PRINCIPLES OF GRAIN STORAGE

by

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Grains can be stored over periods of several years with little or no detectable loss of quality if they are stored under the proper conditions. However, if stored or held under improper conditions, grains can begin to spoil in a matter of a few hours. Extensive research has been and is still being conducted to learn more about what causes grain spoilage.

What constitutes spoilage or loss of quality in stored grain is relative. Drying seed grain with heated air at temperatures above 110°F may significantly reduce germination and thereby damage it for its intended use. If the grain is to be used by the milling industries for the production of grits or by the distilling industry for the production of alcohol, drying with air temperatures which would raise the grain temperature above 140°F would adversely affect it for use by these industries. On the other hand, if the grain is to be fed to animals, there is little evidence to indicate that the drying temperature significantly affects its quality as a feed.

Spoilage of grains is the result of the action of microorganisms (bacteria, yeast, fungi, and molds) which utilize the nutrients present in grain for growth and reproductive processes. Spoilage may result in a loss of nutrients from the grain since microorganisms use these nutrients in much the same way as livestock. Also, microorganisms produce heat during growth which can cause the temperature to rise in stored grains. Heating initiated by microbial growth can cause “heat damage” and can sometimes render grains unfit for feed. Such conditions have also been known to cause fires and dust explosions in storage structures.

Certain microorganisms, when allowed to grow under the proper environmental conditions, can produce toxins or other products which, when consumed by either livestock or humans, can cause serious illness and even death. A number of these toxins and the microorganisms which produce them have been identified. Some of the conditions necessary for growth and the production of toxins are known, but much work remains to be done in this important area of research. With the present public interest in problems associated with pure foods, it is more important than ever that storage problems be avoided.

It must be mentioned at this time that not all microbial action in grains and feed materials is detrimental. Microorganisms are used in the manufacture of such foods as cheese, buttermilk, pickles and alcohol. Note here that the action is called fermentation, rather than spoilage, but the process is the same—the difference being that the action is considered beneficial. The storage of high moisture grains and the ensiling of corn and grasses requires a successful fermentation of these materials. Products produced by the microorganisms in these fermentations serve to limit the growth of other microorganisms, thereby preserving the material being stored.

GRAIN STORAGE

To store grain successfully, grain and the atmosphere in which it is stored must be maintained under conditions which discourage or prevent the growth of microorganisms which cause spoilage. The major influences on the growth and reproduction of microorganisms in grains are:

1. The moisture content of the grain.
2. The temperature.
3. The oxygen supply.
4. The pH.
5. The condition or soundness of the grain.

The degree and rate of deterioration in stored grains, in addition to the above factors, are influenced by the length of time the grain is stored, the degree to which it has been contaminated by microorganisms before it reaches storage, and the amount of foreign material which is present. The activities of insects and mites both directly and indirectly influence grain quality. Insects and mites have a direct influence when they consume nutrients, and their bodies and excreta provide a foreign matter in the grain which is not aesthetically desirable and which can be unhealthy. Also, they produce water as a by-product of their growth and break the fruit coat of the grain (the natural protective layer). By doing this, they indirectly provide moisture which is required for microbial growth and provide easy access for microbes to the nutrients contained inside the fruit coat.

Foreign material, pieces of cracked grain, and trash tend to collect under discharge spouts in bins. These materials provide an excellent breeding ground for microorganisms and some kinds of insects and mites. For long term storage, the less foreign material in the grain, the safer the storage conditions.
MOISTURE

Moisture content is by far the most important factor affecting the growth of microorganisms in stored grains. If moisture can be maintained at a low enough level, the other factors which influence storage will not greatly affect spoilage of the grain.

Moisture content can be expressed in several ways. Most often, and the way it will be used here, it is expressed in what is called moisture content, wet basis. Mathematically it is expressed as:

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\text{Moisture Content} = \frac{\text{Weight of water in sample}}{\text{Total weight of sample}} \times 100
\]

Total weight of sample includes both the weight of the dry matter and the weight of the water.

The relationship between the moisture content of a grain sample and the relative humidity of the air in which the grain is stored must be understood before a logical explanation can be made as to how these factors affect microbial growth and grain spoilage. Relative humidity is a term for the amount of water contained in the air. A relative humidity of 100% indicates a condition at which the air contains all the water it can normally hold at that temperature, whereas a relative humidity of 0% indicates a condition in which there is no water in the air—the air is dry.

