Quality Maintenance in Stored Grains & Seeds

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Preface

Maintenance of quality in grains and seeds requires good storage, and good storage means more than just loading the harvested crop into a bin or tank or silo or warehouse and leaving it there, without care or knowledge about its condition until it is to be used or marketed. Unless preventive measures are taken, such enemies as insects, mites, rodents, and molds can slowly or rapidly reduce the quantity and quality of grains so stored. The golden harvest may end up as dross, unusable and unmarketable, or so heavily damaged that it is of little value. These hazards to quality are present everywhere, from harvest until final use or consumption of the grain.

The book *Grain Storage: The Role of Fungi in Quality Loss* (1969) summarized evidence that established beyond question that fungi or molds are a common and primary cause of loss in quality of stored grains. The information presented there laid to rest the old idea that spoilage was a product of processes within the grains or seeds themselves. Conditions that permit molds to grow and cause damage are known, and they can be avoided.

Information and technology developed by research have greatly reduced losses of quality in grains during storage and transit, but mold-caused damage still occurs throughout the world where grains are stored and transported. These losses are needless. The principles and practices of good grain storage are known, and where these are applied, the quality that grains have at harvest can be maintained indefinitely and losses held to a minimum.

The aim of this book is to summarize these principles and practices in a form readily understandable by farmers and producers, elevator managers and grain merchants, bankers and insurers, all of whom have a heavy financial stake in grain quality. The principles are simple and clear, and the practices are easy to apply; as pointed out in the text, the practices have been in use for some time by informed and progressive individuals and firms responsible for maintaining quality of grains and seeds under their charge. General acceptance of these now well-established principles and practices would be beneficial to all who produce, buy, sell, handle, process, or use grains and seeds.

Both of us have been involved for most of our professional lives in work devoted to the material summarized in this book, which is a summary of our knowledge on the subject. We have, of course, drawn freely and heavily on the works and words, both written and spoken, of other toilers in the field. Rather than cite references in the text to the many publications dealing with the material presented, we have listed, at the end of the book, additional reading for those interested in following up the subjects discussed.

We owe a special debt of gratitude to Dr. D. B. Sauer, Research Plant Pathologist, U.S. Department of Agriculture, Agriculture Research Service, Grain Marketing Research Laboratory, Manhattan, Kansas; Dr. John Tuite, Professor, Department of Botany and Plant Pathology, Purdue University, West Lafayette, Indiana; and Mr. Arvid Hawk, Cargill, Inc., for their critical review of the manuscript – their contributions were greater than we here acknowledge.

We hope that the book will be useful to all who are charged with the responsibility of maintaining quality in stored grains and seeds.

C.M.C. and R.A.M.

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1 ◇ The Problem

Seeds of cereal plants and legumes and a few other kinds of cultivated plants constitute the raw material of most of our foods, animal feeds, and stimulating drinks throughout the world. Both the seeds themselves, before and after harvest, and many of the products made from them are subject to damage by fungi, insects, mites, and rodents. Other agents may sometimes be involved in loss of quality, but these are by far the major ones.

Insects, mites, and rodents have long been recognized as destructive enemies of stored grains, not only by the direct consumption of grain but also by the contamination they add in the way of excreta, hairs or other body parts, undesirable microflora, and unpleasant odors and flavors. A good deal of effort has gone into the development of controls for these agents of destruction; where the controls are applied, losses in quantity or quality of grains are held to a minimum.

The story is somewhat different with fungi or molds. We have long known that some of the fungi that attack developing seeds on plants in the fields reduce the quality of the seeds for food or feed. Only in the last 30 years, however, has the role of storage fungi in the reduction of quality of stored seeds and grains been elucidated. Although information on the nature, causes, and control of deterioration of stored grains by fungi has been published in the research literature, it has not become common knowledge among a number of those who are responsible for the maintenance of storage quality. Briefly, where rodents and insects are controlled and mites are not present, fungi are the only cause of spoilage in stored grains. Even when insects and mites are present, the fungi associated with them may cause much or most of the damage that is mistakenly attributed to the bugs because they are more visible. By the time storage fungi on grains become visible to the unaided eye, their damage is fairly extensive. Some secondary insects and grain-infesting mites feed mainly on the storage fungi associated with them; even if the insects and mites are killed by fumigation or other means, the damage by fungi continues.

