U.S. Grains Council Handbook –

Practical Solutions to Maximize the Value of Imported U.S. Corn

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Executive Summary

This handbook is aimed at addressing three key concerns operations managers at grain warehouses and feed mills are often faced with when receiving imported corn: (1) moisture content at 14.5 percent, (2) high amounts of fines that make handling and storage more challenging, and (3) presence of mycotoxins. The practical solutions presented in this handbook address how to successfully manage these challenges from the perspective of the operations manager.

The handbook is divided into four sections. The first section defines the three key concerns, i.e., moisture content, broken corn and foreign material, and molds and mycotoxins, as well as introduces the key concepts for maintaining quality of U.S. corn during shipment and in-country storage. These include monitoring temperature, moisture content, and carbon dioxide, as well as what constitutes safe storage moisture content and deterioration conditions. The second section introduces a decision tree in the form of a flow chart to guide the user on how to assess corn quality at port arrival and along the in-country supply chain. It takes the user to the appropriate subsections in the third section of the handbook to mitigate potential quality challenges. Section three also goes into greater depth about preparing imported corn for storage and processing, and how to handle and utilize broken corn and foreign material screenings and scalpings as a feed ingredient. Some grain receiving, warehousing and processing facilities are not sufficiently equipped to manage the quality of imported corn during storage. The fourth section focuses on preparing facilities for improved handling of U.S. corn by identifying equipment options for cleaning and reducing the chance for additional breakage during handling. This section also reviews how to determine the value of excessive shrink losses due to poor handling, excessive aeration, and quality deterioration. An approach for evaluating and comparing the benefits and cost savings for equipment upgrades and improved handling systems is presented that is complemented with a spreadsheet tool. An extensive list of reference, additional readings, and Appendices completes this handbook of practical solutions for operations managers and their personnel.

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1. Introduction

The primary purpose of this handbook is to provide practical solutions to operations managers and their personnel who manage grain warehouses and feed mills receiving export shipments of U.S. corn (maize) at their overseas locations. The solution options focus on mitigating moisture content above safe storage conditions, localized accumulation of broken corn and foreign material in silos and warehouses, and mycotoxin development as a result of poor storage practices. In addition to the practical solutions outlined in this handbook, best management practices for the safe storage of imported U.S. corn, other grains, or feed ingredients are covered in other USGC handbooks[1,2] and in a number of other references.

1.1. Broken Corn and Foreign Material

According to the U.S. Grain Standards[3] (see Appendix 6.1), broken corn and foreign material for the five U.S. corn grades is defined as follows.

Broken corn (BC): All matter that passes readily through a 12/64 round-hole sieve and over a 6/64 round-hole sieve according to procedures prescribed in FGIS instructions.

Foreign material (FM): All matter that passes readily through a 6/64 round-hole sieve and all matter other than corn that remains on top of the 12/64 round-hole sieve according to procedures prescribed in FGIS instructions.

Broken corn and foreign material (BCFM): All matter that passes readily through a 12/64 round-hole sieve and all matter other than corn that remains in the sieved sample after sieving according to procedures prescribed in FGIS instructions.

The material sometimes referred to as "fines" (which is not an official designation) is in fact the fines portion of foreign material (FM) that contains small pieces of corn and dust which “passes readily through a 6/64th inch (2.38 mm) round-hole sieve” (excluding what is identified as foreign material in terms of “other than corn that remains on top of a 12/64th inch (4.76 mm) round-hole sieve”) . The white dust in exported U.S. corn consists mostly of starch from broken corn endosperm. Together BC, fines and dust are good feed ingredients but their presence can cause problems in storage and must be properly managed. When corn drops into a silo or warehouse from an overhead spout or cross conveyor, a pile shaped like a cone forms. Corn kernels, larger pieces of broken corn, and light pieces of foreign material (e.g., cob and stalk pieces, soybean pods) flow down the surface of the pile increasing its diameter while BC and the fines portion of FM tend to accumulate in the core of the pile below the peak. In silos only one so-called spoutline forms while in warehouses spoutlines form below each conveyor drop point (Fig. 1.1).

[1] 2002 USGC Handbook on U.S. Corn Storage in Tropical Climates; https://grains.org/wp-content/uploads/2018/10/Corn-Storage-in-Tropical-Climates-English.pdf

[2] 2002 USGC Handbook on U.S. Grain Sorghum Storage in Tropical Climates; https://grains.org/wp-content/uploads/2018/10/Sorghum-Storage-in-Tropical-Climates-English.pdf

[3] 1996 USDA-GIPSA-FGIS U.S. Standard for Corn; https://www.gipsa.usda.gov/fgis/standards/810corn.pdf

Figure 1.1. Illustration of spoutlines formed below drop points of three parallel overhead conveyors running the length of the warehouse filled with corn for longer-term storage. (Source: USGC)

The fines portion of FM in corn consists of particles significantly smaller than the kernels themselves. Most fines in U. S. corn consist of broken pieces of corn, and has about the same nutrient value as the whole corn. While fines are not a separate grade factor, their presence can cause problems in storage unless the condition is handled properly. Spoutlines are the accumulations of these fines and BC beneath the spout where the grain is dropped into a container. Spoutlines in corn have been shown to contain five times or more BC and fines than grain in other parts of the mass

1.2. Molds and Mycotoxins

Mold (or fungal) spores are activated more so by the relative humidity of air surrounding corn kernels than temperature. A relative humidity above 65-70% is the general activation threshold. This implies that moisture contents in equilibrium with a relative humidity of 65-70% at any temperature determines whether fungi will grow or corn will continue to store safely. For example, corn at 15 °C and 15.1% moisture content will be in equilibrium with air at a relative humidity of 75% (Table 1.1). Unfortunately, at a relative humidity of 75% fungal spores will begin to activate which is often observed in the form of surface crusting in corn when headspace temperatures in silos and warehouses increase in warm weather. Ideally, U.S. corn exported to the tropics and subtropics should be stored at moisture levels closer to 13-13.5% to assure relative humidity surrounding grain kernels remains below 65-70% at temperatures above 20 °C.

Table 1.1. Moisture content (%) of corn as a function of temperature and relative humidity of air surrounding kernels in the stored grain mass of a silo or warehouse. A more detailed table is included in Appendix 6.2. (Source: Maier)

Temperature (°C)	Relative Humidity (%)						
	50	**55**	**60**	**65**	**70**	**75**	**80**
15	11.6	12.2	12.9	13.5	14.3	15.1	16.1
20	11.2	11.8	12.4	13.1	13.9	14.7	15.7

25	10.8	11.4	12.1	12.8	13.5	14.4	15.4
30	10.4	11.0	11.7	12.4	13.2	14.0	15.0
35	10.1	10.7	11.4	12.1	12.9	13.7	14.7

The best way to mitigate mold development in storage is to reduce moisture content to the safe storage limit *<u>if</u>* corn is to be stored for more than three weeks. For longer storage periods, or for corn with signs of self-heating, excessive damage levels, or high amounts of fines, refer to the decision tree in Section 2.

Mold inhibitors are often recommended as a mitigation tool. They were originally developed for application to high-moisture corn (greater than 18% m. c.) immediately after harvest as a less expensive alternative to artificially drying corn, or to extend the holding time before corn could be dried. Mold inhibitors never gained acceptance among U.S. grain producers, handlers, and exporters, and thus they are not applied to exported U.S. corn. They are based on propionic acid and are considered safe for human and animal consumption. The inhibitory action is primarily by keeping fungal spores from growing rather than destroying them. In many countries they are used to extend the shelf-life of animal feeds. They should *<u>not</u>* be needed for imported U.S. corn especially when moisture and BCFM are managed with best practices to prevent the on-set of grain spoilage and self-heating.

Mycotoxins are toxic substances produced by molds that are sometimes found in cereal grains. Aflatoxin, deoxynivalenol (DON), fumonisin, T-2 toxin, and zearalenone are the primary mycotoxins of concern. Aflatoxin is a chemical toxin produced by *Aspergillus flavus and Aspergillus parasiticus*. These mold species grow well and produce aflatoxins at temperatures over 20°C and relative humidity conditions between 85-99%. Contamination by mycotoxins usually is a localized phenomenon present in some crop years and not in others. The presence of these substances and location of problem areas is typically discovered long before any contaminated grain enters export channels. All U.S. corn is tested at export for aflatoxin, the most common toxin in corn. Corn containing more than 20 parts per billion cannot be loaded. Some mold species, principally *Aspergillus spp.* and *Penicillium spp.* can attack poorly managed corn stored above safe storage moisture content levels. This can lead to the production of mycotoxins during storage of U.S. corn at an overseas location. Well-managed storage prevents the production of mycotoxins. The same good storage practices that maintain stored grain quality prevent mycotoxin contamination.

A variety of mycotoxin test kits are available commercially to identify and quantify mycotoxins in grains and feed ingredients. An excellent reference of available test kits and their verified performance is available from USDA's Federal Grain Inspection Service (FGIS[4]). Representative sampling and testing before, during and after storage help assure mycotoxin-free feed. When mycotoxin levels above country-specific allowable limits are discovered, refer to the decision tree in Section 2.

Mycotoxin binders are often recommended as a mitigation tool. They are defined as substances that bind mycotoxins and prevent them from being absorbed through the animal gut into the blood

[4] FGIS Performance Verified Aflatoxin Test Kits – Effective 04/28/2020; https://www.ams.usda.gov/sites/default/files/media/FGISApprovedMycotoxinRapidTestKits.pdf

circulation from which they are excreted into animal source foods such as milk. Mycotoxin binders are primarily used as a feed additive. A variety of commercial products are readily available around the world. Additionally, a feed mill can dilute corn with a higher level of mycotoxins by blending (mixing) it with clean grain for the purpose of manufacturing feed. This allows for the reduction of mycotoxins in the blended grain provided this practice is allowed in the country.

1.3. U.S. Corn Quality during Shipment and Storage

Importers of U.S. corn especially into tropical climates face greater challenges to maintain quality during storage than do their counterparts in the United States. Reasons include (a) the repeated handling from farm to export terminal and again from import terminal to end user produces more breakage and dust, (b) the ambient temperature is higher than the temperature corn was held at during the winter storage period in the U.S., and (c) the combination of ambient temperature and relative humidity in the tropics is higher than the equilibrium relative humidity of corn at marketed moisture levels.

1.3.1. Monitoring Temperature, Moisture Content and Carbon Dioxide

Monitoring stored grain is key to successfully preserving grain quality and quantity. Unfortunately, relatively few silos and even fewer warehouses of importers, grain handlers and feed millers are equipped with sensing technologies and monitoring systems that can track temperature, moisture content, and carbon dioxide (CO_2). Most storage problems are caused by moisture infiltration and insect penetration into the storage structure which cause biological respiration from germs, fungi, and insects to increase. Thus, the early detection of spoilage is essential to keep them at levels where they do not cause grain spoilage and affect economic value. Insects and molds are aerobic organisms that respire and release CO_2 into the interstitial air of a stored grain mass. Upward moving convection air currents within the grain mass transport CO_2 into the headspace of a silo or warehouse even from densely packed cores of fines.

The accumulation of fines and broken corn and associated exposure of starch in spoutlines is highly susceptible to the on-set of spoilage especially when the equilibrium relative humidity of the air trapped in the core of fines is greater than 65-70%. Sporulating fungi respire heat, water vapor and CO_2. The densely packed spoutline traps the first two which accelerates mold growth and deterioration – neither is easily detected. Fortunately, CO_2 is a gas that is not trapped and can be detected in the headspace of a silo or warehouse.

Typically, ambient air has a CO_2 concentration of 400 ppm (parts per million). Past research indicates that a stable grain mass has a CO_2 concentration of 450-600 ppm. Higher levels indicate biological activity above normal. Thus, monitoring CO_2 in the headspace air of silos and warehouses, or the exhaust air stream from aeration fans with handheld or permanently installed sensors is an effective and preferred monitoring tool for stored grain managers. Concentrations of 600 to 1500 ppm indicate on-set of mold growth, insect presence, or moisture infiltration. Concentrations of 1500 to 4000 ppm and beyond clearly indicate severe mold infection or insect infestation. Refer to Section 3.2.5 for more on CO_2 monitoring and tools used.

1.3.2. Safe Storage Moisture Content and Deterioration Conditions

At U.S. export terminals, corn is not dried but blended to meet contract specifications. When corn at 15-16% moisture content is blended with corn at 12-13% moisture content, a mix of corn results that has individual kernels at moisture contents that is normally marketed at 14-14.5 percent. Those kernels at moisture contents higher than safe for storage have a substantially shorter shelf-life and will allow fungi to grow especially when relatively colder corn is imported and stored in warmer, more humid climates. This onset of spoilage is a biological process that occurs naturally within three to four weeks and results in self-heating of corn. The onset of spoilage is accelerated when corn contains large amounts of broken corn and foreign material (BCFM). Broken kernels mean starch exposed to fungal spores that together with more dust and higher moisture kernels will accelerate the onset of spoilage and increase the potential for self-heating.

Condensation associated with handling and storage of imported corn in warm climates is another challenge. It often arrives in tropical ports at a temperature at least 10 °C colder than the ambient air. Water condenses on the external surfaces of grain handling equipment when cold corn is unloaded from vessels and transferred into storage silos or warehouses. Condensed water on external metal surfaces does not affect the corn as long as it is not allowed to drip onto the corn. Ideally, corn is transferred in enclosed conveyors rather than open belt conveyors that allow warm, humid air to come into contact with the cold, dry corn. Contact between this cold grain and humid air causes water to condense on the exposed corn which when placed in storage can result in a higher equilibrium relative humidity of the air. This in turn results in activation of fungal spores followed naturally by onset of spoilage and self-heating.

A key process technology for reducing moisture content to safe storage levels is artificial drying. Unfortunately, high capacity continuous-flow dryers are generally not found at U.S. export terminals and overseas import terminals. The equipment is expensive to purchase, own and operate. Thus, drying with heated air is typically not an option for managing moisture content in imported corn. However, drying can also be done using natural air/low temperature drying, which is a slow drying process using aeration fans alone (natural air) or aeration with slightly heated air (low temperature) where the entire drying process is contained in the silo (refer to Section 3.1.4).

Aeration of grain involves forcing ambient or chilled air at low flow rates through a stored grain mass to lower or maintain its temperature. It requires fans and an air distribution system to push or pull air through the grain. Most silos and warehouses at overseas import terminals are not equipped for aeration. However, if needed they can be retrofitted with permanent or portable aeration systems (refer to Section 4.3.2 to 4.3.7). When weather conditions do not allow for cooling and maintaining stored grain with ambient air, portable air cooling units are available for chilled aeration of stored grain. This equipment is expensive to purchase, own and operate, and generally only used to preserve higher value food grains such as rice and wheat to avoid the use of protectants and fumigants.

Key to aeration is understanding the local weather conditions to determine whether, and if so, when to turn on fans. For example, an analysis of five years of weather data for Tunis, Tunisia indicates the average temperature and relative humidity of ambient air throughout the year was 19.6 °C and 65.8%. Averaged relative humidity throughout the year ranged between 54 and 75% which implies a low potential for activating fungal spores (Fig 1.2). Thus, imported U.S. grade 2 corn at 14-14.5% moisture content and a temperature of 10 °C on arrival should store well in Tunis without the need for aeration. If such corn were aerated, it would be warmed on average to 19.0 °C and cause some shrink to 13.2% equilibrium moisture content. This amount of warming and moisture shrink due to aeration would be costly (see Sec 4.4) and would not substantially improve the storability of the imported corn. An additional benefit of keeping stored grain as cool as possible is prevention of onset of spoilage and insect development which are slowed substantially below 20°C and an equilibrium relative humidity of 65-68% within the stored grain mass (see Table 1.1).

