U.S. GRAINS COUNCIL

U.S. Corn: Storage in Tropical Climates

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Table of Contents

About the Study

To enhance trade in tropical locales and help grain processing and feed industries optimize their storage practices, the U.S. Grains Council (USGC) and Kansas State University (KSU) worked with a Malaysian feed manufacturing facility to conduct a research study to determine the best grain management and storage options for U.S. corn over longer periods without affecting grain quality.

The study had three objectives:

- Analyze U.S. corn at origin and destination to determine if transportation affects quality.
- Determine whether removing broken corn and foreign material (BCFM) at destination improves storability and presence of mycotoxins.
- Establish the best and most cost-effective grain quality management and storage strategies based on analysis.

Along the way, there were a couple of challenges:

1) Temperature and humidity affect grain quality, so storing any grain in a tropical location poses issues. When these conditions are present, insect consumption increases, mold growth expands exponentially, grain quality decreases and aflatoxin – toxic to animals and humans – appears. Any form of condensation in contact with grain – water, humidity or other – in storage structures, silos or warehouses can make mold grow even faster.
2) Economically, shorter storage times limit purchasing options for buyers.

With temperature and humidity being the two driving factors in the study, it was important to monitor both. The average ambient temperature during the trials was 28.7° C, with 32.7° C as a maximum and 24.2° C as a minimum. The ambient relative humidity was 70.6 percent, with 90 percent as a maximum and 42.1 percent as a minimum.

Storage Recommendations

This study shows there is no quality loss (increase of aflatoxin levels or mold growth) or moisture absorption on U.S. corn when shipped from the U.S. Midwest into Southeast Asia using containers in good condition. A grain cleaning system can help improve U.S. corn storability by removing BCFM without affecting its quality or chemical composition. Removal of BCFM makes it an optimal tool to control mycotoxin growth.

The results show U.S. corn can be stored in tropical weather locations in properly, well-designed and maintained silos or warehouses with no type of treatment for at least 75 days without having any effect on quality. With a mold inhibitor application upon arrival in Southeast Asia and grain chilling in the silo, U.S. corn can also be stored for at least four months without any effect on quality. Mold inhibitor application can help control any potential growth of fungi spores typically present in the environment in tropical weather locations. Grain chilling keeps corn cool, discourages insect growth and infestation and stifles any potential mold growth.

U.S. corn stored at safe moisture content below 14.5 percent does not show any increase in aflatoxin levels.

Basic Characteristics of U.S. Corn

PRODUCTION

Corn has been the largest crop in the United States for more than a century. More than 70 percent of all U.S. corn grown in the temperate "corn-belt" states of Iowa, Illinois, Nebraska, Minnesota, Indiana, Ohio and South Dakota. This part of North America is one of the world's most productive agricultural areas because of its deep, fertile soil, flat or rolling topography, adequate rainfall and long growing season. High-yielding, hybrid seed is planted early in the North American summer, and the crop is harvested as the cold, winter season begins.

Temperate U.S. "Corn-Belt" States

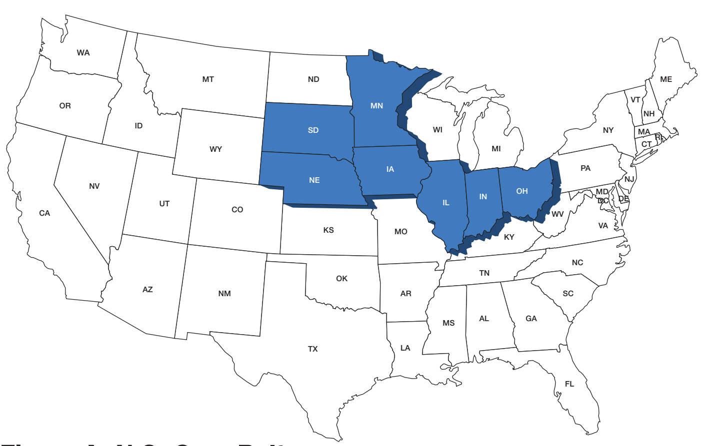


Figure A. U.S. Corn Belt

A vast network of resources is available to help U.S. corn producers maximize the yield and quality of their crop. Private and public entities annually invest millions of dollars in seed breeding programs. Private industry and the U.S. Cooperative Extension Service provide a variety of information related to tillage, fertilization and pest control. Test fields allow farmers to observe side-by-side variety tests and to review yield and quality data. Many of the world's largest and most progressive manufacturers of agricultural machinery complete for the farmer's business.

MARKETING

Some corn is transported directly from the field to grain elevators that provide drying and storage services. Other corn is stored on farms. Many farms have grain dryers and large grain bins. More than 20 percent of the U.S. corn production is exported. Most of this corn moves by river barge to export elevators on the Gulf of Mexico but large quantities also are transported by rail to export elevators on the east and west coasts of the U.S.

QUALITY

Like other grasses, the corn kernel contains a pericarp, a fibrous outer covering produced by the mother plant to protect the seed. Inside the pericarp are the two most important structures of the seed, the germ and endosperm. The endosperm contains the storehouse of energy-producing starches and other carbohydrates the new plant requires when the seed germinates. The germ contains embryonic plant tissues, including a root and a shoot, and a structure called the scutellem that facilitates the supply of nutrients and cell-building materials to the new plant when the seed germinates.

Because these structures have different purposes, they contain different kinds of nutrients. The pericarp represents only about five percent of the total weight of the corn kernel but contributes almost all the fiber. The germ represents about 13 percent of the weight of a kernel of commodity corn but contributes about 85 percent of the lipids (fats and oils) and nearly one-quarter of all protein. The endosperm, which represents more than 80 percent of the total weight of a commodity corn kernel, consists almost entirely of starch and protein.

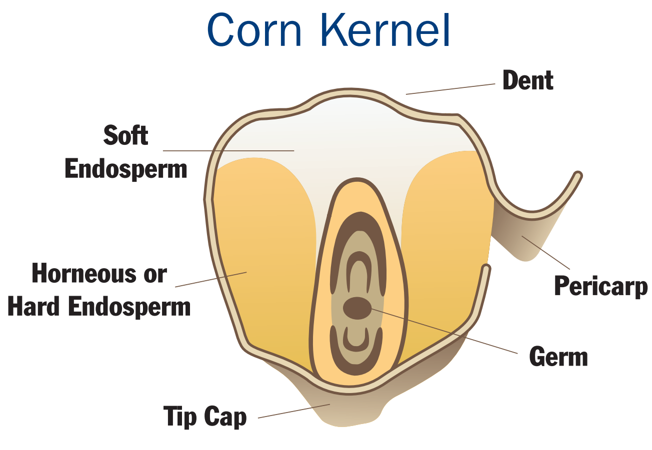


Figure B. Parts of the corn kernel

U.S. hybrid corn varieties produce kernels with two kinds of endosperm and a pronounced dent at the end opposite the germ. The endosperm consists of large cells with very thin cell walls. Inside the translucent (hard) endosperm cells, starch granules are tightly compacted. The compacted starch and the type of protein between the granules produce the glass-like appearance and the brittle texture. In the opaque (soft) endosperm, starch granules are more spherical, allowing for small air spaces between them. The tiny air spaces and the type of protein contribute to the opaque appearance and the softer texture.

The varieties used in the U.S. are developed for high yield potential, resistance to disease and good nutritional quality. They are semi-soft types with a pericarp that happens to contain a relatively low concentration of yellow and orange pigments (carotenes and xanthophylls). The semi-soft endosperm and the relatively pale-yellow color are of little consequence to the domestic market but are of interest to many buyers of U.S. corn. The endosperm type contributes to the tendency of U.S. corn to break during handling after high temperature drying. This creates a challenge for importers because of the repeated elevations, impacts and mechanical forces experienced by the grain during the handling required for export. Small pieces of the soft endosperm are ground into flour during export handling, creating the white dust familiar to importers. In some markets, the low carotene content means additional pigments must be added to poultry feeds to produce the desired color of eggs and meat.

EXPORT CONDITION

Several factors affect the storability of imported grain. Most importers of U.S. corn specify a maximum grain moisture content. This is a recommended practice because it provides a measure of control over one of the most important parameters affecting the rate of deterioration. In recent years, the average moisture content of exported U.S. corn has been about 14.3 percent, probably because of the 14.5 percent maximum moisture specifications in most contracts. Of all the corn grown in the U.S., the corn most likely to be exported is that grown near the rivers upon which it is transported to the export elevators. In this part of the corn belt, corn is likely to be harvested when it contains at least 20 percent moisture. Typically, the corn is dried in grain dryers and stored at 15 to 17 percent moisture. During subsequent aerations and storage through the cold winter months, the grain dries further. Grain lots from various origins and having different characteristics are blended to meeting the moisture content, bulk density and other specifications of the export contract.

Other characteristics important to storability are the percentage of broken and damaged kernels. The average BCFM content of exported U.S. corn is 2.7 percent and the average damaged kernel content is 2.7 percent. These quality factors are presented on the U.S. grade certificate.

Another parameter important to tropical storage of U.S. corn is the number of kernels infected by storage molds. This information is not provided on the grade certificate because the test requires several days. Mold infection is a function of the grain storage and handling history, including the length of storage, moisture and temperature during storage and the blending that occurs during export handling. Recent research shows the percentage of kernels infected by the most important storage molds varies by season in exported U.S. corn. When the infection rate is high, successful storage under tropical conditions is more difficult. It appears likely that from January to June, U.S. corn will tend to be more easily stored under tropical conditions. From July or August through November or December, more precautions may be necessary for successful storage.

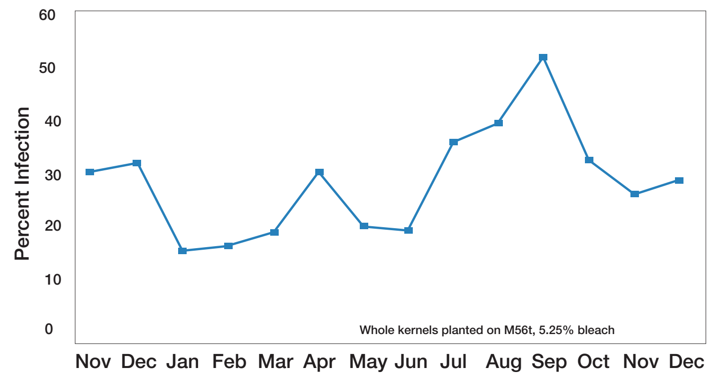


Figure C. Percentage of U.S. corn kernels infected with species of the storage mold *Aspergillus* at destination ports.

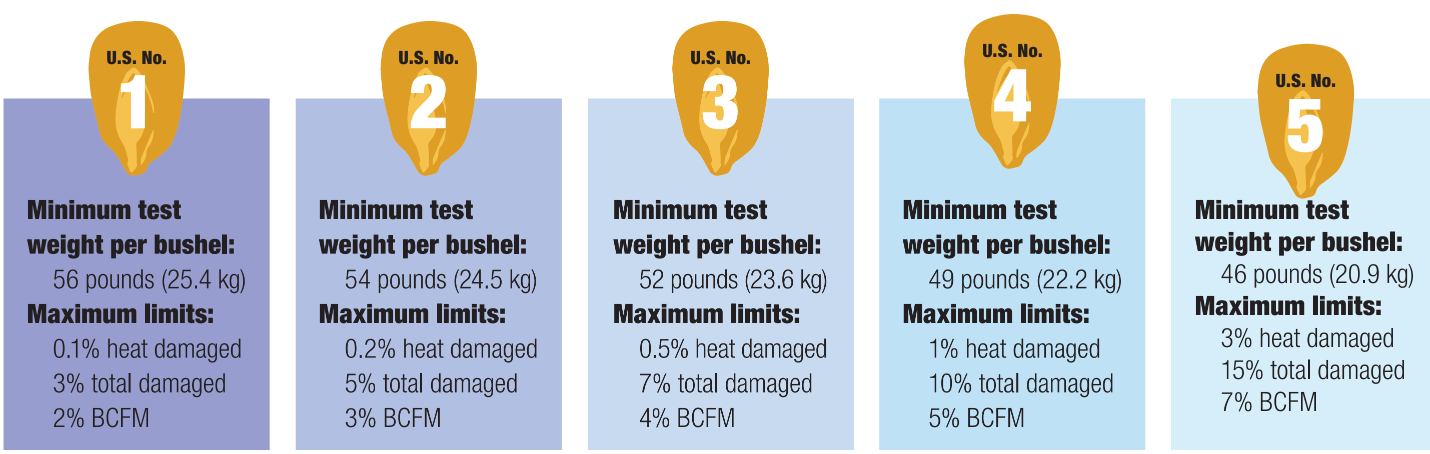
Corn Quality and Value

GRADES

The majority of U.S. corn is purchased as grade U.S. #2. The grade certificate is the buyers' guarantee the samples have been taken and analyzed by Federal Grain Inspection Service (FGIS) employees who are trained, certified and supervised in their jobs; the samples have been handled according to FGIS standards; the apparatus used in grading has been certified and maintained; and a long list of further guarantees have been met. The FGIS is part of a federal government agency called the Grain Inspection, Packers and Stockyards Administration (GIPSA).

USDA Corn Quality Grades

The U.S. has a reliable and transparent quality grading system.



- **Buyers should contract** quality requirements and non-grade factors.
- **Final corn quality** is also impacted by movement through export marketing channels.

Figure D. USDA Corn Quality Grades

Test weight is the weight of corn that occupies a standard volume. It is reported in pounds per bushel and can be converted to kg/hl by multiplying the lb/bu by 1.28. BCFM is the material that falls through a 12/64-inch (4.8 mm) round-hole sieve when a randomized sample of approximately 250 g is shaken on the sieve in the prescribed manner. It also consists of all pieces of stalk, cob or other material that is not corn and that does not fall through the sieve. All corn kernels that remain on the sieve, even if they are obviously broken, are considered whole corn under the U.S. standards.

Damaged kernels have a long and very detailed definition given in the FGIS handbooks. Not every kernel with unusual, misshapen or darkened appearance is considered damaged. Mechanical damage is not considered damaged. Some types of insect chewing are not considered damaged Basically, only kernels deteriorated by molds or insects to a degree that might affect their nutritional quality are considered damaged.