Although our major emphasis throughout this book is on storage fungi and means of coping with them, we will also discuss some of the field fungi that cause damage to seeds or seed products.

FIELD AND STORAGE FUNGI

The multitude of fungi that invade and damage seeds and their products are conveniently divided into two general groups – field or storage fungi – according to their ecological requirements, or the conditions under which they grow.

The terms *field fungi* and *storage fungi* were coined in the 1940s when fungi were first implicated as causes of spoilage in stored grains. Before that time, most people concerned with problems of spoilage in stored grains and seeds and their products had excluded fungi as possible causes. In part, they reasoned that fungi required high moisture contents to grow in grains, whereas spoilage often developed in grains stored at moisture contents of 14–15 percent. Good logic, perhaps, but poor biology. They also were in error about the moisture content at which spoilage sometimes developed because they assumed that the moisture content of the grain in the bin was the same as that shown on the warehouse records; but that is another story, which we will discuss below.

When workers discovered in the 1940s that some groups of fungi causing loss of germinability, germ damage, caking, and mustiness in stored grains were adapted to and lived out their lives in materials whose moisture contents were in equilibrium with relative humidities of 70–75 percent, it seemed reasonable to designate these as *storage fungi*. But many practical grain workers claimed that these storage fungi must have been present and developing in the grains as they came from the fields, because once the grains were stored in their bins the moisture contents never were high enough to permit the fungi to cause any damage. They also believed that the warehouse records accurately reflected the actual moisture contents of the grains in the bins. But in an attempt to find out when and where these storage molds invaded the grains, literally thousands of samples of wheat, barley, oats, sorghum, various wild grasses, and corn were collected at harvest time and tested for number and kinds of fungi. Some came from plants that had lain swathed on the ground in wet weather, with seeds that were heavily stained by various field fungi. Almost no storage fungi were found in any of them.

This work was repeated by different people, over several different crop years and in different regions of different countries, and the results were consistent – storage fungi did not infect the seeds to any significant extent before harvest. Nearly all of these grains, however, were infected to various degrees with a variety of field fungi – principally *Alternaria*, *Cladosporium*, *Fusarium*, and *Helminthosporium*, and corn with ear rot might be invaded with many additional kinds of fungi. In storage tests in the laboratory and in bins on farms and in commercial elevators, where conditions permitted invasion of the grains by storage fungi, the field fungi originally present slowly or rapidly died out. All the common field fungi required a moisture content in equilibrium with a relative humidity of 90 percent or higher to grow; they were not involved in the spoilage of grains that were sound when they went into storage. In other words, the field and storage fungi were sharply distinguished from one another in terms of the time at which they invaded the seeds and the conditions they needed for growth.

This distinction between field and storage fungi is based not on classification or taxonomy, but rather on their life habits. The prevalent and important storage fungi – the *Aspergillus restrictus*, *A. glaucus*, *A. candidus*, and *A. ochraceus* groups – that initiate spoilage and cause germ damage, mustiness, caking, and the first stages of heating in stored grains and their products are primary invaders of these products. They develop and cause damage only if conditions in storage favor their growth. *A. flavus* in corn, peanuts, and cottonseed is an exception because it sometimes invades the seeds of these plants in the field. In cereal grains other than corn and in legumes other than peanuts, however, *A. flavus* is almost strictly a storage fungus.

