U.S. Grain Sorghum

Storage in Tropical Climates


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Preface

U. S. Grain Sorghum is considered a high-value ingredient for least-cost feed formulations around the world.

Its moisture content is lower than many comparable ingredients.

Its palatability is equivalent to corn in grain/soybean-based formulations, when limit-fed.

Its utilization by the animal (nutrient availability) is equivalent to corn when processed appropriately.

It stores easily in warm climates because of its low moisture content.

It breaks little in handling.

It costs less to grind because of its soft kernels.

Its unit cost is lower than many competing ingredients.

It is available year-round at competitive prices.

Misconceptions of U. S. Grain Sorghum

Issue: Palatability

Rumor . . . . . . Palatability of grain sorghum-based rations is lower than corn-based rations.

Fact . . . . When fed without choice, consumption of sorghum-based rations is equivalent to corn-based rations.

Issue: Nutrient Uptake

Rumor . . . . . . Utilization by the animal is lower for sorghum-based rations because sorghum nutrients are not as readily available in the gut.

Fact . . . . When properly processed, uptake in the gut is not significantly different in sorghum and corn-based rations.

Issue: Tannin Content

Rumor . . . . . . Grain sorghum is high in tannins.

Fact . . . . Officially graded U. S. grain sorghum must contain less than 3% of high-tannin varieties. Most shipments contain insignificant levels of high-tannin kernels.

Production and Export of U.S. Grain Sorghum

Grain sorghum was domesticated 3,000 to 5,000 years ago, probably in northern or eastern Africa. Throughout the dry areas of the world, this hardy grass is grown for its seeds, which are used for human and animal food. In the United States, sorghum production is concentrated in the dry states of Nebraska, Kansas, Oklahoma, and Texas (Figure 1). Grain sorghum often is used as a rotation crop with wheat or corn. The ground is prepared and the hybrid seed is planted in the North American spring season (April–June). Sorghum harvest begins in south Texas in July and moves north, finishing in October or November in Kansas and Nebraska. In most of the major production areas, grain sorghum is harvested as the cool season begins. Because of the dry climate, much of the grain is harvested with a moisture content low enough to store without high-temperature drying.

Figure 1. Eighty-five percent of all U. S. Grain Sorghum is grown in these dry states.

Physical and Nutritional Characteristics of Grain Sorghum

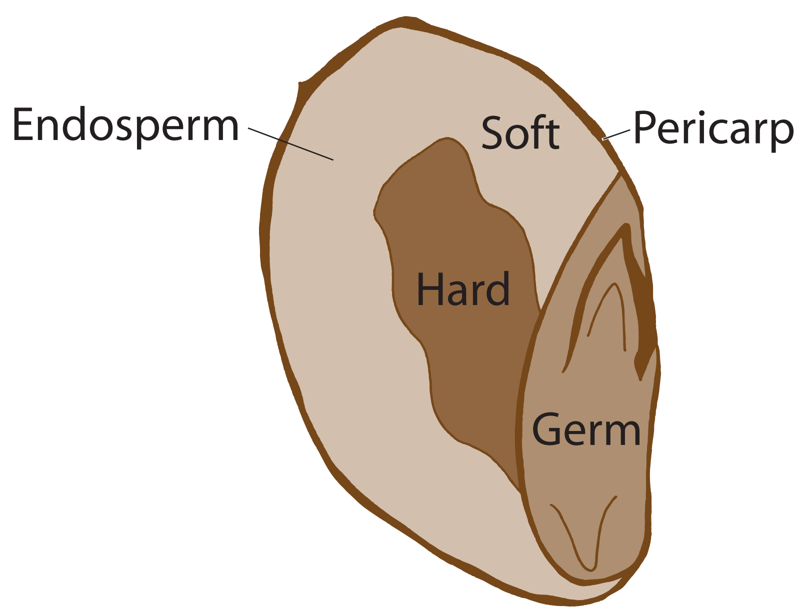
Almost all grain sorghum exported from the U. S. is purchased as U. S. #2. Its average bulk density between 1997 and 1999 was 75.6 kg/hl and its average moisture content was 13.7% (Table 1). Its broken kernel and foreign material content was 4.1% with a dockage content of 0.2%.

Table 1. Average grade factors of U. S. #2 grain sorghum exported from the U. S. 1997–1999.

Year	Bulk Density (kg/hl)	Moisture Content (%)	Damaged Kernels, Total (%)	Broken Kernels (%)	Foreign Material (%)	Dockage (%)
1997	75.7	13.8	0.9	3.0	1.2	0.2
1998	75.7	13.8	1.0	3.0	1.2	0.2
1999	75.4	13.6	1.0	2.9	1.0	0.2
Average	75.6	13.7	1.0	3.0	1.1	0.2

Like other cereal grains, sorghum kernels consist of a germ and an endosperm covered by a pericarp (Figure 2). The pericarp contain the fibrous outer layers of the kernel. The germ contains the embryo of the new plant and associated structures. The endosperm is the nutrient storage area for the new plant and contains mostly protein and carbohydrates. U. S. grain sorghum typically contains more protein than corn, but slightly less protein than feed wheats (Table 2). Its carbohydrate content is about the same as wheat or corn, but its energy value is about 4% lower. It is best utilized in the digestive tract of meat animals and poultry when ground to a particle size of 600 microns or smaller.