Grade factors supply only limited information, especially in the case of corn. Test weight is a measure of compactness and kernel density but is not necessarily an accurate predictor of milling characteristics or nutritional quality. BCFM conveys information about the amount of fine material but does not necessarily indicate storability. If a sample contains a large percentage of damaged kernels, it indicates at some point, some deterioration occurred. However, a moderate level of damaged kernels (less than 10 percent) does not necessarily mean the grain has inferior feeding value.

MOISTURE CONTENT

Moisture content is not a grading factor but is given as an information factor on grade certificates. In general, there is an inverse relationship between moisture content and price. To evaluate the added value of a dryer commodity, the equivalent value may be calculated. Moisture adds weight without adding the proteins, starches, fats, vitamins and minerals that are desired components of corn. The equivalent value at any moisture content can be calculated by multiplying the price per ton by the dry weight ratio at the different moisture contents.

Consider the example of a buyer who is willing to pay $120/ton for some commodity at 15 percent moisture. If he purchased the same commodity at 14 percent moisture content, he would receive more nutrients per ton. The dry weight ratio in this example is (100 percent – 14 percent moisture content)/(100 percent – 15 percent moisture content) = 1.01176. The equivalent value per ton of the commodity at 14 percent moisture content is $120 * 1.01176, or = $121.4/ton. In other words, at 14 percent moisture content and $121.4/ton the buyer pays no more per kilogram of nutrition than at $120/ton for the same commodity at 15 percent moisture content.

NUTRITIONAL VALUE

Typically, U.S. commodity corn contains 8-10 percent protein, about three percent fiber, 3-5 percent oil and a net energy content for growth of about 2 Mcal/kg. High-oil corn and other specialty corns have a significantly different distribution of nutritional components. Screening (cleaning) before storage is recommended to minimize particle-size segregation and resulting accumulations of fine material. The nutritional value of various size fractions varies slightly. The feed value of whole corn is set to a value of 100 to demonstrate relative differences. Both broken kernels and corn dust are good feed ingredients. The dust contains nearly four times the amount of fiber and about 90 percent of the protein and energy compared to whole corn.

Table A. Nutritional value of BCFM and dust in U.S. corn as compared to whole corn.

SIZE	ENERGY	PROTEIN	CRUDE FIBER
Whole corn	100	100	100
BCFM (<4.8 mm)	95	105	155
Dust (<1.8mm)	90	88	368

Adapted from Bern and Hurburgh, 1992

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Executive Summary

Storing any grain or oilseeds in tropical weather locations is a challenge due to the extreme conditions of high ambient temperatures and relative humidity. There is limited data available to provide U.S. corn or oilseed buyers technical information on how to properly store it in tropical weather locations as in Southeast Asia. Therefore, the U.S. Grains Council (USGC), Kansas Soybean Commission, Kansas State University and a private feed manufacturing company teamed up to conduct a series of research trials to obtain data that can help increase the proper storability of U.S. commodities, specifically U.S. corn.

The goals of this research project included:

- Analysis of U.S. corn at origin and destination to determine if transportation to Southeast Asia affects quality,
- Determining whether removing (cleaning) the Broken Corn and Foreign Material (BCFM) of U.S. corn at destination before storage improves storability and removal of any potential mycotoxins, and
- Establishing the best grain quality management strategies based on the available options to optimally store U.S. corn in a cost-effective way in tropical weather conditions.

The results of this research project clearly show there is no quality loss (increase of aflatoxin levels or mold growth) or moisture absorption on U.S. corn when shipped from the U.S. Midwest into Southeast Asia when using containers in good condition. Using a grain cleaning system can help improve U.S. corn storability by removing BCFM without affecting its quality or chemical composition. Since mycotoxins tend to concentrate on BCFM, its removal makes it an optimal tool to control its concentration as part of a grain quality and storage program. The results show U.S. corn can be stored in tropical weather locations in properly well-designed and maintained silos or warehouses with no type of treatment for at least two and a half months without having a detrimental effect on its quality. Also, with application of mold inhibitor at arrival in Southeast Asia and grain chilling in the silo during storage, U.S. corn can be stored for at least four months without detrimental effects on quality. The application of mold inhibitor can help control potential growth of fungi spores typically present in the environment in tropical weather locations. Grain chilling, to keep corn cool and avoid insect growth and infestation, is a viable storage strategy. Finally, U.S. corn stored at a moisture content below 14.5% does not increase aflatoxin levels.

COLLABORATORS:

This research project was funded by USGC, the Kansas Corn Commission and KSU.

1. INTRODUCTION:

Storing grain or oilseeds in tropical weather locations is a challenge due to the extreme conditions of high ambient temperatures and relative humidity.

At temperatures between 25 and 35°C, insects eat and reproduce at higher-than-normal levels. (Christensen and Meronuck, 1986; Navarro et al., 2002). Molds present in stored grain tend to grow exponentially when the temperature around them is higher than 28°C and the relative humidity is above 65 to 70%. Molds tend to spoil grain causing it to lose quality and develop musty and sour odors (Christensen and Meronuck, 1986). Also, certain molds of the *Aspergillus* and *Penicillium* families under the right temperature, relative humidity and moisture content of the grain can produce aflatoxin and ochratoxin during storage. These mycotoxins, as they are widely known, are metabolites of molds toxic to animals and humans (Christensen and Meronuck, 1986; Reed, 2006). Molds benefit when there are forms of water around

DISCLAIMER:

The following report was prepared for the U.S. Grains Council (USGC) by Kansas State University (KSU). It is based on research developed and conducted by the Stored Product Protection Research Group led by Dr. Carlos Campabadal in Malaysia.

them, like liquids or gas (vapor). Therefore, any form of condensation that occurs in storage structures like in silos or warehouses, when in contact with grain, can make mold grow faster and detrimentally affect the overall grain quality. To help maintain grain quality during storage, it is important to pay attention to the temperature, relative humidity and any contact of the grain with any form of water.

These extreme weather conditions that influence stored grain quality are common year round in locations in Southeast Asia, Latin America and some parts of Africa. This makes it difficult for feed millers or grain processors to store grain adequately for more than short periods of time without losing quality. At the same time, there has been a lack of information on how to properly store grains and oilseeds in this type of weather for longer periods. As an example, one of the common mistakes seen in grain quality management is the use of grain aeration, which is the application of airflow to a grain mass to reduce its temperature to acceptable values where molds and insects won't cause issues. However, the ambient temperature needs to be well below 25 to 28°C and relative humidity below 75% for these conditions to be met, and in tropical weather locations, these parameters are harder to achieve. Additionally, most grain quality management strategies to date have been based primarily on chemical controls like the application of mold inhibitors (Morales-Quiros et al., 2017). A limited number of research studies have come up with strategies that give viable options for use in tropical climates. The only way to cool stored grain in most tropical climates is by using grain chilling. This technology is proven effective in tropical and sub-tropical climates to store grain successfully and control insects (Morales-Quiros, et al., 2017).

U.S. corn and co-products - when imported into Southeast Asia - face these challenges which limit the storage time to shorter periods affecting the purchasing power of buyers. Therefore, to enhance trade and help the grain processing and feed industry optimize storage practices, this research study was developed in Malaysia at a poultry feed manufacturing facility and in conjunction with KSU and USGC to determine the best grain management strategies to enhance storability of U.S. corn for longer periods of time without affecting quality.

2. OBJECTIVES:

The main objective of this project was to determine the best grain quality management strategies for storing U.S. corn in tropical locales like the ones present year-round in Malaysia.

The sub-objectives were to:

1. Establish the best grain quality management strategies based on the available options to optimally store U.S. corn in tropical weather conditions;
2. Analyze U.S. corn at origin and destination to determine if transportation to Southeast Asia affects overall quality; and
3. Determine whether removing (cleaning) the BCFM of U.S. corn at destination before storage improves storability and its effect on the removal of any potential mycotoxins.

3. MATERIALS AND METHODS (PROCEDURES)

The research project was conducted in Malaysia at a poultry feed manufacturing facility between September 2018 and February 2019.

3.1. TESTED CORN

This research project was conducted using a total of 4,600 MT of U.S. #2 Yellow Dent Corn sourced from two different U.S. suppliers in Illinois. All corn was shipped in containers from both locations between July 15 and August 15, 2018, and arrived in Malaysia - first into Penang Port to clear customs and then into feed and flour mill facilities between September 14 and October 4, 2018. The load specifications for each supplier are as follows:

- **Supplier 1:** A total of 1,800 MT of corn was loaded into 68 containers (40' long) divided into four bookings of 17 containers, each one resulting in a total of four Official Export Inspection Certificates by FGIS.
- **Supplier 2:** A total of 2,800 MT of corn was loaded in 115 containers (20' long) divided into seven bookings varying between 12 to 20 containers resulting in a total of seven Official Export Inspection Certificates.

3.2 TESTING FACILITIES

The research project was conducted at a Malaysian poultry feed manufacturing facility where there is a loading port to unload vessels, flour mill and feed mill with shared concrete and metal silos, a new aquaculture facility and poultry breeding farms.

3.2.1. GRAIN RECEIVING

All corn entered Malaysia through the port of Penang for customs inspection and was unloaded using a skeet loader (Figure 1) on top of a metal platform into a newly built dumping pit modified for this research project. This platform has metal bars instead of a solid metal sheet as a floor so the grain can flow down from the skeet loader into the dumping pit below it. After unloading, the corn was conveyed into the cleaning system that consists of a series of sifters and aspirators to separate the foreign material, broken corn and dust. Afterward, corn was transferred through a conveying system to a specific spot where mold inhibitor was applied in some cases (depending on the grain strategy that was assigned for the load) before it was stored into its corresponding concrete silo for the storage trials. The amount of corn applied with mold inhibitor at destination will be mentioned below in Section 3.3.

3.2.2. STORAGE TRIALS LOCATION

The storage trials were conducted in eight concrete silos of 1,200 MT capacity, each one located on the flour mill building (Figure 2). Each concrete silo has a temperature cable system setup from OPI Systems (Calgary, Canada) to monitor the stored grain temperature in real-time.

Each silo was loaded from the top through a conveyor system and it was unloaded from the bottom into another conveyor system. A HOBO (temperature and relative humidity data logger) and an insect bioassay were installed in each bin to record the conditions inside each concrete silo and the status of insect mortality, respectively (Figure 3).

3.2.3. FEED MANUFACTURING

After each storage trial was completed, the corn was used to make poultry feed at the feed mill located behind the flour mill. After manufacturing, the feed was transferred to specific poultry houses in nearby locations.

3.3. SAMPLING PROCEDURES

Samples for physical and chemical analysis, mold count and mycotoxin content were taken at different points - from origin, receiving, conveying and during the unloading of the storage concrete silos. A sampling procedure guidance document was developed for consistency in sampling procedures conducted during the research trial. The sampling locations (except at origin) were determined by KSU and the Malaysian facility (Figure 4).

In detail, the sampling was conducted as follows:

3.3.1 SAMPLING AT ORIGIN

At the grain container loading facilities of Supplier 2 and the one contracted by Supplier 1, grain sampling was conducted based on the FGIS sampling procedures used during loading of containers.

Figure 1. Unloading U.S. corn from containers in Malaysia.

Figure 2. Facility in Malaysia with concrete silos where storage trial was conducted.

Concrete Silo Setup

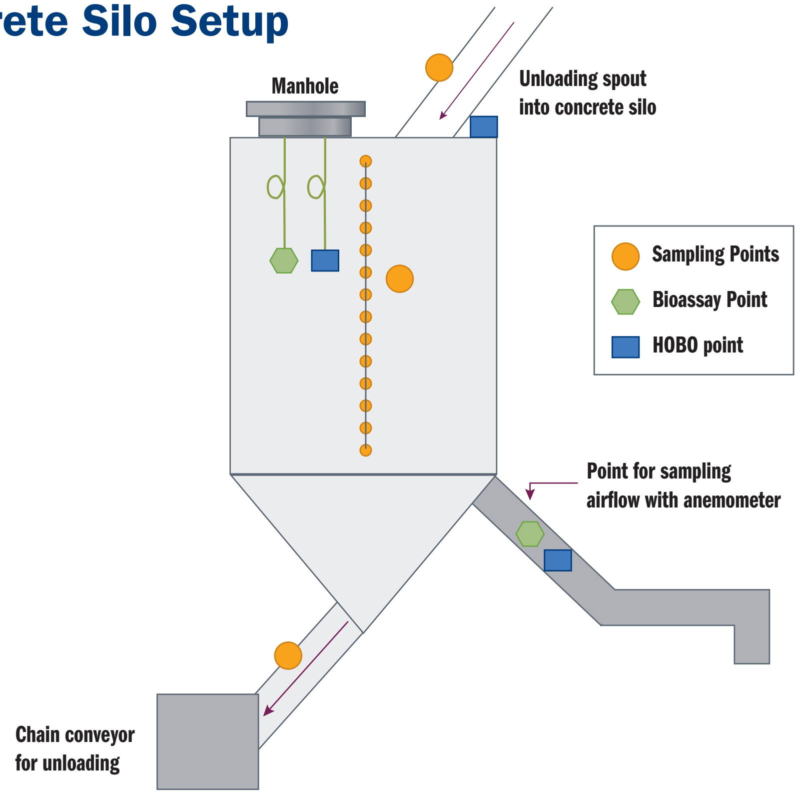

Figure 3. Diagram of concrete silo setup at storage facility with sampling points and location of measuring instruments (temperature cable, HOBOs and insect bioassay).

