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Hermetic Storage of High Moisture Corn under Tropical Conditions

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Abstract: Shelled corn of 26% moisture content (m. c.) was stored in a Cocoon™ under hermetic conditions for 96 days to demonstrate the effectiveness of maintaining its quality prior to subsequent drying or processing into feeds or ethanol. The Cocoon™ was made of a plastic liner and capable of holding 11 tonnes of corn stored in standard bags. Both the Cocoon™ and the control consisting of 3 bags were stored outdoors at the University of the Philippines Los Ba os, Philippines. Corn was sampled before and after storage for determination of m. c., starch, ethanol, aflatoxin, and germination rate. Temperature, oxygen and carbon dioxide concentrations were monitored throughout the storage period. The initial corn temperature in the Cocoon™ reached 45℃ and then equilibrated with that of the ambient at 30℃ after the first week of hermetic storage. The initial oxygen concentration dropped within one day and remained at an average of 0.54% throughout the storage period. Average m. c. at the end of storage increased to 29%. No significant change in starch content was observed throughout the storage period. Corn in the control bags deteriorated after three days and temperature increased to 55℃. The high moisture corn in the Cocoon™ initially had 59 ppb of aflatoxin due to a logistical delay of about 3 days for acquiring the corn from several farmers. Aflatoxin level increased to 90 ppb after one week of storage and remained at that level for 96 days. No presence of insects was observed in the corn samples stored in the Cocoon™. Feeding trials indicated that the corn from hermetic storage was palatable to cows and swine. Results of the study indicate that wet corn can be safely stored for extended periods of time without significant increase in aflatoxin, and without significant changes in starch and ethanol content.

Key words: hermetic storage, high moisture content corn storage, aflatoxin, oxygen, carbon dioxide, starch, ethanol

Introduction

In tropical climates like the Philippines, corn is often harvested under unfavorable conditions. While the need for high capacity mechanical dryers has been recognized to reduce postharvest losses, investments have been high and in between. An alternative to immediate drying is to store freshly harvested corn in a hermetic storage, thereby maintaining its quality prior to subsequent drying or processing into feed or ethanol.

The present study was undertaken to develop an affordable system for long term storage of high moisture corn under tropical climates using the Cocoon™ hermetic storage system. Specifically this study aimed to: 1) demonstrate the effectiveness of storing of high moisture corn under gas tight conditions with minimal losses of weight and quality; 2) to determine the effects of modified atmospheric storage, i. e. oxygen depletion, on the storage environment produced by the biological activity of the commodity and its effect on the control of microflora to prevent development of mycotoxins and the level of ethanol and starch production.

Materials and Methods

Corn Samples

About 11 tons of Monsanto's Bt-corn Dekalb 818 samples were procured from 5 different farmers in Calamba City. Corn was planted between November 28 and December 1 2006, manually harvested between March 11 and 14, 2007 and shelled between March 14 and 15, 2007. The AMDP double-drum corn sheller, suitable for high moisture corn, was utilized in shelling the 25.6% wet basis kernels. Bulk density of the shelled corn is 690 kg/m^3. Corn was delivered and stored in the GrainPro 10 ton Cocoon at ABPROD on March 16, 2007. The second replicate totaled 7 400 kg of Dekalb

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818 which was harvested 25 – 27 June and was procured 28 June 2007.

Only one variety was used in the experiment as Simacha[1] indicated that there is no significant differences in fungal infection and aflatoxin accumulation among varieties.

The experiment was replicated in two periodsone during March to June and the other during July to December 2007. Freshly harvested corn was bought from farmers in the neighboring areas of University of the Philippines Los Ba os (UPLB).

Corn Setup and Sampling

During the first replication, samples of about 1 kg were needed for the various physical and chemical analyses every week. Thirteen bags containing wet corn samples were prepared and placed near the opening of the zipper. One bag was pulled out of the cocoon every week.

After a day of storage, the cocoon ballooned due to the production of carbon dioxide. To regulate the pressure a simple pressure relief consisting of a glass jar, copper tubing and water was installed. The cocoon was also placed under shade to prevent direct radiation which might induce excessive moisture migration and condensation on the corn inside. Visual inspection and simple bubble leak tests were undertaken on a weekly basis to determine the integrity of the cocoon, thus ensuring that there is no leak in the system.

Gas Concentration

Oxygen (O_2) concentration was measured using a portable GrainPro HGA – 11 – B oxygen monitor. Carbon dioxide (CO_2) was measured using a compact Bacharach CO_2 Analyzer 2 820 that displays the detected level of CO_2 in the range of 0 – 60%. The analyzer operates on the infrared-absorption principle to detect the presence of CO_2. Gas concentrations inside the cocoon were measured twice daily.

