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HERMETIC STORAGE TECHNOLOGY: REDUCING POST-HARVEST LOSSES OF DRIED AGRICULTURAL COMMODITIES

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Abstract: Insect infestation and mold growth are major problems during long-term storage of dried agricultural commodities as they result in weight loss, contamination, deterioration, and increase chances of fungal contamination. Mold growth often results in mycotoxin production, which is associated with health problems including aflatoxicosis, cancer, and micronutrient deficiencies. Hermetic storage technology, a bio-generated modified atmosphere based on oxygen-depleted and carbon dioxide enriched atmosphere caused by respiring living organisms in the sealed storage, was utilized for various trials in several locations. Several installations were done using GrainPro hermetic solutions including GrainPro Cocoon, Cocoon Indoor, and GrainPro Hermetic Bags (GHBs). Maize was stored in GrainPro Cocoon in Indonesia and was monitored using EcoWiSe, wireless sensing system designed to remotely monitor temperature, % Relative Humidity, and carbon dioxide level in gastight container. From this set-up, an increase in carbon dioxide level was observed and dead insects were found after long-term storage of maize. In the Philippines, rice bran was stored in GrainPro Cocoon for two months. The Free fatty acid (FFA) level remained low due to low oxygen levels inside the Cocoon. A trial was conducted in India for storage of red chili pepper (RCPs) in Cocoon Indoor and GHBs. Cocoon Indoor and GHBs were proven to be effective in preventing aflatoxin production during storage of RCPs for six months. Hermetic storage technology minimizes storage losses, prolongs shelf-life of agricultural goods by eliminating insect infestation, preserving the quality of stored commodity, and inhibits growth of molds and toxin production.

Keywords: hermetic storage, grains, insects, modified atmosphere, carbon dioxide, oxygen

Introduction

Grain storage is practiced to control the market value due to price fluctuations. During harvest season, prices of grains become low while it increases significantly during lean season. Buffer stocks are also necessary for continuous supply in case of market shortage caused by natural calamity. Moreover, storing the necessary amount of grains ensures continuous supply throughout the year. With these, a storage method that can protect the quality of grains must be utilized. This is to prevent deterioration, spoilage, and contamination for long term storage (FAO, 1994). According to Sallam (2013) farmers store crop products at various periods depending on market demands, size of production, and household needs. During storage, the grain quality is affected by storing conditions and leads to deterioration due to fungi and insect infestation.

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Storage of grains is affected by drying operations. Drying and storage processes affect grain quality hence these operations must be carefully accomplished to make sure that grains are well preserved. Once grains are dried properly into safe moisture level, storage methods that would allow storing the commodity for long term must be carefully selected. A storage method that can resolve several problems while preserving its overall quality. Various factors can cause grains to deteriorate over time during storage. According to Suleiman et al. (2013), deterioration of grains is affected by moisture content, temperature, relative humidity, storage conditions, mold growth, and insect infestation. If these factors are not properly controlled or eliminated, they can render grains to be useless due to spoilage and contamination.

FAO (1992) discussed that the factors affecting grain storage are categorized into biotic and non-biotic. Biotic factors include insects, microorganisms, rodents, and birds. Non-biotic factors are relative humidity, temperature, and time. Unfavorable conditions brought by these factors lead to nutrient loss, discoloration, weight loss, heating, mycotoxin contamination, and decrease in seed germination.

Insects during storage of grains affect its overall quality. Storage insects can be classified as primary and secondary feeders. Some species feed on the endosperm and seed germ resulting in loss of weight, poor germination, and less viability. Most storage insects can increase exponentially within a relatively short period according to Sallam (2013) which causes significant damage to the grains when left uncontrolled. As discussed by Hiruy and Getu (2018), insects are most damaging and difficult to control due to their small sizes. Moreover, insects contaminate the grains through excretion, molting, dead bodies, body fragments, webbing, and unwanted odor or flavor. Insects also increase the chances of microbial contamination by being a potential vector for pathogens. Insect feeding activity is associated with fungal growth and mycotoxin production. Insect activities cause damage to grain by producing heat and condensation leading to mold growth, nutritive value reduction, and toxin formation such as aflatoxins. Hence, insect infestation poses a major threat in food security and food safety to farmers, grain producers, and consumers globally.