Sampling Diagram after Unloading

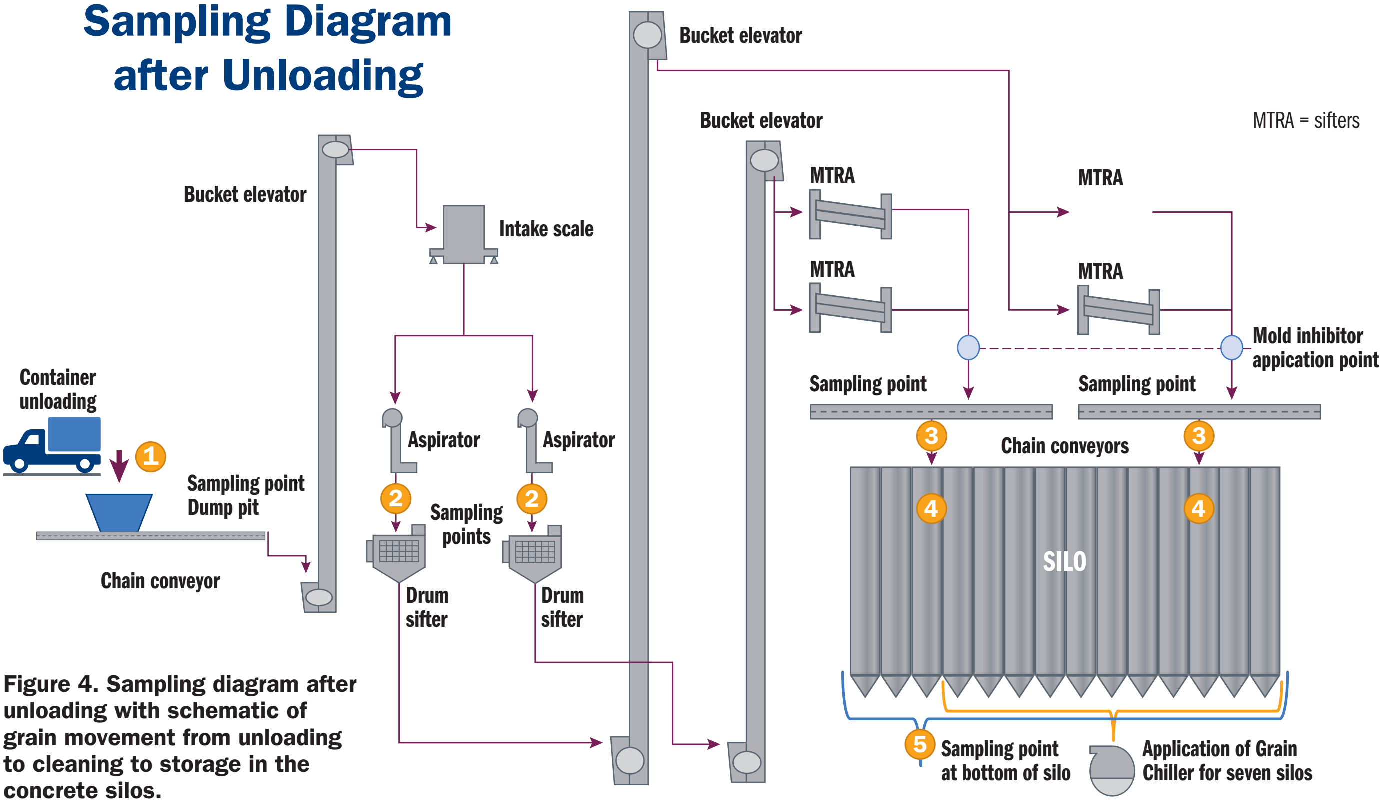

Figure 4. Sampling diagram after unloading with schematic of grain movement from unloading to cleaning to storage in the concrete silos.

3.3.2. SAMPLING AT DESTINATION

A 4 kg composite sample was obtained at the Malaysian facilities, for each arriving container using a 6-foot grain probe (Figure 5) as follows:

- For the 40-foot containers, three samples were obtained during unloading at three points: front (close to the door), middle and back, and then randomly mixed to make one composite sample.
- For the 20-foot containers, two samples were obtained during unloading at two points (due to the smaller size of the container) at front (close to the door) and back, and then randomly mixed to make one composite sample.

3.3.3. SAMPLING DURING CONVEYING INTO THE STORAGE CONCRETE SILOS

During conveying, for each container, two samples were taken after cleaning (separation of BCFM), one after aspiration and one after sifting before storage (Figure 6).

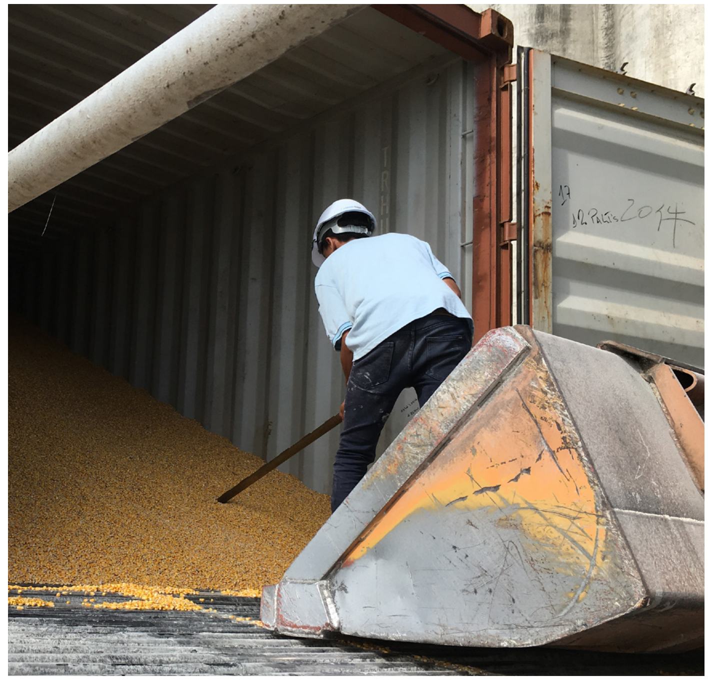

Figure 5. Sampling of U.S. corn from incoming containers at the Malaysian facility using a 6-foot grain probe.

Sampling Point Locations

#	PICTURE OF SAMPLING LOCATION	#	PICTURE OF SAMPLING LOCATION	#	PICTURE OF SAMPLING LOCATION
1	 At unloading	3	 At spout after sifting and before entering silo	6	 After MTRA/ sifter (during usage/transfer to feed mill)
2	  After aspirator	4	 inside silo, to of grain (during storage)	7	 Feed mill incoming conveyor (during usage/ transfer to feed mill)
		5	 bottom silo, (during storage or usage)		

Figure 6. Pictures of sampling locations from unloading, cleaning, storage and transfer to feed mill based on the sampling diagram.

3.3.4. SAMPLING DURING STORAGE PERIOD

During the trial's storage period, two samples (top and bottom) were taken from each of the concrete silos and mixed to create a composite sample (Figure 3). The samples were taken every week or, in some cases, every two weeks, until the corn was unloaded.

3.3.5. SAMPLING AFTER STORAGE PERIOD

After the corn was unloaded from each of the concrete silos, it was transferred into the feed mill for processing. Samples were taken during the conveying after sifting and after conveying into the feed mill. (Figure 8). Then during feed manufacturing, samples were taken at grinding, batching, pelleting and unloading into tanker (feed truck) and at the poultry farms.

3.4. PHYSICAL AND CHEMICAL ANALYSIS OF SAMPLES

To check the overall quality of U.S. corn at the different stages - origin, destination, storage and handling (conveying) - several physical and chemical analyses were performed. Each composite sample taken was of 4 kg. Each sample was divided into two sub-samples, half for storage as a reference and half as the working sample for analysis. Each reference sample was stored at the poultry feed manufacturing facility's Quality Control Laboratory (DPDC) (Figure 7). Table 1 and Table 2 show the physical and chemical analysis to the samples, respectively, for what was quantified. Each analysis shows the method, unit for reporting and frequency of the analysis. All methods were chosen based on the common ones used by international standards. Each analytic method description can be shared, if needed.

Figure 7. Example of reference sample of U.S. corn taken from a composite sample during container unloading.

Sampling Diagram at Discharge from Storage

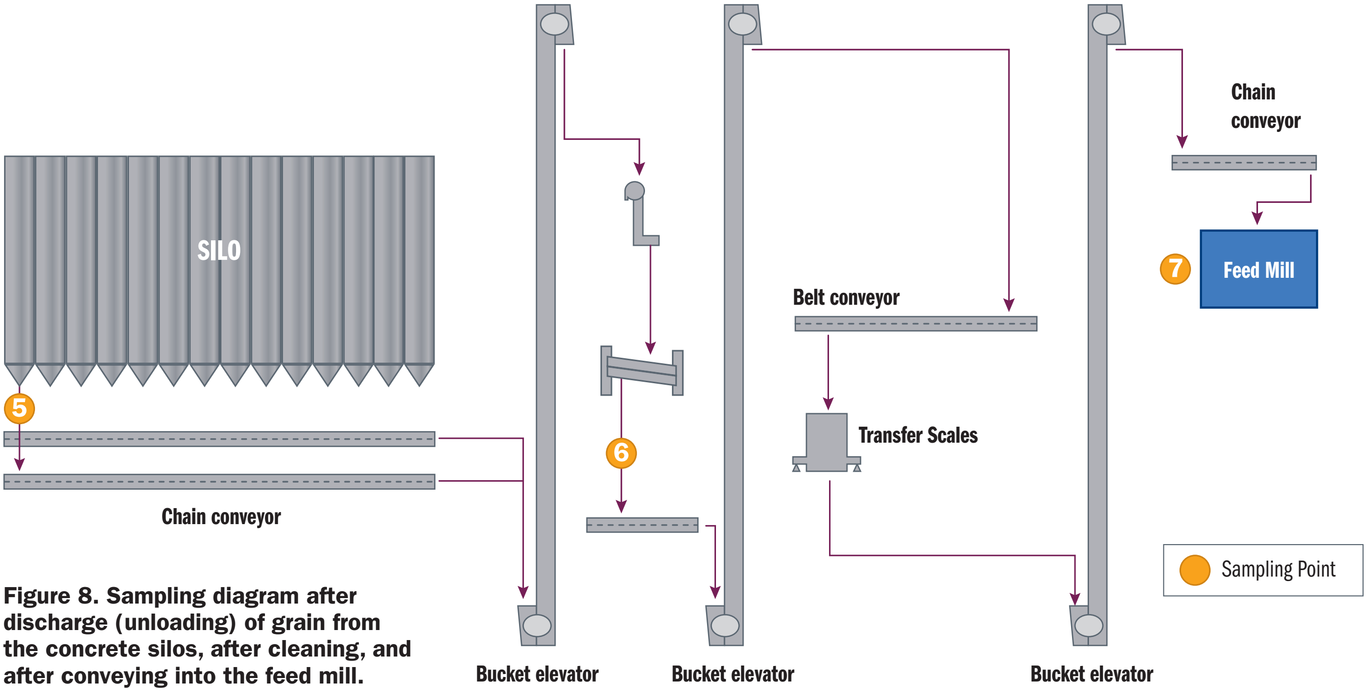

Figure 8. Sampling diagram after discharge (unloading) of grain from the concrete silos, after cleaning, and after conveying into the feed mill.

Table 1. Physical analysis performed on the grain samples obtained at different points (destination, cleaning, conveying, storage and transfer to feed mill).

TEST	METHOD	LABORATORY	FREQUENCY
Moisture Content (%)	AOAC 930.15 (135°C, 2 hours)	DPDC	Incoming, after aspirate, after rotary sifter, storage (weekly), 1 week before feeding, end of the storage trial
Physical Tests: Dust (%), BCFM (%), total Damaged Kernels (%), Test Weight (lb/bu)	FGIS U.S. Standard Methods[1]	DPDC	Incoming, after aspirate, after rotary sifter, 1st week of storage, 1 week before feeding, end of the storage trial
SPC (cfu/g)	Petrifilm Method	DPDC	Incoming, storage (random every 2 weeks), after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Yeast & Mold (cu/g)	Petrifilm Method	DPDC	Incoming, storage (random every 2 weeks), after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Propionic Acid (%)[2]		Kemin Lab	Incoming (3 composites with Mycocurb, 2 composites without Mycocurb)
Mold (cfu/g)[2]			

NOTES:

[1] The physical analysis for U.S. Standards were performed by DPDC using the guidance and same equipment used by the U.S. Federal Grain Inspection Service (FGIS) , under Grain Inspection, Packers & Stockyards Administration (GIPSA).

[2] Propionic acid and mold count at origin (from Supplier 2) were analyzed at the Kemin Laboratory located in Iowa from samples obtained from FGIS during loading of containers.

Table 2. Chemical analysis performed on the grain and feed samples obtained at different points (destination, cleaning, conveying, storage, transfer to feed mill and manufacturing).

TEST	METHOD	LABORATORY	FREQUENCY
Protein Content (%)	AOAC 988.05 (Kjeldahl), NIR (Proximate)	DPDC	Incoming, after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Fat Content (%)	AOAC 920.39, NIR (Proximate)	DPDC	Incoming, after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Ash Content (%)	AOAC 962.09, NIR (Proximate)	DPDC	Incoming, after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Fiber Content (%)	Gerhardt Fiberbag	DPDC	Incoming, after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
NIR Proximate (%)	Adessio NIR	DPDC	Incoming, 1 week before feeding, end of the storage trial
Mycotoxin Content[1] (ppm or ppb)	ELISA Kits Method	DPDC	Incoming (Afla, Ochra (Neogen); Fumo, T-2, Zeara and DON: (AgraQuant),
			Storage (weekly: Afla, Ochra, Fumo, T-2, Zeara and DON), after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial
Gross Energy Content (%)	Bomb Calorimeter	Biosynergy[2]	Incoming, after aspirate, after rotary sifter, 1 week before feeding, end of the storage trial

NOTES:

[1] The mycotoxin content analysis was done for Afla = Aflatoxin, Ochra = Ochratoxin, Fumo = Fumonisin, T-2, Zeara = Zearalenone, and DON. At DPDC, two ELISA kits were used, one from Neogen and the other from Romer Labs.

[2] The Biosynergy Laboratory is an external lab used since DPDC does not have the necessary equipment to conduct the gross energy content analysis.

3.5 RESEARCH PROCEDURE FOR EACH SUB-OBJECTIVE

For each of the three sub-objectives, an explanation of the research procedure is detailed.

3.5.1. PROCEDURE FOR SUB-OBJECTIVE 1 – ESTABLISHING THE BEST GRAIN QUALITY MANAGEMENT STRATEGIES BASED ON THE AVAILABLE OPTIONS TO OPTIMALLY STORE U.S. CORN IN TROPICAL WEATHER CONDITIONS

The grain quality management strategies refer to the specific combination of treatments administered to the grain to maintain its quality with minimal loss during the storage time. Three treatments were used:

a. Mold inhibitor application at origin to reduce the growth of mold at the grain export facility in the U.S.

b. Mold inhibitor application at destination to reduce the growth of mold during silo storage

c. Grain chilling application to lower the grain mass temperatures to values where there is no or minimal mold growth and lower insect activity in the storage silos

Therefore, eight grain quality management strategies were employed –based on the combination of the three treatments (seven strategies) and a control silo with no treatment. No aeration strategy was tested since a previous analysis conducted on the five-years weather history of the area showed there was a very limited window of days available with some hours where aeration could be performed when the outside temperature is below 25 to 26°C (the suggested maximum temperature to aerate in any location is 28°C, but it is recommended to use 2°C of lower temperature due to the fan warm that occurs when using positive pressure fans like the ones present in the Malaysian facility) and the relative humidity is below 70%.