Figure 2. Internal structure of a grain sorghum kernel.



U. S. grain sorghum has a large portion of soft endosperm and, therefore, can be processed easily. When ground to 900 microns, U. S. sorghum requires about 34% of the energy required by U. S. corn. For a 500 micron or smaller particle size, U. S. grain sorghum requires about one-fourth the energy needed for corn. Grinding rates are often much higher for U. S. sorghums than for corn. Pelleting energy, percentage of fines, and pellet durability of U. S. sorghum are equivalent to those of corn.

Table 2. Nutritional qualities of grains.

Grain	Protein (g/kg)	Fat (g/kg)	Carbohydrate (g/kg)	Crude Fiber (g/kg)	Energy (Mcal/kg)
Sorghum	108	31	720	21	2.0
Wheat	125	17	720	18	2.1
Corn	92	45	716	27	2.1

Advantages of U. S. Grain Sorghum

SEED. U. S. grain sorghums are hybrid varieties developed through multi-million-dollar breeding research programs funded by private seed companies, producer groups, and government entities. A network of seed companies and university evaluators provide grain producers with the latest information on variety trials. The resulting seed is adapted to the dry plains on which U. S. grain sorghum is produced.

SOIL AND CLIMATE. The deep, rich soils of North America provide an excellent terrain for grain sorghum. Because of the dry climate in most of the production areas, U. S. grain sorghum rarely experiences the mold and mycotoxin problems that plague sorghums grown and harvested in wet climates.

INFORMATION. A network of private suppliers, government and academic scientists provide growers with the latest research and technology information on agronomic practices, including tillage, crop protection, fertilization, and mechanization. This information helps the grain sorghum producer make the best use of the fertile soil and dry climates to which U. S. grain sorghums are adapted and assures the efficient production of high-quality grain.

MACHINERY. U. S. grain sorghum is planted, tilled, and harvested mechanically. During exceptionally wet years, some of the crop is dried in high-temperature grain dryers before storage. Grain sorghum is not as susceptible to breakage after drying as is corn, and even when the grain is high-temperature dried, grain quality is maintained easily. Some sorghum grain is stored on farms, usually in metal bins, and the remainder is stored in commercial grain elevators, which may have either metal or upright concrete bins. Most grain sorghum is cooled quickly after storage and is stored cold, until it is used domestically or moved to export. The cool temperature and low moisture content of most grain sorghum helps managers maintain quality in storage at minimal cost.

MARKETING. A massive and sophisticated system of marketing information, official grain inspection, and grain storage and transportation equipment allows sorghum to be moved to the export elevator efficiently. Most sorghum is transported from inland elevators on dedicated grain trains directly to the export elevators or to border transfer points in Texas. Large quantities also are transported by river barge to Louisiana Gulf export elevators.

QUALITY. Throughout the system, grain is sampled to determine quality characteristics. At inland locations, grain in trains and barges bound for export facilities is sampled by trained inspectors who are supervised by federal government inspectors. At export, all grain is inspected by the Federal Grain Inspection Service (FGIS) unless the contract mandates otherwise. Most contracts reference a U. S. grain grade as the basis of quality inspection. The U. S. grain grading system provides a well-known standard that does not vary from year to year with the quality of the crop (Appendix 1).

SUMMARY. The U. S. grain sorghum crop begins with quality-assured seed of varieties developed to provide maximum yield and excellent feeding value. The seed is one component of an agricultural system operated by experienced producers aided by a vast network of private and public sources of information and agricultural inputs. Tillage, fertilization, harvesting, and marketing take place in a mechanized system that provides maximum grain value at minimum cost. The highly capitalized merchandizing and transportation system assures that this value is transferred to the point of export in the most efficient way possible. Thus, importers of U. S. grain sorghum are assured of a product that has high intrinsic value and is delivered to them at minimum cost.

Storage of U. S. Grain Sorghum in Tropical Climates

When U. S. grain sorghum arrives at tropical destinations, it often must be stored before processing. Some grain is stored for short periods without the benefit of a protective structure. In dry climates, grain sorghum stores better in unprotected piles than do most grains because of its low initial moisture and ability to withstand light rains with little or no damage. However, outdoor piles provide no protection against rain or wind, and the grain is subject to contamination by insects, birds, and rodents. Therefore, all grain should be stored inside protective structures such as warehouses, metal bins, or concrete silos, especially in tropical climates. Each storage structure has associated advantages and disadvantages for tropical storage.