If a sample of grain is placed in a closed jar, water will move both from the grain into the air in the jar and from the air into the grain. If the grain and air are maintained at a constant temperature, a condition will be established at which the rate of water movement from the grain will exactly equal the rate of movement into the grain. The net amount of moisture in the grain and in the air will be constant. Thus, an equilibrium condition will be established between the water in the grain and that in the air. The moisture content of the grain in this condition is known as the equilibrium moisture content, and the relative humidity at this condition is known as the equilibrium relative humidity. The equilibrium moisture content increases with an increase in equilibrium relative humidity. The relationship between these is shown for shelled corn in Figure 1. As indicated in Figure 1, at a given moisture content a higher temperature will result in a higher equilibrium relative humidity while a lower temperature will result in a lower equilibrium relative humidity.

If a relatively wet sample of shelled corn, for example a sample of 25% moisture content, is placed in an environment being maintained at 65% relative humidity it will dry to the moisture equilibrium corresponding to this relative humidity, about 13% moisture content. Likewise, if a dry sample is placed in this environment, it will absorb moisture until it reaches the equilibrium moisture content. The drying of grains is accomplished by forcing air with low relative humidities through grain. The grain dries as it attempts to come into equilibrium with the low relative humidity air.

Conversely, if a large quantity of grain is placed in a tight storage structure, the air between the particles in the grain mass will come into moisture equilibrium with the grain. For example, if shelled corn at a moisture content of 13% is placed in a bin where the air has a relative humidity of 40%, the grain will lose moisture and the relative humidity of the air will increase to approximately 65% as indicated in Figure 1. It should be mentioned that the moisture content of the grain would decrease slightly during this equilization period but that, in view of the normally large amount of grain and small amount of enclosed air, this loss of moisture would be insignificant and change the moisture content of the grain only slightly.

Microorganisms respond to their environment in somewhat the same way as grains. They absorb water in which the nutrients required for their growth and reproduction are dissolved. Nutrients can enter the microorganism cell only if they are dissolved. When the relative humidity is high enough, microorganisms can absorb moisture; but, if the relative humidity drops below a critical level, they cannot absorb water and their growth and reproduction is stopped. Figure 2 indicates the relationships between growth and relative humidity for fungi and bacteria. Note
that at 62% relative humidity growth is minimal for fungi. Bacteria generally require relative humidities of 90% or more for growth. Fungi have been recognized as a major cause of spoilage in grains. For these reasons, if the moisture content of a grain is maintained at a level such that the equilibrium relative humidity of the air surrounding it remains at or below 62%, microbial growth will be minimal (or arrested) and spoilage will not occur. For shelled corn this moisture content is approximately 13% at normal summer temperatures as indicated in Figure 1. This is why it is generally recommended that shelled corn be dried to 13% moisture content for storage if the corn is to be stored into or through the summer months.

Temperature affects the equilibrium relative humidity of grains as indicated in Figure 1. At higher temperatures the equilibrium relative humidity increases for a given grain moisture content. Grain that has a moisture content safe for storage at 75°F (for shelled corn a moisture content of 13% and equilibrium relative humidity of approximately 65%) may not be safe for storage at 95°F since the equilibrium relative humidity would increase. This is the reason (along with some other factors to be discussed in the effects of temperature on storage) that in the warmer climates of the South the recommended safe storage moisture content for shelled corn is lower than 13% and in colder climates it is higher.

**TEMPERATURE**

Temperature is an important factor affecting the storage of grains. The effect of temperature on growth is illustrated in Figure 3 for two general groups of microorganisms—the thermophiles, whose growth is optimum at higher temperatures; and the mesophiles, whose growth is optimum at normal atmospheric temperatures. The growth curve for a third group, the psychrophiles, whose growth is optimum at low temperatures, is not shown. Most indications are that the psychrophiles are not a major factor in grain spoilage although they are known to grow at temperatures below freezing.

Common storage fungi grow most rapidly at temperatures of 85° and 90°F. Below these temperatures, growth rates decrease and growth is very slow at 35° and 40°F. This is one of the reasons it is recommended that stored grains be cooled to about 40°F by aeration when possible. The highest known temperature at which microorganisms can grow is around 176°F.