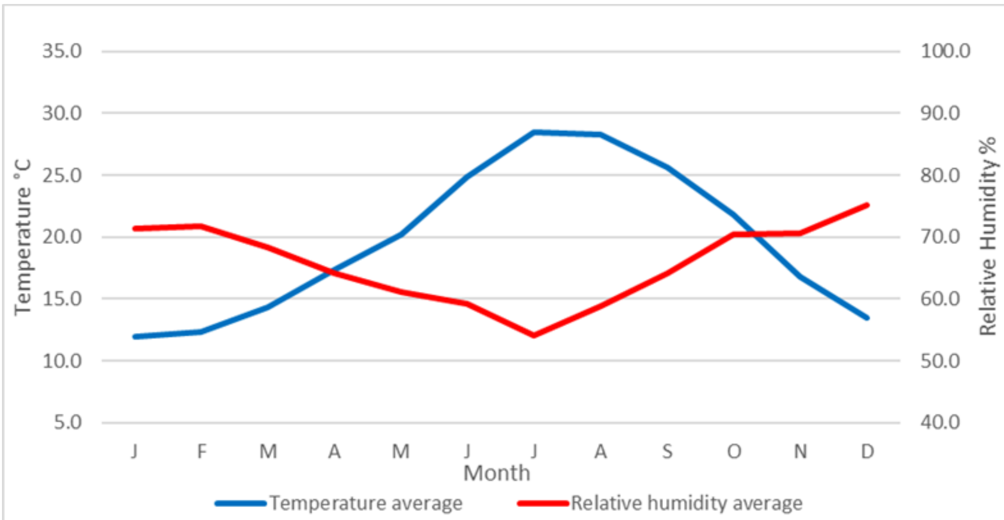


Figure 1.2. Monthly temperature and relative humidity averaged over five years (2015-19) for Tunis, Tunisia. Winter (December-February) temperatures and relative humdities range from 10-14°C and 70-75%, spring (March-May) and autumn (September-November) from 14-25°C and 60-70%, and summer (June-September) from 25-29°C and 54-64%. This is a safe range with a low potential for activating fungal spores. (Source: Maier)

2. Assessing U.S. Corn for Storage and Processing

Use the following decision tree to determine how you should manage the incoming corn received. For corn between 13-13.5% moisture content, BCFM content of less than 4%, total damage below 7%, and without any signs of live insects, deterioration, mustiness, or off odors, corn can be placed into a steel or concrete silo, or warehouse for ***longer term storage*** of 3 months or longer depending on the prevailing weather conditions. Note that good quality, dry corn must be monitored and kept cool to prevent it from going out of condition. The grain mass should be cored after being placed in a silo or warehouse (refer to Section 3.12 for best practices and Section 4.3.6 for equipment). Ventilating the headspace routinely to prevent condensation must be practiced. For a guide on aeration and maintaining safe storage temperatures, refer to Section 1.4.2 and 3.3.

For corn between 13.5-14.0% moisture content, BCFM content of less than 4%, total damage below 7%, and without any signs of live insects, deterioration, mustiness, or off-odors, corn can be placed into a steel or concrete silo for ***medium-term storage*** up to 3 months depending on the prevailing weather conditions. However, it must be monitored closely during periods of higher ambient temperatures and relative humidities especially in the tropics and subtropics with favorable conditions for corn spoilage and insect infestation. The grain mass should be cored after being placed in a silo or warehouse (refer to Section 3.12 for best practices and Section 4.3.6 for equipment). Ventilating the headspace routinely to prevent condensation must be practiced. For a guide on aeration and maintaining safe storage temperatures, refer to Section 1.4.2 and 3.3.

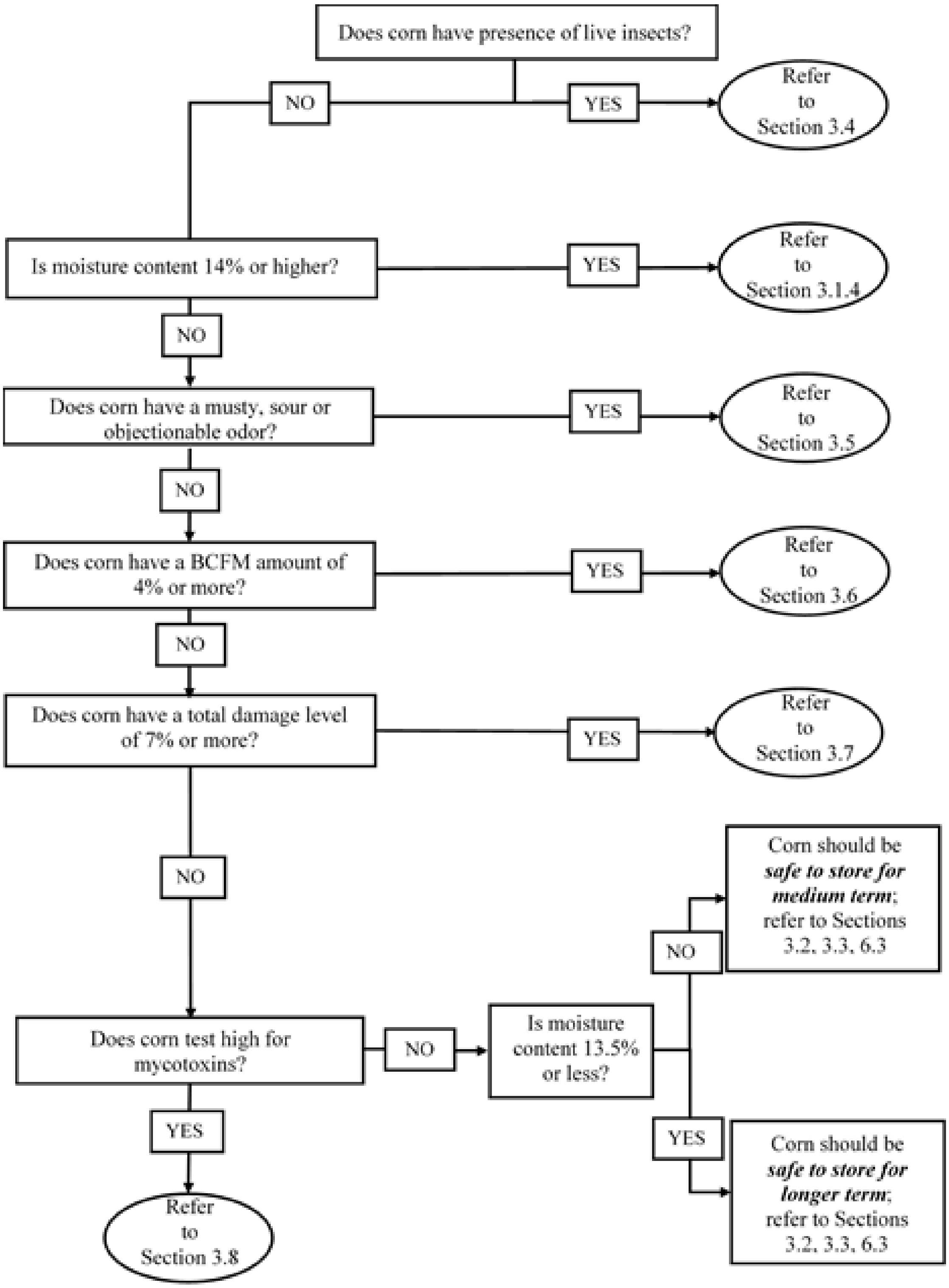
For corn between 14.0-15.0% moisture content, BCFM content of less than 4%, total damage below 7%, and without any signs of live insects, deterioration, mustiness, or off-odors, corn can be placed into a steel or concrete silo for ***short-term storage*** up to 1 month depending on the prevailing weather conditions. However, it must be monitored closely during periods of higher ambient temperatures and relative humidities especially in the tropics and subtropics with favorable conditions for corn spoilage and insect infestation. The grain mass should be cored after being placed in a silo or warehouse (refer to Section 3.12 for best practices and Section 4.3.6 for equipment). Extra attention must be paid to handling the higher moisture cored material from spoutlines. Ventilating the headspace routinely to prevent condensation must be practiced. If short-term storage within the limits of the indicated quality parameters is not an option, return to the decision tree in Section 2 and proceed to consider lowering the moisture content using natural air (refer to Section 3.1.5).

For a guide on aeration and maintaining safe storage temperatures, refer to Sections 3.2, 3.3 and 6.3.

For corn that smells musty, has off-odors, and shows signs of caking[5], or heating due to a localized hotspot that might have developed in the shiphold, determine corn moisture content, BCFM content, and total damage level. Corn at any moisture content smelling musty or having off odors, and showing signs of caking, or heating (hotspot), should be moved to a flat storage warehouse. Ensure that clumps of caked corn are broken up and spread out, especially if active heating has begun. Check for signs of extreme heating and damage due to spoilage. The use of a front loader in a warehouse provides room for breaking up caked grain to dissipate heat. Do not mix corn with active deterioration or self-heating with good quality grain. Rather the corn with active deterioration should be blended out appropriately with quality grain as it is processed into feed. Do not load corn going out of condition into a silo but keep separate and test for mycotoxins. The results should guide how it should be best utilized in manufactured feed. Refer to Section 3.5. on treating corn for mustiness.

[5] When mold spores grow and corn begins to spoil, kernels are enveloped by the spores which over time also fill in the airspace between kernels and eventually cause a growing mass of corn to stick together into a larger chunk or clump. This process is known as “caking”. The core of a caked together grain mass typically contains the self-heating “hot spot” which under extreme conditions can initiate “char coaling” of corn, and if disturbed can catch corn on fire.

2.1. Decision Tree based on Corn Quality Assessment at Arrival and In-Country Supply Chain[6]



[6] Comparisons are based on official U.S. Corn Quality Standard (enclosed copy is from the above mentioned USGC Handbook); actual version will be a visual decision tree chart

3. Preparing U.S. Corn for Storage and Processing

3.1. Storage and bulk handling infrastructure considerations in managing imported grain

Imported corn from the U.S. is typically shipped in bulk carrier vessels such as a Panamax vessel. Good handling and storage systems are needed to preserve corn quality (physical, nutritional and phytosanitary attributes) from its origin (export terminal) to the final storage destination of the importing country. *Good equipment is critical for minimizing damage, however, it is best operations management practices that are key to maintaining stored grain quality.* Thus, operations must be carefully thought out from when grain is offloaded from the vessel hold through transport to the final storage site in order to prevent losses and negatively impact quality. To avoid demurrage charges, importers thrive to unload and move grain to storage as quickly as possible, and in some cases during a rainfall event. Should this occur, the impact of this rain event on moisture increase of the grain load and its subsequent impact on storage life should be evaluated. Careful documentation of these types of events and measurement of moisture content must be made in order to prepare for best management of grain for storage and processing. Key practices to prepare U.S. corn for storage and processing, and how to utilize them effectively under challenging conditions are as follows.

3.1.1. Grain Sampling and Moisture Measurement

Grain sampling: Grain sampling is one of the most important operations at any facility. It should be considered as the gate keeper for addressing issues with incoming grain. It is important to know the initial conditions and make informed decisions on how to handle, store and utilize the incoming load based on moisture content and quality attributes. Therefore, it is important that a facility develop and follow a standard operating procedure (SOP) for representative sampling of incoming loads of grain, and follow the decision tree in Section 2 as a guide for operations personnel to assess quality and make an informed decision about preparing the grain for storage and processing.

It is important to develop a rigorous sampling plan for corn off-loaded from a vessel because this is the only way that effective management of incoming loads of imported corn can be implemented. Sampling interval at the port facility should be based on observed quality of the grain as it is being off-loaded. When non-uniformity in grade becomes apparent, such as clumping, self-heating, etc. the sampling routine should be changed to reflect the greater quality risk. A standard set of procedures should be developed and followed to address the quality issues and to ensure management is alerted to these conditions.

Figure 3.1. Gravity in-line grain stream samplers used for representative sampling as shipholds are unloaded and grain is transfer to a conveying system.

At grain warehouses and feed mills where trucks are received, it is more ideal to sample trucks using a *telescopic probe* as shown in Fig 3.2, before the grain is dumped. Samples should be pulled from the grain in the truck bed using the guide indicated in Fig 3.3. Probe samples of corn collected from a single truck can be mixed and should be checked according to the decision tree in Section 2, unless the operator notices non-uniformity, in which case, individual probes may be necessary to determine the location of the possible issue. The mixing of probe samples from several trucks, commonly called composite sampling to attain a "average" over a period of time, should only take place when uniformity of grade is apparent. If non-uniformity in quality is discovered, then individual sampling and analysis should be followed, and is highly recommended.

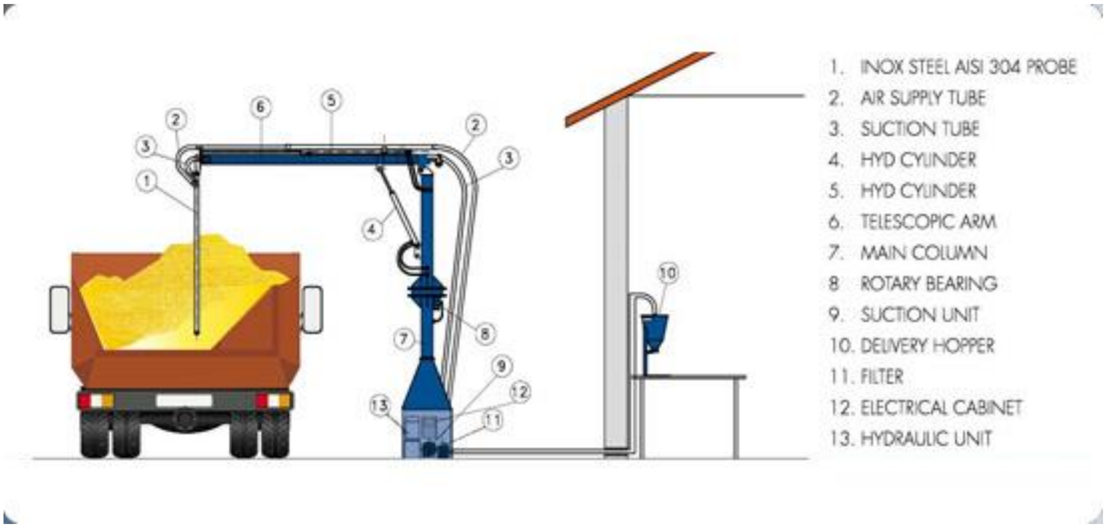


Figure 3.2. Illustration of a telescopic pneumatic probe used in sampling truckloads of grain

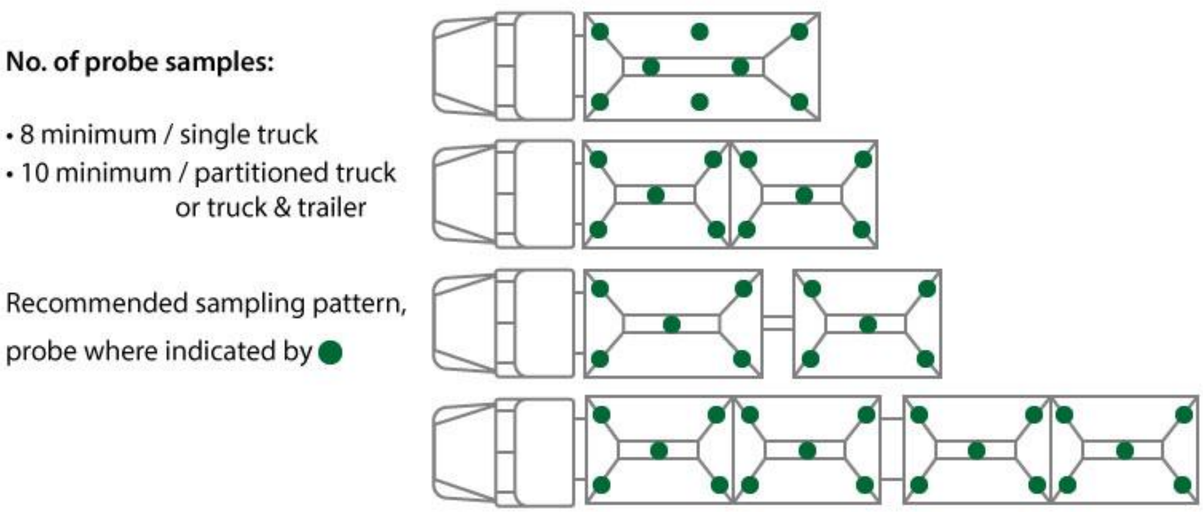


Figure 3.3. Recommended pattern for representative sampling of truckloads of grain (top view of the grain bed shown) at the receiving station.