Storage Structures

Warehouse (flat stores)

Advantages . . . . . . Initial cost is low
Use of space is flexible

Disadvantages . . . . Grain loading and discharge are costly
Protection against rodents and birds is poor
Temperature monitoring and fumigation are difficult

Metal Bins

Advantages . . . . . . Protection against rodents and birds is good
Grain loading and discharge can be automated
Fumigation can be effective
Temperature monitoring is simple

Disadvantages . . . . Initial cost is high
Metal roof and walls provide little insulation against tropical sun

Concrete Silos

Advantages . . . . . . Grain loading and discharge are fully automated
Concrete roof and wall insulate grain against tropical sun
Fumigation is simple and effective
Temperature monitoring is simple

Disadvantages . . . . Initial cost is high

Causes of Grain Deterioration

During grain handling and storage, many factors may contribute to grain quality deterioration.

Mechanical breakage. When mechanical forces encountered in harvesting and transport cause breaks in the pericarp, the nutritious endosperm and germ tissue is exposed to attack by insects and molds. Small pieces of broken kernels and other small particles fill the open spaces between kernels, compacting the area and slowing the dissipation of metabolic heat and moisture out of the grain mass. Although the broken kernels of grain sorghum contain the same nutrients and energy value as the sound kernels, large numbers of cracked or broken kernels facilitate deterioration and should be avoided, if possible.

Leaks. In transport or storage, leaks may allow rain or seawater to contaminate the grain. Areas of moldy grain may result.

Molds. Some of the same molds that thrive in the wet grain caused by leaks are able to grow slowly in warm, dry grain. At the low moisture contents typical of exported U. S. grain sorghum, molds develop so slowly that, for practical purposes, they can be considered dormant as long as the grain is cool. However, when the grain is exposed to the warm, humid air of tropical climates, molds at the grain surface may begin to develop colonies that could affect grain quality if storage is extended.

Grain deterioration often occurs even though the mold that caused the deterioration never is visible. This invisible threat is controlled better if the storage manager understands certain parameters of mold-induced deterioration.

Not all the molds present in the grain are active during storage. Molds of the genera *Fusarium* and *Alternaria*, among others, infect the seed before it is harvested. These “field” molds become dormant when the seed dries to below 20% moisture and remain dormant unless the available moisture becomes very high. This may occur if water leaks on the grain or if excessive water is added during processing. In contrast, “storage” molds, mostly members of the genera *Aspergillus* and *Penicillium*, are able to develop using the water available in grain containing as little as 13% moisture, depending on temperature. Various species of these molds are able to exploit slightly different moisture and temperature conditions within the grain mass.

The molds commonly found in U. S. grain sorghum occur in all types of grains, regardless of country of origin, in all climatic zones. Mold spores and other reproductive structures are microscopic. They germinate under favorable temperature and moisture conditions to produce a tubular body called a hypha. As hyphae continue to grow, they form a tangled, branched mass called a mycelium. Mycelia are nearly transparent and difficult to observe; though experimental procedures using a microscope allow stained mycelia to be seen on the surface and under the outer layers of stored grain. Under optimum conditions, mature masses of mycelia produce spores. The spores and other reproductive structures have color, and masses sometimes can be seen with the naked eye, if the deterioration is severe.

The first four toxins (DON, T2, zearalenone, and fumonisins) are produced by field fungi before the grain is harvested. Thus, even severe deterioration by storage molds cannot result in the production of these substances. In contrast, aflatoxin is produced by certain *Aspergillus* molds that can infect seeds either before harvest or during storage. In those rare instances when aflatoxin is observed in U. S. grain, it usually is produced before harvest. This is typically observed in grains other than sorghum. It is much more likely to be found in grain harvested wet in tropical climates than in grain imported from temperate climates such as the U. S. However, under rare and unusual circumstances, rapid growth of certain strains of certain *Aspergillus* species in moist grain under high temperatures can cause aflatoxin contamination of the stored grain. Aflatoxicosis can produce liver cancers, reduced feed consumption, poor feed conversion, and many other symptoms depending on the species and age of the animal. To control the risks associated with mycotoxins, many feed millers routinely screen feed ingredients. Quick-test kits are available from several vendors to test for the most common toxins.

Insects. A variety of small insects can infest dry grain sorghum. The genera and species of grain-infesting insects are similar throughout most of the world. Cosmopolitan beetles likely to be found in stored grain sorghum include the weevils (*Sitophilus* spp.), the lesser grain borer (*Rhyzopertha dominica*), the sawtooth grain beetle (*Oryzaephilus* spp.), flour beetles (*Tribolium* spp.), and flat or rusty grain beetles (*Cryptolestes* spp.). A few species of moths, psocids, and mites also inhabit stored grain sorghum. Grain held long-term in the dry tropics also is attacked by indigenous insects such as *Trogoderma granarium* or *Prostephanus truncatus*. Because nearly all importers of U. S. grain sorghum store the grain for less than two months, insect problems seldom are reported.

Insects can contribute to heating problems in grain sorghum stored under tropical conditions. *Sitophilus* and *Rhyzopertha dominica* can cause major damage because immature forms develop within kernels. The other cosmopolitan pests do not damage the grain, but can cause contamination. The insects require nearly a month to develop from the egg, through the larval and pupal stages, to emerge as adults under tropical conditions. Because only the adults reproduce, several months are required to develop a damaging infestation. Additional information about insects and molds is found in Appendix II.