On the other hand, the common field fungi (*Alternaria*, *Cladosporium*, most species of *Fusarium*, *Helminthosporium*, and the multitude of fungi involved in corn ear rots) invade the grains in the field and do their damage before harvest. They do not develop to any degree in storage except in occasional cases of high-moisture corn. However, some fungi, including various species of *Penicillium*, a few of *Fusarium*, some yeasts, and miscellaneous fungi, invade seeds before harvest and continue to grow and cause damage to seeds stored with moisture contents in equilibrium with relative humidities of 85–90 percent. One of these "in between" groups may be prevalent on a given kind of seed at a given time or place, but they do not usually constitute major elements of the microfloral population of seeds and do not significantly damage seeds in storage. The distinction between field and storage fungi is thus not absolute (as few things are in biology), but the field fungi remain – in their habits and patterns of damage – sharply distinguished from the common and prevalent storage fungi.

Field Fungi

Hundreds of species of fungi invade seeds on plants growing in the field or after the plants have been cut and swathed but before the seeds are threshed out. Some field fungi are so common and prevalent as to be almost an integral part of the seeds they infect. Mycelium of the common field fungus *Alternaria*, for example, is present under the outer pericarps of just about all seeds of wheat, even those grown in dryland areas (fig. 1). Unless the fungus grows extensively enough to discolor the seeds, as it sometimes does in years of moist weather at or before harvest, it causes no harm and is of no concern. In laboratory tests to determine conditions and storability of different lots of wheat, *Alternaria* can serve as an indicator or marker fungus: if it grows from most of the surface-disinfected kernels plated on agar, we know that the wheat was harvested recently, that it has been stored at a safe moisture content, and that it is a good risk for continued storage. This is discussed in more detail in chapter 8.

Figure 1. Mycelium, probably of *Alternaria*, under the pericarp of wheat.

If moist or humid weather prevails just before or during harvest, some of the many field fungi that invade seeds can cause grade-reducing discoloration. For some uses to which seeds are put, this discoloration or staining is of little or no significance; for other uses, however, it is. When wheat is milled into flour, for example, or durum wheat into semolina for pasta products, a few particles of bran always end up in the flour. Normally these are invisible, but if the bran coats have been blackened by fungus invasion, the resulting black flecks in the flour or macaroni make it unacceptable to consumers. The flecks are not harmful, they are just unattractive.

Fusarium growing on the heads of wheat and barley before harvest causes what is called "scab." The infected kernels are gray or pink, shrunken, and decayed. The gray, decayed kernels have a chalky appearance and consistency; in grain inspection they are referred to as "tombstone damage," which is a rather peculiar designation. Some of the species of *Fusarium* that cause scab in wheat and barley, and some of those that cause ear or cob rots in corn, can produce exceedingly unwholesome toxins, and such grains are properly discriminated against by food and feed producers. These toxins are discussed in chapter 6, and the fungi themselves are described in chapter 8.

Damage by field fungi is beyond the control of the grower, except for the use of varieties with some resistance to infection by them. Some of the many field fungi that cause ear rots of corn in the field may result in heavy losses from decay, but they are not otherwise harmful. Damage by these field fungi is one of the hazards of farming.

All field fungi require moisture contents in equilibrium with relative humidities of 90 percent or more in the starchy cereal seeds, or a moisture content of 20–25 percent on a wet weight basis. Once the moisture content of the seed is below that level, these fungi can no longer grow. Most of their damage is done by the time the seeds are threshed out. Some can continue to grow and produce mycotoxins on high-moisture ear corn stored in cribs. That is where toxin-producing strains and species of *Fusarium*, having infected the ears on the field, produce most of their toxins. Moderately low temperatures favor the initiation of toxin production by these fungi. With the advent of low-temperature drying of corn, it has also been found that some field fungi in the corn at harvest continue to grow during drying. When drying is done correctly, however, no damage results beyond that present when the corn was harvested.