If a facility is not equipped with a telescopic probe, manual sampling of grain using a 2.7 m (*8 ft) long grain probe* should be used to sample trucks (Fig 3.4a). However, this method is laborious, and may discourage operations personnel from conducting representative sampling of incoming grain. Samples can be collected with a manual probe by operations personnel (1) standing on top of a mobile ladder platform and probing the grain mass in the truck bed (Fig. 3.4b), or (2) probing a pile of grain after it was dumped. *Never allow personnel to climb onto the grain in the truck bed while it is being emptied to prevent engulfment of personnel by flowing grain.* The total of all probe samples of one delivery vehicle can be mixed together to attain a truck by truck grain quality average. Probe samples should be placed in a sealable jar or plastic bag, and labeled accordingly.

Note that collected samples must be sealed air-tight to preserve their original integrity as sampled. Evaluate samples according to the decision tree in Section 2.

Figure 3.4a. A grain probe for manual sampling of trucks.

Figure 3.4b. Mobile ladder stand platform[7] for probing truck beds with a manual sampling probe.

A third approach to sample grain is by using a *hand scoop device* shown in Fig. 3.5. A hand scoop device can be easily fabricated locally. It should be able to scoop about 50 to 200g of grain at a time while a truck bed or hopper bottom trailer is discharged at the receiving pit or warehouse. Determine the sampling interval to be used in grabbing scoops by dividing the time is takes to fully discharge a load by 10, and grab samples at this interval when the truck or trailer is being

[7] https://www.wildeck.com/newwp/wp-content/uploads/2018/09/Rolastair-Standard.jpg

discharged. Grab samples can be pooled and should be placed in a sealable jar or plastic bag, and labeled accordingly. Note that collected samples must be sealed air-tight to preserve their original integrity as sampled. ***Also, it is preferable that sampling of corn be conducted ahead of the dump-pit or its final storage destination because the results of the sampled corn would guide where and how its should be stored.*** Follow the decision tree in Section 2 to guide what best management practice to implement based on the results obtained.

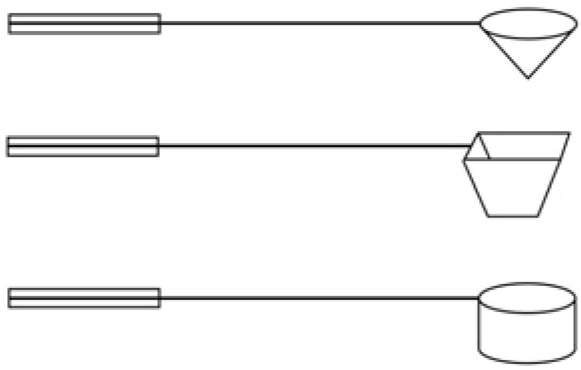


Figure 3.5. A hand scoop for sampling flowing grain.

Moisture Content Measurement: Moisture content is a primary quality parameter to check for all incoming grain. Therefore, it is absolutely critical to have several portable moisture content meters where grain is first sampled and received as well as a bench-top moisture meter kept at the quality control lab where all collected grain samples are analyzed. Manufacturers' instructions need to be followed to properly operate moisture meters, to maintain them in working order, and to utilize the most current calibrations. Some hand-held moisture meters and most bench-top moisture meters also measure the test weight (bulk density) of grain.

3.1.2. Grain Receiving and Transfer Operations

Grain receiving operations: Grain receiving is another critically important unit operation that often is a bottleneck in many facilities especially when not designed for high enough capacity, effective truck traffic flow, and operational efficiency. Grain receiving infrastructure when imported corn is transferred from the vessel into trucks must be designed for high-throughput operations so that truckloads can be unloaded quickly at the port facility (Refer to Section 4.2.1). Similarly, if grain is transferred from the vessel into belt or drag conveyors those must be of sufficient capacity for speedy transfer into temporary port-side storage.

The grain receiving pit is typically the entry gate to the facility storage, and should be a control point to catch quality issues, which might have been missed during sampling. Personnel at the receiving pit should watch for large clumps of grain, grain flowability (how grain flows) and any foreign items that might not have been discovered during sampling or transfers from the vessel. For example, should a large clump of grain be found, unloading should be stopped to determine the damage level according to the decision tree in Section 2. Issues to watch for at the receiving pit from clumped corn are localized wet spots, excessing molding and heating; all of which would lead to hotspot development once the corn is in the silo. Note that it is better to segregate excessively damaged corn for use immediately than mixing with a huge load of good quality grain.

Grain receiving and transfer operations to flat storage warehouses: The use of trucks with a tipping bed (dump truck) is typically used to unload grain on the floor of a flat storage warehouse. Ideally, the dumped load is first sampled before it is moved using a front end loader and stacked onto the bigger pile using a mobile grain pile loader (Fig 3.7). In this process of stacking the pile, loads of grain are mixed and fines are distributed more or less uniformly throughout the pile. Efficient and safe operation of this process, which typically involves one or more front end loaders inside the warehouse, and requires coordination of incoming dump truck traffic, must be carefully planned out with a trained crew.

Figure 3.6. Front loader moving grain to a grain pile loader.

In some flat storage warehouses, trucks are sampled before grain is unloaded into a dump pit and conveyed into the warehouse using a belt or drag conveyor installed in the headspace. Grain is dropped from the conveyor at several spout locations to form a more or less continuous pile along the length of the warehouse (Fig 3.8). This results in minimal or no use of front-end loaders to move the grain in place. This system saves operational costs because it eliminates the need for front end loaders and associated labor costs during filling. Front end loaders are still needed to retrieve grain and empty the warehouse.

Figure 3.7. Warehouse with an overhead filling conveyor.

Bulk grain conveying systems: Bulk grain conveying systems are a key component of a facility's infrastructure because it enables the efficient and high-capacity transfer of grain from one location (e.g., receiving pit) to another (e.g., storage silo). For high-throughput systems, the use of permanently installed equipment is needed. The type of conveying equipment can impact the breakage of corn during handling (Refer to Section 4.2). Breakage of corn kernels typically occurs during conveying when equipment is not properly operated or maintained, when grain is transferred from one conveyor to another, and when grain is discharged and drops a substantial distance into a silo or warehouse. In addition to physical damage due to dropping from excessive heights, damage also occurs due to excessive speeds down steep-angled or vertical gravity spouts, and due to impact on metal surfaces at the dead-end of a spout. To reduce physical damage during conveying, use cushion boxes, inline flow retarders, grain ladders, and other methods to reduce grain speed and impact force as grain is conveyed into the bin (Refer to Sections 4.2.4 to 4.2.8).

Belt conveyors are best for high through-put conveying and cause very little mechanical damage to the grain. Chain drag conveyors and screw conveyors are least desirable for conveying over longer distances considering breakage, product carry-over, and capacity versus power requirement, and are therefore best used for shorter transfer distances.

3.1.3. Grain Storage Structure Operations

There are three types of grain storage structures typically used at port facilities, grain warehouses and feed mills, i.e., flat- or V-bottom warehouses, and flat- or hopper-bottom steel and concrete silos. Each has advantages and disadvantages for storing corn (Refer to Section 4.3.1). All can be used to store corn or other grains at their recommended safe storage moisture contents. As long as the storage structure has a well-designed aeration system, is fitted with monitoring systems, and best stored grain management practices are implemented, it is possible to maintain the quality of stored grain.

Management of the storage structure involves ensuring that there are no holes, cracks or structural damage, especially on the roof from which water could ingress into the structure and onto corn. Undetected leakage from roof damage in silos is one of the causes of grain spoilage. In warehouses, ensure that the headspaces are sealed, especially areas having screens to prevent the entrance of birds. Silo and warehouse vents and exhaust fans should be screened to exclude the entrance of birds, rodents or other creatures that are harmful to grain. Routine inspection for damaged and plugged screens is highly recommended.

The structure must be cleaned after it has been emptied because insects typically harbor in residual grain, cracks and crevices. Silo and warehouse walls should be swept down or cleaned using hard brush brooms (with heavy bristles), an industrial vacuum cleaner or air pressure cleaner. For extra protection against residual insect pests, spray the structure's floor, interior and exterior wall surfaces up to 1.8 m (6 ft) with an approved empty-bin treatment insecticide such as Cyfluthrin (e.g. Tempo SC Ultra brand). Ensure that workers undertake all safety measures while spraying insecticides inside the silo such as wearing protective clothing, gloves, masks and goggles and having all entry hatches/manholes open to allow for good ventilation of the space. Where climbing is involved, use appropriate safety harnesses for fall protection from ladders and bucket lifts.

It is advisable to clean out broken kernels and fines from aeration plenums beneath the false floor or aeration pits of a silo. Broken kernels and fines accumulate in this area over time and decrease the effectiveness of aeration systems by increasing static pressure and thus reducing airflow. They also become a harborage for insect pests. Inspection should take place when the silo is emptied, and if fines have accumulated, a thorough cleaning is recommended.

3.1.4. Drying using Natural Air/Low Temperature (NA/LT)

Drying of corn in a silo or warehouse with natural air or air heated by a few degrees (3 to 6 ^{o}C) above ambient using fans sized with higher airflow than typically used for aeration can be successfully applied to reduce corn moisture content by about 2 to 3 percentage points. In-storage drying is a slow process and requires air with properties (temperature and RH) that reduce corn moisture. A one-degree rise of air temperature will reduce air RH by about 4.5 percentage points. That is air at 20^{o}C and 80% when heated to 23^{o}C will be at 66.5% RH and would dry corn to about 13% on average. Drying corn in a silo or warehouse needs adequate airflow (0.75-1 m^3/min per metric ton[8]) provided by high-capacity fans, full perforated floors or properly sized and placed perforated ducts for uniform airflow through the grain bulk, and well ventilated headspace above the grain mass with adequate roof vents or ideally power exhausts. In-storage drying moves a drying front from the bottom layer of the grain mass to the top grain layer from where it exits into the headspace (in a positive pressure airflow system). Airflow determines the time the drying front progresses through the grain bulk. The goal is to maximize the speed at which the drying front moves through the grain bulk for the fan size used while minimizing over-drying of the bottom layers. The depth of grain is limited by the power of the fan motors and is typical not more than 6-7 m. In-storage drying in warehouses can be facilitated by compartmentalizing the space with dividing walls. Each compartment can be filled and dried independently. Key for in-storage drying in silos and warehouses is the avoidance or removal of spoutlines and the leveling of grain surfaces.

[8] For consistency with the U.S. Grains Council Grains Conversion Calculator app, metric ton (mt) is used throughout this handbook which is defined as having a mass of 1000 kg.

Without uniform airflow drying will be non-uniform and can cause substantial differences in moisture content as well as extra electric utility costs. It should be noted that despite the higher airflow rates the drying process takes 30-50 times longer than the cooling of grain.

Once moisture content has been lowered to 14% or below, return to the decision tree in Section 2 and proceed to the next step.

3.2. Monitoring corn in storage, tools and how to use them

There are several variables and tools to monitor corn in storage to ensure it remains in good condition. The primary factors that determine the susceptibility of corn to fungal spoilage are temperature and moisture content. The on-set of spoilage can be determined early by monitoring CO_2 which results from respiration of corn kernels, fungal spores, and insect pests (*Sec 1.4.1*). For monitoring moisture content, temperature and CO_2 of corn stored in bulk, the recommended best practices are:

3.2.1. Moisture monitoring

Moisture content is the single most important factor that determines the storability of corn (*Sec 1.4.2*). Storability, or shelf-life, is based on the time it takes for fungi to consume about 0.5% of the stored corn dry matter, and by this damage to the kernels, at a given moisture content and temperature after which its U.S. grade would decrease by one level, e.g., U.S. No. 2 corn would decrease to U.S. No. 3, and so forth. Therefore, it is important to determine the moisture content of each incoming load of corn before it is dumped at the receiving pit. Representative sampling and determination of moisture content are best management practices to determine what actions to take such as (1) transfer to a silo for longer-term storage, (2) transfer to a silo for short-term storage requiring moisture management by aeration, or (3) transfer to a flat storage building for medium-term storage (*Sec 3.1.1*). Key tools for moisture measurement during grain receipt are portable and benchtop grain moisture meters.

3.2.2. In-store moisture monitoring

Thanks to advanced technology, moisture content of grain can also be monitored in silos and warehouses during storage. These typically consist of small relative humidity (RH) sensors that are integrated with temperature sensors and mounted on cables fastened to the underside of roof structures. The vertically hanging cables have sensors about 680 mm apart, which determine the RH/temperature of the interstitial air surrounding corn kernels in the bulk. These values are used to estimate the equilibrium moisture content of corn at each sensor location (Fig 3.9). This allows for monitoring moisture content and tracking changes in the grain bulk over time. It also allows for monitoring aeration cooling fronts and if intended to what extent a safer storage moisture content is achieved, or to what extent moisture shrink loss is incurred. Cables are most typically installed in silos but can also be installed in warehouse buildings. They usually work in conjunction with automated systems that enable programming and scheduling of fan aeration cycles targeted to specific stored grain management strategies such as selecting suitable ambient air to lower or maintain stored grain temperatures, change moisture content by ambient air drying, or ventilate the headspace above the stored grain mass to mitigate condensation conditions that could cause spoilage of the surface grain layer.

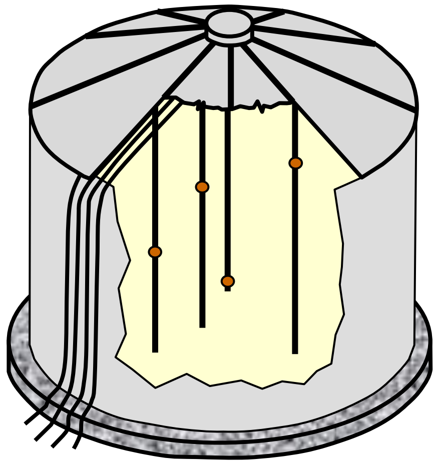


Figure 3.8. Schematic showing cables inside a silo, which are mounted with RH/temperature sensors.

3.2.3. In-store temperature monitoring

Temperature cables for monitoring stored grain is a technology that has been available commercially since the 1950s. Temperature sensors are mounted on vertically hanging cables about 2 m apart (Fig 3.9). They allow for monitoring temperature spatially and tracking changes in the grain bulk over time. They also allow for monitoring aeration cooling fronts and if intended cooling targets are achieved. Cables are most typically installed in silos but can also be installed in warehouse buildings. They usually work best in conjunction with automated systems that enable programming and scheduling of fan aeration cycles targeted to specific stored grain management strategies such as selecting suitable ambient air to lower or maintain stored grain temperatures, or ventilate the headspace above the stored grain mass to mitigate condensation conditions that could cause spoilage of the surface grain layer. Ideally, the stored grain bulk is cooled uniformly using ambient air to achieve temperatures below 20^{o}C that are not conducive to fungi and insect development. Whether aeration can be effective depends on local weather conditions (Sec 1.4.2). In some U.S. export grain locations, running fans at night or early in the morning can achieve cooling below 20^{o}C during certain times of the year (Sec 6.3). In many locations only maintenance aeration is possible unless grain chillers are utilized.