**OXYGEN SUPPLY**

One or more groups of microorganisms will grow and reproduce at any oxygen concentration. The growth characteristics are illustrated in the graph in Figure 4 for bacteria, molds, and yeast. Microorganisms are classified as anaerobic, aerobic, facultatively anaerobic, or microaerophilic, according to their oxygen requirement. Anaerobes grow in the absence of free oxygen while aerobes require free oxygen for their growth. Facultatively anaerobic microorganisms grow either in the presence or absence of free oxygen, and microaerophilic microorganisms grow in the presence of minute quantities of free oxygen. Bacteria are represented in all of these categories. Yeasts are moderate aerobes and molds are strong aerobes.
It would seem that it might be advantageous to control at least some bacteria and most yeast and molds by controlling oxygen concentration in storage. Attempts to do this in large grain storage where grain has been dried to near safe storage moisture contents have been made, but this practice is not in widespread use. Apparently, it is difficult to maintain the concentration of oxygen at a low enough level to be effective in unsealed storage structures designed for dry grain storage.

**ACIDITY**

The acidity of a solution is measured by a term called pH. It is a measure of the hydrogen ion concentration in a solution and normally ranges in value from 1 to 14. Pure water, which is considered neutral, has a pH near 7.0. When acids are placed in solutions they will lower the pH value and increase the acidity of the solution.

The effect pH has on microbial growth is illustrated in Figure 5 for fungi and bacteria. This effect, along with the control of oxygen, is utilized in sealed storage for ensiling grains. Sealed storage will be discussed later.

**CONDITION**

An increase in the amount of cracked or damaged kernels in stored grains can increase spoilage. This is one of the reasons it is impossible to establish an absolute maximum safe storage moisture for grains. Exactly why condition affects spoilage is still a matter of speculation, but it certainly involves in some way the ability of microorganisms to attack the grain kernel. Grain which is in poor condition must be dried to a lower moisture content than grain in good condition if it is to be stored over long periods. The relationship between condition and safe-storage moisture content has not yet been quantified.

**OTHER FACTORS INFLUENCING SPOILAGE**

The length of the storage period influences the amount of spoilage in grain. Microbial growth and reproduction will probably occur even under conditions normally considered safe for storage, though the growth would be difficult to detect. Over long periods of time this effect would accumulate and eventually could be detected. In general, the longer the storage period, the lower the moisture content should be for safe storage.

The degree of infestation of the grain by microorganisms is also important. If grain which is in poor condition and at a high moisture content, and which has undergone some spoilage, is mixed with sound grain at a low moisture content to bring the mixed lot to an average safe-storage moisture content, the chance for spoilage in the mixed lot is greatly enhanced. The mixed lot would have a heavy infestation of microorganisms provided by the partially spoiled grain. If for any reason the moisture content of the mixed lot should increase slightly, the potential would be present for rapid development of microbial growth. A change of as little as 0.2% moisture content could be critical under such conditions.
The foregoing discussion hopefully gives an understanding of the basis for the general recommendations that are often made relative to moisture content and other conditions necessary for safe grain storage. The recommendations made by knowledgeable Extension and research personnel generally will be what is considered absolutely safe, although under certain conditions (as has been pointed out), problems may develop even under these presumably absolutely safe storage conditions. To make recommendations that grains be stored at higher than safe storage moisture contents without the user of these recommendations being fully aware of the serious problems that might develop would be irresponsible. Often, however, the user of recommendations is not aware of potential problems. Indeed, conditions might be such that a problem does not develop until after many years of use of a recommendation which is not considered absolutely safe, and, in many cases, the advantages gained may be worth much more than the risk taken. In other cases, perhaps not.

Recommendations for safe storage moisture contents are still quite variable at different locations in the United States, and justifiably so. Grain producers in Alabama might ask why their counterparts in Kentucky may store corn safely at higher moisture contents than they can in Alabama. Kentucky farmers might ask the same question relative to northern Indiana farmers. The answer to this question was given earlier, but further elaboration may provide a clearer understanding of grain storage problems.

Figure 6 shows a graph of an expanded portion of Figure 1 - the relationship between equilibrium moisture content and equilibrium relative humidity. Plotted on the graph are the curves for air and grain temperatures of 40, 60, 80 and 100°F. It can be noted that the equilibrium moisture content varies with temperature. At a constant equilibrium relative humidity of 65% we find that:

- at 40°F the equilibrium moisture content is 14.8%
- at 60°F the equilibrium moisture content is 13.8%
- at 80°F the equilibrium moisture content is 12.8%
- at 100°F the equilibrium moisture content is 11.8%.