Monitoring Grain Quality

Sampling. Grain exported by ship from the U. S. is sampled and inspected by agents of the FGIS/GIPSA. Destination ports also may require sampling and grain testing. Nevertheless, sampling and testing grain as it is received at the storage site is important to detect problems that might arise during port handling and transport to the plant. Parameters to be inspected include:

Grain Temperature: grain temperature warmer than ambient indicates heating
Grain Moisture: moisture greater than that indicated on the grade certificate may indicate that the grain was wetted by rain or seawater
Odors: odors may indicate contamination

Periodic sampling while the grain is in storage also is recommended if the grain is held longer than two months. Because sampling large masses of grain in a representative manner is difficult, many stores have temperature cables that provide an indication of the grain's condition.

Monitoring grain temperature. Most temperature-monitoring systems consist of steel cables and thermocouple wire suspended from the bin roof. Each bin may contain several cables, each with several temperature-sensing couples. Although grain sorghum is not likely to experience heating in storage, understanding the basic principles of grain temperature interpretation is useful. The storage manager should maintain the grain cool, because both molds and insects develop slower at lower temperatures. The grain should be monitored frequently during storage to detect any heating within the grain mass. Examples of grain temperatures and how to interpret them are given in Appendix III.

Maintaining Grain Quality

U. S. grain sorghum provides several advantages for tropical storage.

- It is drier than most other feed grains. Exported sorghum consistently contains about 13.7% moisture.
- It contains a lower damaged-kernel content than do most feed grains. The average damaged-kernel content of exported U. S. grain sorghum is only one percent.
- It contains a lower count of mold-infected kernels than other feed grains. A recent survey found that less than 7% of exported U. S. grain sorghum kernels were infected with storage molds (*Aspergillus* spp.), even after some time in a tropical climate. In a simulation, the rate of infection by storage molds did not increase significantly when grain was held at 30º C and 13.5% moisture content for two months.
- Fine material in grain sorghum does not aggregate under the fill spout to the extent it does in corn. This eliminates a major potential problem in tropical storage.

The superior properties of U. S. grain sorghum for tropical storage means there is little chance of quality deterioration, if the manager follows a few standard rules of the warehouseman.

- **Sanitation.** Bins and other areas should be cleaned after use. In tropical areas, insects survive year-round in all parts of the environment. Thus sanitation in the grain handling equipment as well as in the bins is especially important.
- **Rotation.** Stock must be rotated on a first-in, first-out basis. In storage bins that are not self-cleaning, this means that all grain must be removed from the bottom of the bin before new grain is added. However, if grain begins to heat, it should be used first, out of order.
- **Monitoring.** The grain quality and grain temperature should be monitored. Grain moisture content and temperature are good indicators of the potential for successful storage.
- **Aeration.** Under certain circumstances, aeration is a useful storage tool. Appendix IV provides detailed information about aeration in the tropics.
- **Fumigation.** Severe infestations may require fumigation. Appendix V provides detailed information about fumigation safety and efficacy.

Appendix I. Grade Standards

Grading Factors	Grades U. S. Nos.			
	1	2	3	4
Minimum limits of:				
Test Weight lb/bu	57.0	55.0	53.0	51.0
kg/hl	73.4	70.8	68.2	65.6
Maximum percent limits of:				
Damaged Kernels				
Heat (part of total)	0.2	0.5	1.0	3.0
Total	2.0	5.0	10.0	15.0
Broken Kernels and Foreign Material				
Foreign Material (part of total)	1.5	2.5	3.5	4.5
Total	4.0	7.0	10.0	13.0
Maximum count limits per 1000-g sample, of:				
Other Material				
Animal filth	9	9	9	9
Castor beans	1	1	1	1
Glass	2	2	2	2
Stones	7	7	7	7
Unknown foreign substance	3	3	3	3
Cockleburs	7	7	7	7

U. S. Standards for Grain Sorghum

U. S. Sample Grade

Sorghum that

- does not meet the requirements for U. S. Nos. 1, 2, 3, 4; or
- has a musty, sour, or commercially objectionable odor (except smut or garlic odor)
- is badly weathered, heating, or distinctly low quality.

For further information, downloadable publications, and e-mail address, access the Federal Grain Inspection Service (FGIS/GIPSA) web site at: *www.usda.gov/gipsa*

Appendix II. Molds and insects most commonly found in stored U. S. grain sorghum

Molds found in exported U. S. grain sorghum stored in tropical climates.