Grain is a good insulator. Thus, heat generated in a localized hotspot as little as 0.3 m away from a temperature sensor will likely not be picked up until deterioration is well advanced. Therefore, changes in temperature readings during aeration from the bottom of the grain mass to the top over time might help detect evolving hotspots and potential storage risks.

3.2.4. Wireless temperature and RH devices:

The use of wireless Internet of Things (IoT) plug-n-play devices with embedded temperature and RH sensors that can be easily placed anywhere in a silo or warehouse is on the rise. These wireless devices can be installed in the headspace above the grain surface to monitor temperature, RH and spoilage volatiles (CO_2) that determine when to ventilate to prevent condensation or send an early on-set of spoilage alert. Condensation on the top grain layer is one of the primary causes of surface crusting and deterioration in stored grain. Condensation conditions can be mitigated by controlling exhaust fans installed on silo roofs or the end walls of warehouse buildings. They can be programmed to exchange air from the headspace based on the dew point temperature of the air and the steel roof temperature. IoT devices can be easily installed by the end-user because they do not require electrical wiring. They are powered by built-in photovoltaic panels and communicate through Bluetooth and local GSM to cloud-enabled devices. They access nearby weather stations and provide management recommendations using smart phone apps. They can also access other IoT devices to turn on and off aeration fan and roof exhauster motor starters.

3.2.5. In-store CO_2 monitoring:

CO_2 monitoring of the headspace in a silo or warehouse, or in the exhaust stream of aerated corn is a good indicator of the onset of early biological activity in the stored grain bulk (Sec 1.4.1). Biological activity caused by fungi deteriorating corn produces CO_2, water and heat. Also, higher moisture corn undergoes a higher rate of respiration than low moisture corn. And, CO_2 levels increase as a function of insect activity in stored grain. Therefore, irrespective of the nature of the biological activity, CO_2 levels can be broadly used as an early indicator of unfavorable storage condition and over time an increasing amount of stored grain going out of condition.

CO_2 sensors are available as stand-alone sensors or incorporated into IoT devices that can be installed in the headspace of a silo or warehouse for continuous monitoring. They are typically coupled with temperature and RH sensors, and are most useful when tracking and displaying changes in readings over time. Another approach to measuring CO_2 is the use of a portable hand-held CO_2 meters. They are used to measure CO_2 in the exhaust airstream of a silo or warehouse aeration system. In the case of negative pressure (suction) aeration systems exhaust air can be sampled at the ground level; in positive pressure (push) aeration systems exhaust air has to be sampled out of the silo roof or warehouse end wall. Hand-held devices are also equipped with a temperature sensor that might pick-up increased temperatures from self-heating near where the measurement is taken when the fan is first turned on. Meaningful CO_2 measurements in an exhaust airstream are captured when fans that were off are turned on just before a measurement cycle is started. This allows for the build-up of CO_2 gas in the grain bulk to be moved out of the storage structure and past the sensor typically displaying an increase from ambient conditions to a peak value and then decreasing to a steady state level in the grain bulk.

3.2.6. Use the following recommendations to interpret CO_2 levels in stored corn

CO_2 levels in the range of 600 to 800 ppm are indicative of good storage conditions. Note that the steady-state CO_2 level of ambient air through dry, good quality corn ranges between 450-600 ppm because even good quality corn still undergoes respiration, albeit at very slow rates. CO_2 levels beyond 600 ppm are an early warning indicative of some biological activity due mold growth, insect presence, or moisture infiltration (Fig 3.12). Operators should first investigate whether there are any visible signs of condensation on the underside of roofs, crusting on the top grain layer surface, or insects flying in and out of the structure or active on the grain surface. CO_2 is highly sensitive indicating biological activity of as little as 0.1% of the total grain bulk. Thus, beginning to pay closer attention to changes in CO_2 readings on a weekly basis is more important than taking any immediate action. Once CO_2 levels rise steadily above 1500 ppm, investigating potential causes in more detail including reviewing temperature cable readings for any obvious changes and checking for a build-up in surface crusting should be conducted.

If CO_2 levels continue to rise above 1500 ppm and continue an upward trend towards 4500 ppm and beyond, severe mold infection, insect infestation or a combination is likely taking place. If this is detected in a silo, some grain should be unloaded but only after confirming the grain surface has not built up a thick crust of moldy, spoiled grain. Such a crust should be physically broken up first to avoid chunks of grain being drawn into the core of the grain mass during unloading and potentially blocking the floor wells of the silo. Only enough grain needs to be unloaded to detect grain damaged due to active spoilage and self-heating that must be dislodged and removed (Fig 3.13). Unloaded corn should be transferred into a flat storage warehouse, where it can be further broken up and spread out to dissipate heat. Samples should be taken to analyze damaged corn for moisture content and mycotoxins, and then the best practices outlined in Section 3.3 should be followed. Lastly, CO_2 levels can also be used to detect whether fans operated as scheduled, especially for automated systems capable of programming fan run times. When fans do not operate as scheduled to aerate the corn bulk, CO_2 levels will build up and remain high over time.

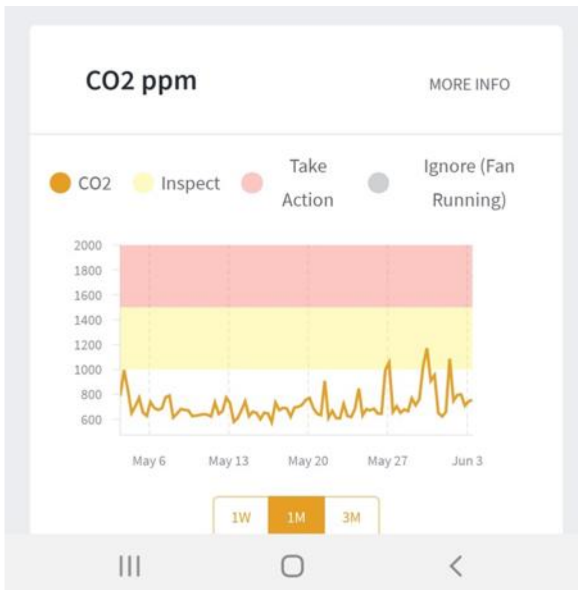


Figure 3.10. Headspace CO_2 reading in a silo over a one-month period indicating CO_2 spiking above 800 ppm on several occasions in late May indicating on-set of some spoilage activity. Turned out there was a small crack in a silo roof panel that allowed water to drip onto the grain surface whenever it rained.

Figure 3.9. Evidence of the small amount of spoiled grain after some grain was removed from the silo after spiking CO_2 readings were observed in a silo over a one-month period indicating on-set of some spoilage and revealing the location of the small crack in the silo roof panel that allowed water to drip onto the grain surface whenever it rained. After the crack was properly repaired, the problem was eliminated.

3.3. Temperature and relative humidity management in stored grain systems

Aeration is a temperature management tool using ambient or chilled air to maintain the grain bulk in a silo or warehouse as cool as possible to slow biological activity of insects and molds. Aeration requires turning on fans when ambient temperatures are such that they reduce grain temperatures, while limiting weight loss (shrink loss). Using aeration in tropical and subtropical regions where high relative humidities prevail can be a challenge, and may not be desirable nor necessary (see Sec 6.3). A good aeration system is ideally tied to a grain monitoring system and a weather station, which are used to determine bulk grain conditions when temperature thresholds are reached to turn on fans.

Aerating grain with ambient or chilled air to maintain safe storage moisture content of 14.0% or below can be successfully achieved using properly designed aeration systems. *Refer to Section 4.3.2 to 4.3.7 for information on aeration equipment.* It should be noted that ambient and chilled aeration utilize low airflow rates (0.05 to 0.15 m^3/min per metric ton) that are typically insufficient to achieve substantial moisture reduction in a timely manner. Cooling fronts take a minimum of 120-150 hours to move through a grain mass at an airflow rate of 0.1 m^3/min/mt. Moisture shrink results due to the evaporative cooling effect which causes corn to lose moisture as a function of the equilibrium moisture content relationship and the initial grain temperature being higher than the ambient air temperature. When that is not the case then the only option for lowering moisture content is artificial drying (Sec 1.4.2) or in-storage drying (Sec 3.1.4).

3.3.1. Aeration with ambient air

Ambient aeration can be used strategically to manage temperatures in stored corn once it has been transferred into a silo or flat storage building. Incoming shipments of U.S. corn will typically be cooler than the ambient air at the receiving port or in-country destination especially in the tropics and subtropics. Rather than warm corn up, it is preferable to keep it as cool as feasible because cooler corn is much less susceptible to deterioration by fungi and infestation by insect pests.

Tables 1.1 and 6.2 indicate the EMC of corn that can be achieved by aerating with ambient (or chilled) air at various temperatures and relative humidities. Note that an EMC of 13.9% can be achieved with air at 20ºC and 70% RH. Aerating corn with air of 70% RH or below in the temperature range of 20ºC to 35ºC will reduce grain moisture content to as low as 10.1%. As indicated in Section 1.4.2., key to successful ambient aeration is understanding the local weather conditions to determine whether, and if so, when to turn on fans, and for how many hours to operate them. See Sec 6.3 on best practices to manage stored grain at key locations for U.S. corn exports.

3.3.2. Aeration with chilled air

Chilled aeration systems use conditioned air to cool grain in silos or warehouses to temperatures as low as 10-15ºC and relative humidity's of 55 to 75%. At these conditions moisture shrink is minimized, and growth of fungi and insect pests is slowed or even stopped which preserves grain quality but can be expensive in terms of electric energy consumption. Due to the evaporative cooling effect of chilled aeration even under tropical weather conditions condensation of moisture can occur on the underside of silo and warehouse roofs that can drip onto the grain surface. Condensation must be mitigated by ventilating the headspace using silo roof or warehouse end wall exhaust fans (see Sec 3.12.3). Grain chillers are typically mobile units that can be connected to existing aeration fan ducts of silos and warehouses (refer to Section 4.3.3).

3.3.3. Managing the headspace microclimate

Condensation of moisture on the underside of silo and warehouse roofs can cause water to drip onto the grain surface. This is a common occurrence that leads to fungal sporulation, mold growth, sprouting of grain kernels, and eventually crusting of the grain surface. Condensation occurs when warm humid air in the headspace, which accumulates during high daytime temperatures, condenses on the underside of roofs and internal surfaces when the dew point temperature is reached after sundown. This condensed moisture drips back onto the grain surface, increasing the moisture content of the top grain layer, thus increasing the incidence of surface crusting.

Additionally, the higher RH of headspace air during night-time hours causes the moisture content of the top grain layer to equilibrate above safe storage conditions. For example, according to Table 1.1, headspace air at 30°C and 80% RH equilibrates towards 15% EMC compared to 12.4% EMC at 65% RH. Condensation can be mitigated by ventilating the headspace using silo roof or warehouse end wall exhaust fans (refer to 4.3.4). Fan control can be tied into a humidistat or a headspace monitoring unit to turn on when the dew point temperature is reached, typically soon after sundown when warm daytime air begins to condense on the underside of cooling roofs. Exhaust fans can also be turned on with a timer to run at sundown for a pre-determined amount of time to minimize runtime and electric energy consumption.

3.4. Mitigating Insect Presence

The U.S. and most importing countries follow WTO agreement on the application of sanitary and phytosanitary measures (SPS) to prevent or limit other damage within the territory of the member from the entry, establishment or spread of pests. For this reason, most shipment contracts specify shipboard fumigation after the vessel is loaded regardless of the grade level indicated on the official inspection certificate. In the U.S., shipboard fumigation is regulated by *U.S. Code of Federal Regulations Title 46 Part 147A – Interim Regulations for Shipboard Fumigation*[9]. It specifies that if a vessel leaves port during the fumigant exposure period, the person in charge of the vessel is responsible for ensuring completion of the fumigation including venting of the fumigated holds while at sea. Thus, detecting live insects in U.S. corn at ports of receiving is a rare event. When live insects are detected it is likely that infestation occurred during the port unloading process or along the in-country supply chain. The best recommended practices to mitigate insect presence are:

3.4.1. On-vessel fumigation after port arrival

This should always be conducted by a licensed fumigator and according to all applicable laws, regulations, and best industry practices such as the *GAFTA Standard for Fumigation and Pest Management*[10] or the *Code of Practice on Safety and Efficacy for Marine Fumigation*[11]. Phosphine fumigation using aluminum phosphide or magnesium phosphide pellets or tablets are the primary method used for shipboard fumigation of grain. It is important for importers to note that shipboard fumigation carried out during transit should be complete well before port arrival. Nevertheless, all required precautions should be taken to safely open the hatches to unload the vessel. Precautions such as ensuring that phosphine gas levels in the cargo holds reached safe levels before unloading grain should be adhered to. The U.S. Environmental Protection Agency (US-EPA) specifies 0.3 ppm as the maximum threshold concentration limit to which workers could be repeatedly exposed to without adverse effects. Also, note that aluminum and magnesium phosphide are flammable in humid air and could spontaneously combust in grain if it was not fully spent and is subsequently exposed to moisture. For more information, refer to the respective *Material Safety Data Sheets (MSDS) for aluminum phosphide*[12] *and magnesium phosphide*[13].

3.4.2. In-storage fumigation

In-storage fumigation might be necessary because grain storage and feed processing facilities provide good harborage for insect pests. Depending on the sanitation level and practices at a facility, insect pest infestation could occur upon receipt of grain and after transfer to a silo or warehouse. Tropical and subtropical countries have optimum climatic conditions for the development of insect pests.

3.4.2.1. *Fumigating silos:*

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[9] https://www.govregs.com/regulations/title46_chapterI_part147A

[10] https://www.gafta.com/write/MediaUploads/Trade%20Assurance/Draft_Gafta_Standard_for_Fumigation_and_Pest_Control.pdf

[11] https://www.imfo.com/IMFO_Code_of_Practice.pdf

[12] http://www.t3db.ca/system/msds/attachments/000/001/756/original/T3D1520.pdf?1413587740

[13] http://www.logbookcreator.com/docs/book/sheets/Fumi-Cel-MSDS.pdf

As with vessel fumigation, a properly trained and licensed fumigator should be employed whether that is an external contractor or an in-house employee. Phosphine fumigation utilizes most frequently pellets or tablets, but phosphine gas can also be supplied from cylinders or generators. Following guidelines on safe fumigation practices (such as the *GAFTA Standard for Fumigation and Pest Control*[10]) to achieve the dosage concentration levels over a given period of time (dosage × time) and especially proper sealing of the silo are key to achieving successful fumigation and mitigating the build-up of phosphine resistant insects. Phosphine resistance is a real concern among stored grain managers, fumigators, and phosphide manufacturers around the world.

3.4.2.2. Fumigating warehouses: The same guidance and advice as in the above sections applies.

Once insects have been mitigated, return to the decision tree in Section 2 and proceed to the next step.

Mitigating against musty, sour or objectionable odor –When corn samples taken from a vessel upon arrival at the port or along the in-country supply chain exhibit a musty, sour or commercially-objectionable foreign odor, then the shipment has at least some corn that has begun deteriorating due to moisture content and temperature above safe storage levels. Often only the surface grain in a shiphold is affected because the cover may have been opened during fumigant venting while at sea and a rain event may have surprised the crew before the holds were closed. Therefore, the location and extent of deterioration should be determined first. For example, if spoilage and self-heating occurring in a localized hotspot in a portion of the load, or is an entire shiphold affected. If only a portion of the load is affected, then this portion should be unloaded to a warehouse or similar location where front end loaders can break up the clumps of spoiled grain by dropping them on the floor and picking them up repeatedly to dissipate the heat. Ideally, deterioration is slowed or stopped. The mold-damaged corn should be kept separate and tested for mycotoxins. Depending on results, it can then be considered for utilization.