Contamination of grains with molds and fungi is one of the most serious food safety problems in tropical countries and throughout the world. In tropical and subtropical regions, large amounts of grains are harvested and stored under hot and humid conditions. Properly dried grains are hygroscopic thus absorbing water when exposed to moist conditions. At high moisture, maize grains are more susceptible to microbial attack leading to mycotoxin and aflatoxin production according to Suleiman et al. (2013). Toxigenic storage fungi require moisture at relative humidity of 70% to 90% including *Aspergillus spp.* (*A. flavus, A. parasiticus and A. nomius*). Aflatoxin contamination has been associated with stunting in children, immune suppression, micronutrient deficiencies, higher prevalence of cancers and liver cirrhosis (Suleiman et al., 2013).

Various hermetic storage solutions were installed in different locations. The objective of the set-up was to test the effectiveness of hermetic technology in controlling insect infestation, preserving quality of commodity, and inhibiting aflatoxin production during storage.

Materials and Methods

Hermetic Storage

Several hermetic storage solutions were utilized for this study including GrainPro Cocoon, Cocoon Indoor, and GrainPro Hermetic Bags (GHBs). Hermetic storage, also known as sealed storage, airtight storage or assisted hermetic storage, protects the commodities from insects, molds, and rodents, preventing infestations and oxidation, and eliminating moisture entry (Navarro, 2006). It is a bio-generated modified atmosphere based on an oxygen-depleted and carbon dioxide enriched atmosphere caused by respiring living organisms in the sealed storage. From studies conducted by Navarro et al. (1995) using wheat, insect populations were successfully controlled with an average carbon dioxide level between 10% and 15%. Carbon dioxide above 10% has a toxic effect on insects which makes its spiracles to remain open permanently.

Hermetic technology eliminates the use of chemicals, fumigants, and cold storage. Applications for hermetic technology has been most widely accepted for long-term storage of cereal grains, primarily rice, corn, barley, wheat, and variety of seeds to preserve germination potential and vigor, and quality preservation of high-value commodities such as cocoa and coffee (Villers et al., 2010).

GrainPro® developed Ultra-Hermetic™ gastight storage solutions in Figure 1 are designed for organic-use and the long-term storage of agricultural commodities. Ultra-Hermetic technology is bio-generated storage modifying the internal atmosphere to create a low oxygen, high carbon dioxide environment. The GrainPro® storage solutions, as shown in Figure 1, are made of liner materials equipped with a gas barrier which blocks the moisture and oxygen from coming in. This in turn kills insects, arrests fungal growth, and prevent aflatoxin production in the commodities. The process requires no chemicals, instead, relies on the respiration of insects, grains, and microorganisms to reduce oxygen to unbreathable levels.

Figure 1: The GrainPro® Ultra-hermetic storage solutions for storage and transport of grains

Under humid and warm conditions harvested grains are susceptible to mold growth and rapid deterioration. Therefore, grains should be dried to safe moisture levels that inhibit the activity of microorganisms.

The GrainPro EcoWiSe

The GrainPro® EcoWiSe is a wireless sensing system designed to remotely monitor the environment within a hermetic storage unit in real time. The sensor collects and sends out data such as relative humidity (%RH), temperature (°C) and CO_2 levels (% CO_2) to a receiver that is wirelessly connected to a Smart Android Tablet via Bluetooth. The Android App transmits information via the Internet to designated users who can monitor the data on their computers or smartphones through a WebApp. EcoWiSe is excellent for grains, cocoa, seeds, pulses, and nuts as well as for controlled atmosphere applications. EcoWiSe uses Long Range (LoRa) communication which enables collection of data for a maximum distance of 5 km in a direct line of sight. Users receive data through a dedicated WebApp which will be accessible with a Username and Password supplied on purchase of a receiver. Users will be notified immediately if preset critical points are reached through email. Subsequently, predictive failure analysis can be conducted in the future through data gathered by the EcoWiSe. This solution is designed to monitor crops stored in a GrainPro Cocoon of any kind.

