains and seeds and their products, in equilibrium with different relative humidities, and the fungi that will invade them at those moisture contents, are given in table 4.

The moisture contents and temperatures that make for low storage risk are known. In general, starchy cereal seeds with a moisture content of 13.5 percent or below can be stored for just about any length of time without damage from molds. This is the upper limit of moisture permitted in all the numerical grades of wheat. Soybeans with a moisture content of 12.5 percent can be stored indefinitely without risk of spoilage. These moisture content limits for safe storage imply that nowhere in the bulk is the moisture content higher than that specified.

To illustrate the interaction of the moisture content - temperature - time in storage risk, soybeans of 14.0-14.3 percent moisture can be stored at 5°-6° C (40°-45° F) for several years without the slightest invasion by storage fungi and without any loss in quality. Stored at the same moisture content but at 30° C (86° F), they will be invaded by storage fungi within a few weeks, and within a few months they will be obviously musty. Grade No. 2 corn is permitted a maximum moisture content of 15.5 percent. If it is sound when put into storage it can be kept for a year without damage at a temperature of 15° C (59° F), although during that time it will have been invaded to some extent by storage fungi. If stored at 30° C (86° F) it will develop moderate to severe damage within a few months. Corn of 18.5 percent moisture that is sound when stored can be kept at 5° C (41° F) for at least 4-5 months without damage, but at 25°-30° C (77°-86° F) it will be heavily invaded by storage fungi within a week.

Some cases of spoilage in stored grain occur because those in charge of the grain knowingly risk the chance that the grain might not hold up under the conditions that prevail and for the expected length of time the grain is to be stored. Most cases of damaging or grade-reducing spoilage, however, occur because the persons in charge of the grain do not know the moisture content of the grain under their care. For various reasons, the moisture content of the grain in the bin may differ, sometimes radically, from the moisture content on the warehouse records. The moisture content of a representative sample, regardless of how well it is taken, cannot indicate the range in moisture content of the lot. It may give an entirely false idea of the storage risk of that lot. We have found samples from truckload, carload, and bargeload lots and from bins with moisture contents as much as two to three percent above that shown in the records.

In the range of moisture content between about 14.5 and 16.5 percent in the starchy cereal seeds, a difference of only 0.5 percent can mean the difference between safe storage and damaging invasion by storage fungi. If any portion of the lot has a high enough moisture content to permit storage fungi to grow, they will grow, regardless of the moisture content shown on the official record. And once spoilage is under way, it is self-perpetuating and self-accelerating. For buying and selling grain, it is essential to know the average moisture content of the lot, but for safe storage and often for safe shipment, it is essential to know the highest moisture content that prevails anywhere in the lot. This can be determined by taking a number of samples and testing each one separately for moisture content. Also the accuracy of the moisture meter should be checked occasionally; the precision of moisture meters sometimes is overestimated, and both humans and machines can err.

If different temperatures prevail in different portions of the bulk, moisture will be transferred from the warmer to the cooler portions, the rapidity of the transfer depending on the moisture content of the grain and on the magnitude of the temperature difference. In corn with a moisture content of 15.0—15.5 percent a difference in temperature of only 5°-10° C (9°-18° F) between one portion and another can result in an increase of two percent in the moisture content of the grain on the cool side in 10 days, with accompanying damage by storage fungi.

Respiration of insects, mites, and fungi produces water so that even if the grain is of uniform and low moisture content when stored, the moisture may increase later. Also openings in the storage structure may permit water to enter.

Table 4. Equilibrium moisture contents of common grains, seeds, and feed ingredients at relative humidities of 65-95+ percent, and the fungi likely to be encountered at each moisture content.

Relative humidity %	Moisture content, % wet wt. of materials[1] Starchy cereal seeds,[2] alfalfa pellets	Soybeans and soybean meal	Peanut meal, copra	Fungi
65—70	12.5—13.5	12.0—12.5	5.5—6.0	*Aspergillus halophilicus*
70—75	14.5—15.0	14.0—14.5	6.0—6.5	*A. Restrictus, trictus, A. glaucus, Sporendonema*
75—80	15.0—15.5	14.5—15.0	7.0—7.5	*A. candidus, A. ochraceus, A. versicolor,* + the above
80—85	18.0—18.5	17.0—17.5	8.5—9.5	*A. flavus,* a few species of *Penicillium,* + the above
85—90	19.0—20.0	18.5—19.5	10.0—12.0	Several species of *Penicillium* + the above
95—100	22.0—24.0	20.0—22.0	15.0—16.0	All advanced decay fungi, yeasts, and bacteria

[1]The figures are close approximations, but some variation can be expected in practice.
[2]Wheat, barley, oats, rye, rice, maize, sorghum.