Note that corn in the same shiphold not undergoing active spoilage can still be contaminated by the off-odors from the deteriorating corn. Therefore, the odor-affected corn should also be kept separate but in a silo where it can be aerated to remove off-odors and prevent the risk for deterioration. Aerating odor-affected corn immediately is one of the quickest solution to dissipate the effects of grain exposure to deterioration and self-heating from a hotspot. *Refer to Sections 1.4.2 and 3.3 for more information on good aeration practices*. Irrespective of the relative humidity, the aeration fans should be operated at night-time when temperatures are typically cooler and ideally below 20^{o}C. Run fans through a number of night-time cycles until grain is cooled to the average night-time ambient temperature. This should drastically reduce off-odors and prevent risk for deterioration. The extent to which the fans need to be run depends on the residual off-odor and whether deterioration has occurred. If silos are equipped with temperature cables, the movement of the cooling front can be monitored to ensure the bulk has been adequately cooled. A CO_2 monitor held into the exhaust air or installed in the silo headspace can be used to detect whether aeration has stopped deterioration. *Refer to Section 3.2 for more information on best stored grain monitoring practices.*

Vertical aeration system: Aerating corn with a vertical aeration system might be the only option in a warehouse storage building without permanently installed aeration ducts. Just as with in-silo aeration systems, aerating corn using cooler night-time temperatures must be implemented immediately after the odor-damaged corn has been off-loaded and transferred to storage. It is important that clumped grain has been broken up and mixed well to avoid localized heating and before installing vertical aeration. This will ensure that should deterioration occur it is stopped and there is sufficient air movement for cooling the bulk. *Refer to Section 4.3.5 for more information and guidelines on vertical aeration systems.*

3.5. Ozonation

Ozone introduced into the grain bulk in gaseous form is an effective means of removing off-odors, deactivating mold spores, and killing insect pests. Ozone gas is manufactured by an ozone generator in-situ from abundantly available oxygen in air. Applying ozone to grain is best done in a dedicated treatment silo, rather than in a storage silo or large warehouse. This is because ozone needs confinement to prevent the disintegration of ozone molecules back to oxygen and maintain higher concentrations of ozone (50 ppm and above) to ensure high efficacy. Ozone gas is best supplied into the headspace of the silo to maintain 50 ppm and a small capacity fan and tubing is used to recirculate the ozone gas introduced in the headspace into the plenum and pushed up through the grain bulk. Ozone is continuously introduced into the headspace during the ozonation period to ensure 50 ppm is maintained. This treatment process could last for up to 3 or more days. After ozonation is complete, the silo should be cooled to the average night-time temperature as described above.

Once musty, sour or objectionable odor has been mitigated, return to the decision tree in Section 2 and proceed to the next step.

3.6. Mitigating against BCFM level greater than 4%

When corn samples taken from a vessel upon port arrival have a BCFM level greater than 4%, corn will continue to incur mechanical damage during unloading the vessel and transferring to trucks, conveyors, receiving pits, and storage structures. Each handling step results in more BCFM as it is transported from the ocean vessel to the import terminal and final in-country destinations. Therefore, the amount of BCFM reported on the export certificate will generally be lower than what is actually received at the destination feed mill. Once received, additional damage occurs during conveying from the receiving pit through several bucket elevator and drag conveyors to storage in a silo or warehouse. Given the nutritional value of BCFM remains the same as whole corn kernels, the operational strategy of a feed mill should be on how best to incorporate BCFM in the finished feed to maximize profitability. The best recommended practices are based on reducing the amount of BCFM to a level that (1) enables better stored grain management of the remaining grain bulk and the separated amount of BCFM, and (2) economically incorporates the separated amount of BCFM as a feed ingredient into finished feed.

3.6.1. Screening

Screening (cleaning) is undertaken primarily to remove broken corn and fine material from larger broken and whole kernels. *Refer to Section 4.1 for a more in-depth review on screening and equipment options.* Screening is not intended to eliminate BCFM and reduce the level to zero.

Instead, reducing the amount of BCFM below, for example, 4% (U.S. grade 3), the remaining grain bulk will allow for better storage management. Specifically, flowability of the grain bulk will be improved, spoutlines under gravity drops will be less pronounced, and airflow through the grain bulk during aeration will result in faster cooling. This has financial benefits with respect to operations management, handling, and safety. The BCFM screened off should be stored as a separate feed ingredient in a bay of a warehouse or in a pile on the floor of a flat storage building or in a hopper silo designed for feed ingredients. It can then be formulated into feed rations and blended back into corn ahead of hammer milling. *Refer to Section 3.9 for handling BCFM screenings.*

Note that BCFM might contain higher levels of mycotoxins than whole kernels because the exposed starch of broken corn is more susceptible to mold development when exposed to relative humidity's above 65-70%. It is advisable to determine the levels and types of mycotoxins (*aflatoxins*, *penicillium and fumosins*) that may be present to determine at what ratio it can be blended in ahead of hammer milling. For example, beef cattle are most tolerant to higher levels of mycotoxins. *Refer to Section 3.8 for more information on testing for mycotoxins.*

3.6.2. Scalping

Scalping is undertaken primarily to remove foreign material other than grain kernels that would not pass through a chosen screen size. In the case of the U.S. corn standard that is defined as "all matter other than corn that remains on top of the 12/64 round-hole sieve according to procedures prescribed in FGIS instructions". *Refer to Section 4.1 for a more in-depth review on scalping and equipment options.* The size of screen to choose depends on the goal of scalping. Most scalping processes aim to remove large foreign objects that would contaminate finished feed, and damage handling and milling equipment. *Refer to Section 3.10 for handling BCFM scalpings.*

Once high BCFM levels have been mitigated, return to the decision tree in Section 2 and proceed to the next step.

3.7. Mitigating against Total damage level greater than 7%

Determining total damage levels greater than allowed in the U.S. corn grade purchased in U.S. corn at ports of receiving is a rare event. The primary reason this could occur during ocean transport is due to kernel damage related to spoilage or insect infestation increasing. When corn samples taken from a vessel upon port arrival or along the in-country supply chain have a total kernel damage level greater than 7%, the damage type and percentage amounts should be determined. Damaged kernels as defined by the U.S. Grain Standards for Corn are
"kernels and pieces of corn kernels that are badly ground-damaged, badly weather-damaged, diseased, frost-damaged, germ-damaged, heat-damaged, insect-bored, mold-damaged, sprout-damaged, or otherwise materially damaged". Most of these types of damage are caused in the field prior to harvest with some than can also be caused during post-harvest handling, drying and storage such as germ-damaged, insect-bored , mold-damaged and sprout-damaged. Germ, mold and sprout damage can occur when corn spoils during storage, and insect damage can occur when insect pests infest corn during storage.

Heat-damaged kernels are a sub-category of total damaged "kernels and pieces of corn kernels that are materially discolored and damaged by heat". They are caused due to excessively high drying temperatures during artificial drying aimed at lowering harvest moisture content to around 15% moisture content which is the recommended safe storage moisture content in the U.S. corn growing region. Relative quantities of each damage type varies from season to season. In some years when harvest moisture contents are high in the U.S. corn growing region, heat-damaged kernels might be more common because more of the U.S. corn had to be dried using high-temperature dryers. The primary concerns with these damage types are the reduced nutrient level of corn primarily in the form of damaged starch (energy), and the potential for mycotoxin contamination. Both concerns reduce the nutritional value of feed made from such corn. The best recommended practices are:

3.7.1. Heat-damaged kernels

For corn with the maximum amount of heat-damaged kernels the U.S. grade for corn allows (e.g., 0.2% in #2, 0.5% in #3, 1.0% in #4) in the damaged kernel total, the corn can be stored and processed without special treatment. The heat-damaged kernels will most likely be uniformly distributed in the grain bulk. Studies have shown that heat-damaged kernels can be successfully utilized in feed for beef cattle, dairy cow, and poultry with minimal impact on energy levels.

3.7.2. Damaged kernels other than heat-damaged

For corn with the maximum amount of damaged kernels other than heat-damaged kernels the U.S. grade for corn allows (e.g., 5.0% in #2, 7.0# in #3, 10.0% in #4), mold-damaged kernels is the primary concern because of the potential level of mycotoxin contamination. This is especially true if mold damage increase due to spoilage problems of the corn during ocean transport. Refer to Section 3.8 for mitigating mycotoxins in corn. Depending on types and levels determined, guidance should be sought from qualified animal nutritionists or veterinarians as to recommended amounts to blend into good quality corn ahead of hammer milling for feed rations designated for certain species such as large ruminant diets (e.g., beef cattle).

Once high total damage levels have been mitigated, return to the decision tree in Section 2 and proceed to the next step.

3.8. Mitigating mycotoxins

All U. S. corn is tested at export for aflatoxin, the most common mycotoxin in corn. Corn containing more than 20 parts per billion cannot be loaded. Thus, detecting aflatoxins in U.S. corn at ports of receiving above this level is a rare event. When aflatoxins or other mycotoxins are detected above allowable levels, it is likely that they developed as a result of spoilage problems of the corn during ocean transport.

Identification and quantification of mycotoxins and other contaminants should always be undertaken by qualified personnel and according to all applicable laws, regulations, and best industry practices such as the *United Nations FAO and WHO Codex Alimentarius*[14] *General Standard for Contaminants and Toxins in Food and Feed*[15].

Aflatoxin is a chemical toxin produced by the storage fungi *Aspergillus flavus and Aspergillus parasiticus*. These molds grow well and produce aflatoxins at temperatures over 20°C and relative humidity conditions between 85-99%. Mitigation of mycotoxins should always be undertaken by qualified personnel and according to all applicable laws, regulations, and best industry practices such as the *Codex Alimentarius Code of Practice for the Reduction of Aflatoxin B1 in Raw Materials and Supplemental Feedingstuffs for Milk Producing Animals*[16]. Corn with higher aflatoxin levels can be blended with good quality low-moisture content corn ahead of hammer milling to achieve feed rations below the maximum limits recommended for an animal species (*Table 3.1 a, b, c*). Corn with higher aflatoxin levels should be kept segregated and only for short-term storage (less than one month).

BCFM is more susceptible to colonization by mold, and therefore might have higher mycotoxin levels compared to whole kernels of corn. Screening out BCFM is a practical strategy to reduce aflatoxin levels in a load of corn. The screened-out BCFM should be kept segregated and can be blended with good quality low-moisture content corn ahead of hammer milling to achieve feed rations below the maximum limits recommended for an animal species *(Table 3.1 a, b, c)*. Also, corn with a higher aflatoxin level can be directed to more tolerant livestock species such as beef cattle (*Table 3.1 a, b, c*).

Once mycotoxin levels have been mitigated, return to the decision tree in Section 2 and proceed to the next step.

3.9. Handling BCFM Screenings

When corn is screened to reduce the amount of BCFM in a batch of corn, samples of the screenings should first be analyzed for moisture content and mycotoxins specifically aflatoxins *(see Section 3.8)*. Even if a corn shipment was initially certified as mycotoxin-free, molds develop more readily on broken corn, fines and grain dust, and thus can concentrate in BCFM screenings. BCFM screenings can be lower in moisture content than whole corn kernels in the same batch. Nevertheless, they should be stored separately similar to other meal-like feed ingredients in a bay of a warehouse, in a pile on the floor of a flat storage building, or in a separate hopper silo designed for feed ingredients. If mycotoxins do not exceed regulatory or guidance levels in the destination country, the best recommended practices for handling BCFM screenings are:

3.9.1. Add back BCFM in future corn shipments

BCFM can be added back at a desired ratio to the bulk whole corn prior to shipment in the case where the facility is selling commodity corn. This strategy enables uniform distribution of BCFM in a shipment and can be used to deliver corn economically at contracted BCFM levels. *Refer to Section 4.4 on the benefits and costs savings considerations of this strategy.*

[14] http://www.fao.org/fao-who-codexalimentarius/en/
[15] www.fao.org/fileadmin/user_upload/agns/pdf/CXS_193e.pdf
[16] www.fao.org/input/download/standards/331/CXP_045e.pdf

3.9.2. Add back BCFM to corn destined for Processing

BCFM, once tested for mycotoxins, can be added back to and formulated into feed rations ahead of hammer milling. This strategy can help ensure manufacturing of a consistent feed formulation, and maximizes milling efficiency. It also reduces and limits the inherent risks associated with "batch feed" from storage, particularly when BCFM is not uniformly distributed in the storage structure. *Refer to Section 4.4 on the benefits and costs savings considerations of this strategy.*

3.10. Handling FM Scalpings

When corn is scalped as part of the screening process to reduce the amount of FM in a batch of corn, the scalpings should be checked as to whether they primarily consist of plant material such as corn stalk and cob pieces, soybean straw or pods, or truly non-plant foreign material such as stones, mud balls etc. Plant material has nutritional value (primarily fiber) and can be utilized in feed rations, especially for ruminants. The best recommended practices are:

3.10.1. Discarding scalpings

Scalpings should be discarded as trash when they primarily consist of non-plant foreign material.

3.10.2. Utilizing scalpings

Scalpings can be utilized as a feed ingredient when they primarily consist of corn stalks and cobs, straw, pods and dry plant forage. It is best to visually examine the quality of the scalpings to determine whether they have undergone severe deterioration and are suitable for use. It is advisable to prioritize the use of scalpings in ruminant feed since beef and dairy cows are more tolerant to higher levels of fiber. *Refer to Section 4.4 on the benefits and costs savings considerations of this strategy.*

3.11. Utilizing BCFM Screenings and Scalpings in Feed Milling

BCFM screenings that have been tested for mycotoxins and plant-based scalpings can be utilized in feed rations. BCFM has the same nutritional value as whole corn kernels as do scalpings that are free of non-plant foreign material and primarily consist of corn cobs/stalks and bean pods. The practice of screening and scalping improves the storage quality of bulk corn and ensures that these materials can be uniformly added back into feed rations ahead of hammer milling. The best recommended practices are described in *Sections 3.9 and 3.10.*

3.12. Reducing the impact of BCFM on storage

3.12.1. Coring to improve airflow in aerated storage structures

Coring is the practice of removing BCFM that have accumulated under a spout-line in a silo or flat storage building. The larger and smaller size particles contained in corn segregate while they drop into the storage structure during the filling operation. Smaller particles such as broken corn and fines accumulate within the spout-line, for example, in the center of a silo. Larger particles such as large whole kernels and plant materials (corn stalk, soybean pods) flow on the grain surface away from the spout-line. This spout-line is compacted with smaller particles, so porosity is reduced, and airflow is hindered. Less airflow during aeration during storage can result in a higher susceptibility to fungal growth, self-heating, and spoilage. Coring therefore has several important benefits to maintaining stored grain quality: (1) more uniform airflow during aeration results in less cooling time and electric energy use, (2) a less conducive environment for insect pests and fungi to develop, and (3) profitable utilization of cored grain, typically containing high levels of BC and fines screenings as a separately stored feed ingredient.

3.12.2. Single versus multiple coring cycles

In large silos (> 15 m radius) and with grains containing high levels of BCFM (>7%) it is advisable that grain in the center (spout-line) be cored (drawn out) repeatedly as a silo is filled. (Fig 3.15) This ensures that most of the accumulating BC and fines in the spout-line are being pulled out before the silo is completely filled. A practical rule to follow is to core the grain mass until about 1/3 to 1/2 of the silo diameter becomes an inverted cone from the surface (Fig 3.16).

3.12.3. Alternative use of cored grain material

The cored grain material has a similar nutritional value as BCFM and whole corn. As such it should be considered a meal-like feed ingredient. The practices of coring and screening improve the storability and management of the stored grain bulk. The cored material and screened BCFM should be stored in a separate warehouse bay for utilization as described in Section 3.9.