The summary of treatments (including the amount of corn stored in each silo, the source of the corn from the U.S. and if an insect bioassay was used to check for insect mortality) is shown on Table 3.

At origin, the mold inhibitor was applied only at Supplier 2's facility to all 2,800 MT of corn loaded into the containers at a rate of 1 kg/mt. The mold inhibitor was provided by Kemin Industries with a product called MycoCurb[1]. No mold inhibitor was applied to the 1,800 MT loaded into the containers at the facility used by Supplier 1. Kemin Industries analyzed the application of mold inhibitor by measuring mold count, moisture content and quantification of Aflatoxin, Zearalenone, T-2, DON (Vomitoxin), and Fumonisin. At destination, the application of mold inhibitor was performed in the Malaysian facility's receiving system after the grain cleaning process (Figure 9). The mold inhibitor used was a locally available product called: DMX-7[2] which is based on a surfactant and propionic acid.

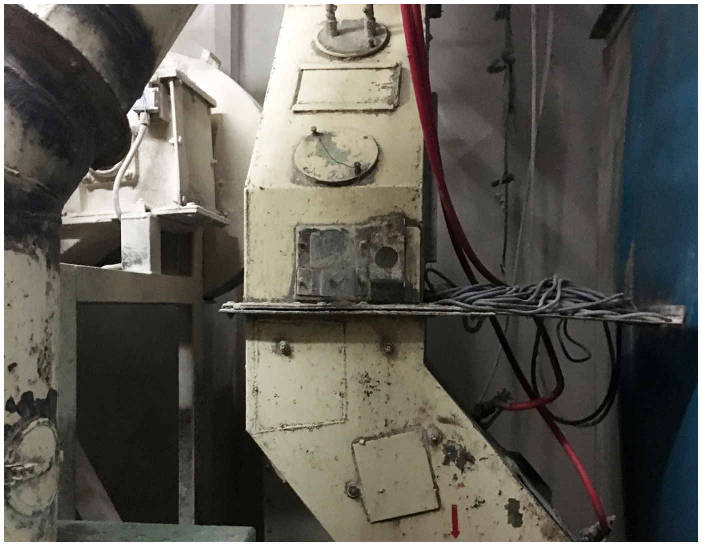

Figure 9. Mold inhibitor application system located in the grain receiving system at the Malaysian facility.

Table 3. Grain quality management strategies tested at MFM storage silos with the amount of corn used per silo, if insect bioassays were used and the source of the corn from the U.S.

STRATEGY	MOLD INHIBITOR APPLICATION	CHILLING APPLICATION	AMOUNT OF CORN IN SILO (MT)	INSECT BIOASSAY	SOURCE OF CORN
1	Origin	No	304	No	Supplier 2
2	Destination	No	158	No	Supplier 1
3	No	Yes	1,002	Yes	Supplier 1
4	Destination	Yes	885	No	Supplier 1
5	No	No	129	Yes	Supplier 1
6	Origin & Destination	Yes	1,007	No	Supplier 2
7	Origin	Yes	996	No	Supplier 2
8	Origin & Destination	No	282	No	Supplier 2

[1] [2] Technical data is available on request.

The grain chilling application was used to insert cooler air into the storage silos from the Granifrigor System model KK440 Tropic with a power capacity of 78 kW (Figure 10). This grain chiller has a capacity to chill two 1,200 MT concrete silos at the same time in eight to 12 hours depending on the grain temperature and outside weather conditions. The grain chiller outlet cooled air temperature was set at 18°C for days 1 and 2 and at 16°C for day 3 of treatment. The chilled air outlet was connected through insulated ducts (or commonly available ducts) to the current aeration system of the grain silos.

3.5.1.1. EQUIPMENT USED AT STORAGE SILOS

The equipment used to conduct the research trials for sub-objective 1 included the following:

1. A total of eight concrete silos that have:
    a. Aeration fans with access to measure power consumption and air velocity (if needed to check grain chilling application).
    b. Access to the silo to sample grain during storage either by probing on the top (Figure 11) and from the unloading conveyor at the bottom.
    c. Temperature cables to monitor the temperature front inside each silo (Figure 3).
    d. Storing capacity of 1,200 MT of corn. KSU and the Malaysian facility determined the amount of corn used in each treatment based on the risk of spoilage to reduce any potential economic loss to the facility. Therefore, all treatments with only mold inhibitor applied at origin or destination used amounts of corn between 158 to 304 MT. For grain chilling, the amounts of corn used were between 885 to 1,007 MT. For grain chilling to be effective, the storage silos need to be almost full so the cooled air can move uniformly throughout the grain mass. Using lower amounts of corn (below 70% of the storage capacity of the silo) can result in uneven cooling of the grain mass since air has the tendency to move through the path of least resistance.
2. Insect bioassays to measure insect mortality because of grain chilling and mortality in the control silo (no treatment). They were installed on the top internal part of the silo and on the unloading conveyor at the bottom of the silo (Figure 3). The insect bioassays (Figure 12) were developed to hold 20 adult insects per container with a plastic lid with a hole covered with mesh to allow air movement for insect breathing) and with corn for feeding purposes since the insects are trapped inside the bioassays.

Figure 10. Grain chiller used to insert cooler air into each of the storage silos that had the grain chilling treatment (www.frigortec.com).

Figure 11. Example of the sampling port (shown in circle) at the top of the concrete silos used for each of the grain quality management strategies.

The insect species of *Tribolium sp* (commonly known as red flour beetles and classified as an external feeder pest due to feeding on grain dust) and *Sitophilus sp.* (commonly known as maize weevils and classified as internal feeder pests due to feeding on whole kernels) were chosen to add 20 insects per bioassay (per container). These two species were chosen due to their common appearance in grain storage facilities worldwide including at the Malaysian facility. For every month during the storage period (maximum of three months for the treatments used to test insect mortality), two insect bioassays (one of each of the two species) were pulled out to quantify insect mortality (Figure 13).

3. Data loggers (HOBOs) to collect temperature and relative humidity data on a recorded basis. KSU provided 24 distributed as follows:
   a. Each silo had one inside and another on the aeration/chilling duct for a total of 2 x 8 silos = 16 HOBOs.
   b. One next to the chiller equipment to monitor ambient conditions = 1 HOBO.
   c. One in the basement next to the bottom of the silos = 1 HOBO.
   d. Spare ones in case of loss or malfunction = 6 HOBOs.

Figure 12. Example of plastic containers (with a hole on the lid covered with a mesh) used as insect bioassays.

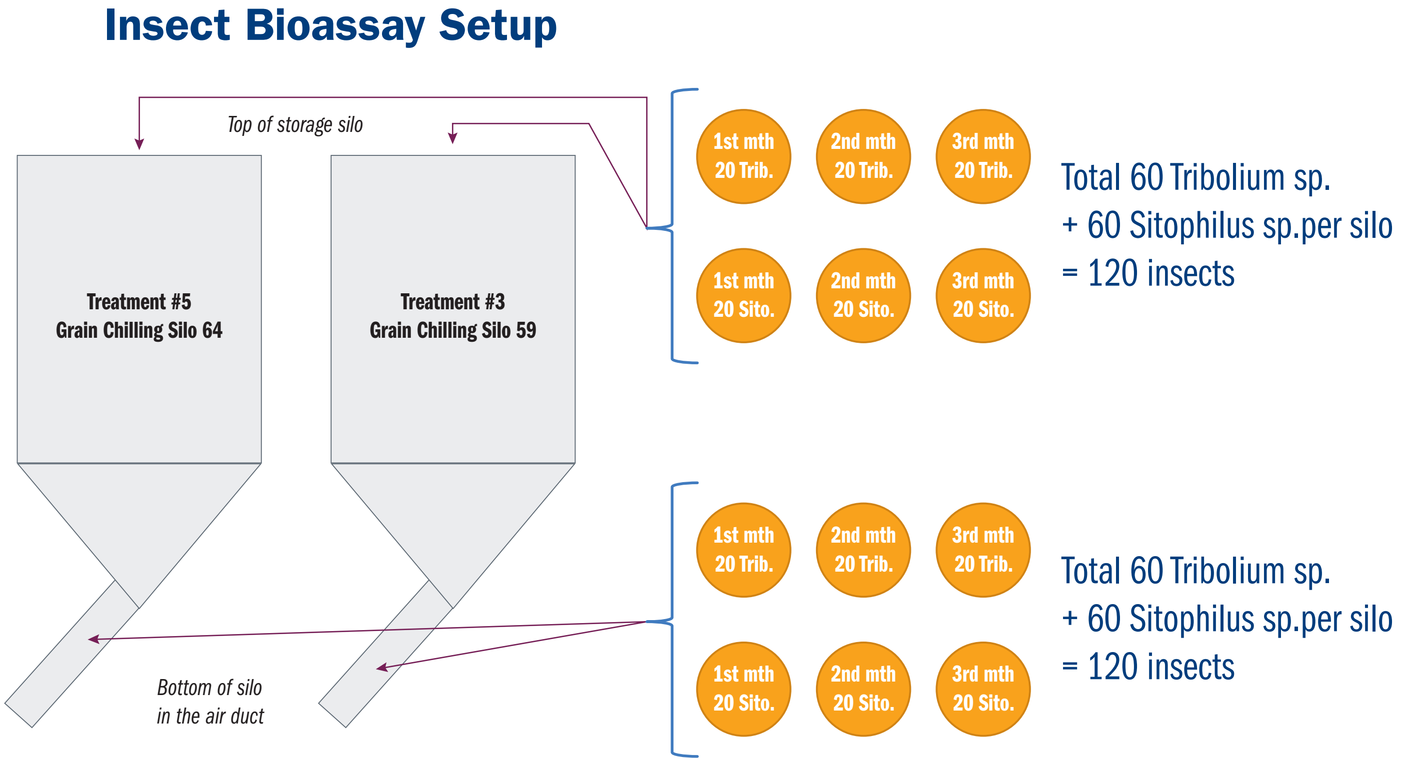

Figure 13. Diagram with schematic of insect bioassay setup on the silos used for treatment with only grain chilling and with no treatment.

3.5.1.2. EVALUATION OF GRAIN QUALITY MANAGEMENT STRATEGIES

The evaluation of each of the grain quality management strategies and control was based on the quantification of the parameters of final moisture content of corn, insect mortality (insect bioassays on grain chilling and control silos), mold and mycotoxin analysis and grain grading parameters after the end of each storage period for each one. Once containers arrived, each grain quality management strategy was started immediately after each storage silo was filled The containers from both suppliers arrived at different dates to the Malaysian poultry feed manufacturing facility. Therefore, the trials were not started all at the same time, but that had no direct impact on the results.

3.5.2. PROCEDURE FOR SUB-OBJECTIVE 2 - ANALYZE U.S. CORN AT ORIGIN AND DESTINATION TO DETERMINE IF TRANSPORTATION TO SOUTHEAST ASIA AFFECTS OVERALL QUALITY

The second sub-objective had the goal of analyzing the quality of U.S. corn at origin and destination to determine if transportation in containers to Southeast Asia affects overall quality. For analysis purposes, at origin, the quality measurements were obtained from the grain grading analysis for corn performed by FGIS using the U.S. Grading Standards. These values at origin were reported based on the results of the Official Export Inspection Certificates developed from composite samples that came from the specific number of containers per booking. Containers loaded with U.S. corn supplied by Supplier 1 and Supplier 2 were grouped in four and seven bookings, respectively. The number of containers varied between 11 to 20 containers per booking. At destination, samples were obtained from each container during unloading and compiled as composite samples to match the same containers from the bookings as it was reported on each of the Official Export Certificates. The parameters for evaluating quality between origin and destination were moisture content, BCFM, damaged kernels, mold count and the following mycotoxins: Aflatoxin, Zearalenone, T-2, Vomitoxin and Fumonisin. The same analysis performed at origin by FGIS was done at destination by the Malyasian facility's Quality Control Laboratory (DPDC). DPDC used the same techniques and methods utilized and approved by FGIS.

The analysis at origin for Aflatoxin was performed by FGIS as part of its grain grading procedure for export of U.S. corn and the analysis of the other mycotoxins and mold count was performed by Kemin's Customer Laboratory Services located in Des Moines, Iowa and by KSU's partner laboratory. All mycotoxin analysis performed at destination, was done by DPDC using Elisa kits from Neogen and Romer Labs (commonly used kits in the grain industry and approved by FGIS).

3.5.3. PROCEDURE FOR SUB-OBJECTIVE 3 - DETERMINE WHETHER REMOVING (CLEANING) THE BCFM OF U.S. CORN AT DESTINATION BEFORE STORAGE IMPROVES STORABILITY AND ITS EFFECT ON THE REMOVAL OF ANY POTENTIAL MYCOTOXINS

The third sub-objective had the goal of proving whether removing (cleaning) the BCFM and dust out of U.S. corn at destination before storage improves the corn's storability and its effect on the removal of any potential mycotoxins. Removal of BCFM and dust was performed using the Malaysian facility's grain cleaning system composed of sifters and aspirators installed after the unloading dumping pit, before the application of spot mold inhibitor and before the storage silos. Samples were obtained at three different points (Point 1 after unloading, Point 2 after aspiration and Point 3 after sifting) shown on the sampling diagram on Figure 4. From each point, whole kernel samples were taken to evaluate any moisture content, chemical composition and mycotoxin content differences. Additionally, the amount of BCFM and dust at each sampling point was also quantified. After cleaning, samples of the final whole kernels, BCFM and dust were analyzed for moisture content, chemical composition and mycotoxin content to evaluate the effect of cleaning on U.S. corn quality before storage and any possible concentration of mycotoxins on BCFM and dust.

4. RESULTS

The following results of the research trials are detailed for each sub-objective. It is important to note all corn purchased by the Malaysian facility from the two suppliers was contracted as U.S. #2 Yellow Dent Corn. Therefore, the analyses conducted on quality were compared against the quality grading parameters for U.S. #2 (Table 4).