Storage Fungi

Storage fungi are adapted to growing in materials whose moisture content is in equilibrium with relative humidities from 65–70 to 85–90 percent: that is, moisture contents of about 13–20 percent in the starchy cereal seeds; 12–19 percent in soybeans; and 9–12 percent in peanuts, sunflower seeds, copra, and other plant materials of equally high oil content (see table 1).

Table 1. Equilibrium Moisture Contents[a] of Common Grains, Seeds, and Feed Ingredients at Relative Humidities of 65–90 Percent and Fungi Likely to Be Encountered

Relative Humidity (%)	Starchy Cereal Seeds, Defatted Soybean and Cottonseed Meal, Alfalfa Pellets, Most Feeds	Soybeans	Sunflower, Safflower Seeds, Peanuts, Copra	Fungi
65–70	13.0–14.0	12.0–13.0	5.0–6.0	*Aspergillus halophilicus*
70–75	14.0–15.0	13.0–14.0	6.0–7.0	*A. restrictus*, *A. glaucus*, *Wallemia sebi*
75–80	14.5–16.0	14.0–15.0	7.0–8.0	*A. candidus*, *A. ochraceus*, plus the above
80–85	16.0–18.0	15.0–17.0	8.0–10.0	*A. flavus*, *Penicillium*, plus the above
85–90	18.0–20.0	17.0–19.0	10.0–12.0	*Penicillium*, plus the above

Source: C. M. Christensen and D. B. Sauer. 1982. Microflora. Pages 219–40 in *Storage of Cereal Grains and Their Products*. 3rd ed. C. M. Christensen, ed. St. Paul, MN: American Association of Cereal Chemists.

[a]Percentage wet weight. The figures are approximations; in practice, variations up to ± 1.0% can be expected.

Some grain-infesting insects also develop in grains of relatively low moisture content, but these insects have a high moisture content in their interior body parts where the processes of life go on; they are protected from desiccation by a waxy coating on the outside of their bodies. If this protective coating is broken, the insects lose moisture and die. Thus, adding abrasive material to grain is one method of controlling insects in stored products. The storage fungi, however, carry on their functions with whatever moisture is available to them at relative humidities from 65–70 percent to 85–90 percent. Some of them, notably strains or species in the *Aspergillus restrictus* group, and *A. halophilicus*, not only are adapted to but *require* limited water to grow; they can be isolated from the materials in which they are growing only by the use of an agar medium with a high content of sugar or salt. *A. halophilicus* even grows on and over crystals of sodium chloride piled up in agar saturated with the salt. At moisture contents in equilibrium with the lower limits of growth for these fungi, they grow exceedingly slowly; even at the temperatures most favorable for their development, it may take several days to a week or more for their spores to germinate and form a microscopically visible germling, and several days longer and on a medium high in sugar or salt to form a colony visible to the unaided eye. These common and sometimes prevalent low-moisture-content fungi are not detected on agar media ordinarily used in quality control laboratories to detect fungi. Their detection requires something more than the routine approach.

The moisture content levels given in table 1 for the growth of different fungi in different materials are approximate. Seeds, like other biological materials, are variable, and different lots of even the same variety of wheat exposed to the same relative humidity come to somewhat different moisture contents at equilibrium. Different varieties of corn have greatly different amounts of oil, and so at a given relative humidity they have different moisture contents. Moreover, the moisture in seeds is not evenly distributed among the different portions of the seeds or fruits (the seeds of wheat and other small grains technically are fruits). At relative humidities of up to 85–90 percent, the moisture content of the germ or embryo is lower than that of the endosperm: most of the oil is in the germ, and oil does not absorb much water. Each of the common storage fungi has a lower limit of moisture content below which it cannot grow. Near this lower limit, each of these fungi invades the germ of the seed preferentially, and sometimes exclusively. "Sick" or germ-damaged wheat, a common result of invasion of the germs by *A. restrictus*, *A. glaucus*, and *A. candidus*, often develops without much or any outward sign of moldiness because the fungi are growing only in the germ. More about this sort of damage in chapter 3.