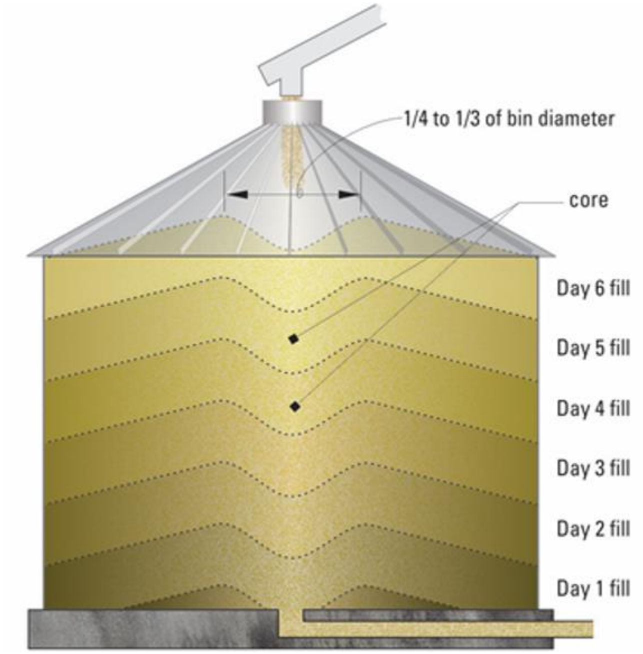

Figure 3.10. An illustration of multiple coring cycles for large diameter silos to remove high accumulation of broken corn and the fines portion of foreign material (Source: MWPS-13, Iowa State University).

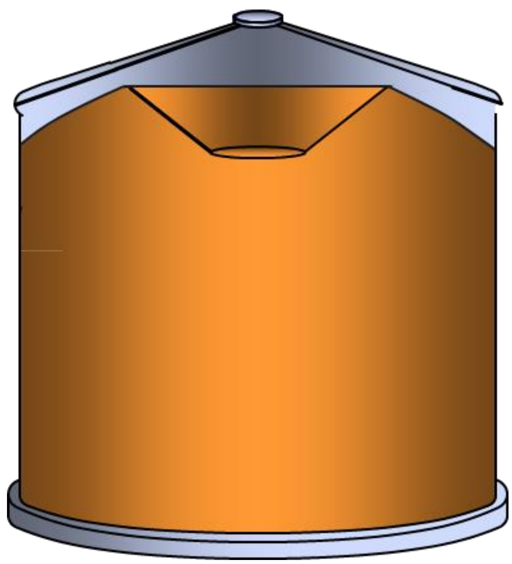

Figure 3.11. An illustration of a cored bin after the fines and broken corn have been pulled from the center, enabling more uniform airflow during aeration (Figure is courtesy of Dr. Sam McNeill, University of Kentucky).

4. Preparing Facilities for Improved Handling of U.S. Corn

Key to maintaining quality of imported corn during handling and storage is the combination of best practices and good equipment. ***Good equipment is critical for minimizing damage and best operations management practices are critical for preserving grain.*** The focus of this section is on the equipment options available for modifying and preparing facilities for improved handling and storage of U.S. corn, and on determining the value of making investments in upgrading and adopting improved operational practices. A key challenge in maintaining stored grain quality is mitigating negative effects of broken corn, foreign material, fines and dust. Thus, two concepts need to be defined first.

Scalping - While scalping and cleaning (screening) are sometimes used synonymously, they are, however two distinct and opposite functions. Scalping is the removal of material "larger than" and cleaning is removing material "smaller than" the grain being handled.
In scalping, the amount that is removed in this process depends on the size of the screen openings that the material is flowing over. The larger the size of the opening, the more material will stay with and flow through with the grain. Typically, this material consists of stalks, cobs, mud balls, and such non-grain materials considered foreign material (FM) but can also contain materials that are non-organic in nature. These can include items like rocks, stones, elevator buckets (both whole and pieces), wood boards, large bolts, chain conveyor paddles, cans, water bottles, cell phones, wallets, tools, hammers, lining materials, and so on.

Cleaning (Screening) - is the process of removing fines from the grain stream, and in the case of corn, this includes both BC and FM, material that is "smaller than" the whole kernel. The percentage of fines that is removed varies greatly, primarily dependent on the specific screen opening, depth of flow over the screen, and the percentage of fines in the grain stream prior to cleaning. The material that is removed consists primarily of fine dust, broken corn, and other organic material. The single greatest variable with regard to "particle size" of the material that is removed is the size of the screen openings. Screen opening and screen type can be varied to achieve the desired cleaning effect. Below are various types of machinery that can be utilized to achieve the desired results for the facility.

4.1. Equipment Options for Cleaning Corn

4.1.1. Gravity Cleaners

A gravity cleaner consists of an enclosure (varying types), typically with one inlet for the uncleaned grain stream and two outlets, one for the cleaned grain and one for the fines and BC portion (Fig 4.1). Grain flows over a set of screens inside the enclosure. Total screen surface area and the screen openings determine capacity while actual removal rates depend primarily upon the level of fines in the uncleaned grain stream. Most gravity cleaners can be purchased with a "bypass option" that allows the operator to adjust the amount of corn that can "bypass" the screens sections. By adjusting this valve, the operator can vary the amount of grain that bypasses the screens from 0 to 100 % (full bypass). While this valve is generally offered as a "manual adjustment, it can be automated. Either way, both the cleaned grain and the bypassed grain are recombined at the bottom discharge of the cleaner. The fines from the cleaning process accumulate under the screens, and are discharged at the bottom of the cleaner via a separate spout. Gravity cleaners are simple in design and require no power to operate. The screen material and screen sections can be easily changed to meet current conditions and customer needs. They require little maintenance. Due to the simplicity of design, they are effective, efficient, and comparatively inexpensive. There are numerous manufacturers, with slightly different designs, but the operating principles and equipment operation are basically identical. The most common units are diamond shaped. Capacities range from 25 TPH (metric tons per hour) up to 1,500 TPH.

Figure 4.1. External and internal views of typical gravity cleaners with replaceable screens of different sizes.

4.1.2 **Powered Cleaners** (with or without built-in scalper)

These units operate on the same principles of fines removal, and particle separation, but as the name suggests they are powered. These units are offered in single and multiple deck configurations (Fig 4.2). They can separate FM from BC in corn. There are almost endless screen options and can operate at capacities exceeding 1,500 TPH. The units generally have one common inlet but require multiple outlets for each particle size separation that the end user desires.

Some units have the ability to both scalp and clean in one enclosure, in a single pass, but may require aspiration and dust control. Due to the complexity of these units, they can be expensive to purchase and operate, require routine maintenance, and require a sizable structure to support their physical size. If a unit does not have a built-in scalper, it is highly recommended that a separate scalper unit be installed upstream to provide protection for the internal components when a "screen only" unit is installed. Similar to gravity units, screen sections can be installed that allow for different types of grains to be cleaned. While these units allow the facility to be far more flexible in its cleaning capabilities, it generally comes with significant investment. Typical installations would be at terminal and export facilities, food grade and seed grade cleaning facilities, or any facility where extremely close control of BCFM and fines is desired by the end user.

Figure 4.2. External and internal views of typical powered cleaners with multiple decks and replaceable screens of different sizes.

4.1.3 Rotary or Drum Style Cleaner and Scalper

As the name suggests, these units are round drums that are covered with material for screening and in some cases can scalp and screen in one pass (Fig 4.3). These units can be either fixed or mobile with capacities that are typically less than 50 TPH. However, multiple units can be set up in a parallel configuration to increase capacity. These units can be easily moved, with equipment generally found at most grain handling facilities, so investment can be spread across multiple facilities. They can be powered by fixed electrical, portable generators, farm tractors, or any piece of equipment with a power take off (PTO) drive. Because of their design, these are not typically "in-line" units but rather require separate equipment (matched to their capacity) to feed product in and take away product after cleaning. They require little to no structure and can be positioned at virtually any location within the grain handling system. They generally have a single inlet, and multiple outlets (clean grain, fines, and scalps). Due to their simple yet effective design they are cost effective, require little maintenance, but do require that operators be continuously present while in operation to monitor.

Figure 4.3. Rotating drum-style cleaner that allows for screening and scalping.

4.1.4 In-Line Screening and Scalping Devices

Custom modifications are unique to each facility and material handling systems. The concepts of scalping and cleaning are similar, and the intent is to remove fines and overs by modifying existing equipment. The significant difference is that each unit installed must be designed and installed with a single point of use concept. And while these concepts can be duplicated, each design needs to be matched to the capacity of the existing material handling system.

The pit grates are an excellent example of scalping that takes place at the receiving building (Fig 4.4). The grates that support the delivery vehicles and its contents act as the first line of defense to keep unwanted material from entering the grain stream **(scalping)**. A widely accepted practical pit grate opening is 6.35 cm (2 1/2 inches) maximum to help prevent the introduction of unwanted materials such as rocks, stones, tramp metal, and other undesirable materials.

Figure 4.4. Typical receiving pit grate designed as a first line of defense to keep unwanted material from entering the grain stream.

In addition to the fixed grates, consideration could be given to applying large sections of screen material (with smaller openings) over the fixed grates to form another "layer" of scalping at the receiving pit.

Similar concepts can be extended to other points downstream in the grain handling system to protect that equipment, and remove unwanted materials that inherently enter the grain stream during cleaning operations, maintenance and/or other equipment related items.

If scalper grates are installed downstream from the discharge of any piece of equipment, access must be provided in order for the operator to clean the scalper grates. From a design standpoint, consideration must be given to provide adequate surface area to maintain flow, remove desired material, and yet not cause a restriction that could hamper system performance.

Custom **Screening** devices require a thorough review of the material handling system, and generally involve modification to existing spouting and conveying equipment. They generally do not require the addition of any structure for installation, but most require some form of additional spouting to take away the fines that are collected in this process. Some examples would be:

1. Removing the solid bottom (trough) of a screw conveyor, and replacing the bottom with screen material. As the screw conveyor pushes the grain forward over the screen material, the fines drop out, are collected in a hopper directly below, and the fines are spouted to some form of storage vessel. The efficiency of this process is affected by many factors, including speed of the screw (RPM), length of the screen material, and the size of the screen opening. For this type of a custom device to be most effective, it should be installed closest to final storage (building, silo, tank).

2. Removing the solid bottom (pan) of a flat bottom chain conveyor, and replacing the bottom with screen material. This modification will act in a similar fashion as the screw conveyor. However, as the solid pan provides support for the chain, additional consideration must be given to supporting the chain and attachments. This will prevent premature wear of the to the screen material and protect the chain and attachments. The effectiveness of this type of "cleaning" is dependent on chain speed, length of the screen material, and opening size, and grain depth within the conveyor.

4.2 Equipment Options to Reduce Corn Breakage during Handling

4.2.1 Grain Receiving Pit

In facilities that unload grain to be stored in steel or concrete silos, multiple grain receiving pits are preferred for high-throughput operation. The following are guidelines to ensure grain receiving pits are designed for high-throughput (Fig 4.5):

- Ensure that receiving pits are sized large enough to adequately handle the largest truck loads without spilling grain during unloading.

- Ensure trucks can drive forward into the assigned receiving pit from the weigh scale and drive out forward without the need to back up (drive through receiving pit).
- Ensure trucks, and in many cases truck and trailer rigs, can be hoisted and allowed to unload during the lifting operation. Dump trucks that use their built-in hydraulic cylinders to tip up grain beds slow down unloading capacity, and should they fail in the process can endanger operations personnel and truck drivers.
- Ensure that conveyors below the receiving pit have adequate capacity to take away the grain out of the pit to prevent spillage during unloading.
- While many places still use hoists to unload grain trucks, a modern facility should be designed to handle hopper-bottom trailers.
- Ensure that receiving pits are covered with heavy-duty steel grates to allow trucks to drive over and also prevent persons, large animals and/or pets from falling through without hindering grain to pass through.
- Ensure that the receiving pit area is enclosed by a roofed structure so that unloading operations can be carried out when it is raining.
- Ensure that receiving pits can be easily cleaned out and covered when not in use to prevent non-grain materials and other contaminants from falling in or be swept in.
- Ensure there is dust suppression and collection installed at each receiving pit ideally using an integrated point-of-use dust collection system.
- Ensure that receiving pits are built in a well-drained area, or have sump pumps installed below to prevent water from getting into the take-away conveyors.

Figure 4.5. Drive-through receiving pit with heavy duty grate and dust suppression and control system. Note cleaning tools including brooms and shuffles hanging on the wall for easy access to cleaning up the receiving pit area after trucks have been unloaded.

4.2.2 Minimizing or Eliminating Extra Handling

Any effort to reduce and or eliminate additional grain handling activities is highly recommended. Through the examination of existing practices and procedures, operations managers may be able to identify opportunities to help reduce losses and damage due to unnecessary handling. An example would be the installation of a cleaner to screen corn during transfer into storage instead of screening corn during coring or during unloading at the end of storage.

4.2.3 Slowing Conveying Speeds

Slowing chain speeds of drag conveyors can reduce breakage and fines generation. By reviewing design and operation, there may be the opportunity to slow chain speed and thereby increasing grain depth in the conveyor. This can help reduce breakage and resulting fines generation while corn is transferred.

4.2.4 Cushion Boxes

Cushion boxes are typically installed at the end of a downspout run, just prior to the grain being dropped into the storage silo or warehouse. They operate on the principle of establishing a center section of grain within the spout, that forms a "cushion" of grain (Fig 4.6). As the grain flow increases and the grain contacts the "cushion", velocity is lowered by grain contacting grain instead of grain contacting a metal surface. As flow increases, additional grain flows around the cushion slowing due to grain-on-grain friction. This reduces damage due to high velocity and the resulting impact on metal. Access should be provided to occasionally clean out the cushion section. Automatic clean-out of the center cushion between flow of different grains (corn versus soybeans) is possible via an adjustable baffle at the bottom of the spout.

Figure 4.6. Example of a cushion box that reduces grain velocity as grain flow comes in contacts with the "cushion" as a result of grain contacting grain instead of metal surfaces.

4.2.5 In-Line Flow Retarders

These devices are installed in downspout runs, typically between the bucket elevator leg and the distributor and/or the drop-point into the storage silo (Fig 4.7). Their primary purpose is to slow the velocity of grain similar to a cushion box. The primary difference is location. Flow retarders should be installed about every 10 m along the incline section of the spouting. Some studies have shown that these devices can actually increase the generation of BCFM, but more studies are needed. *Personnel access is required, and must be provided, to remove materials that could* *become lodged, and eventually restrict flow. Given their location, this is challenging. Without it, removal of the spouting will be required with the help of a crane or other specialized equipment that is expensive to rent or contract, and can result in significant downtime.*

Figure 4.7. Example of a flow retarder installed in a gravity down spout that reduces grain velocity as grain flow expands in the volume of the retarder.

4.2.6 Gravity and Powered Grain Spreaders

Gravity (Fig 4.8) and powered grain spreaders alike perform one primary function during filling a silo. They disperse (spread) broken corn and fines more evenly throughout the grain mass, and reduce particle separation that leads to the accumulation of BC and fines in a spout line. Capacities range from 10-1000 TPH, and can be installed in silos with diameters from 6 to 45 meters. Gravity and powered spreaders are designed to operate at a specific grain flow rate. As the flow rate changes, adjustments must be made to achieve the desired results. Failure to do so can negate any advantages the operator is hoping to achieve. Large gravity spreaders have a series of spouts along the chutes giving them somewhat of a spiderlike appearance. Spreaders can help eliminate the need to core. While some manufactures suggest they may reduce fines generation, experience indicates this is marginal at best and not well documented.