Field Installation

GrainPro Cocoon was utilized for storage of maize in Indonesia from September 2019 to April 2020. The storage conditions of the Cocoon were checked using the GrainPro EcoWise, a remote monitoring system that can be accessed through computers and mobile devices with internet connection. Another GrainPro Cocoon was installed in the Philippines for storage of rice bran for 2 months. Moisture content and free fatty acid (FFA) were tested with rice bran. Oxygen levels were also monitored using the GrainPro Oxygen Analyzer. A demonstration trial was conducted in India for 6-month storage of red chili peppers (RCPs) at warehouse ambient conditions. The RCPs were stored in GrainPro Cocoon Indoor and GrainPro Hermetic Bags (GHBs). Aflatoxins were measured for this trial.

Results and Discussion

Maize was stored in GrainPro Cocoon in Indonesia from September 2019 to April 2020. EcoWiSe readings including percent relative humidity (%RH), temperature in °C, and percent carbon dioxide were recorded as shown in Figure 2. These data were measures of the actual conditions inside the Cocoon installed outdoors.

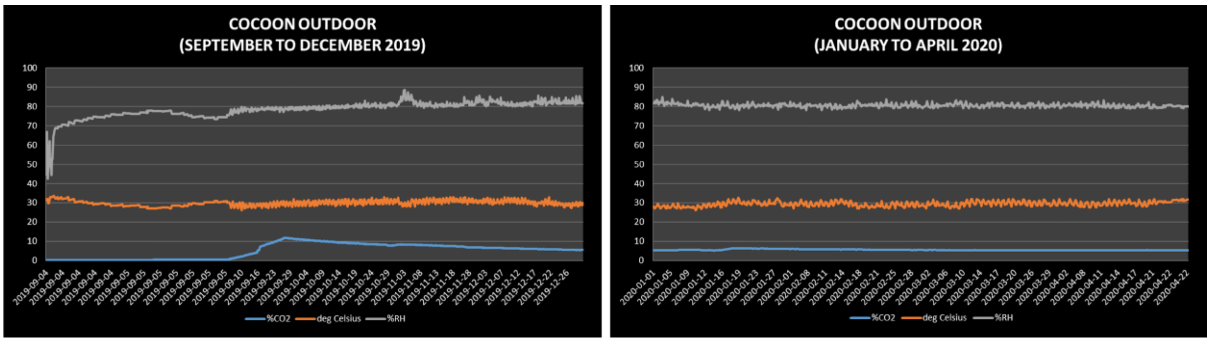

Figure 2: EcoWiSe readings from GrainPro Cocoons taken last September 2019 to April 2020

Temperature inside the Cocoon (outdoor installation) was maintained at 30 °C for 6 months of storage which was similar to average temperature of the ambient surroundings. A temperature of 25°C and above is favorable for insect development. Respiration rate of insects at this temperature is sufficient to modify gas concentrations in a hermetic storage. The recorded temperature and relative humidity of the ambient surroundings with fluctuating values between 35 to 93% are shown in Figure 3.

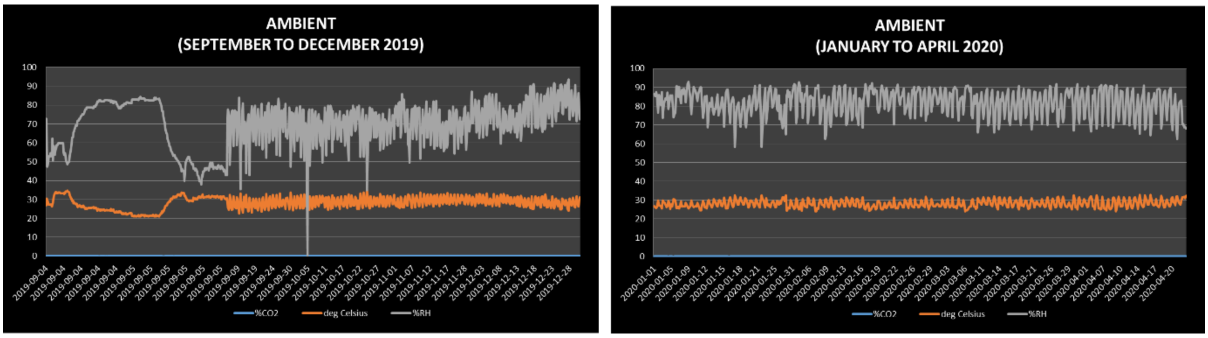

Figure 3: EcoWiSe readings of ambient surroundings taken last September 2019 to April 2020