Ambient conditions

Temperature and relative humidity were measured using Lascar EL – USB – 2 which stores relative humidity and temperature readings in the range of 0 to 100% RH and – 35°to + 80℃.

Grain composition and quality

Moisture content was determined at the Agricultural and Bio-Process Division (ABPROD) using the ASAE Standards for Moisture Content Determination. Starch content was analyzed by Lipa Quality Control Center using AOAC Official Methods of Analysis, 17^{th} edition, 2002. Ethanol content was determined at ABPROD using the Ebulliometer method. Germination rate was determined at ABPROD using the International Seed Testing Association's Rolled Paper Method. Aflatoxin content was determined by the National Institute of Molecular Biology and Biotechnology (BIOTECH) using the Monoclonal Antibody Based ELISA. Some of the analyses were also undertaken by the Lipa Quality Control Center using R-Biopharm AG, Ridascreen, Fast Aflatoxin Enzyme Immunoassay ELISA.

Results and Discussion

Oxygen and Carbon Dioxide Concent – ration inside the Cocoon

After an hour of loading the wet corn inside the cocoon, the CO_2 Analyzer indicated a concentration above the maximum analyzer capacity of 60% CO_2 content. Throughout the experiment, the CO_2 concentration was over the limit of the equipment. With the dramatic production of carbon dioxide during the first four days, the cocoon ballooned, requiring pressure relief.

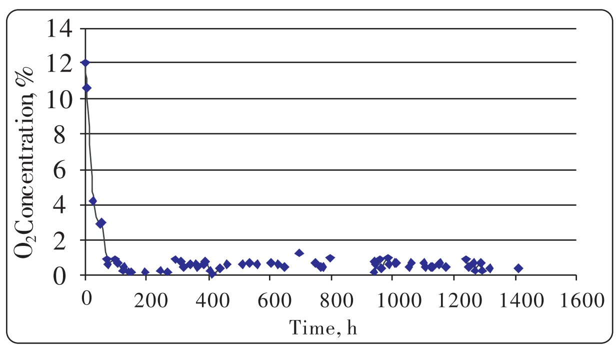

Fig. 1 O_2 concentration in the cocoon with time.

Figure 1 shows the level of O_2 in the cocoon which was at the first hour after sealing the cocoon 12%, and subsequently dropped to lower levels. During the first couple of days after sealing, excessive pressure accompanied by the production of CO_2 from respiration was observed. For three months, O_2 levels in the cocoon (Mar – Jun 2007) had an average value of 0.54%. The second replicate exhibited the same pattern where O_2 concentration greatly decreased after the first two days of storage. In trials carried out by Weinberg et al.[2] similar observations were made; as the moisture level increased the time for O_2 depletion below 1.0% shortened, from 600 h at 14% moisture to 12 h at 22%.

Temperature and Relative Humidity inside the Cocoon

Temperature and relative humidity dataloggers were placed in the top corner and middle portions of the cocoon. Another datalogger was used to measure the temperature and relative humidity of the ambient air. All dataloggers were set to record data every hour (Fig. 2).

Initial observations indicated that the cocoon had a higher temperature compared with the ambient temperature during the first several days of storage due to the accumulation of heat of respiration. During this time, the temperature inside the cocoon reached 45℃. After the first week, however, germination of the grains inside the cocoon dropped to zero and respiration ceased. Without respiration, there was no heat generation. Temperature of the air inside the cocoon approximated the temperature of the ambient air.

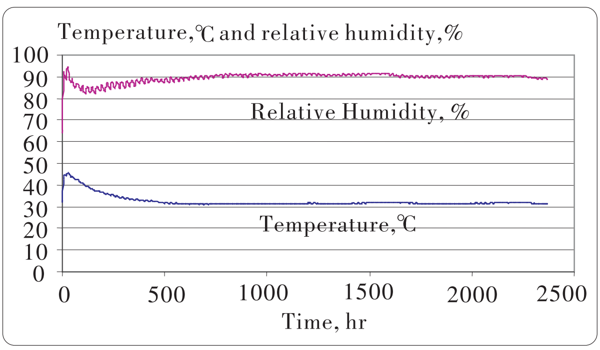

Fig. 2 Temperature and relative humidity at the center of the cocoon.

Moisture Content

Initial average moisture content of the corn was measured as 25.6%, wet basis. Figure 3 shows that the moisture content was initially constant then increased with storage time. The increase in moisture content is attributed to the water produced as a result of respiration of the organisms on corn. After three months of storage, average moisture content of the whole cocoon taken from 27 samples, was 29.1% which is an increase of 3.5 percentage points from the initial moisture content.