Figure 4.8. Example of a gravity cone spreader (left) and a gravity-driven, rotating multi-chute spreader (right) dispersing grain into the silo. This avoids the accumulation of broken corn and fines in the core, and prevents peaking of the grain mass.

4.2.7 Grain Ladders (or Bean Ladders)

Grain ladders, commonly called bean ladders, are generally found in seed and food grade facilities where "broken kernels" equal a low value, often unusable product (Fig 4.9). They are installed between the downspout and floor to gently flow the grain into the silo instead of dropping it. The reduced velocity of the grain by the "back and forth" flow essentially eliminates breakage. While most commercial units are designed for low capacity (5-50 TPH), the concept can be scaled up with known examples of 250 TPH or higher with proper design.

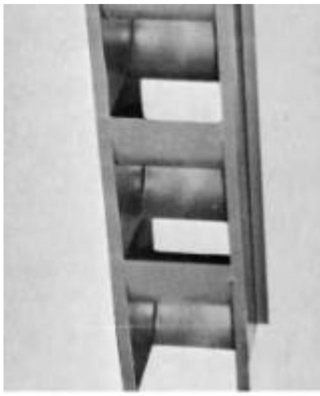

Figure 4.9. Lower section of a grain ladder used to gently lower grain from the downspout into the silo. This avoids dropping the grain and causing additional breakage of kernels and segregation of larger versus smaller particles.

4.2.8 Spout and Conveyor Lining Materials

By using softer lining materials in areas of high impact, operators can reduce additional breakage that is inherent in handling systems. Steel, ceramics and other hard, durable materials are by design installed to reduce wear to the original metal spouting, and conveyor or distributor housing (Fig 4.10). By using softer materials (generally rubberlike and up to 2.5 cm thick) to cushion impact, additional breakage can be reduced effectively. While these "softer" materials are good for impact locations, they are not recommended in "sliding" applications because they decrease flow rates due to greater friction and increase maintenance due to frequent replacement.

Figure 4.10. Examples of lining material installed inside downspouts to reduce additional corn breakage and wear of internal metal surfaces.

4.2.9 Vented Bucket Elevator Cups to Improve Handling

The venting of bucket elevator cups (buckets) can improve both material loading (uptake at the boot) and discharge (at the head) of product (Fig 4.11). By allowing air to be more easily displaced when picking up grain, cup fill will be increased. Discharge of cups will improve during emptying which reduces the chance for "backlegging", and thus maintains conveying capacity. Backlegging results when grain from the discharge head section returns inside the bucket elevator casing back down to the bottom boot section. The primary cause of backlegging is excessively high belt speeds that do not allow the grain to be flung out of the buckets when they move across the head pulley. The amount of grain returning from the head section impacts conveying capacity and can lead to excessive generation of broken corn and fines.

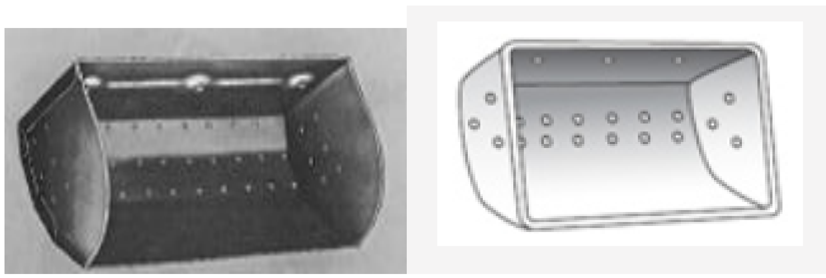

Figure 4.11. Vented bucket elevator cups to improve uptake and discharge of product in a bucket elevator.

4.2.10 Replacement of Screw and Chain Conveyors with Belt Conveyors

Both screw and chain type conveyors are a lower cost alternative, and are widely used when multiple discharge points are required. The use of belt conveyors is recommended to reduce BCFM generation which is inherent to both screw and chain conveyors. Worn screw flights, paddles, liners, chains, sprockets and product carryover can all lead to unwanted BCFM generation.

4.2.11 Modification of Existing High Impact Locations

Replacement or modification of downspout ends ("deadheads"), and other high impact locations, should be of high priority to reduce unwanted BCFM generation. Examples are leg discharges, spouting, and any location where abrupt directional change takes place in a handling system. Actual design and modification vary greatly and depend on existing spouting, etc., but every opportunity should be explored in an attempt to reduce additional handling shrink and BCFM generation.

4.3 Equipment Options to Preserve Stored Grain Quality

4.3.1 Grain Storage Structures

Flat- or V-bottom warehouses: Warehouse structures with flat floors or V-shaped bottoms can be used to safely store corn and other grains. Flat bottom warehouses are the most flexible storage systems because they can handle both bulk raw materials and bagged finished products (Fig 4.12). Warehouses can be partitioned with fixed walls or movable bulkheads to store several commodities or feed ingredients at the same time. Warehouses with V-shaped bottoms substantially increase storage volume under the same roof but are only feasible in areas with low water tables. One of the drawbacks of warehouse structures is installation of aeration systems to condition stored grain if no aeration system was installed when the structure was first built. Above floor aeration systems can be laid out but are a challenge for front end loaders to maneuver around during filling and reclaiming operations. Additionally, monitoring grain temperatures using cables and controlling the headspace conditions between the grain surface and roof of the warehouse can be a challenge. Filling and reclaiming grain from warehouse structures requires more labor and the use of front-end loaders because in-floor or above-floor conveying systems to take advantage of gravity flow during unloading are seldom installed.

Figure 4.12. Flat-bottom storage warehouse showing concrete bulkhead to partition grain and feed ingredient holding capacity.

Steel silos: Corrugated bolted or welded flat wall steel silos are the most affordable (USD per metric ton capacity) and most common storage structures used on-farm, at bulk grain facilities, and at grain processing facilities and feed mills around the world (Fig 4.13). They are easily equipped with PLC-operated grain conveying systems and automated grain monitoring systems, which makes their operation and management less of a challenge compared to warehouses. If space is not an issue, it is preferred to install larger diameter silos instead of taller silos for two reasons. Larger diameter silos cause less static pressure for fans to push or pull air through an equivalent size grain mass during aeration. Larger diameter silos also result in smaller surface to volume ratios which keeps grain cooler especially when galvanized steel is new or older steel silos are painted white to reflect solar radiation. This is especially beneficial in tropical climates where solar load and ambient temperatures are quite high during the daytime. Taller, smaller diameter steel silos with larger surface to volume ratios absorb comparatively greater thermal loads. This makes cooling grain or keeping grain cool in such silos a greater challenge in the tropics.

Figure 4.13. Corrugated, bolted steel silos holding bulk corn at a feed mill.

Concrete silos: Concrete silos are cylindrical shaped grain storage structures similar to steel silos (Fig 4.14). They too can be easily equipped with PLC-operated conveying systems and automated grain monitoring systems. They are typically taller and smaller diameter structures than steel silos. Concrete is an excellent insulating material, and when concrete silos are poured as an integrated structure with interstices between four cylindrical silos, grain can be maintained at cooler temperatures much better than in steel silos. However, concrete silos are typically about 10-15% more expensive to construct than steel silos which is less than in past years given recent increases in global steel prices.

Figure 4.14. Concrete silos holding bulk corn at a grain aggregation location.

4.3.2 Portable (Vertical) Aeration Systems

Portable aeration systems typically consist of a number of small(er) (~1/12 - ½ HP) vane axial fans, connected to a perforated piece of tubing (metal or plastic) that is inserted into the surface of the grain mass after filling of the structure (Fig 4.15). Depending on the quality of the grain and amount of BCFM, these can be effective for localized cooling including arresting self-heating of grain due to mold spoilage. The depth to which these can be inserted into the grain mass varies, limiting their performance. These should be combined with headspace ventilation to avoid build-up of humidity, temperature and condensation potential.

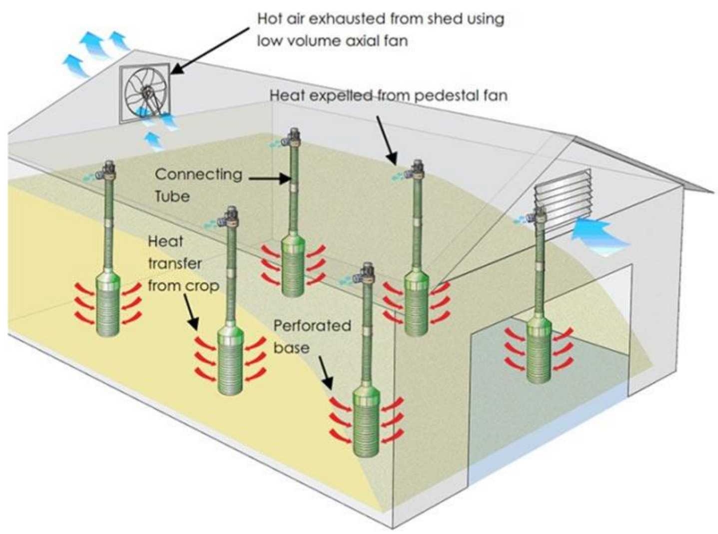

Figure 4.15. Vertical aeration system for flat-bottom storage buildings that allows for cooling and maintaining stored grain quality. It can be moved into place before filling and removed during unloading for maximum space utilization.

4.3.3 Grain Chillers

Grain chillers can be used when grain temperatures need to be reduced below those possible with ambient air, for example, in the tropics and subtropics as well as during summer in temperate climates (Fig 4.16). By lowering grain temperature, the operations manager can reduce insect and mold activity, and thus reduce damage to grains. These units are expensive to own and operate (due to high electric utility costs), and thus are most applicable to preserve end use value of grains such as milled rice and popcorn, and in organic grains to prevent insect development without chemical means. The air conditioning capacity of a unit is sized based on prevailing weather conditions, airflow rate needed, and targeted cooling temperature and time.

Figure 4.16. Chilled grain aeration system connected to the aeration ducting of an individual or set of steel silos. Mobile unit can be moved from silo to silo as well as along a warehouse and connect to aeration ducting to cool and maintain stored grain quality independent of ambient weather conditions.

4.3.4 Roof and Headspace Venting

Headspace venting is necessary to remove excess moisture that may have accumulated due to updraft aeration, and to prevent heat buildup in the air space above the grain surface in a silo or warehouse. There are numerous types, including power ventilators, box vents, ridge vents, wind turbines, end wall ventilators (Fig 4.17), and more. Insufficient ventilation can lead to condensation problems and surface crusting, potentially reducing the effectiveness of existing aeration systems. Refer to Section 3.3.3 on managing headspace microclimate.

Figure 4.17. High airflow, low electric power exhaust fan venting headspace air from a flat storage building.

4.3.5 Semi-Permanent Aeration Systems

Aeration systems can be installed on the flat floor of a warehouse before it gets filled, and removed during unloading to enhance reclaim. Once reclaim is complete the ductwork can be reinstalled, connected to the outside fans, and the system is ready for reuse. Ductwork is commonly constructed from either perforated metal or plastic (drainage style) piping, ranging in diameter from 0.5 to 1 meter (Fig 4.18). Fans are typically vane axial, but can also quieter and more expensive centrifugal fans. Ductwork can be installed to run parallel or perpendicular to the grain reclaim process.

Figure 4.18. Semi-permanent aeration system showing half-round perforated on-floor ducts to aerate grain in a flat storage building before it is filled

4.3.6 Coring and Reclaim System for Flat Storage Building

Coring is an essential and important tool for grain quality management, especially with large storage structures. Due to costs, most flat storage structures do not have the ability to core fines out of the multiple spoutlines along the center line of the grain mass. One design concept is to install a properly designed tube or structure directly below and parallel to the center line. Inside of that tube, a small chain conveyor can be installed offset to one side to allow personnel access. Through the tube, spouts and gates can be installed that can be operated to allow grain from spoutlines to flow into the conveyor. Spacing depends on the distance between the drop points of the overhead conveyor. With this type of system, the operator can open gates, drawing out (coring) the fines, then convey them to the outside for further transfer. Once coring is accomplished, the inverted cones could be refilled with clean grain to regain storage capacity of the structure. Additionally, this system can be utilized to reclaim grain from the warehouse by gravity flow.

4.3.7 Aeration System added to 4.3.5

In concept, the operator could add aeration cells or pods to the above combination coring and reclaim system. By attaching the above-floor pods to the center duct, and installing fans of sufficient size to the center duct outside the building frame, the operator could have a permanently installed coring, aeration and reclaim system. Unlike most “on-floor” aeration systems, the impact on the operation is minimal because little is required in the way of setting tubes, pods and fans, and potentially disassembling the system if the warehouse is to be used for something other than bulk grain storage.

While this is a “concept only” for flat storage buildings, similarly designed systems have been successfully used for over 30 years in the U.S. on large (up to 45,000 metric ton) temporary storage structures and 12,500 metric ton steel storage silos. This system has a high initial cost but long-term the operator will see benefits due to reduced handling costs, lower labor costs, and much reduced grain quality issues.

4.4 Determining the Value of Handling Loss, Weight Shrink, and Utility Expenses

4.4.1 Improved Grain Aeration = Reduced Utility Costs

Removing or reducing the amount of BCFM, fines and dust by cleaning grain and coring the grain mass will reduce total aeration time. This in turn will have an impact on reducing electric utility costs. Costs to operate fans can be determined if the following is known:

- power rating of the fan motors (kW)
- amperage load when fan motors are powered
- hours of fan run time
- electric utility costs per kWh

Fan Operating Cost = Fan motor [kW] x Amperage load [%] x Run time [h] x Electricity cost [USD/kWh]

Below is an example of a spreadsheet used to calculate costs in the U.S. that can be easily adapted for any currency.

Table 4.1. Estimated electrical costs (USD) for operating total number of aeration fans as a function of electric fan motor power (1 HP = 0.746 kW), full amperage load (100%), fan run hours and average electric energy cost per hour (USD/kWh).

	September	October	Nov	Dec	Jan
Fan HP	100	100	100	100	100
Fan Hours	150	250	75	300	175
Avg kw cost per hour	$ 0.12	$ 0.20	$ 0.30	$ 0.12	$ 0.12
Estimated electrical cost	$ 1,350	$ 3,750	$ 1,688	$ 2,700	$ 1,575

4.4.2 Improved Grain Preservation = Reduced Shrink due to Deterioration

In general, for every 3% of total grain damage, the loss of kernel weight is about 0.5% (0.005). Thus, shrink loss due to deterioration damage can be calculated as follows:

Deterioration Shrink Loss = Grain Amount (mt) x 0.05% x (final total damage [%] – initial total damage [%]) / (3%)

For example, 75000 mt of corn deteriorating from 2.9% to 12% total damage would experience the following shrink loss:

$$\text{Deterioration Shrink Loss} = \frac{75000 \text{ x } 0.05\% \text{ x } (12 - 2.9)}{3}$$

$$\text{Deterioration Shrink Loss} = \mathbf{1138\ } \boldsymbol{mt}$$

Table 4.2. Cost (USD) per U.S. bushel and metric ton as a function of increase in damage level (%) and associated weight loss and commodity value (USD).

For every 3 % of degregration, weight loss is equal to ~ 1/2 of 1 %		
Quality Deterioration Shrinks		
	Bushels	Tons
Bushels	3,000,000	75,000
Original Damage Level	2.9	2.9
Final Damage Level	12	12
% increase in damage	9.1	9.1
Basis change	3.03	3.03
Weight loss	45,500	1,138
Commodity Value	$ 4.13	$ 165.00
Projected cost of deterioration	$ 187,687.50	$187,687.50
Cost per bushel or per ton	$ 0.06	$ 2.50

4.4.3 Improved Grain Handling = Reduced Shrink due to Handling

Handling shrink is defined as the accumulated weight loss associated with the normal moving of grain through a conventional grain handling system. The actual amount varies greatly and depends on multiple factors including age of equipment, level of or lack of equipment maintenance, type of equipment, dust collection systems, number of impact points, and drop heights into silos and warehouses. Extreme examples are evidenced when there are excessive leaks, spills, high BCFM values, and other housekeeping issues occurring at a facility. The table below is an example of how a U.S. company that operates numerous types of facilities, from small local grain aggregation facilities to large export terminals, some with newer and some with older equipment, would track handling shrink across all facilities. The situation will vary at each facility and for each company. However, assessing and calculating handling shrink is important to determine value of amount of grain lost and compare that against how quickly investments in equipment upgrades and better operations practices will pay back.