Table 4. U.S. Grain Grading Parameters for #2 Corn.

	MINIMUM LEVEL OF -	MAXIMUM LEVEL OF -		
GRADE	TEST WEIGHT PER BUSHEL (LB)	HEAT DAMAGED KERNELS (%)	DAMAGED KERNELS TOTAL (%)	BCFM (%)
U.S. #2	54.0	0.2	5.0	3.0

Also, all the quality comparison on maximum allowable mycotoxin contents at receiving and during the research trials were based on the recommended maximum values utilized by the poultry feed manufacturing facility in Malaysia. These maximum values are based on FDA guidelines and scientific information for the mycotoxins that don't have FDA information guidelines (Table 5).

4.1 RESULTS FOR SUB-OBJECTIVE 1

The goal of this objective was to test different grain quality management strategies based on the available options at the Malaysian poultry feed manufacturing facility with the goal of determining the best techniques that can be used by U.S. corn buyers in tropical weather locations to achieve longer storage times with minimal quality loss. The U.S. corn was stored in different quantities (due to the limitation on the availability of U.S. corn) in specific concrete silos dedicated for each of the seven strategies and one with no treatment to serve as the control parameter of the study (Table 6). The treatments utilized were application of mold inhibitor at origin (MI Origin), application of mold inhibitor at destination (MI Destination) and grain chilling (GC). These treatments were combined to develop seven different strategies. The storage time for each one varied depending on the need of stored U.S. corn by the Malaysian facility's poultry feed production.

The average ambient temperature during the trials was 28.7°C, with 32.7°C as a maximum and 24.2°C as minimum (Figure 14). The ambient relative humidity was 70.6%, with 90% as a maximum and 42.1% as a minimum (Figure 15). It has been proven in science that mold grows exponentially at temperatures higher than 28°C and at relative humidity levels higher than 70%. Therefore, at this location, due to the values of the ambient conditions, mold growth occurs at a faster pace.

Table 5. Recommended maximum values for mycotoxin content for poultry feed.

MYCOTOXIN	CONCENTRATION	SOURCE
Aflatoxin (ppb)	20	FDA Guidelines
Zearalenone (ppb)[1]	100-400	Company Guidelines
T-2 (ppb)[1]	100-400	Company Guidelines
Vomitoxin (ppm)	5	FDA Guidelines
Fumonisin (ppm)	30	FDA Guidelines

NOTES:

[1] The Food and Drug Administration of the U.S. does not have guidelines for Zearalenone and T-2 mycotoxins since its presence in U.S. corn is not common. U.S. grain buyers, like the poultry feed manufacturing facility in Malaysia, use maximum levels mentioned in scientific journals as reference on their quality control specifications

Table 6. Grain quality management strategies based on strategy.

#	STRATEGIES	START DATE	END DATE	STORAGE TIME (DAYS)	AMOUNT TREATED (MT)
1	MI Origin	9/24/18	11/9/18	45	304
2	MI Destination	10/4/18	12/22/18	78	158
3	Chilling	10/4/18	12/22/18	78	158
4	MI Destination + Chilling	9/15/18	1/17/19	122	885
5	No treatment (Control)	10/4/18	12/23/18	79	132
6	MI Origin & Destination + Chilling	9/25/18	12/22/18	87	1,007
7	MI Origin + Chilling	9/25/18	1/17/19	112	1,000
8	MI Origin & Destination	9/26/18	10/17/18	21	282

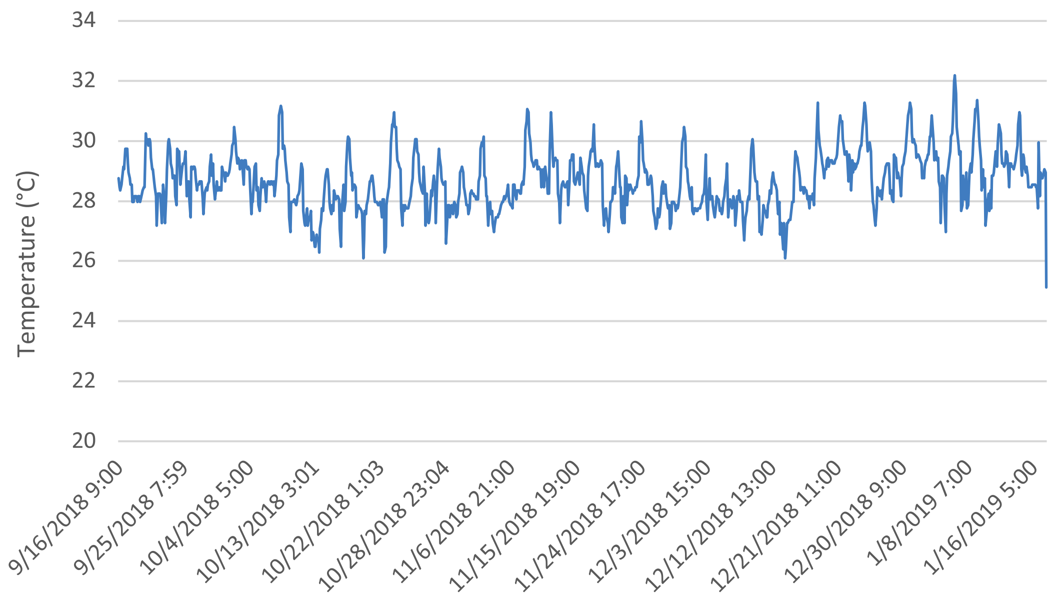

Figure 14. Ambient temperature (°C) from September 16, 2018, to January 16, 2019, in Malaysia.

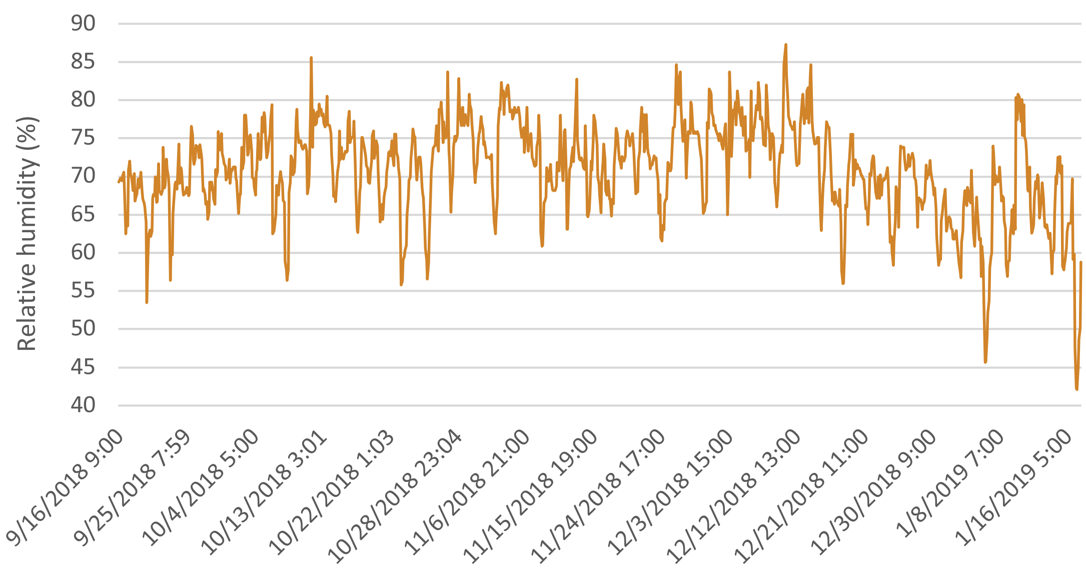

Figure 15. Ambient relative humidity (%) from September 16, 2018, to January 16, 2019, in Malaysia.

4.1.1. RESULTS OF QUALITY ANALYSIS

The results of the quality analysis (Table 7) showed that - for the physical analysis for Strategies #4 and #7 - there was a considerable increase in BCFM. This increase was probably caused by the handling of the corn during the unloading procedure from the container and the loading procedure into the storage silos. There was a considerable increase in damaged kernels (DK) on strategies #4, #7 and #8.

The moisture content of the stored corn only slightly increased in strategies #4, #7 and #8. This increase can be caused by absorption from the humidity of the environment or just by differences in the lot during sampling. However, all final values were below the safe storage moisture content utilized in the U.S. of 14.5% - 15%.

The mycotoxin analysis showed the Aflatoxin content on the U.S. corn at the start of the trials had low values of 5 and 6 ppb in strategies #1, #2, #6 and #7, and was not detected in strategies #3, #4, #5 and #8. The analysis also showed the Aflatoxin content was not detected in any of the strategies at the end of the storage trials since they did not increase or were not present at the end of the trial which means it was not produced during the storage time inside each of the storage silos. It is important to note only Aflatoxins and Ochratoxins can be produced during storage by the *Aspergillus* family of molds if the right conditions are present (temperature and relative and high moisture content of the grain). It is important to mention that at least on the corn supplied by Supplier 2, no *Aspergillius* molds were found by the analysis conducted by Kemin Industries Laboratory at origin. The rest of the mycotoxins analyzed on the study did not have any values above the limits by FGIS guidelines (Table 5). In many cases, these mycotoxins were not detected at all.

The mold count analysis showed there were very few mold spores (range 0 to 500 cfu/g) present on the U.S. corn at the start of the research trials. Also, mold did not grow during storage even on the control silo (strategy #5) that did not have treatment. It is important to note the mold count maximum limit normally used by the grain and feed industry is 50,000 cfu/g. The low values of mold present are more likely due to the lower moisture content of the U.S. corn and no contact with water as liquid or humidity during the storage time.

Table 7. Physical, mycotoxin and mold count analysis for U.S. corn samples taken at the silo at the start and end of each of the strategies.

STRATEGIES	SAMPLE	MC (%)	BCFM (%)	DK (%)	AFLA (PPB)	ZEA (PPB)	T-2 (PPB)	VOM (PPM)	FUM (PPM)	M (CFU/G)
1	Initial	13.44	2.04	4.11	6	43	ND	0.37	ND	300
	Final	13.64	1.69	3.15	ND	ND	ND	0.54	ND	0
2	Initial	14.48	1.14	5.89	5	43	ND	0.75	0.31	100
	Final	13.54	1.58	5.24	ND	ND	ND	0.54	ND	400
3	Initial	13.29	1.11	3.65	ND	41	ND	0.32	ND	200
	Final	13.67	1.70	3.56	ND	ND	ND	0.48	ND	300
4	Initial	13.14	2.03	2.00	ND	ND	ND	0.29	0.27	500
	Final	14.05	7.27	6.44	ND	86	ND	0.55	0.27	200
5	Initial	13.81	0.98	5.22	ND	27	ND	0.33	ND	200
	Final	13.94	1.79	3.28	ND	ND	ND	0.7	1.34	300
6	Initial	13.57	0.90	2.94	6	27	ND	0.42	0.25	200
	Final	13.87	1.67	3.74	ND	ND	ND	0.51	ND	200
7	Initial	13.60	0.96	3.69	6	27	ND	0.48	ND	300
	Final	14.39	4.89	11.01	ND	ND	ND	0.47	ND	300
8	Initial	13.51	1.38	2.65	ND	ND	ND	0.26	0.31	100
	Final	14.32	1.54	7.88	ND	ND	ND	0.52	ND	200

NOTES:

MC: Moisture content, BCFM: Broken Corn and Foreign Material, DK: Damaged Kernels, Afla: Aflatoxin, Zea: Zearalenone, Vom: Vomitoxin, Fum: Fumonisin, and M: Mold count.

4.1.2. GRAIN TEMPERATURE ANALYSIS

The grain temperature was monitored in each silo for verification to assess if the strategies had any effect. An increase in grain temperature during storage is an indicator of quality loss due to insect infestation or mold growth that can result in spoilage and bad odors.

Even though the ambient temperature in Malaysia was high during the trials, the grain chilling treatments on strategies 3, 4, 6 and 7 decreased the average temperature inside the silos around 20°C (Figure 16 to 19). Nevertheless, it was not possible to maintain these temperatures due to leaks in the aeration system, which caused rewarming of the corn due to high ambient temperatures of the area.

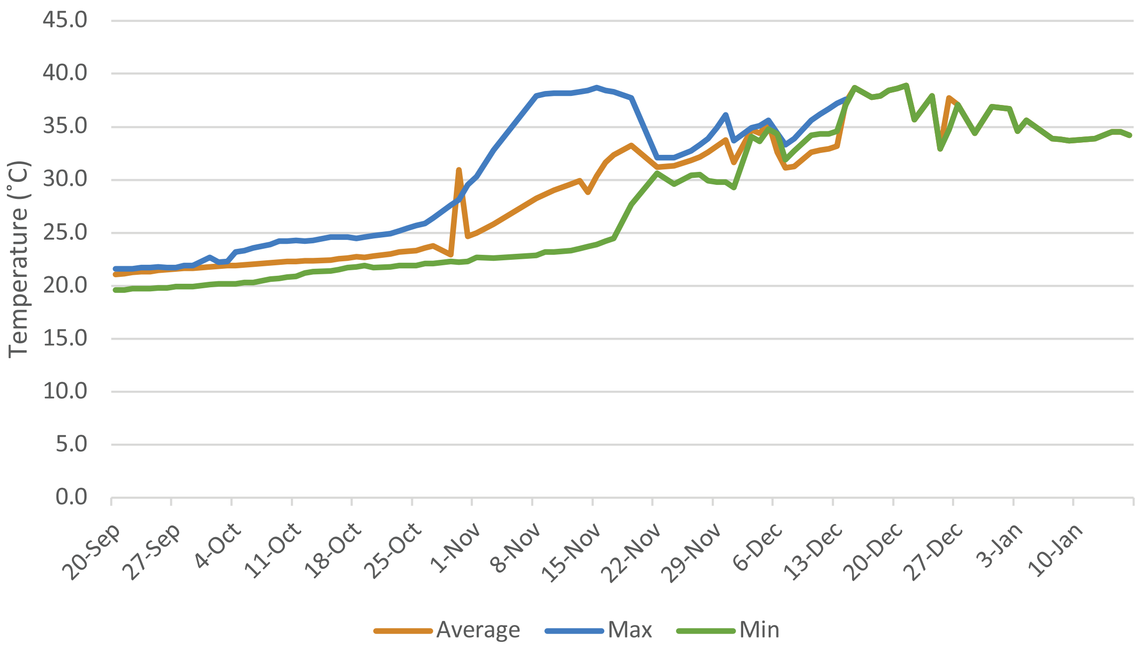

Figure 16. Grain temperature (°C) inside Silo 42 from September 20, 2018, to January 10, 2019, treated with grain chilling and mold inhibitor at destination in Malaysia.