Final moisture content of corn samples throughout the cocoon ranged from a low of 26.2% to a high of 38.5%. It was noted that corn at the top of the pile had higher moisture content compared with those samples in the middle layer of the cocoon. This was attributed to the condensation of moisture on top of the cocoon during the early part of the day. Corn at the top of the stack subsequently absorbed the

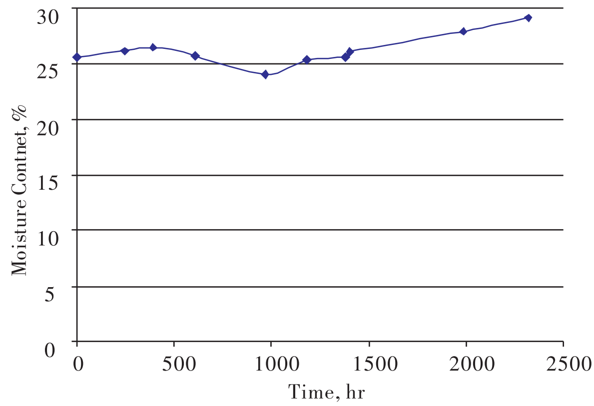

Fig. 3 Moisture content of corn with time in the cocoon

moisture. Corn at the bottom sides of the cocoon has been observed to have higher moisture content than the initial average moisture content. Some of the water condensing on top of the cocoon dripped down along the outer lining to the bottom panel where it was absorbed by the corn in bags on the bottom layer.

The second cocoon had an average initial moisture content of 31.6 % wet basis. After six months of storage, the moisture content was reduced to 28.9%. There was some variation in moisture content of the kernels inside the cocoon, as observed in the first replicate. It was also observed that condensation took place along the cocoon lining due to temperature fluctuation of the ambient air. Standing water was observed on the bottom portion of the cocoon, which explains the loss of moisture from the kernels.

Starch and Alcohol Content

During the three months of storage, starch content in the corn varied from 60% to 65%. Figure 4 shows that there was only minor change in starch content with storage time, stabilizing close to 60% after 600h.

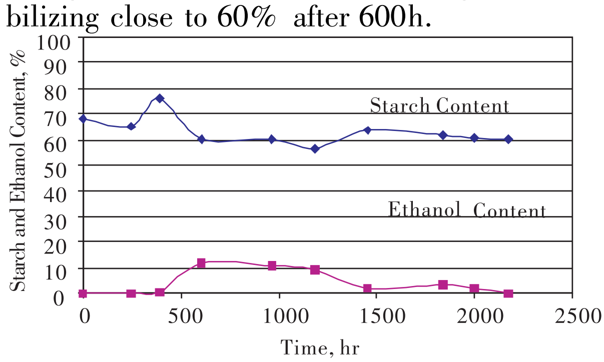

Fig. 4 Starch and Ethanol Content with time during storage in cocoon

The initial ethanol content of the kernel was found to be 0%, but it showed an increase after 600h, then a subsequent decrease to 1% – 2% occurred after 1400h. After three months of hermetic storage at the opening of the cocoon, 27 samples were collected and subjected to ethanol content analysis. Average value was 0.14% indicating a marginal amount of ethanol in the corn. The data indicates that there is an insignificant conversion of starch into sugar, and to ethanol. However, after six months (4 320h) of storage, the ethanol content increased to an average of 4.4 % by volume. According to Weinberg et al. [2] the major fermentation product in the hermetically sealed corn was ethanol (0 to 5 g kg^{-1} DM), along with lower concentrations of acetic acid (0 to 1 g kg^{-1} DM). The familiar smell of lactic acid during the storage, especially during sampling, was present. There was no attempt to determine the actual concentration of lactic acid in the samples.

Molds

Three bags of freshly harvested corn were left near the cocoon to serve as a control sample. It was observed that after three days, the kernels deteriorated with the presence of black spots. It was also observed that the temperature of the grains increased to about 55℃, while the ambient temperature was only about 30℃. Moisture content of the grain in the control sample decreased to 19.9% during the first week of storage. Germination was also significantly reduced. Mold identification of the control sample revealed the presence of *Rhizopus spp*. and *Penicillium spp*.