The %RH inside the Cocoon was maintained at an average of 80% RH for 6 months of storage which did not adapt %RH of ambient surroundings with fluctuating values between 35 to 93%. The Cocoon is made of materials that limits the transmission of water vapor from the surroundings hence protecting the commodity from adsorbing moisture and maintaining the moisture content of the stacks within the storage period. The carbon dioxide started to increase after one week of installation and a faster rate of increase was observed after 15 days of storage at 7.12%. Maize was fumigated prior to storage hence it took two weeks for the remaining infestation to impact the rate of change in carbon dioxide level inside the Cocoon. After 20 days of storage, 10.04% of carbon dioxide was achieved which is needed to control insect infestation. The carbon dioxide peaked at 11.84%, obtained after 23 days of storage. After 35 days, the carbon dioxide level started to decline to 10.01%. Carbon dioxide at 10% or above needs to be maintained for 15 days which is necessary to control insects of all life stages. The decreasing carbon dioxide was due to a declining insect population since the condition was not favorable for its growth and survival affecting its respiration rate. The carbon dioxide declined to 6%. This level was maintained until 6 months of storage. Prior to installation, the stack contained maize with MC above 14%. When equilibrium moisture content (EMC) is above 70% RH, microflora becomes an agent for respiration hence further decline in carbon dioxide was not observed though insects were eliminated during the first month of storage. Insect count was also conducted during the trial. Table 4 shows the results from maize stored in GrainPro Cocoon and control bags stored in the warehouse using PP sacks.

Table 4: Average Insect count per 100 grams of maize stored in the warehouse in PP sacks and GrainPro Cocoon

Storage		Initial	Insect Count (Live)	Insect Count (Dead)
Cocoon	Top	0	0	5
	Middle	0	0	1
	Bottom	0	0	1
Warehouse	PP Sacks	0	10	3

Live and dead insects per 100 grams of maize were observed from maize in non-hermetic woven polypropylene (PP) sacks stored in the warehouse. Maize in the warehouse were exposed to the surroundings which favored insects' growth and development due to presence of oxygen in ambient air. Temperature at 30 °C was favorable for insect activities. No live insects were observed from maize stored in Cocoons. Dead insects were recorded per 100 grams of maize taken from bags placed inside the Cocoons. Dead insects were found at the perimeter of the Cocoon as they tend to look for remaining oxygen inside the gas-tight storage. Modifying the atmosphere level inside a gas tight container was proven to effectively control insect infestation of agricultural commodities without the need for chemical fumigation or low temperature applications.

Rice bran, a natural by-product obtained from the milling process of rice, which is composed of 11–15% proteins, 34–62% carbohydrates, 7–11% crude fibers, 7–10% ash and 15–20% lipids, is the outer layer of rice grain (Chen and Chen, 2016). Rice bran has very short shelf-life due to high fat content and potent enzyme lipase that degrades the oil, making bran rancid and inedible. In the Philippines, rice bran was stored in GrainPro Cocoon to control insect infestation and minimize rancidity. The storage period lasted for two months from April to June 2018 with results shown in Figure 4. The oxygen level dropped below 3% after 43 days. At the start of the trial, the rice bran was observed to be free from visible and live insects signifying that the stack was initially fumigated. After two months of trial, dead insects were observed along the perimeter of the Cocoon. Slight changes were observed for moisture content (MC) and Free Fatty Acid (FFA) levels of the stored rice bran due to sampling method employed during the trial. The sampling was done randomly by withdrawing samples through the transparent port using a grain spear. Stack may contain different MC and quality. Since hermetic container is a closed system, it allows moisture to migrate within the stacks of commodity due to change in temperature during storage. Free fatty acid or FFA level remained low due to high carbon dioxide and low oxygen inside the Cocoon. This limits oxidation of oil-containing commodities including rice bran.