Alternaria spp.	Field fungus. Infects grain sorghum seeds while still on the plant. Does not grow in storage.
Cephalosporium spp.	Field fungus. Infection occasionally found in exported U. S. grain sorghum. Does not grow in storage.
Fusarium spp.	Field fungus. Infection infrequent in exported U. S. grain sorghum. Does not grow in storage.
Aspergillus glaucus	Storage mold. Only about 5% of exported U. S. grain sorghum seeds are infected. Presence of this species indicates a potential for deterioration, but *A. glaucus* does not cause major heating.
Aspergillus flavus and *Aspergillus candidus*	Storage molds. Tend to be present in exported sorghum when infection has increased or the grain moisture is high. Cause heating and grain discoloration if infection rate is high.
Other *Aspergillus*	Storage molds. Sometimes present in exported U. S. sorghum.
Penicillium spp.	Storage mold. Infection infrequently found in exported U. S. grain sorghum. Not a major contributor to deterioration.

Insects commonly found in exported U. S. grain sorghum in tropical storage.

Cryptolestes spp.	Beetle. Distinguished by small size, large antennae. Quickly infests warm grain, but causes no grain damage.
Oryzaephilus spp.	Beetle. Distinguished by slender appearance, active behavior. Quickly infests grain sorghum, but causes no grain damage.
Tribolium spp.	Beetle. Prefers processed grain, but often is found in stored whole grain. Does not produce grain damage.
Various moths	Most are members of family *Pyralidae*. Tend to produce webbing on grain surface and in handling equipment, but cause little grain damage.
Sitophilus spp.	Weevil. Distinguished by head elongated to a snout. Produces heat and moisture that promotes mold growth. Causes major grain damage and contamination.
Rhyzopertha dominica	Beetle. Distinguished by cylindrical shape and head held downward. Produces dust, heat and moisture that promotes mold growth. Causes major grain damage and contamination.
Psocids and Mites	Not insects, but have insect-like form. May be too small to be easily visible. Produce contamination, but no major grain damage.

APPENDIX III. MONITORING GRAIN TEMPERATURE IN TROPICAL STORAGE

Typically, braided-steel temperature cables carry thin copper wires that terminate in contact with a wire made of constantan, a metal alloy. Where these dissimilar metals make contact, a thermocouple is formed and an electron current is generated. The strength of the current is related directly to temperature and is interpreted by the thermocouple reader. Most cables have these couples at two-meter intervals.

To most easily interpret grain temperature data, data should be recorded in a way that facilitates comparing the same place in the bin at several sampling dates. For example, consider a facility with three storage bins, each having four cables, where each cable has eight thermocouples (sensors). Temperatures were recorded last on 26 December. The most useful way of constructing the temperature log is to place readings from the same cable close to one another, as follows:

			Sensor							
Date	**Bin**	**Cable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5 Dec	1	1	24	22	22	22	21	21	22	23
11 Dec	1	1	25	22	22	22	21	21	22	24
17 Dec	1	1	25	23	22	22	21	21	23	25
23 Dec	1	1	25	23	23	22	21	21	24	26
29 Dec	1	1	25	23	23	22	21	22	24	28
5 Dec	1	2	24	23	23	23	22	22	22	23
11 Dec	1	2	24	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.

The above example illustrates that grain in contact with the #1 and #8 sensors, near the top (#8) and bottom (#1) of the grain mass, is slowly increasing in temperature, whereas deep within the grain that surrounds cable #1, temperatures are not changing. It is usually helpful to compare temperature profiles over at least a one-month period in order to interpret the data.

An alternate, less helpful method of recording the same readings is to place all the data from the same day together, as follows:

Date	Bin	Cable	Sensor 1	2	3	4	5	6	7	8
5 Dec	1	1	24	24	24	25	24	25	30	30
	1	2	24	26	26	27	29	24	24	30
	1	3	24	23	22	22	21	22	22	29
	1	4	24	23	22	22	22	21	22	29
	2	1	26	22	21	22	21	20	25	27
	2	2	24	23	23	22	22	21	21	24
	2	3	24	22	23	23	24	24	25	25
	2	4	24	22	23	23	24	24	24	25
	3	1	26	26	24	25	22	23	23	25
	3	2	27	26	25	26	23	25	24	24
	3	3	27	25	25	24	23	23	25	25
	3	4	27	25	25	24	23	23	25	25
11 Dec	1	1	27	24	24	25	25	22	24	24
	1	2	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.	Etc.

Here, the manager cannot immediately determine whether the high temperatures indicate deterioration or the effect of ambient conditions. The high temperatures at the top sensors (#7and 8) on cable #1 in bin 1 may lead the manager to believe there is a hot spot. (In this case the high temperature simply indicates that the thermocouple is not covered by grain.) Similarly, it is not possible to determine whether the grain near the 5th position on cable #2 of bin #1 is heating or whether the cable has been displaced close to the outside wall.