Shrink loss due to multiple handling operations can be calculated as follows:

Handling Shrink Loss = (Grain Receipts + Grain Shipments + Grain Transfers) x 0.05% (or 0.0005)/ 2

To calculate handling shrink loss, in this example, in January, the operator received 5000 mt of corn into storage, and during the month, transferred 5000 mt from storage to processing, ending the month with 5000 mt "handled". On this basis the associated shrink loss is calculated:

$$\text{Handling Shrink Loss} = \frac{(5000\text{mt} + 5000\text{mt}) \text{ x } 0.0005}{2}$$

$$\text{Handling Shrink Loss} = 2.5mt$$

or 0.5% of total amount of grain handled.

Table 4.3. Losses attributed to mechanical handling of grain

Normal losses attributed to spills, equipment clean out, etc				
Mechanical Handling Shrink :				
		Jan	Feb	Mar
Receipts into facility	Tonnes Received	5,000.0	5,000.0	5,000.0
Shipments to another facility	Tonnes Shipped	-	1,000.0	-
Transfers to processing (use)	Tonnes to Process	5,000.0	5,000.0	3,000.0
	Tonnes Handled	5,000.0	5,500.0	4,000.0
	Mechanical Shrink	2.5	2.8	2.0
		Tonnes		
Calculation = Rec + ship + Tranfers / 2 *.0005				

4.4.4 BCFM and its Equivalent Value

Similar to moisture content, the value of BCFM can be determined based on (1) the value of the commodity, (2) the percent of BCFM contained in the imported corn, and (3) the percent of BCFM increase during handling which is estimated to be 1-2 percentage points during each successive handling operation especially when grain moisture content is less than 13.5%.

Value of BCFM = Grain Amount (mt) x (initial BCFM amount + increase in BCFM amount during handling) x Grain Value ($/mt)

For example, 25000 mt of corn purchased for $165 per mt at a contract BCFM content of 4% increases in BCFM by 1% during receipt and transfer to storage. This results in the following estimated value of BCFM:

$$\text{Value of BCFM} = 25000 \text{ mt} \times (4\% + 1\%) \times \$165/\text{mt}$$
$$= \$206250, \text{ or } \$8.25 \text{ per mt purchased}$$

It is important to remember that the nutritional value of BCFM is comparable to whole corn in terms of production of animal feeds.

4.5 Benefits and Cost Savings for Equipment Upgrades and Improved Handling Systems

The table below is an Excel spreadsheet designed to assist operations managers when considering various practical capital investment alternatives. It can be used to compare the various benefits based on an estimated value in relation to its impact factor (low, medium or high) and its relationship to four primary classes of investment. The estimated impact value is based on operations experience within the U.S. context and can be modified by the end user in the online version of the spreadsheet. The purpose is to provide owners and operators of facilities with a list of practical options when determining the value of making investments in upgrading and adopting improved operational practices. The four classes of investment are:

1. Grain Quality/Profit Preservation
2. Profit Adding Opportunities
3. Operational Efficiency Gains and Expense Reductions
4. Employee Safety, Quality of Life and Environmental Considerations

To illustrate the intended purpose of the table below, a comparison is made to evaluate two distinct project options. The “Pre-Clean” option includes installing equipment such as a cleaning system prior to storage, allowing the operations manager to clean all or some amount of incoming corn to a desired level. This option is compared to “Coring only”, which involves the installation of equipment for coring the spoutline(s) to remove fines from the grain mass after a storage silo or warehouse is filled. As actual project costs depend on the local situation, this is a comparison of benefits only. In order for the end user to determine ROI, project costs and other variables must be taken into consideration. The impact factors corresponding to operational value were chosen as 1 = low, 3 = medium, and 5 = high. To the right of this column is a column labeled “see section” which takes the user, via hyperlink, to the respective section in this handbook to review equipment options in more detail via a hyperlink.

In this example (Table 4.4), by installing a pre-cleaning system, the impact value is high (5) compared to medium (3) for coring only based on the premise that “Reduction of Deterioration Shrinks” during storage is greater when BCFM is reduced with screen cleaning ahead of storage. The rational is that by cleaning prior to storage, the operations manager does not have to find time, storage space, and labor needed for coring after filling silos or warehouses. Additionally, by cleaning “all grains” going to storage instead of coring only the spout lines, the operator has much better control over grain quality. When all value options and benefits are added up, an investment in pre-cleaning outweighs an investment in coring only by a score of nearly two (116) to one (63). Based on years of operations experience, cleaning prior to storage has proven time and again far more effective in managing stored grain quality, and gaining operational efficiency considering space, labor, utilities, and process disruptions.

Table 4.4. Example of evaluating and comparing the various benefits of three practical capital investment alternatives based on an estimated value in relation to its impact factor (low, medium or high) and its relationship to four primary classes of investment.

Investment Strategy and Cost Benefit Analysis	Section	Pre Clean	Core Only	Core w/ Aeration
Value / Benefits / Cost Savings	Link to Section	Value L=1,M=3,H=5	Value L=1,M=3,H=5	Value L=1,M=3,H=5
Grain Quality / Profit Maintaining				
Reduced Deterioration Shrinks	4.4.3	5	3	3
Reduced shrinks due to additional handling	4.3.3	5	3	3
Reduced Aeration Shrink	4.3.4	5	3	5
Reduced Aeration Requirements	4.3.1	5	3	5
Impact FILO / FIFO ... flow of product from storage			5	5
Reduced potential / incidence of insect infestation	4.5.7	5	3	3
Reduced mycotoxin load/level in whole grain inventory	4.5.9	5	3	3
Profit Adding Opportunities				
Opportunity to purchase high bcfm @ discount to market	4.5.5	5	1	1
Opportunity to capture fines / new business opportunities		5	3	3
Opportunity to handle higher moisture levels	4.3.4	5	1	3
Longer stable storage = less market exposure		5	1	3
Additional storage space for whole grains		5	3	1
Opportunity to maintain moisture content vs shrinks		5	1	3
Install grain dryer to control mositure and reduce aeration requirements		3	3	5
Operational Efficiencies and Expense Reductions				
Reduction in labor / benefit costs		5	1	3
Reduction in utilities costs		5	3	5
Operational control of re-blending bcfm to process		5	3	1
Reduced fumigation costs		5	3	3
Improved ability to migiate hot spots		3	3	3
Impact FILO / FIFO ... flow of product from storage		1	3	3
Reduced maintenance costs for mobile equipment		1	3	
Reduced aeration hours to control hot spots		5	1	3
Reduced use of Propionic acid		5	3	3
Employee Safety, Quality of Life, Environmental Considerations				
Improved control over mycotoxins when present	4.5.9	5	1	1
Reduction / Elimination of Confined Space Entry	4.5.8	5	1	1
Safer work environment for employees; dust, fumes, etc	4.5.8	5	1	1
Capture fines and dust / Separate from bc		3	1	1
Total Project Valuation		116	63	74

4.6 Opportunity Analysis for Purchasing Higher BCFM Level Corn

Buyers of U.S. corn generally desire to purchase corn with lower levels of BCFM which is understandable. However, the opportunity to buy corn with higher BCFM levels exists and should be explored in terms of costs and benefits. For example, by contracting a lower grade with higher BCFM value such as U.S. Grade 4 (5% BCFM maximum) instead of U.S. Grade 3 (4% BCFM maximum), the buyer could take advantage of cost savings in the purchase price. *This slightly higher BCFM corn has essentially the same nutrient value in terms of animal feed as the corn with one percentage point lower BCFM.* ***Even though this higher level of BCFM can create some operational and quality challenges, experienced operations managers with access to the right equipment can mitigate these challenges and add to the bottom line of their company.***

The primary investment needed, if the equipment is not already available at the facility, is a pre-cleaning system. The value of investing in such a system was documented in Section 4.5. Specific benefits are presented in further detail below.

4.6.1 Savings in Purchase of U.S. Corn with higher BCFM levels

The average savings per metric ton by purchasing U.S. Grade 4 rather than U.S. Grade 3 can be calculated. However, as pricing and contract terms exist between the seller and buyer only, the potential cost savings can only be calculated at the time of purchase. However, as an example, if there were a $1.95/mt discount based on BCFM only, and it applied on a 50000 metric ton purchase, the buyer could realize a savings of $97500 for the additional percentage point of BCFM. As shown in Sections 4.4.4 and 4.4.5, these potential savings can be analyzed for different periods of a marketing year, over multiple marketing years, and for different U.S. locations of origin.

4.6.2 Optimized Grain Aeration and Energy Usage

Cleaning corn to lower BCFM level by a specified amount prior to transfer into silos and warehouses results in much improved airflow through the grain mass. Research and past experience has shown that a reduction in one percentage point of BCFM can improve airflow. Movement of an aeration front for the purpose of cooling grain or maintaining uniform temperatures is directly proportional to airflow rate. Thus, the improvement in airflow rate will reduce amount of fan runtime and associated electric utility costs by the same relative amount. An additional benefit of shorter fan runtimes is the opportunity for the end user to take advantage of shorter periods of favorable ambient temperatures especially in the tropics and subtropics. (See Section 4.4.1 to determine the value of improved aeration.)

4.6.3 Suppression of Insect Pests and Lower Fumigation Expenses

Cleaning corn to lower BCFM level by a specified amount prior to transfer into silos and warehouses also reduces the risks of infestation by common post-harvest insect pests of corn. Insect pests typically thrive when corn consists of larger amounts of BCFM. If as a result of lowering the amount of BCFM a fumigation cycle can be eliminated or the application of a chemical protectant can be avoided, substantial cost savings can be incurred. Estimates of applying a grain protectant and fumigating grain range from $2/mt -$6/mt.

4.6.4 Improved Handling and Reduced Risks to Workers

In general, corn with higher levels of BCFM has poorer flow characteristics and tends to plug discharge wells during unloading more likely especially when spout-lines were not cored and some grain spoiled. Therefore, cleaning corn to lower BCFM level by a specified amount prior to transfer into silos and warehouses will also reduce the risk to workers who are often sent into a silo after grain stopped flowing to dislodge plugged wells. ***This is an extremely dangerous situation that an employee should never be exposed to! There are other means to resolve a no-flow, plugged well situation that are outside the purpose of this handbook. Qualified experts and guidance documents should be consulted, and all applicable laws and regulations should be followed!***

Avoiding the plugging of discharge wells will also reduce downtime during unloading and result in cost savings. Additionally, sending employees into dangerous work situations that could result in serious injury due to entrapment in grain or even death due to engulfment in grain can result in substantial fines and litigation costs.

4.6.5 Reduction and Mitigation of Mycotoxins

Cleaning corn to lower BCFM level by a specified amount prior to transfer into silos and warehouses provides opportunity for reducing and mitigating mycotoxins. Refer to Sections 3.5.1, 3.7., 3.8. and 3.10 for best practices and options to capture value from segregated BCFM streams with elevated mycotoxin levels.

5 References and Recommended Reading

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6 Appendices

6.1 U.S. Grades for Corn

Grading Factors	Grades U. S. Numbers 1	2	3	4	5
Test Weight Minimum per bushel (pounds)	56.0	54.0	52.0	49.0	46.0
Damaged kernels					
Heat	0.1	0.2	0.5	1.0	3.0
Total	3.0	5.0	7.0	10.0	15.0
Broken corn and foreign material	2.0	3.0	4.0	5.0	7.0

U. S. Sample grade corn is corn that:

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

b) Contains 8 or more stones that have an aggregate weight in excess of 0.2% of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds, 2 or more castor beans, 4 or more particles of an unknown foreign substance or a commonly recognized harmful or toxic substance, 8 or more cockleburs or similar seeds singly or in combination, or animal filth in excess of 0.2% in 1000 g; or

c) Has a musty, sour, or commercially-objectionable foreign odor; or

d) Is heating or of distinctly low quality.

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

6.2 Equipment Glossary

	Equipment	Referenced Section (Figure)	Catalog Search Keywords
Sampling and Monitoring			
	Gravity in-line grain stream samplers	3.1.1. (Fig. 3.1)	*Samplers, Probes*
	Telescopic pneumatic grain probe	3.1.1 (Fig. 3.2)	*Samplers, Probes*
	Manual grain probe	3.1.1 (Fig. 3.4a)	*Samplers*
	Mobile ladder platform	3.1.1 (Fig. 3.4b)	*Samplers*
	Hand scoop	3.1.1 (Fig. 3.5)	*Samplers*
	Portable moisture meter	3.1.1; 3.2.1 (Fig 3.6a)	*Grain Grading/Lab Testing*
	Bench-top moisture meter	3.1.1; 3.2.1 (Fig 3.6b)	*Grain Grading/Lab Testing*
	Moisture/RH sensors on cables	3.2.2 (Fig. 3.9)	*Grain Temperature Systems*
	Temperature sensors on cables	3.2.3 (Fig. 3.9)	*Grain Temperature Systems*
	Moisture/RH/Temperature sensors (portable IoT devices)	3.2.4 (Fig. 3.10)	*Grain Management Monitors/Software*
	Roof mounted CO_2 sensors (IoT device)	3.2.4 (Fig. 10)	*Grain Management Monitors/Software*
	Portable CO_2 sensors	3.2.5 (Fig. 11)	*Grain Management Monitors/Software*
Grain Handling			
	Mobile grain pile loader	3.1.2 (Fig. 3.7)	*Conveyors*
	Belt conveyor	3.1.2 (Fig. 3.8)	*Conveyors*
	Gravity cleaners	4.1.1 (Fig. 4.1)	*Cleaning Equipment*
	Powered cleaners	4.1.2 (Fig. 4.2)	*Cleaning Equipment*
	Rotary Cleaner/Scalper	4.1.3 (Fig. 4.3)	*Cleaning Equipment*
	Cushion boxes	4.2.4 (Fig. 4.6)	*Conveying and Material Handling*
	In-Line Flow Retarders	4.2.5 (Fig. 4.7)	*Conveying and Material Handling*
	Gravity and Powered Grain Spreaders	4.2.6 (Fig. 4.8)	*Conveying and Material Handling*
	Grain Ladders (or Bean Ladders)	4.2.7 (Fig. 4.9)	*Conveying and Material Handling*
	Vented Bucket Elevator Cups	4.2.9 (Fig. 4.11)	*Bucket Elevators*
Grain Conditioning			
	Ozone generator	3.1.6 (Fig. 3.8)	*Ozonation*
	Portable (Vertical) Aeration Systems	4.3.2 (Fig. 15)*	*Aeration, Cooling*
	Semi-Permanent Aeration Systems	4.3.7 (Fig. 4.18)	*Aeration, Cooling*
	Grain Chiller	4.3.3 (Fig. 4.16)	*Chilling*
	Roof and Headspace Venting	4.3.4 (Fig. 4.17)	*Aeration, Exhaust*
Storage Structure			
	Flat Warehouses	4.3.1 (Fig. 4.12)	*Flat Storage*
	Steel Silos	4.3.1 (Fig. 4.13)	*Storage/Steel*
	Concrete Silos	4.3.1 (Fig. 4.14)	*Storage/Concrete*

Online catalog for grain sampling/monitoring, grain handling, grain conditioning and storage structure:

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