All of these factors make for increased storage hazard. A program of sampling and testing, as outlined here, will enable those in charge of the grain to detect incipient damage before it has become severe enough to cause significant reduction in quality. As a matter of principle, anyone in charge of stored grain should always suspect that somewhere in the grain mass, conditions are not as good as they appear to be. Wariness, not complacency, is the watchword. Some elevator superintendents in charge of large quantities of grain and even in relatively high-risk regions, never suffer serious losses in quality. Others suffer such losses occasionally or periodically. The same information, processes, and procedures are available to both: some use them; others do not.

Monitoring temperature in stored grain—Most processes that result in reduction in quality or in spoilage in stored grain are accompanied by a rise in temperature. Devices to monitor temperatures in bulk stored grain were developed more than 50 years ago as an aid to good storage. They have been in use throughout the world wherever grain is stored in bulk. Their usefulness is unquestioned. Yet in 1975, an elevator superintendent in west Texas who had suffered an almost total loss of more than a million bushels of corn, stated that he "did not believe in temperature detection systems." This is equivalent to an airline pilot not believing in fuel gauges, altimeter, or landing approach guides. As with other aids to good grain storage, the mere installation of a temperature monitoring system does not in itself prevent spoilage. It must be functioning properly, and the warning it gives must be heeded. Most commonly, these temperature monitoring systems consist of thermocouples attached to cables that extend from top to bottom of the bins. The thermocouples are spaced about 2 meters or 6 feet apart on each cable, and the cables are from 3 to 4 meters, or 20 to 25 feet apart, which means that there is one thermocouple for each 60 cubic meters or, roughly, 2,000 cubic feet of grain. Relatively dry grain is a good insulator, and so a hot spot may develop without this being detectable immediately by a temperature rise at the nearest thermocouple, but no extensive spoilage will develop without some temperature rise being detectable. Any temperature rise of more than a few degrees means that advanced spoilage is likely to be underway in that portion where the heat is being generated. In stored malting barley, any detectable rise in temperature, even so little as 1 or 2 degrees, is regarded as an indicator of trouble, to be investigated and taken care of at once.

While some persons in charge of hundreds of thousands of bushels of corn or soybeans do not become alarmed or even concerned about consistent small rises in temperature from day to day and week to week, sometimes as a result they suffer heavy losses that could have been easily avoided had they only heeded the warning given by the temperature monitoring system. Even today some firms store large quantities of high priced and perishable corn and soybeans in large metal tanks with no aeration, no temperature monitoring system, no provision for inspection or sampling, and no more knowledge of the moisture content of the bulk than is given by tests of unknown accuracy on one or a few samples taken as the tanks were loaded some months before. They are not taking advantage of the aids to good grain storage available to them. If they are not concerned, their bankers and insurers should be.

Aeration—The major function of aeration is to bring about a uniform and moderately low temperature throughout the grain. The uniform temperature reduces the transfer of moisture from place to place in the bulk, and a moderately low temperature (5°-10° C, 41°-50° F) reduces the rate of growth of storage fungi if the grain has a high enough moisture content for them to grow. Grain infesting insects become inactive below about 15° C (59° C), and although both mites and some storage fungi can develop slowly down to a temperature of 0°-5° C (32°-41° F), they will not cause any significant damage within a year in grain of 15-16 percent moisture that was sound when stored. If the grain is to be processed on or near the premises where it was stored, and is not to be transported so that condensation as it is loaded out is of no concern, it can be cooled to a temperature of 0°-5° C (32°-41° F) or below. The aeration rate for cooling is on the order of 0.1 cubic foot per minute per bushel. This establishes a uniform temperature throughout the grain in 100-120 hours. Once the desired temperature is attained, aeration can be discontinued until such time as inequalities in temperature arise. Even in such a high humidity, high temperature, and high storage risk site as San Juan, Puerto Rico, it is possible to select periods for aeration that combine moderate temperatures with moderately low relative humidities.

Spoutlines—When grain is loaded into a bin or tank or barge or ship hold from an overhead spout, the fine material collects in a cone or column directly beneath the spout. This is known as the "spoutline." The width of the spoutline is proportional to the width of the bin. When corn or soybeans containing 2-3 percent fines are loaded into a bin, the spoutline may contain 50 percent fines. In corn these fines consist mainly of kernel fragments. In soybeans they consist of seed fragments and weed seeds. These weed seeds are likely to be high in moisture because they were immature when harvested, and the seed fragments are more susceptible to molding than are sound soybeans. Molds can begin to grow in this spoutline almost immediately, and within 50 to 60 days this may lead to heating and sometimes to fire. If the bin is aerated, the air will pass around this solidly packed spoutline. One way to avoid or alleviate this spoutline problem is to draw out the central core of fines after the bin is filled and to store it separately. Another is to remove the fines by screening. Either approach involves extra handling and extra expense. Also screenings sold as such command a lower price than whole kernel corn or whole soybeans. This is an especial problem in corn because the kernels tend to break up in handling so that the percentage of screenings increases with every transfer from the farm to the final user. Sometimes these screenings accumulate in discrete layers as barges of ships are loaded, and this increases the spoilage hazard, especially if the voyage lasts more than a few weeks. Also when the ship is unloaded at a foreign port, it is impossible to redistribute these screenings uniformly; one truck or barge leaving the port for inland processing plants may contain a very small amount of foreign material and another may contain a very great deal. The customer who receives a load containing the larger amount of screenings is likely to complain.