Examples of Grain Temperature Records

The top sensors on the temperature cable often are not covered by grain. They detect the temperature of the air in the headspace above the grain. Sensors not covered or barely covered by grain are characterized by fluctuating readings that vary depending on the time of day when the temperatures are recorded. This results in records showing alternately higher or lower readings. A typical example in which the top two sensors are not covered by grain is:

Date	Bin	Cable	Sensor 1	2	3	4	5	6	7	8
5 Dec	1	1	26	26	27	27	25	27	32	32
11 Dec	1	1	26	25	26	27	27	27	25	26
17 Dec	1	1	27	25	27	28	27	28	34	34
23 Dec	1	1	27	26	27	27	27	29	32	33

In the following example, the temperature line has been displaced to near the bin wall, exposing sensors #5, 6, and 7 to near-ambient conditions. Note that the temperatures at these points are alternately higher and lower, depending on ambient conditions when the temperatures were recorded.

			Sensor							
Date	**Bin**	**Cable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5 Dec	1	1	24	24	24	28	31	29	25	26
11 Dec	1	1	25	25	26	27	29	29	25	28
17 Dec	1	1	25	25	25	26	29	27	25	27
23 Dec	1	1	25	25	26	29	30	30	24	28

True "hot spots" create a different pattern, one of steadily increasing temperatures. The rate of increase usually is moderate, and usually, only one or two sensors are affected at first. This differentiates a hot spot from surface warming, where sensors on several lines are affected equally.

			Sensor							
Date	**Bin**	**Cable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
5 Dec	1	1	29	28	29	30	31	30	31	32
11 Dec	1	1	29	28	29	32	31	31	32	29
17 Dec	1	1	30	29	30	33	32	31	33	32
23 Dec	1	1	31	29	30	35	32	31	33	35

In this case, the grain temperature deep within the grain mass (#4) increased by 3° C in only 12 days while temperatures at other points closer to the surface (#7) gained only two degrees and those at most positions remained relatively stable (sensor #8 is out of the grain). This point is beginning to heat and deteriorate. A good grain manager will monitor this bin very closely and will take action if the temperature continues to increase at the rate of more than one degree per week.

Summary

Monitoring the grain temperature is especially important in tropical areas. Grain temperature changes provide the storage manager with one of the best indicators of grain condition. Points to remember include:

- Increases in grain temperature may be due to environment or deterioration. High temperature itself does not cause deterioration, but deterioration causes high grain temperature.
- Grain temperatures must be recorded methodically and correctly in order to be useful.
- The grain manager must know the location of the temperature lines in the grain mass in order to interpret the temperature information correctly.
- Warming caused by ambient changes is erratic, whereas hot spots caused by deterioration produce a slow, steady increase in grain temperature. An unexplained, consistent increase of more than two or three degrees deserves investigation.

Appendix IV. Managing aeration in tropical climates

Background

In general, cool grain stores better and deteriorates less than warm grain. Both insects and molds grow faster and cause more damage at higher temperatures. Therefore, grain should be maintained as cool as possible. In temperate climates, this is relatively simple and inexpensive. However, in warm climates, especially in the humid, lowland tropics, it may not be feasible without chilling equipment. An inexpensive and reasonable alternative is to store grain for only short periods, monitor it closely, and consume grain that is heating or in marginal condition before the more storable grain. The following information and suggested aeration practices may be useful for this basic strategy, depending on the problem and the climate.

Determining when to operate the aeration fans is often the first decision. To help make that decision, it is useful to review the objectives of aeration and the physics of heat in stored grain. In imported grain, aeration is used to remove heat of respiration before hot spots develop and quality deterioration occurs. Aeration also is used to remove temperature gradients. Hot spots are produced by intense mold or insect activity. Temperature gradients may form if the grain is held for several months. One part of the mass may become warmer than the rest because of ambient heating, shading, or day-night temperature differences. In locally produced grain, where large variations in moisture content may occur, aeration is helpful to equalize the moisture.

Grain aeration involves passing ambient air slowly through the grain to transport heat out of the grain mass. The low airflow rates used for aeration are not efficient for drying the grain. The air must be several degrees cooler than the warm grain to make the process efficient. In many aeration systems, where fans at the base of the bin move air upward to the surface, the air is likely to be warmed by the fan motor and by heat of compression before it reaches the grain. Air is compressed as the fan forces it into the ducts or plenum chamber under pressure. To equalize this pressure, air moves through the grain to the surface. The pathways through the grain mass are narrow, and the air must change direction many hundreds of times before it exits the grain surface. This produces a resistance to airflow, which is measured as static pressure. The higher the static pressure, the more power is required to deliver the desired airflow rate. The static pressure can be overcome, resulting in a higher airflow, by increasing the size and power of the fan, with an associated rise in heat of compression.

As cool air enters a warm grain mass, it exchanges both heat and water with the grain until it achieves an equilibrium condition. This exchange takes place rapidly and affects only the first layer of grain in contact with the air. Once the air has warmed to approximately that of the grain, it can no longer accept heat energy from the grain and passes through the rest of the grain mass without further effect. As more cool air is passed through the grain, the layer of cooled grain becomes thicker, and the proportion of the mass that has not cooled becomes smaller. The layer of grain at which the change takes place is called the thermal front and is said to “move” through the grain mass. The fan must be operated until this front “moves” all the way through the grain or until the front has “moved” the hot spot out of the grain. The grain temperature must be monitored frequently to determine when this has occurred. The number of fan-hours required to achieve this depends on the airflow rate, which is a function of the size and power of the fan and the static pressure of the grain. The grain quantity and the height of the grain mass determine the static pressure.