The relative humidity of 65% was chosen because it is near the moisture level that microbial growth is minimal and spoilage is essentially stopped. (Note: The graph in Figure 3 indicates microbial growth would be minimum at 40°F. This is a temperature limitation of microbial growth which certainly exists but is not being considered for the purpose of this part of the discussion.) The same type of data can be taken from the graph in Figure 6 for any of the equilibrium relative humidities shown.

To regress for a moment, consider the mean temperatures during the Fall, Winter and early Spring for three locations roughly displaced by approximately 250 miles of latitude as shown in the graph of Figure 7. The locations are Birmingham, Alabama, Owensboro, Kentucky and Chicago, Illinois. The approximate harvest periods for corn at these three locations are indicated on the graph.
Figure 8 shows a graph which is actually a rearrangement of the data presented in Figure 6. It shows how the equilibrium moisture content varies with air and grain temperature for four different levels of equilibrium relative humidity. Also, shown on the graph are lines indicating the mean temperature during the harvest period for the three locations described in the preceding paragraph. Two lines are shown for Chicago, one for the mid-harvest period average and the other for late-harvest period average. Descriptive adjectives have been used to indicate the degree of safety associated with storing shelled corn at various equilibrium relative humidities. The term “safe” is used for the 65% equilibrium relative humidity line since microorganisms have minimal growth at this relative humidity. The term “safer” is used for the 60% relative humidity line since a greater degree of safety would be expected for grains stored at this relative humidity. The terms “some risk” and “more risk” are used for the 70% and 75% relative humidity lines, respectively, to indicate that as the equilibrium relative humidity increases, there may be some additional risk involved in storage at these conditions. No statistical or quantitative significance can really be attached to these terms—they are intended only to describe trends. It is entirely conceivable that grain stored in an environment maintained at either 70 or 75% relative humidity could develop microorganisms which could produce toxins. The chances of this happening increase as the relative humidity of the storage environment increases. Circumstances would dictate that any storage condition in which toxins are produced is dangerous and involves something more than some risk. Nothing is intended by the descriptive words other than to indicate increased risk of storage spoilage as relative humidity increases.

![Graph of air and grain temperature vs. equilibrium moisture content]

Figure 8. Effect of air and grain temperature and equilibrium relative humidity on the safe storage moisture content of shelled corn.

The question of why grain producers in Kentucky might store corn safely at higher moisture contents than producers in Alabama can now be answered. In Birmingham, the average temperature at the mid-harvest period is indicated in Figure 7 to be 75°F. For this temperature, the safe storage moisture content corresponding to an equilibrium relative humidity of 65% is approximately 13% as indicated in Figure 8. In Owensboro during the mid-harvest period a month later, the temperature averages 60°F and the safe storage moisture content of 65% relative humidity...
is approximately 13.8%. Still further north at Chicago and a half-month later, average temperature at the mid-harvest period is approximately 48°F and the safe storage moisture content at 65% equilibrium relative humidity is increased to 14.4%. At the more northern latitudes, the harvest dates are later in the fall. The decrease in temperature with later harvest dates plus the average decline in temperature with the more northern latitudes combine to give lower temperatures at harvest time. As indicated in Figure 8, this decrease in temperature allows grains to be safely stored at higher moisture contents.

As a final example, the range in moisture contents between a grain producer in Birmingham wishing to dry corn to a "safer" storage moisture content and one in Chicago harvesting in November and willing to assume "more risk" than normal might be determined from Figure 8. The Alabama producer would dry his grain to near 12% moisture content whereas the Northern Indiana farmer might store his shelled corn at 16.6% -- a difference of 4.6%. This is a considerable difference when a change of 0.2% can be critical to safely storing grains. Consider the potential storage problems of the Alabama farmer who might dry his grain to a moisture content based on a recommendation given to him by his brother producing grain in northern Indiana with no knowledge of the potential risk involved in storing grain at high equilibrium relative humidities. If the northern Indiana brother were willing to take some risk and store his grain at a moisture content of 16.6% and the Alabama brother used the same recommended moisture content, the grain stored in Alabama would be in an environment of perhaps 75°F and 85% relative humidity. Referring to Figures 2 and 3 both of these conditions are well within the range where microbial growth and spoilage will occur.