Degree to Which a Given Lot Is Invaded by Storage Fungi Upon Arrival at a Given Site—Some lots of grain from farm, country elevator, or terminal elevator storage are almost free of storage fungi; others have been invaded

to various degrees. A maximum of 15.5 percent moisture is allowed in Grade No. 2 corn, and so much corn is stored and handled from the farm on at a moisture content of 15.0-15.5 percent. And this means a moisture content of 15.0-15.5 percent in a representative sample of the lot. What with the inadequacy of representative samples as indicators of storage risk, opportunities for moisture transfer, the added risk posed by accumulation of screenings and moisture uptake from exposure to humid air during transfer, by the time the corn has been stored for 9 months to 1 year, some of the grain is likely to be at least moderately invaded by storage fungi. This will not be evident to bare-eye examination. By the time moldy grain is detectable to the unaided eye it is in a fairly advanced state of deterioration. The mold invasion can be detected readily in the laboratory. Obviously, grain moderately invaded by storage fungi is of much higher risk for continued storage than is sound grain because it already has progressed part of the way down the road to ruin.

SAMPLING AND TESTING

Without question, we now know the major agents that cause grain to spoil and the conditions under which they cause spoilage. We can detect these agents in various ways, and can measure their increase long before they cause serious spoilage. We can, in other words, evaluate precisely the present condition and future storability of a given lot. The procedure is as follows: Samples of about 0.5 kg (a bit more than ½ pound) are taken from as many different portions of the bulk as desired, periodically after the bin or tank or warehouse has been loaded (a vacuprobe permits taking of samples from almost any depth of any mass of grain or other granular material.) Each sample is put into a moisture-proof plastic bottle and sent to the laboratory. There each sample is tested for moisture content, and examined for damage by fungi, insects, and mites. Presence of storage fungi can be detected by microscopic examination or by plating surface-disinfected kernels on a suitable agar medium, or both. Some grain firms have facilities for this. Some do not, but commercial testing laboratories are available for such work.

GRAIN PRESERVATIVES

High moisture corn can be protected from spoilage by treatment with propionic acid, sold under various trade names. Chemstor, manufactured by Celanese Chemical Corporation also is an effective preservative of high moisture corn. Numerous proprietary compounds, many of them worthless and most of them costly, have been and doubtless will continue to be promoted and sold to the unwary as grain preservatives. We do not know of any effective grain preservatives other than the 99+ percent pure propionic acid or Chemstor. Corn treated with propionic acid or Chemstor is suited only for feed and is not welcomed in commercial channels.

MYCOTOXINS

Some fungi growing in some materials under some conditions produce compounds that are toxic when consumed. These are known as mycotoxins. One of these toxins is aflatoxin, said to be the most potent naturally produced carcinogenic or cancer-causing agent known. It is produced by the fungus *Aspergillus flavus*. Usually *A. flavus* is considered to be a storage fungus, but this is not always true. If developing ears of corn in the field are damaged by earworms, borers, or weevils, *A. flavus* may invade the kernels, and this invasion may be accompanied by the formation of aflatoxin. Federal law prohibits the marketing of grains (or other food or feed ingredients) that contain more than 20 parts per billion of aflatoxin. Corn in interstate commerce is subject to surveillance by the FDA, and it is expected that corn and other grain sold locally within states soon will be subject to the same surveillance. Aflatoxin contamination of corn in the field is relatively uncommon throughout the corn belt, but is relatively common in the southern and southeastern U.S., sometimes in corn not injured by insects. Kits involving use of ultraviolet light for tentative identification of aflatoxin-contaminated samples of corn are available and are in use in many country and terminal elevators. Positive identification of aflatoxin contamination requires confirmatory tests in the laboratory.

Different species of the fungus *Fusarium* infect cereal grains as they are developing in the field, causing a variety of diseases such as scab in wheat and barley and stalk and cob rots of corn. What in commercial grain inspection is called "tombstone damage" in wheat consists of kernels heavily infected by *Fusarium*. It is common in some regions when warm and rainy weather prevails just before harvest. The estrogenic syndrome in swine, characterized by swollen vulvas in the females, is mainly a product of a toxin produced by *Fusarium*. *Fusarium*-invaded grain may also contain other toxins that cause feed refusal and vomiting in swine and reduced weight gain and reduced egg production and various sorts of lesions in poultry. The main production of these toxins is in corn still in the field, and to some extent in ear corn stored in cribs, but not in shelled corn. Further information on mycotoxins in relation to the health of farm animals is given in the second publication listed below.

ADDITIONAL READING

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