Examples of Heat-Related Storage Problems

When Grain Is Warming at the Surface

If the grain is warming to above ambient temperature because of the hot air between the bin roof and the grain, extraction fans may be helpful. In warm climates, the sun heats metal bin roofs, causing the air over the grain to become much warmer than the ambient air. Because nighttime air in the tropics is also warm, much of this heat does not escape during the night, so the grain surface is exposed constantly to air warmer than ambient temperatures.

Extraction fans are small fans, usually ½ to 1 HP, that usually are positioned near the peak of bin roofs. As they remove the hot air from the peak of the bin roof, cooler outside air is pulled into the bin beneath the eaves and through roof vents. The function of these fans is twofold. When the grain is not being aerated, they help prevent the daytime temperature of the headspace air from becoming excessively warmer than the ambient temperature. When the grain is being aerated by aeration fans that move air upwards through the grain mass, extraction fans mix ambient air with the hot, moist air leaving the grain mass, thus avoiding condensation on the metal roof at night. Extraction fans can be connected to automatic controllers that activate them whenever the aeration fans are turned on or whenever the headspace temperature is above a preset limit.

When Grain Arrives Cold

During the North American winter, grain sometimes arrives at the receiving port much cooler than the ambient air. When cool grain is placed in storage bins, the pattern of temperature change may indicate that the cool grain is coming to equilibrium with the environment at the storage site. The manager knows this is happening if the top, bottom, and outside are steadily warming and the inside of the grain mass is warming much slower. In this case, the best management decision is to “keep the cold in” by not operating aeration fans and by covering ground-level openings. Extraction fans could be operated on warm afternoons, because they do not pull air through the grain.

When Cool Air Is Available

In highland tropics and dry tropics, cool air may be available during nighttime hours. This cooler air may be used to extend the safe storage time of grain, sometimes for several months. After storage, the grain temperature is monitored closely as explained in Appendix III. Aeration is not activated unless the temperature of a significant portion of the grain mass exceeds the daily average temperature. If aeration is required, fans are activated during the night except during rain. Fans often are operated only during the coolest 3 to 4 hours, because the ambient temperature must be at least 3º C cooler than the warm grain for aeration to be efficient. When the cooling front has exited the grain, nightly aeration is stopped. This practice eliminates temperature gradients within the mass and brings the bulk of the grain mass to a temperature below the daily average ambient temperature.

When the Grain Is Heating due to Molds or Insects

In the worst case, it is hot spots produced by molds or insects that cause the grain temperature to change. The best management strategy in this case is to use the grain immediately, before it heats to above 30–35° C, at which point deterioration takes place more rapidly and the possibility of toxin formation is greater. It is more important to use the heating grain immediately than to follow the standard warehousemans' rule of "first in—first out". One of the advantages of metal bins is that the grain at the peak and top center, where hot spots are most likely to occur, usually exits the bin soon after discharging begins. Therefore, it may be necessary to use only 15 or 20% of the heating grain out of turn.

During the grain movement, samples should be taken for insect detection. If large numbers of *Rhyzopertha dominica* or *Sitophilus* weevils are observed, the heating can be stopped by fumigation. If few insects are present, and if the grain cannot be consumed immediately, aeration may be the only way to minimize grain damage. When aeration is needed to control hot spots, ambient air is used to carry the excess heat and moisture from the grain, thus maintaining grain temperatures no more than a few degrees above ambient. Outside air should be at least 3° C cooler than the hot spot before this will work well, and the fans should be left on for several days, long enough for the heat and moisture to be carried all the way out of the bin. Operating the fans for just a few hours will only move the heat and moisture to other grain.

Summary and Recommendations

Storing imported grain sorghum in the humid tropics is a difficult task that requires a good understanding of the physical and biological processes inside the grain mass and good management skills. Steps to follow include:

1. Monitor grain temperature closely.
2. Record grain temperatures so the same point in each bin can be followed easily over time.
3. Maintain cool grain cool as long as possible.
4. Take action as soon as heating is detected.
5. Use heating grain before its temperature reaches 35° C.
6. Consider an exhaust fan if “rain inside the bin” during aeration or excessive head-space heating are observed.
7. Monitor grain temperatures to determine when to begin aeration. If heating grain cannot be used immediately, aerate until the excess heat is removed from the bin completely.
    - Use aeration to control grain temperatures, not to dry the grain
    - Begin aeration only when the grain temperature exceeds the average daily temperature, or if a part of the mass begins to heat
    - Operate fans when the air temperature is less than the average daily temperature, and when the relative humidity is less than 95%, unless a hot spot exists
    - Monitor grain temperature to determine the progress of cooling fronts
    - Airflow rates of no less than 0.3 $m^3/min/m^3$ are recommended for the tropics
    - For long-term storage, limit aeration to less than 30 hours per month

Appendix V. Fumigation

U. S. grain sorghum is an infestible commodity and may require fumigation if held for several months under tropical conditions. Fumigation is expensive and potentially hazardous. Consistently safe and effective grain fumigation requires trained personnel. The following is intended as general information, not as a substitute for proper grain fumigation training.