Aflatoxin Levels

The high moisture corn inside the cocoon initially had about 59 ppb of aflatoxin, having been exposed to ambient temperatures for about 3 days after harvesting. Figure 5 shows that the aflatoxin level increased to 90 ppb after one week of storage and remained at that level during the storage. After 96 days of storage, 27 samples at different locations in the cocoon were analyzed for aflatoxin content. Results show that the average aflatoxin of the corn was 98.3 ppb with a sample standard deviation of 54.3 ppb. Although there was a large variability in measurement, we observe in Fig. 5 that the aflatoxin level in the cocoon did not increase significantly with storage time.

Retrieval of weekly bag samples for analysis necessitated opening of the cocoon, which provides opportunity for oxygen ingress. Hocking[3] noted that atmospheres containing high CO_2 levels are more effective in controlling fungal growth than those which exclude O_2 by replacement of N_2. Many spoilage fungus species are efficient scavengers and are capable of near normal growth in O_2 concentration of less than 1 percent. Hocking[3] concluded that atmosphere containing about 20% CO_2 generally inhibits mold growth but greater than 80% CO_2 may be required to prevent deterioration of high moisture commodities. Only when oxygen is completely unavailable, are microorganisms inhibited [4].

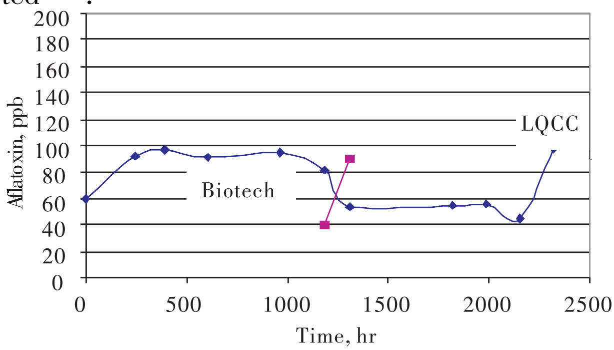

Fig. 5 Aflatoxin levels in the grains with time stored in the cocoon.

In the second replicate, the initial aflatoxin level of corn was found to be 53.9 ppb. After six months of storage, the level increased insignificantly to 72.9 ppb. At this level the grain can still be used for feeding – cattle and swine.

The present experimental data indicate that even after 96 – 150 days of storage, high moisture corn can be used to feed breeding – cattle and swine, mature poultry, finishing swine and beef cattle as presented in Table 1.

Insect Infestation

No presence of insects was observed in the corn samples stored in the cocoon.

Proximate Analysis

Table 1 shows the results of the proximate analysis of the kernels stored in the cocoon after drying. Kernels were dried in a flatbed dryer to 14 percent moisture. Since crude protein is a major constituent of ruminant diets, a high protein level is desirable in the feeds because it requires less supplementation and therefore results in lower feed costs. The data indicated that storage of wet kernels in hermetic storage increases its protein content.

Crude fiber which is a measure of the fiber content of the corn is less desirable since it is less digestible than the non-fiber constituent of the kernel. Samples with high fiber content have lower energy. That is the reason low fiber content is desirable for animal feeds. In wet corn storage, carbohydrates are converted into organic acids predominantly lactic and acetic acids during the hermetic storage of corn.

The odor of the samples was light and pleasant with no indication of putrefaction. Although preliminary feeding trials on cows did not show differences in palatability and digestibility of the animals an additional feeding trial is recommended to determine the palatability and its effect on the growth of cattle and swine.

Table 1. Proximate analysis of corn after 3 months of hermetic storage compared with AACC values

	Moisture Content, % wet basis	Ash, % dry basis	Crude Protein, % dry basis	Crude Fat, % dry basis	Crude Fiber, % dry basis
Experiment	10.06	1.87	12.23	5.35	2.70
AACC	16.0 (7 – 23)	1.4 (1.1 – 3.9)	9.5 (6 – 12)	4.3 (3.1 – 5.7)	9.5 (8.3 – 11.9)

Note: 1. AACC values from White PJ & Johnson LA. 2003. Corn Chemistry and Technology. American Association of Cereal Chemists. Range values are in parenthesis.
2. Wet corn was hermetically stored for 3 months, and then it was dried using a flat bed dryer.

Conclusions

High moisture corn can be stored hermetically without reduction of quality. The results of the study indicated that the moisture content increased with storage due to respiration. Temperature of the corn in the cocoon increased during the first few days but dissipated after reduction of respiration and equilibrated with the ambient temperature after a week of storage. Starch and ethanol contents were relatively constant with time. Despite a large variability of measurement for aflatoxin, it can be concluded that the aflatoxin level in the cocoon did not increase significantly. An added benefit of hermetic storage of corn is the increase of protein of the kernels. Feeding trials on cows did not show significant difference in palatability and digestibility of the animals.

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