The foregoing examples were based on monthly temperatures estimated from long-term averages. In practice the actual seasonal temperatures during the harvest and storage period are the ones of real importance and the ones on which each producer bases a judgement. If the season is cold it may not be necessary to dry to as low a moisture as if the season is warm. However, it is impossible to predict exactly how the weather will behave. Also, the examples given were based on the temperature at the time of harvest. Temperatures will generally decrease after harvest so that storage conditions would be safer for higher moisture grains from this standpoint. However, temperatures will increase in the spring, and if the grain is not used by the time the temperature begins to increase, it will need to be dried for safe storage during the warmer months.

AVERAGE MOISTURE CONTENTS OF GRAINS IN BINS

The foregoing discussion has indicated why the level of moisture content in grain is important to its safe storage. However, it must be pointed out that it is not sufficient to have the average moisture content of a large bin of stored grain at a safe level if this average is determined by averaging a very wet lot of grain and a very dry lot. If the wet lot is placed in the bin in one location (not mixed with the dry grain) microbial growth can take place in the wet lot and cause problems in the entire bin. Also, if moisture migrates within the storage bin, the part to which the moisture is migrating may become wet enough to support microbial growth which would result in spoilage. Some reasons why moisture migrates in stored grain will be discussed in the next section. When thoroughly mixed, wet and dry grain will equilibrate to a moisture content at some point between the original moisture contents of the two lots.

Research tests have shown that well mixed lots of 8, 20, and 25 percent moisture content white corn will equilibrate to a point where the final moisture content of the high moisture portion is 1.4 to 2.6 percent above that of the low-moisture fraction. The higher the temperature, the smaller the difference. Also, the lower the temperature, the slower the rate of equilization. Again, if the wettest kernels of the mixed lots are not below a safe storage moisture content, microbial growth can occur on the wetter kernels.

MOISTURE MIGRATION IN STORAGE

Moisture often accumulates in the top layers of stored grain even though the grain is stored at a safe moisture content in weathertight bins. The accumulation is a result of moisture migration which is caused by temperature differences in the grain mass. Grain harvested and placed in storage during the warm months of late summer or early fall loses its heat slowly as the weather gets colder. Grain near the surface and next to the walls cools first, while that in the center of the bin remains warm. This temperature difference creates slowly moving air currents as illustrated in Figure 9. Cool air near the walls moves downward, forcing warm air upward. When the warm air reaches the cold grain near the top surface, condensation may occur in the same way moisture condenses on the exterior of a
HIGH MOISTURE STORAGE OF GRAINS

High moisture grain (above 23%) can be stored under conditions where oxygen is excluded from the stored mass. If high moisture grain is placed in a hermetically sealed space, the aerobic microorganisms present in the gain will use the oxygen present in the space. However, as indicated in Figure 4, anaerobic (or facultatively anaerobic) bacteria can and will grow under oxygen free conditions. However, these microorganisms produce chemical compounds as a byproduct of their growth which lower the pH of the grain. When the pH is lowered to around 4 to 4.5, bacterial growth will be minimal—the bacteria are essentially stopped by their own wastes. Since fungi do not grow under oxygen free (anaerobic) conditions, as indicated in Figure 4, all microbial growth will be minimal and the grain will not heat and can be stored. Management of these types of systems can be very critical, and careful consideration should be given to their use.

Organic acids (propionic, acetic, and formic) are currently being used to treat high moisture grains to prevent microbial growth so that the grain can be stored under normal atmospheric conditions (the storage is not hermetically sealed). When sprayed on the grain, these acids lower the pH to approximately 4, thus reducing microbial growth as indicated by the graph in Figure 4. In addition, propionic acid appears to have fungicidal properties. Although the concept of using this preservation method dates back to 1918, it has only been in the last few years that it has found commercial use. A number of questions such as the economics of its use and its effect on storage structures remain to be answered.

INSECTS & RODENTS

Insects which infest grains in storage, like microorganisms, are sensitive to temperature. Their growth and reproduction are greatly reduced at temperatures below 70°F and cease to develop below 50°F. If grain is maintained at temperatures below this they will die. Good housekeeping and spraying operations are generally sufficient for control. Rodents can be controlled by storage in rodent-proof bins.