Both methyl bromide ($MeBr_2$) and phosphine (PH_3) grain fumigants sometimes are used in tropical countries. Although both fumigants kill insects and disinfest grain, they have very different characteristics.

Phosphine Fumigants	Methyl Bromide Fumigants
Traditionally, are supplied as flasks of pellets or tablets or as powder incorporated into packs or sachets. New formulations generate PH_3 on-site or carry PH_3 in compressed carbon dioxide	Are supplied as a compressed gas
Require several days of exposure to insects	Require a few hours of exposure to insects
Require a sealed structure	Require a vacuum vault or recirculation
Produce PH_3, with a molecular weight similar to that of air, so it moves with air currents	Are much heavier than air and move downward unless recirculated
Leave no significant phosphine residue in grain	May leave objectionable residues of inorganic bromine, if the fumigation technique is not adequate
Typically are used in raw grain storage	Typically are used in grain processing areas or equipment, or in warehouses
Sorb slowly to grain	Sorb quickly to grain
Currently are not threatened by international agreement	Currently are scheduled to be phased out because of their potential destructiveness to the ozone layer

Except for fumigation of small quantities of grain or grain product in bags under gas-tight sheets in warehouses, fumigations with methyl bromide are likely to be conducted by fumigation companies. In contrast, PH_3 fumigations often are conducted by employees of the grain-handling company. This is because phosphine fumigants are easy to handle and apply and provide additional security because the toxic gas is not generated for several hours. The following information and recommendations are offered relative to fumigation of grain with **phosphine** fumigants.

General

- Both tablets and pellets can be applied with a mechanical dispenser.
- Tablets generate 5 times the amount of gas as a pellet and are slower to generate gas.
- The aluminum or magnesium hydroxide powder remaining after the PH_3 generates usually contains a tiny amount of unreacted formulation.
- The rate of PH_3 generation from fumigant placed in the grain mass depends on grain temperature and moisture content and is generally unrelated to ambient conditions.
- Phosphine moves easily through plastic, porous concrete, and similar materials.

Insect response to phosphine

- The lethal dose depends on species, temperature, length of exposure, and life stage.
- Longer exposures at 200 to 500 ppm produce a better fumigation than high doses for short exposure periods.

Air movement in upright concrete bins

- Air currents in upright bins move upward if the grain is warmer than the outside air, but can move downward if the grain is cooler than the air.
- Rate of fumigant escape from grain headspace is affected by wind speed and direction.
- Extraction fans operating on a bin in a block of intervented bins will withdraw fumigant from the fumigated bin.
- Unsealed fill ports on bins adjacent to the fumigated bin allow gas to enter the gallery.
- Phosphine enters bintop-level conveyors through bin spouts.

Application Rate

- Calculate the dose based on total bin volume.
- Calculate pellet/tablet application rate based on grain handling rate.
- Calibrate the applicator and apply only the total calculated dose.

Metal warehouses and bins

- Unless the bin will be filled in less than two days, it should not be fumigated when filled.
- Ground-level openings must be sealed to hold the fumigant gas within the bin.
- A tarpaulin or plastic sheet over the grain surface reduces air currents that dilute the fumigant concentration and carry it out of the bin.
- Recirculation usually is helpful.
- Consider professional fumigators, because sealing is difficult and the potential for worker exposure is high.

Fumigant Storage

- Fumigant storage areas must meet the specifications on the label.
- Storage areas must be ventilated and locked.
- Only authorized personnel must have access.

Respiratory Protection

- Gas masks with viable canisters must be on-site during fumigant application.
- SCBA equipment must be readily available.

Monitoring Equipment

- Inexpensive glass tube and hand pump equipment is available to monitor fumigant levels in worker areas.
- Personnel safety equipment with electro-chemical cells and data-logging capability is available for monitoring during fumigation and for atmosphere monitoring prior to confined-space entry.

Placarding

- The structure containing the fumigated grain should be sealed and placarded wherever grain can be removed and wherever the bin can be opened.
- Worker areas that may contain phosphine should be placarded.

Poor Practices

- Not completely sealing the bin
- Basing fumigant dose on grain quantity rather than bin volume
- Operating aeration or extraction fans during fumigation
- Fumigating in an open pit or on a truck
- Fumigating grain into a bin or warehouse that requires more than 2 days to fill
- Allowing fumigant to accumulate in piles
- Applying fumigant at an elevator leg or dump pit
- "Storing" pellets or tablets in applicator between fumigations
- Applying fumigant in a damp plenum chamber

Good Practices

- Keeping fumigant flasks tightly closed
- Opening each flask outside the building just prior to use
- Directing flask away from face and body when opening
- Assuring that at least two people are present during the application

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