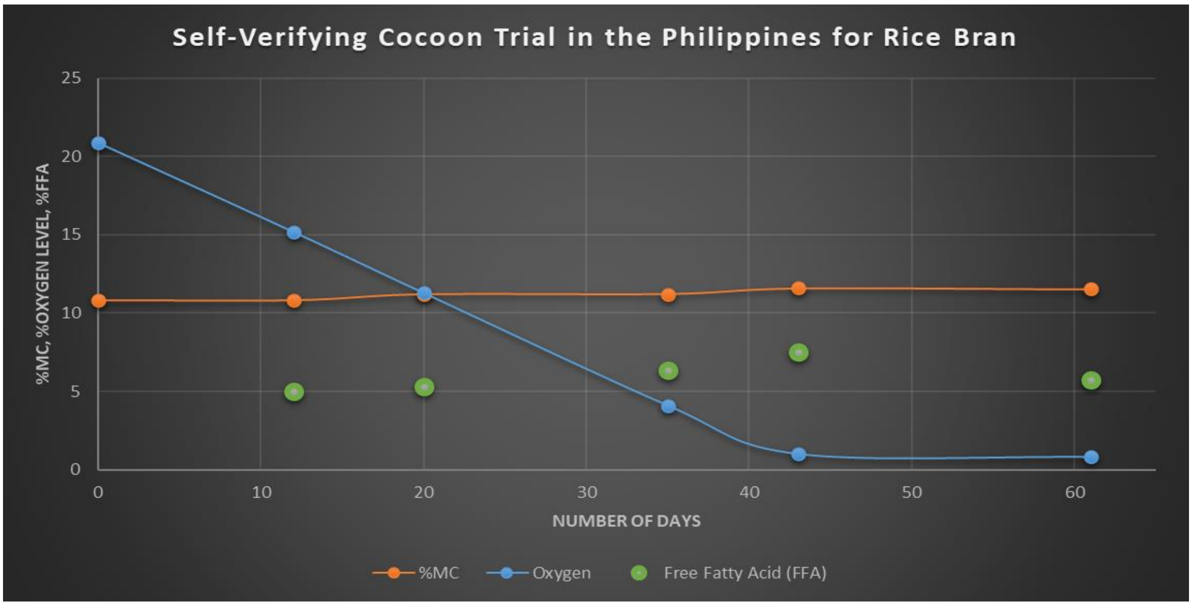

Figure 4: Data taken from a 2-month storage of rice bran in GrainPro Cocoon

A demonstration trial was conducted in India and lasted for six months for storage of red chili peppers at ambient conditions using Grain Cocoon Indoor and GrainPro Hermetic Bags (GHBs). The common practice was to store whole dried red chili peppers (RCPs) requiring lot of space in the storage facility or during transport. It was recommended to test storing dried RCPs in grounded or powdered form to maximize capacity for storage and transport. Various parameters were measured every month for 6 months of storage including aflatoxins as shown in Figure 5.