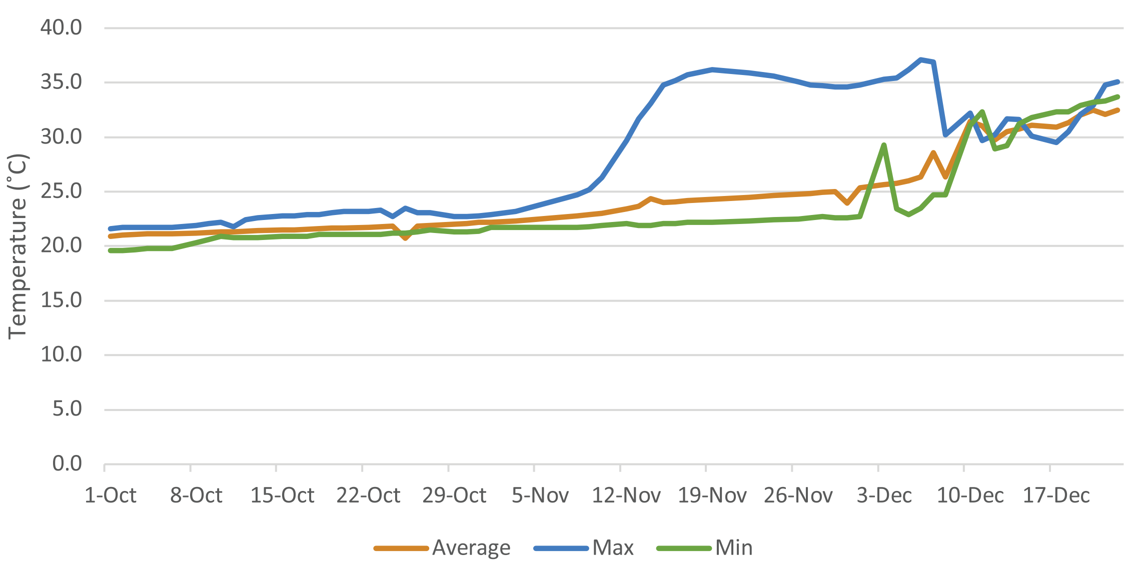

Figure 17. Grain temperature (°C) inside Silo 45 from October 1 to December 17, 2018, treated with grain chilling mold inhibitor at origin and destination in Malaysia.

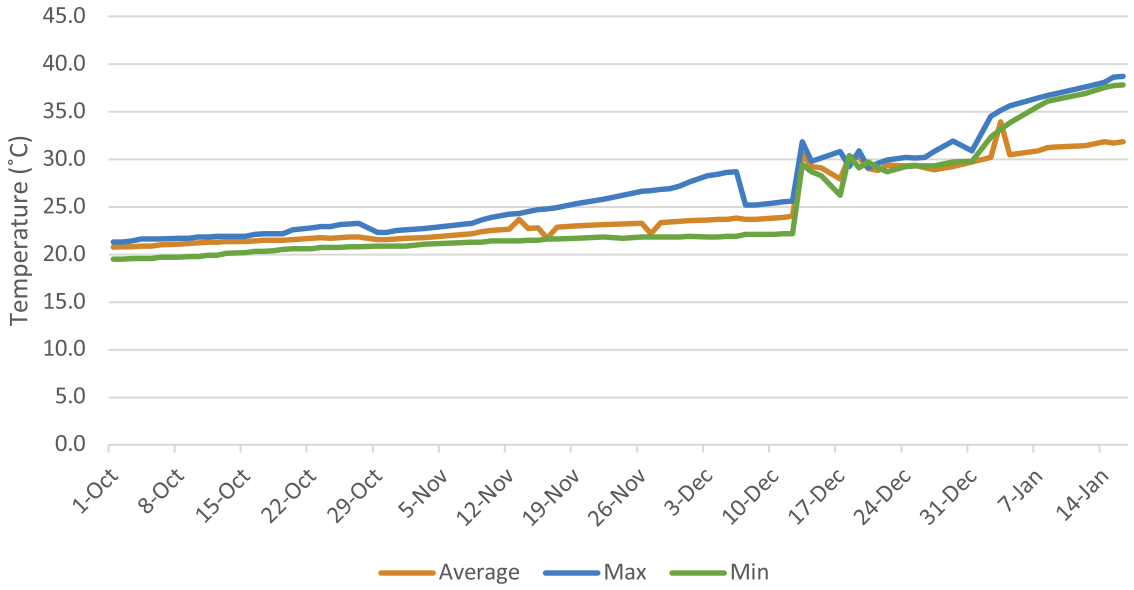

Figure 18. Grain temperature (°C) inside Silo 48 from October 1, 2018, to January 14, 2019, in Malaysia and treated with grain chilling and mold inhibitor at origin.

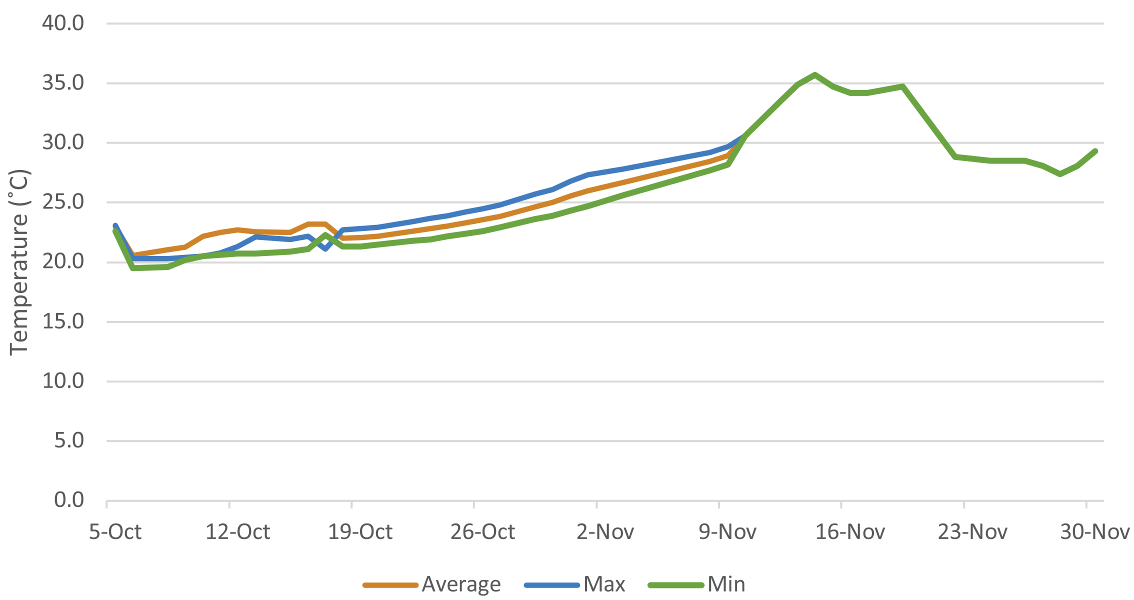

Figure 19. Grain temperature (°C) inside Silo 59 from October 5 to November 30, 2018, and treated with grain chilling in Malaysia.

After the initial grain chilling treatment, the corn temperature increased gradually, and in most cases, reached approximately the average ambient temperature after 60 days of storage. The temperature of corn stored for a longer time, around 100 days, increased up to temperatures between 35°C and 40°C (Figure 17 to 19).

The inability to maintain temperatures below 20°C made it impossible to determine the effect of low temperatures in pest control. The corn stored for a longer time presented higher pest infestations, according to standards of the company[3].

The silos not chilled (Figure 20-24) remained on average between 25°C and 30°C during the storage trials, which was under 79 days for all of them. Two of these silos had to be completely emptied at 21 (Figure 20) and 45 (Figure 21) days of storage because the maize was warming up over 35°C, which was determined as a trigger point before initiating the trials. In other silos, like silo 64 (Figure 22 and 23), grain temperature decreased but this was due to the gradual discharge of corn that the Malaysian facility did during the storage period.

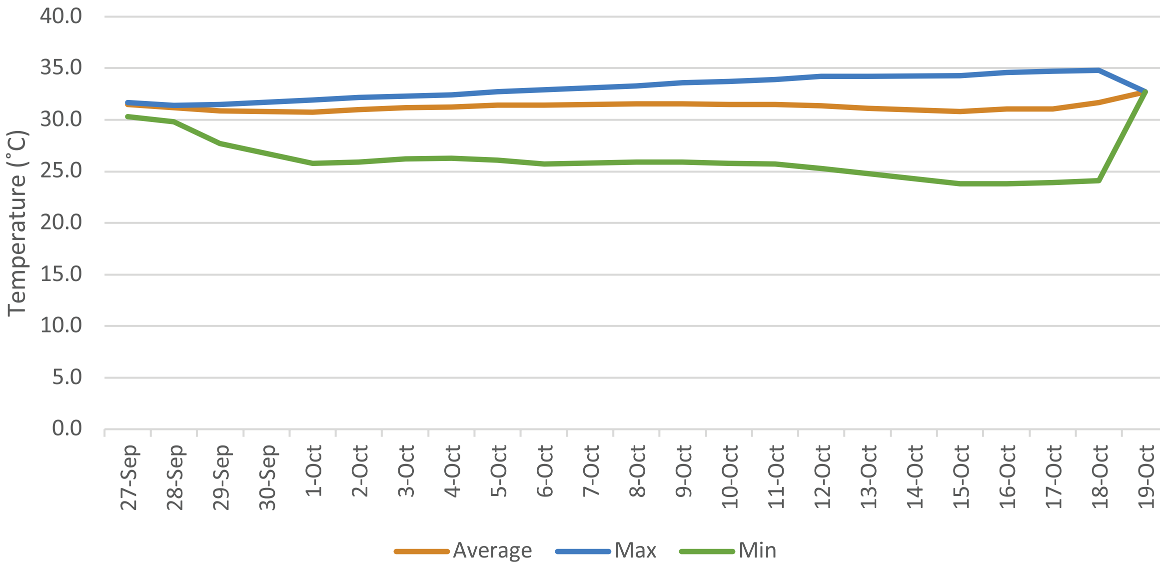

Figure 20. temperature (°C) inside Silo 46 from September 27 to October 19, 2018 and treated with mold inhibitor at origin and destination in Malaysia.

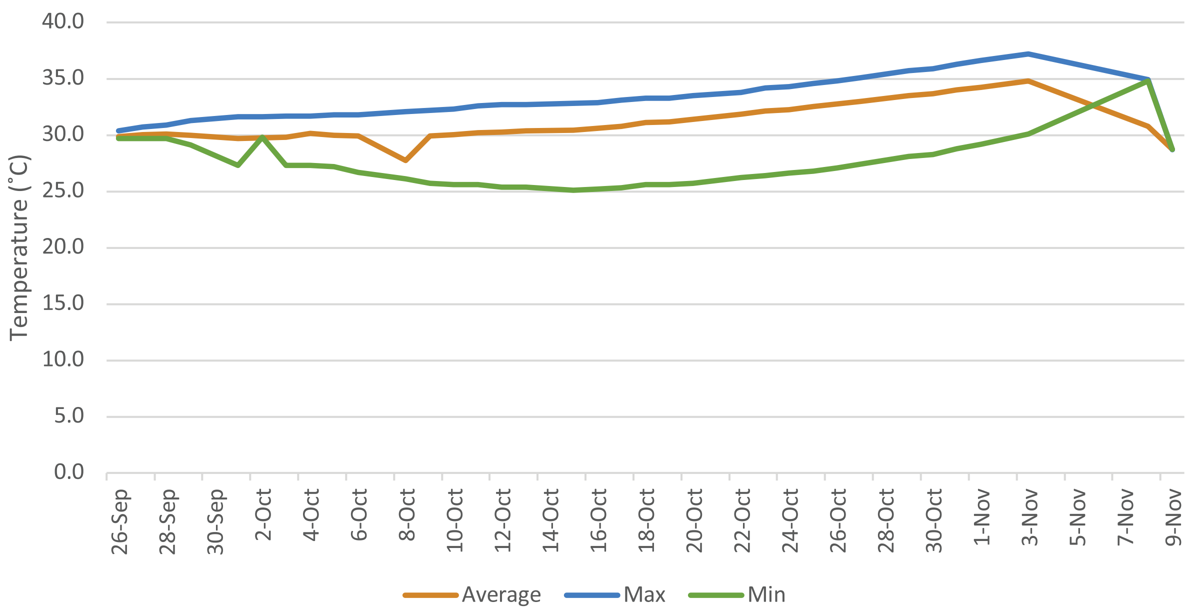

Figure 21. Grain temperature (°C) inside Silo 54 from September 26 to November 9, 2018, in Malaysia and treated with mold inhibitor at origin.

[3] According to the Malaysian facility's standards, if under five weevils are observed in a 500 g sample, it is classified as moderate. If > 10 insects, it is classified as high infestation.