So when we say that *A. restrictus* can invade wheat with a moisture content of 14 percent, we mean only that an entire sample of several hundred kernels tested – if we are determining the moisture content by oven-drying a sample of several grams – has a moisture content of 14 percent. We do not know what the moisture content of the germ is where the fungus is growing, but it is probably lower than that of the whole kernel (see Shelef and Mohsenin 1966).

There are other complications in this scenario of equilibrium moisture content and storage fungus invasion. Once seeds have been invaded to some extent by storage fungi, they absorb more water at a given relative humidity than seeds not so invaded. And seeds that are losing moisture usually come to a higher equilibrium moisture content than those gaining moisture. Time also enters into the picture, because a combination of moisture content and temperature that protects seeds from molding for 6 weeks will not protect them for 6 months. Damage by *A. restrictus*, in fact, is never encountered in a storage period of less than 6 months, and sometimes it does not appear until the grain has been in storage for a year or more: at the lower moisture content that permits its growth, the fungus grows so slowly that it takes that long to cause any detectable damage.

Accurate measurement of moisture in seeds is also difficult. Many different methods are in use, and work continues on new ones because none of those now available is completely satisfactory.

These remarks should be enough to indicate why the figures in table 1 are given in ranges, with some leeway. They are approximations – fairly close, but approximations still. The figure on moisture content of a given lot of grain that is obtained by measuring that of a single half-pint sample by a moisture meter is also an approximation. It may be satisfactory for buying and selling (although serious questions have arisen about that in recent years); sometimes, however, it is not satisfactory for storage, especially long-time storage at moisture contents near those where damage from storage fungi might occur in a given time at a given temperature. Moisture content of grains is one of the important controllable factors in determining storability, which is reason enough for emphasizing it in a book devoted chiefly to maintenance of quality of grains and seeds in storage.

2 ◇

Grain Grades and Grain Quality

For many of the uses to which grains and seeds are put, especially for planting, processing into food, and malting or sprout production, high quality is essential; the seeds must be sound, clean, free of mechanical injuries, and of high and even germinability. For industrial processing to obtain starch, oil, syrup, or gluten, high quality is also essential or desired, as it is for fermentation to produce potable alcohol, but not for the production of alcohol for fuel or other industrial purposes. Some farmers who raise feed for their own flocks and herds are not too fussy about the quality of grain fed to the animals, and if the animals go off feed or become ill it may be blamed on feed or feed supplements from sources other than their own grains. Seeds and grains in interstate commerce in the United States and those grown in the United States and shipped abroad are sampled, inspected, and rated according to established procedures and specifications. Lots of lower grade receive lower prices; so if a farmer is growing grain for the market, it is reasonable to say that it pays to market high-quality grain.

This statement, however, requires some qualification. In general, it is true that corn of grade No. 2 commands a higher price than corn of grade No. 3 or that of grade No. 4 or 5. But it is not quite that simple: sometimes farmers who bring higher quality grain to the elevator find that they are not getting their due reward for it. The fault lies partly in the system of grades that prevails in the United States.

Corn is graded according to four criteria: bushel weight; moisture content; broken corn and foreign material (BCFM), or the percentage of corn fragments that pass through a 12/64-inch round-hole sieve, and any material other than corn that remains on the sieve; and damaged kernels, which are divided into "total damaged" and "heat damaged." Similar specifications for other grains are given in the Official United States Standards for Grain (tables 3-5).

It looks straightforward, but it isn't. For example, corn with 14.1 percent moisture, zero percent BCFM, and zero percent damage is grade No. 2 (on the basis of moisture content, a maximum of 14 percent being allowed in grade No. 1). On the basis of the other characteristics, this lot of corn is grade No. 1. The producer who brings in this excellent corn is given the same price for it as the neighbor who brings in a load with 15.5 percent moisture, 3 percent BCFM, and 5 percent damaged kernels, the maximum permitted in corn of grade No. 2.