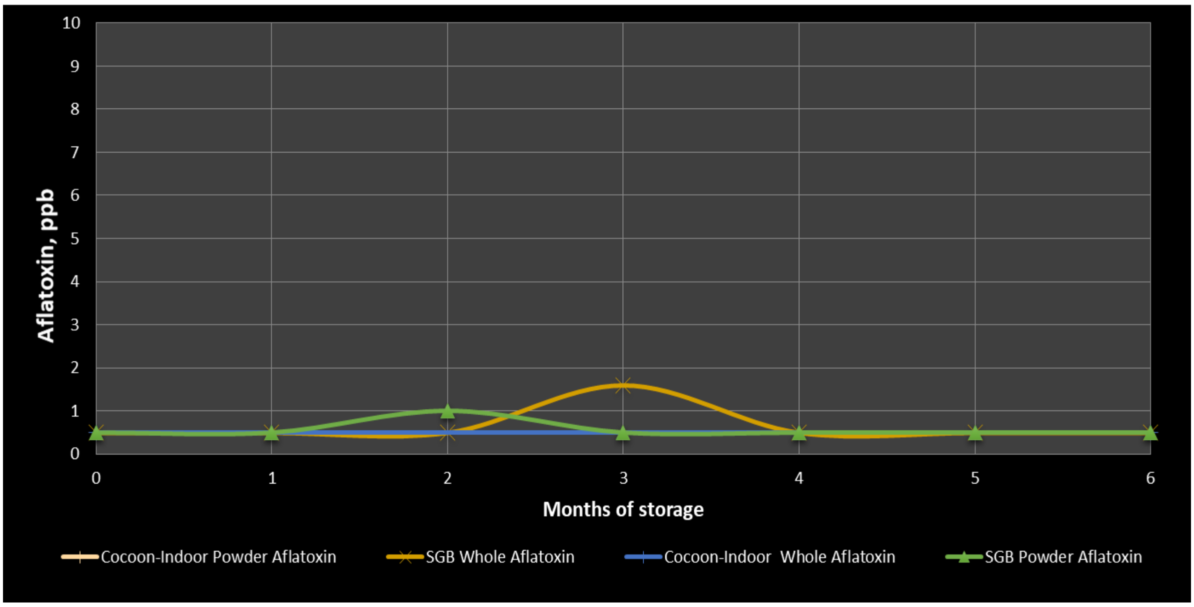

Figure 5: Aflatoxin levels measured from RCPs stored in hermetic storage for six months at ambient conditions

For RCPs stored in Cocoon Indoor, the moisture for whole RCP slightly decreased from 7.15% to 7.11%, while for powdered RCP, no change in moisture was observed. For whole RCPs stored in SGBs, fluctuating moisture was observed due to non-uniform moisture content of RCP lots in this trial. Cocoon Indoor and GHBs are designed to prevent moisture ingress during storage, maintaining moisture of the stored commodity. It is a must that properly agricultural commodities are dried and stored in safe moisture to inhibit mold growth thus preventing aflatoxin or mycotoxin production. In the case of RCPs, a final moisture content of about 8% is ideal, as moisture content above 11% allows mold growth, and below 4% causes excessive color loss (Klieber, 2000). The aflatoxins of RCPs were observed at 0.5 initially up to six months, except on the second month for powdered RCPs and third month for whole RCPs in SGBs. These fluctuations might be brought by the random sampling method utilized to check the aflatoxin. GHBs and Cocoon Indoor were effective in preventing aflatoxin production during storage. Moisture ingress was prevented when using GHBs and Cocoon Indoor thus inhibiting molds by maintaining safe moisture for dried RCPs during storage. When molds are inhibited, production of mycotoxins including aflatoxins are also prevented. GrainPro Hermetic Bags are also utilized for storage of spices including red chili to retain its pungency.

Hermetic storage products are designed to create a modified atmosphere to control insect infestation and prevent moisture ingress from surroundings. The GrainPro storage and transport products are made from materials with excellent gas barriers that do not allow entry of oxygen or water vapor from the surroundings. Due to low gas permeability of materials, the GrainPro storage solutions allow carbon dioxide build-up inside the container, while the living agents such as insects and grains, consume the remaining oxygen. With a low oxygen environment, insect growth and development are halted.

The GrainPro Hermetic Bags (GHBs) products are made from multilayer film with gas barrier that are formulated and certified as food grade. The GHBs are utilized by coffee producers all over the world to preserve coffee quality including its flavor and aroma. A study by Borem, et al. (2013) using the GHBs presented results that hermetic bags were able to keep the high cupping scores of coffee beans stored for 12 months.

Hermetic storage technology minimizes storage losses, prolongs shelf-life of agricultural goods by eliminating insect infestation and damage without the use of pesticides or fumigants. The hermetic storage also inhibits growth of molds and toxin production. GrainPro designed these products without the need for electricity which makes them mobile and flexible. GrainPro is committed to reduce post-harvest losses while promoting safe food products by offering solutions that are efficient and chemical free.

Conclusion

Modifying the atmosphere level inside a gas tight container was proven to effectively control insect infestation of maize without the need for chemical fumigation. free fatty acid or FFA level remained low due to high carbon dioxide and low oxygen inside a gastight container. This limits oxidation of oil-containing commodities including rice bran. Moisture ingress was prevented when using multi-layer PE with gas barrier layer; thus, inhibiting production of aflatoxins by maintaining safe moisture of dried whole and grounded red chilli pepper during storage.

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