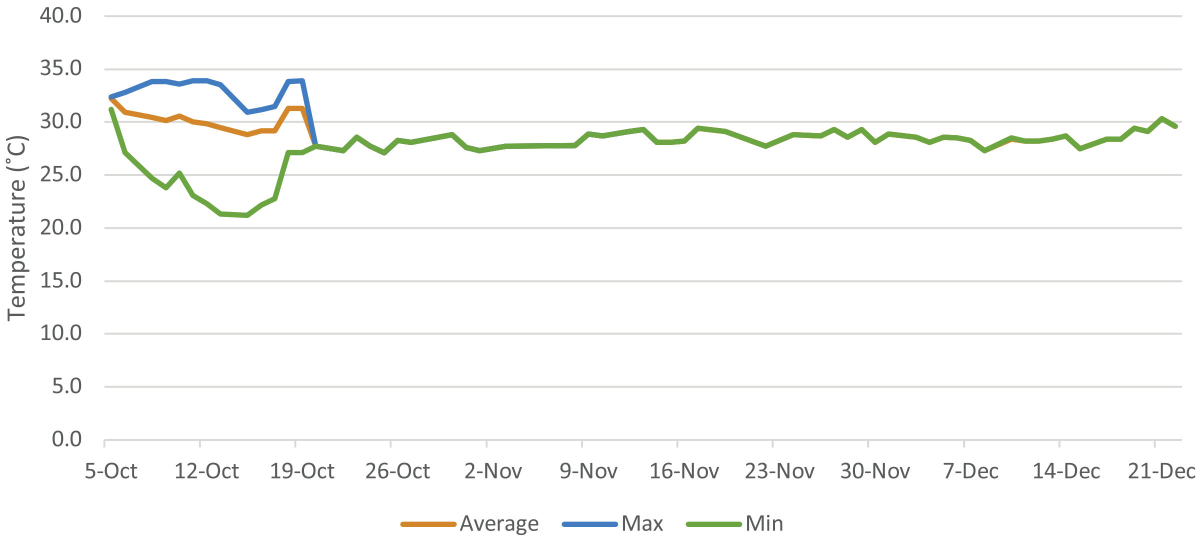

Figure 22. Grain temperature (°C) inside Silo 58 from October 5 to December 21, 2018 and treated with mold inhibitor at destination in Malaysia.

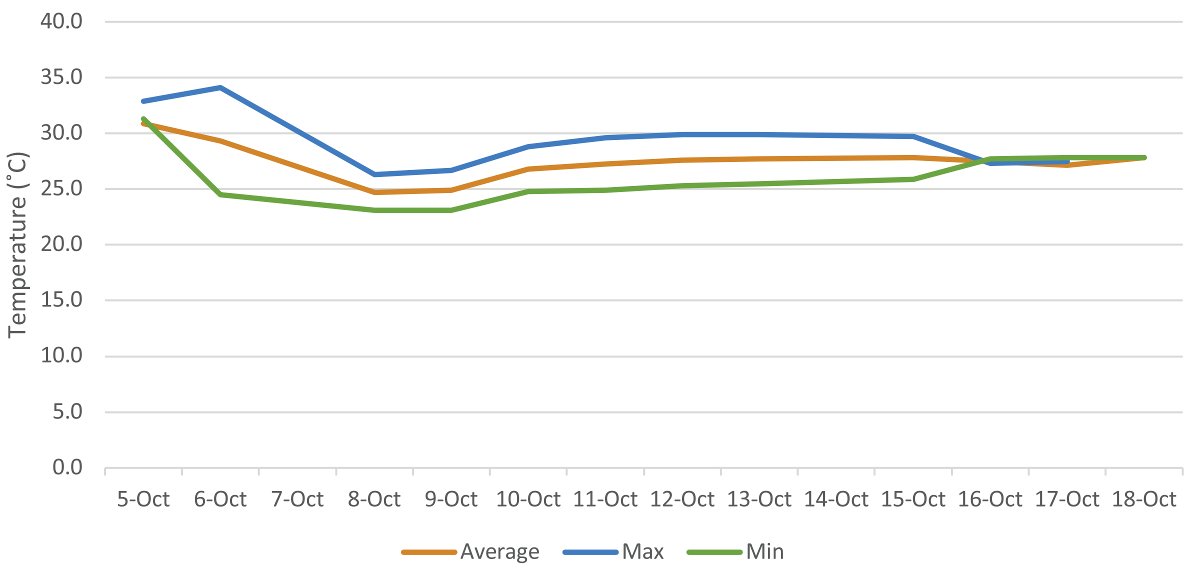

Figure 23. Grain temperature (°C) inside Silo 64 from October 5 to October 18, 2018, in Malaysia with no treatment.

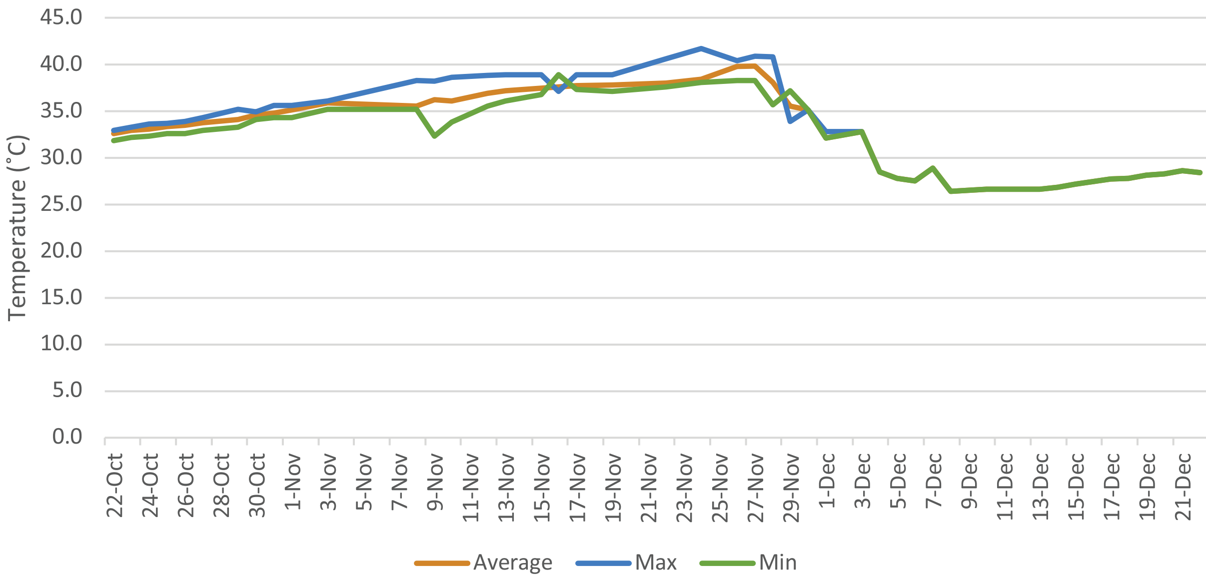

Figure 24. Grain temperature (°C) inside Silo 64 from October 22 to December 21, 2018, in Malaysia with no treatment.

4.1.3. RESULTS OF INSECT MORTALITY

The insect mortality was analyzed based on the results of the two sets of insect bioassays installed on the grain-chilled and no-treatment silos. The results showed at the beginning of the storage trials, some of the *Sitophilus* located on the insect bioassays at the bottom of the silos, were found dead possibly due to the exposure with insecticide applied at the external bottom part of the silos as a normal procedure by the Malaysian facility. For both species *(Tribolium and Sitophilus*), after the first month of the storage trial, populations grew between four to five times. This trend continued after the second month of storage especially at the insect bioassays located at the top of the silos. In the last month of the trial, in the control silo some caking of corn allowed insects to feed inside the bioassays. This caking was most likely due to a combination of the excessive condensation and the dust generated by the insects after eating. These overall results of insect bioassays showed there was no effect on insect mortality inside the storage silos by application of grain chilling or any other external agent.

Insect Bioassay Results

DATE	4TH OCT 2018				3RD NOV 2018				10TH DEC 2018				10TH JAN 2019			
Types of weevil	Chilling		Control		Chilling		Control		Chilling		Control		Chilling		Control	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Sitophilus sp.	20	20	20	20	104	73	135	33 (all dead)	411	148	412	39	234	120 (Additional found with 51 Tribolium sp.)	-	84
Tribolium sp.	20	20	20	20	81	112	177	4 alive, 107 dead	281	177	125	Caking	119	Total 264 (61 – progeny, 203 adult) Maggots found: 42	413	Caking

Grain Chilling on Silo 59 No Treatment on Silo 64

Figure 25. Insect bioassay results for the silos applied with grain chilling and no treatment.

NOTES:

[1] Caking of the broken corn (food for external feeders insect pests) could be due to excessive condensation especially at the bottom of the silo which was placed at the grain cooling ducts.

[2] Some of the *Sitophilus sp.* were found dead during initial stages, possibly due to exposure to fumigant which was inadvertently applied to the external part of the bottom of the storage silos.

4.1.4. RESULTS OF THE ANALYSIS OF THE GRAIN QUALITY MANAGEMENT STRATEGIES

The results of the analysis of each of the grain quality strategies (Table 6 and 7) showed corn stored with no treatment can be held for 79 days without loss of quality. The key parameters of quality of moisture content, mold count and aflatoxin did not increase. There was a slight increase in BCFM more likely due to the handling of the corn during the loading procedure before the trial.

The results showed there is no difference in quality during storage when applying mold inhibitor at origin or destination. However, the decision on where to apply it should be based on where it has operational and logistical advantages.

There was no difference in quality of stored U.S. corn when using grain chilling or mold inhibitor at destination or origin. However, the use of any of these techniques can provide assurance that quality is maintained. All strategies using grain chilling showed it can help reduce potential growth of mold during storage by keeping the internal conditions of temperature and humidity constant and below the minimum values for exponential growth at temperatures of 28°C and relative humidity of 70% (Figures 16 to 19).

The results showed the U.S. corn applied with mold inhibitor at destination and grain chilling during storage can be held up to 122 days without loss of quality. However, it is recommended to monitor more closely the grain temperatures after 100 days of storage since the results showed that molds tend to increase faster (Figure 17) at this point. For this strategy, the aflatoxin and mold count contents did not increase. There was a slight increase in moisture content, probably due to the humidity absorbed by the grain brought into the silo during the chilling process. The level of BCFM and DK increased more likely due to the handling of the corn during the loading procedure before the trial (Table 7). It is important to keep in mind that in this study, the results showed that only four of the strategies had aflatoxins present at destination and in very low quantities (<6 ppb, which is well under the 20 ppb maximum allowed by FGIS (Table 5)). For all strategies, during storage and the end of the trials, the mycotoxin analysis showed there was no increase in aflatoxin content which is the only mycotoxin analyzed on this study that can be produced during storage. The rest of the mycotoxins analyzed in this study are only produced in the field during the growing phase of corn. Therefore, the increase in the zearalenone content shown on the final sample at the end of the trial for the application of mold inhibitor at destination and grain chilling is due to the differences in sampling. However, the value of 86 ppb is still below the maximum limit of 100 to 400 ppb allowed by the Malaysian facility (Table 5). Mycotoxins tend to concentrate in pockets and are usually not uniformly distributed through the whole load of corn.

4.1.5. RESULTS OF ECONOMIC ANALYSIS OF APPLYING THE GRAIN QUALITY MANAGEMENT STRATEGIES

The information obtained from the Malaysian facility showed the following cost of applying each of the treatments at the facility in U.S. dollars/metric ton of corn as of January 30, 2019:

Grain chilling cost is based on an application for a duration of 36 hours which was similar to the time applied for each of the strategies where grain chilling was used as treatment.

The comparison of the cost per metric ton for each grain quality management strategy showed the best value of lower cost compared to longer storage time with minimal quality loss is (Table 9) for the strategy of no treatment since nothing was applied and could be stored for 79 days (almost 2.5 months). If there is a concern on the risk of no treatment application or the moisture content of the stored grain is higher than the safe levels (higher than 13% for tropical weather locations), then the best strategy would

Table 8. Cost of application for each of the treatments of US dollars per metric ton.

TREATMENT	COST $/MT
Mold Inhibitor MycoCurb by Kemin	$2.75
Mold Inhbitor DMX-7	$1.94
Grain Chilling	$0.27

NOTES:

[1] US dollar = 4.104 Ringetts as of January 30, 2019.

Table 9. Cost of application for each grain quality management strategy per metric ton per day.

#	STRATEGIES	STORAGE TIME (DAYS)	COST ($/MT)	COST ($/MT/DAY)
1	MI Origin	45	$2.75	$0.061
2	MI Destination	78	$1.94	$0.025
3	Chilling	78	$0.27	$0.003
4	MI Destination + Chilling	122	$2.21	$0.018
5	No treatment (Control)	79	$0.00	$0.000
6	MI Origin & Destination + Chilling	87	$4.97	$0.057
7	MI Origin + Chilling	112	$3.02	$0.027
8	MI Origin & Destination	21	$4.70	$0.224

be to apply mold inhibitor at destination with grain chilling since it can be stored for 122 days (four months) with a cost of $0.018 per MT/day.

4.2 RESULTS FOR SUB-OBJECTIVE 2

The results of sub-objective 2 on the effect of overall quality on U.S. corn during transportation on containers to Southeast Asia showed there was no change in the average moisture content of the corn during transit between the loading export facilities of Supplier 2 and Supplier 1 and at unloading at the Malaysian facility (Table 10).

It is important to note the MycoCurb product from Kemin Industries has a surfactant component that is supposed to minimize any potential moisture content loss. Therefore, this could have influenced the results of no moisture content loss for the corn shipped from Supplier 2. However, the corn shipped from the facility used by Supplier 1 had no application of this sort and the results of the analysis showed no moisture gain or loss during transit (Table 11).

The analysis of BCFM, showed there was an increase of an average of 2.1% during transit (Table 8). The corn supplied by Supplier 1 had a higher difference between origin and destination, although no cause was determined. When compared to U.S. #2 maximum levels (Table 4), corn from both suppliers had values above the 3% limit, which would have caused them to change the grade to U.S. #3. In general, the probable causes for the extra breakage of corn from both suppliers were:

- Handling of the corn during at-origin loading into each container after the composite samples were obtained.
- Handling of the corn in the containers during transit on rail in the United States and during loading and unloading of the container to and from the vessels.
- Handling of the corn during the unloading procedure using skeet loaders at the Malaysian facility.

The analysis of the damaged kernels showed there was an increase of an average of 1.7% during transit (Table 10).

Table 10. Average results of physical analysis of U.S. corn from both suppliers at origin and destination.

PARAMETER	ORIGIN	DESTINATION
Moisture Content (%)	13.9 ± 0.1	13.7 ± 0.1
BCFM (%)	2.4 ± 0.3	4.5 ± 0.7
Damaged Kernels (%)	2.4 ± 0.3	4.1 ± 0.6

Table 11. Average results of physical analysis of U.S. corn by each supplier at origin and destination.

	MOISTURE CONTENT (%)		BCFM (%)		DAMAGED KERNELS (%)	
	ORIGIN	DESTINATION	ORIGIN	DESTINATION	ORIGIN	DESTINATION
Supplier 1	13.9 ± 0.2	13.8 ± 0.2	2.3 ± 0.2	3.7 ± 0.7	2.2 ± 0.2	3.3 ± 0.8
Supplier 2	13.9 ± 0.1	13.7 ± 0.1	2.5 ± 0.3	5.3 ± 0.8	2.6 ± 0.5	4.9 ± 0.5

The corn supplied by Supplier 1 had a higher difference between origin and destination, although no cause was determined. When compared to U.S. #2 maximum levels (Table 4), corn from both suppliers had values below the 5% limit. Therefore, in terms of grade for both suppliers, it would have stayed at U.S. #2. However, once one parameter goes beyond the limit, then the whole grade changes. The probable cause for the overall increase from both suppliers can be accounted due to a difference in visual identification and quantification of the damaged kernels between FGIS-experienced personnel and DPDC newly trained personnel, since damaged kernels are usually caused by damages produced at the growing field, during post-harvest activities or any potential insect infestation.

The mycotoxin analysis showed all values (Table 12) at origin and destination were below the Food and Drug Administration (FDA) guidelines for corn on poultry feed for Aflatoxin at 20 ppb, Vomitoxin at 5 ppm, and Fumonisin at 30 ppm. For the mycotoxins of Zearalenone and T-2, there are no FDA guidelines for poultry feed. However, the values for T-2 were below the company's guidelines of 100 to 400 ppb. For zearalenone, it was only detected in one sample at origin for 500 ppb, which is higher than the company's guidelines of 100 to 400 ppb. At destination, it was only detected on four samples where the average of 76 ppb was below the maximum limit for poultry feed.

The amount of the average mold count found at origin and destination of 8,785 and 784 cfu/g, respectively, were very low (Table 10) with no effect on the quality of corn. The range of mold count by each of the composite samples from the corn supplied by Supplier 2 were within the range of 400 to 30,000 cfu/g. However, they were below the company's guideline of a maximum level of 50,000 cfu/g. This guideline is used by many different feed mills all over the world. However, no scientific publication has been found to corroborate this value as safe. The low value at destination showed there was no increase in mold growth during transit due to the application of mold inhibitor on the corn from Supplier 2 and for the corn from Supplier 1 due to the optimal moisture content of the corn and probably due to the good seal of the containers. The identification of molds (done by the Kemin Industries Laboratory) found on the composite samples for each booking of corn supplied by Supplier 2 showed the majority of molds were from the *Tricoderma* and *Fusarium* families with nothing showing from the *Aspergillius* family, which is the one that can produce Aflatoxins during storage.

4.3 RESULTS FOR SUB-OBJECTIVE 3

The average chemical composition of both suppliers' corn did not have any significant variation after cleaning (aspiration and sifting) since its structure was not affected during this process (Table 13). The mycotoxin analysis for the corn before and after the cleaning process showed no significant reduction of mycotoxin concentration. However, all values were below the FDA's or company's guidelines on maximum levels allowed and were very low. The mold count for the corn samples was slightly higher after aspiration compared to the samples before cleaning and after going through the sifter. No reason was determined on why this value was higher. However, the values were very low when compared to the Malaysian facility's maximum allowable level of 50,000 cfu/g.

The comparison of the chemical composition between the corn, BCFM and dust showed very few differences (Table 14) and is summarized as follows:

- No significant variation between moisture content for corn and BCFM, and a slight reduction for dust.
- Slight reduction for protein content between the corn and dust.
- Slight reduction on the ash and fat content between the corn with BCFM and dust.
- No differences between fiber contents.
- The comparison of the mycotoxin analysis between the corn, BFCM and dust showed that for all mycotoxins, there was a slightly higher concentration except for aflatoxin that was not detected in any sample.
- The comparison of the mold count analysis for the corn, BCFM and dust showed that after cleaning, mold tends to concentrate in smaller particles which is justified by the higher values on the BCFM and even higher on the dust.

Table 12. Mycotoxin analysis and mold count of U.S. corn at origin and at destination.

PARAMETER	ORIGIN	DESTINATION
Aflatoxin (ppb)	ND	ND
Zearalenone (ppb)	500[1,2]	76 ± 12
T-2 (ppb)	28[1]	ND
Vomitoxin (ppm)	0.6 ± 0.1	0.5 ± 0.1
Fumonisin (ppm)	ND	0.4 ± 0.1
Mold (cfu/g)	8,785 ± 2,974	784 ± 468

NOTES:

[1] Presence in only one composite sample

[2] Value is above the desired maximum levels

ND: No value was detected utilizing the approved by FGIS Elisa kit

Table 13. Chemical composition and mycotoxin content of U.S. corn sampled during unloading and after cleaning with an aspiration and sifting system.

WHOLE CORN			
PARAMETER	**UNLOADING**	**ASPIRATION**	**SIFTING**
Moisture Content (%)	13.85 ± 0.04	13.79 ± 0.06	13.71 ± 0.04
Protein (%)	6.87 ± 0.04	6.68 ± 0.07	6.75 ± 0.05
Ash (%)	1.11 ± 0.02	1.10 ± 0.01	1.10 ± 0.03
Fat (%)	2.81 ± 0.09	2.90 ± 0.16	3.00 ± 0.05
Fiber (%)	1.82 ± 0.05	1.72 ± 0.07	1.84 ± 0.03
Aflatoxin (ppb)	ND	ND	ND
Zearalenone (ppb)	66[1]	26[1]	35[1]
T-2 (ppb)	ND	ND	ND
Vomitoxin (ppm)	0.37 ± 0.05	0.28 ± 0.02	0.30 ± 0.01
Fumonisin (ppm)	0.25 ± 0.01	ND	0.46 ± 0.13
Mold (cfu/g)	100 ± 31	360 ± 166	100 ± 44
Removed Dust (%)	0.49 ± 0.15	0.04 ± 0.01	0.02 ± 0.01
Removed BCFM (%)	4.89 ± 1.24	1.45 ± 0.16	2.04 ± 0.28

NOTES:

[1] Presence in only one composite sample

ND: No value was detected using the approved by FGIS Elisa Kit

Table 14. Chemical composition and mycotoxin content for whole corn, BCFM and dust removed from U.S. corn sampled during unloading and after cleaning with an aspiration and sifting system.

PARAMETER	WHOLE CORN	BCFM	DUST
Moisture Content (%)	13.85 ± 0.04	13.74 ± 0.07	13.47 ± 0.06
Protein (%)	6.87 ± 0.04	6.73 ± 0.11	6.66 ± 0.10
Ash (%)	1.11 ± 0.02	0.76 ± 0.05	0.81 ± 0.04
Fat (%)	2.81 ± 0.09	1.06 ± 0.14	1.03 ± 0.10
Fiber (%)	1.82 ± 0.05	1.82 ± 0.05	1.72 ± 0.07
Aflatoxin (ppb)	ND	ND	ND
Zearalenone (ppb)	66[1]	119.6 ± 52	560.8[2] ± 225
T-2 (ppb)	ND	ND	23[3]
Vomitoxin (ppm)	0.37 ± 0.05	1.20 ± 0.2	3.62 ± 0.5
Fumonisin (ppm)	0.25 ± 0.01	1.14 ± 0.17	2.44 ± 0.58
Mold (cfu/g)	100 ± 31	2,620 ± 1,270	48,760 ± 35,855

NOTES:

[1] Presence in only one composite sample

[2] Value is above the desired maximum levels

ND: No value was detected using the approved by FGIS Elisa kit

5. CONCLUSIONS:

There is no quality loss or moisture absorption of U.S. corn when shipped from the U.S. Midwest into Southeast Asia when using containers in good condition. The use of a grain cleaning system can help improve U.S. corn storability by removing BCFM without affecting its quality or nutritional composition. Since mycotoxins tend to concentrate in BCFM, if present, its removal makes it an optional tool to control their concentration. U.S. corn can be stored in tropical weather locations in proper, well-designed storage structures like silos for at least two and half months without affecting quality. Also, it can be stored for almost four months when treated with mold inhibitor at origin or destination and applying grain chilling during storage without affecting quality.

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Summary of Recommendations

CONTRACTING	Specify a maximum moisture content (14.0–14.5%).
CLEANING	Clean (screen) the corn to remove fine material.
INVENTORY ROTATION	Use the oldest grain first unless other grain is heating. The proper rotation includes removing all the grain from the bin before refilling the bin.
CORING	Core the grain before storage to remove spout lines and equalize the grain height for efficient aeration.
SANITATION	Clean bin bottoms and handling equipment, and remove accumulations of grain material.
MOISTURE MONITORING	Segregate corn containing more than 14.5% moisture content and use it first.
TEMPERATURE MONITORING	Monitor grain temperatures with installed temperature cables, push rods or by grain sampling.
AERATION	▪ Grain temperature should be monitored to determine when to begin aeration. The grain temperature also should be monitored to determine the location of cooling front. ▪ Aeration should be used to control grain temperatures, not to dry the grain. ▪ Aeration should begin only if the grain temperature exceeds the average daily temperature, or if a part of the mass begins to heat. ▪ Unless there is a hot spot, fans should be operated when the air temperature is less than the average daily temperature. ▪ Airflow rates of no less than 0.3 m3/min/m3 are recommended for the tropics. ▪ Small extraction fans (roof fans) may be used to cool air above the grain.

U.S. GRAINS COUNCIL

Storing U.S. Corn In Tropical Conditions Without Quality Loss

About the study

To enhance trade in tropical locales and help grain processing and feed industries optimize their storage practices, the U.S. Grains Council and Kansas State University worked with a Malaysian feed manufacturing facility to conduct a research study to determine the best grain management and storage options for U.S. corn over longer periods without affecting grain quality.

Three study objectives:

- Analyze U.S. corn at origin and destination to determine if transportation affects quality.
- Determine whether removing broken corn and foreign material (BCFM) at destination improves storability and presence of mycotoxins.
- Establish best and most cost-effective grain quality management and storage strategies based on analysis.

Challenge No. 1

Temperature and humidity affect grain quality, so storing any grain in a tropical location is a challenge. When these conditions are present, insect consumption increases, mold growth expands exponentially, grain quality decreases and aflatoxin – toxic to animals and humans – appears. Any form of condensation in contact with grain – water, humidity or other – in storage structures, silos or warehouses, can make mold grow even faster.

Challenge No. 2

Economically, shorter storage times limit purchasing options for buyers.

Study temperature

The average ambient temperature during the trials was 28.7°C, with 32.7°C as a maximum and 24.2°C as minimum.

Study humidity

The ambient relative humidity was 70.6%, with 90% as a maximum and 42.1% as a minimum.

STUDY RESULTS

Application of Mold Inhibitor at Origin

Number of Days Stored	Moisture Content %	Aflatoxin* (ppb)	Mold Count** (cfu/g)
1	13.69	6	300
8	13.71	<5	300
15	13.59	<5	4,000
22	13.26	<5	2,000
30	13.54	<5	11,000
40	13.21	<3	0

* A value of <5 means that if there is any presence of mycotoxins, it is below the detection levels of the ELISA kit (approved by FGIS) utilized for quantification. Both values of <5 and <3 should be reported as 0.

** Mold count is counted as cfu/g, cfu = colony forming units. It is the standard way to measure mold on a grain sample. There is no standard value, but in industry and research, the common value used as the maximum safe amount is 50,000 cfu/g. Above it means there is a high amount of mold spores in just one gram of corn (grain).

Application of Mold Inhibitor at Destination

Number of Days Stored	Moisture Content %	Aflatoxin* (ppb)	Mold Count** (cfu/g)
1	13.83	5	100
8	14.47	<5	100
15	12.85	<5	100
20	14.00	<5	200
28	12.89	<5	0
35	13.40	<5	-
42	13.85	<5	-
49	14.84	<3	4,500
56	14.75	3.19	-
65	12.40	<3	-
71	12.91	<3	-
73	13.64	<3	400

STUDY RESULTS CONTINUED

Application of Grain Chilling

Number of Days Stored	Moisture Content %	Aflatoxin* (ppb)	Mold Count (cfu/g)
1	12.86	<5	200
8	13.16	<5	100
15	12.91	<5	200
20	13.10	<5	100
28	13.44	<5	200
35	13.03	<5	-
42	13.38	<5	-
49	13.24	3.74	0
56	13.64	<3	-
65	13.10	<3	-
71	12.64	<3	-
73	13.72	<3	300

Application of Mold Inhibitor at Origin and Grain Chilling

Number of Days Stored	Moisture Content %	Aflatoxin* (ppb)	Mold Count** (cfu/g)
1	13.65	<5	100
8	14.16	5	100
38	14.34	<5	200

Application of Mold Inhibitor at Destination and Grain Chilling

Number of Days Stored	Moisture Content %	Aflatoxin (ppb)	Mold Count** (cfu/g)
1	13.55	<5	100
8	13.28	<5	300
18	13.20	<5	200
26	13.66	<5	400
33	13.71	<5	-
40	13.8	<5	-
47	14.29	3.97	100
54	13.1	<3	-
63	13.08	<3	-
69	13.01	<3	-
75	14.10	<3	-
83	13.49	<3	-
97	14.38	<3	200

No Treatment

Number of Days Stored	Moisture Content %	Aflatoxin* (ppb)	Mold Count** (cfu/g)
1	13.80	<5	400
13	13.90	<5	300
21	14.19	<5	1,200
28	14.17	<5	-
35	14.51	<5	1,900
42	13.88	3.26	200
49	13.95	<3	-
58	13.69	<3	-
64	13.39	<3	-
67	14.24	<3	300

Storage Recommendations

This study clearly shows no quality loss (increase of aflatoxin levels or mold growth) or moisture absorption on U.S. corn when shipped from the U.S. Midwest into Southeast Asia when using containers in good condition. A grain cleaning system can help improve U.S. corn storability by removing broken corn and foreign material (BCFM) without affecting its quality or chemical composition. Removal of BCFM makes it an optimal tool to control mycotoxin growth.

The results showed that U.S. corn can be stored in tropical weather locations in properly, well-designed and maintained silos or warehouses with no type of treatment for at least 75 days without having any effect on quality. With a mold inhibitor application upon arrival in Southeast Asia and grain chilling in the silo, U.S. corn can also be stored for at least four months without any effect on quality. Mold inhibitor application can help control any potential growth of fungi spores typically present in the environment on tropical weather locations. Grain chilling keeps corn cool, discourages insect growth and infestation and stifles any potential mold growth.

Finally, U.S. corn stored at safe moisture content below 14.5 percent does not show any increase in aflatoxin levels.




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