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Field testing of Purdue improved crop storage (PICS) bag maize storage in Haiti

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Maize is widely grown by Haitian farmers and its sale is the only income for some. The average farmer produces less than 100 kg per year and postharvest losses average 30%. Purdue improved crop storage (PICS) bags use hermetic storage to decrease post-harvest losses in grain stored on smallholder farms. Our objective was to test PICS bags for long-term, on-farm storage of maize in Haiti. Three each of 50 kg PICS bags and control bags (pre-used polypropylene rice or bean sacks) were tested. Bags were each loaded with 50 kg of maize and then stored without opening for 170 days. Data recorded before and after storage included live maize weevil counts, aflatoxin levels, maize moistures and bag weights. Live weevil counts in the PICS bags did not change significantly from the initial five weevils/kg maize, but increased significantly from five to 199 weevils/kg in the control bags. Aflatoxin levels were mostly <3 ppb before and after storage. No maize moisture changes were significant. Average weight of PICS bags did not change significantly, but control bags, on average, lost 5% (2.5 kg) of weight, which was significant. PICS bags effectively protected maize over 170 days, while control bags allowed unacceptable maize weevil infestation and weight loss.

Key words: Purdue improved crop storage (PICS) bags, maize storage, maize weevil, Haiti, aflatoxin, postharvest loss.

INTRODUCTION

Maize, along with rice, wheat, sorghum, beans, peas, yams, cassava, sweet potatoes, bananas and plantains are staple crops grown in Haiti on mostly small scale subsistence farms that average less than two ha and produce ~100 kg of maize. Maize is grown throughout Haiti's 10 departments, in all agro-ecological zones. Haiti's crops are extremely vulnerable to climatic factors such as droughts, floods and hurricanes and it has the highest risk index of natural disasters in the world. Over 60% of the workforce is employed in agriculture, which contributes over 25% of the national GDP (Venort et al., 2018). But performance of the agricultural sector is poor and as a result, half of Haiti's population is undernourished (Quellhorst et al., 2020) and the country imports about 50% of its food (Quellhorst et al., 2019). Maize yields in Haiti average 0.8 Mg/ha (FAOSTAT, 2019) compared to a world average of about 6 Mg/ha (Lyddon, 2020). In the central Cul-de-Sac Plains, maize production per farm averages 288 kg/year. Farmers sun-dry maize on the ground and on mats and then usually

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store the maize in sisal sacks or metal drums. Postharvest loss of cereal grains in Haiti is estimated at 30% (Venort et al., 2018).

Nearly 80% of farmers reported storage losses due to rodents, nearly 60% had losses due to insects, and about 5% from mold (Quellhorst et al., 2019). The lack of road infrastructure in rural areas and poor storage technologies, along with the inefficiency of the marketing system often lead producers to sell their crops immediately after harvest while the quality remains high. Ground maize is a main dish in rural households and is considered a sovereign food because of its nutritional value, its consistency in protein and its essential contribution to the nutrition of children (Venort et al., 2018).

Mycotoxins

Mycotoxins are toxic compounds produced by fungi that grow on grain and can contaminate the grain before, during and after harvest. The most important group of mycotoxins that occur in maize are aflatoxins (Miller, 2016). The main fungi responsible for production of aflatoxins are *Aspergillus flavus* and *Aspergillus parasiticus.* Maize grown in high humidity and high temperature climates is especially susceptible to these fungi and the aflatoxin risk is amplified when maize is not properly dried, processed and stored (World Health Organization, 2018). Accurate detection of aflatoxins in maize is important to prevent ingestion because they have major health repercussions for both humans and animals. The potential health risks associated with human exposure to aflatoxins include liver cancer, immunosuppression, childhood stunting, and, in extreme cases, death (Shephard, 2008). The United States Food and Drug Administration has established an action level for total aflatoxins (the sum of B_1, B_2, G_1, and G_2 aflatoxins) in foods of 20 ppb, except for milk which has an action level of 0.5 ppb (U. S. Food and Drug Administration, 2018).

Aflatoxin B_1 is the most common food contaminant and is one of the most potent naturally occurring contaminants of staple food. Daily consumption of contaminated food can result in chronic aflatoxicosis and the risk is higher in tropical countries where aflatoxin regulations are not in force and crops are consumed without monitoring the mycotoxin levels. Aristil et al. (2020) states that the Haitian population, which on average consumes 50 g of maize per person per day, is strongly exposed to aflatoxin risk. They analyzed food samples of maize and maize meal from subsistence farms in South Haiti and found that over half of the samples were contaminated with B_1 and B_2 aflatoxin and that the average aflatoxin levels in the contaminated samples were 186 and 514 ppb, respectively. These levels are over five and 25 times the USFDA aflatoxin action levels.

Purdue improved crop storage (PICS) bags

The PICS system is a bag-based hermetic storage technology developed at Purdue University in the USA to decrease post-harvest losses due to insects in grain stored on smallholder farms and, secondarily, to prevent development of mycotoxins on the grain by hindering fungal growth (PICS, 2015). These 50 and 100 kg bags allow farmers, at a cost of $2 to $4 US per bag, to safely store their grain long term, eliminate post-harvest insecticide use, and reduce contamination due to mycotoxins. With secure long-term storage, farmers have the flexibility to sell their grains when prices are high or to store their grains for use through the year. The technology uses a triple-layer (two 0.08 mm-thickness polyethylene layers and one outer woven polypropylene layer) bagging method to create a hermetic environment that kills insects when oxygen is used up. No insecticide is used. PICS bags were developed by Professor Larry Murdock for storage of chickpeas in West Africa in 1987 (PICS, 2019), but they are now used for storing many crops including maize in over 40,000 villages across Africa, Latin America, the Caribbean, and Asia (Baributsa, 2020). The Bill and Melinda Gates Foundation have provided funding for the PICS project since 2007. PICS bags have a median life of three years when used for hermetic storage of cowpea (Baributsa et al., 2015). Following Hurricane Matthew in 2016, Sacred Heart Parish in Winnetka, Illinois USA implemented a successful Pilot Program with farmers using PICS bags for maize storage in Sassier, Grand'Anse province, Haiti. Several groups of farmers took part in training sessions and purchased PICS bags which allowed them to safely store dried maize at harvest and sell it later at higher prices (Zanmi, 2017). One group reported losses due to rodents infesting maize loaded in PICS bags stored in an insecure location and chewing holes in the bags (Venort et al., 2018). PICS bag user instructions say that the user should store bags on an elevated platform and away from walls to minimize rodent attacks (Baributsa et al., 2015). The objective of this experiment was to determine the suitability of using PICS bags to prevent postharvest losses of maize during on-farm storage in Haiti.

MATERIALS AND METHODS

A controlled replicated storage experiment was conducted at Universite Chretiene De La Communaute De Caiman (UCCC) near Pignon, Haiti. About 400 kg of wet shelled maize was purchased locally in November, 2019. This lot of experimental maize was sun dried on a tarp until four grab samples all measured between 11 and 12% moisture wet basis. This took four days of drying to accomplish. Each night, drying maize was loaded in bags and placed in a secure location to protect it from rats, theft and rain. All maize moistures were measured using a Dickey-John M36 grain moisture tester (Dickey-John, Auburn, Illinois, USA). The dry experimental lot was spread on a tarp, mixed thoroughly with shovels and then divided into six sections while still on the tarp. A one-kg sample was drawn from each of the six sections and spread

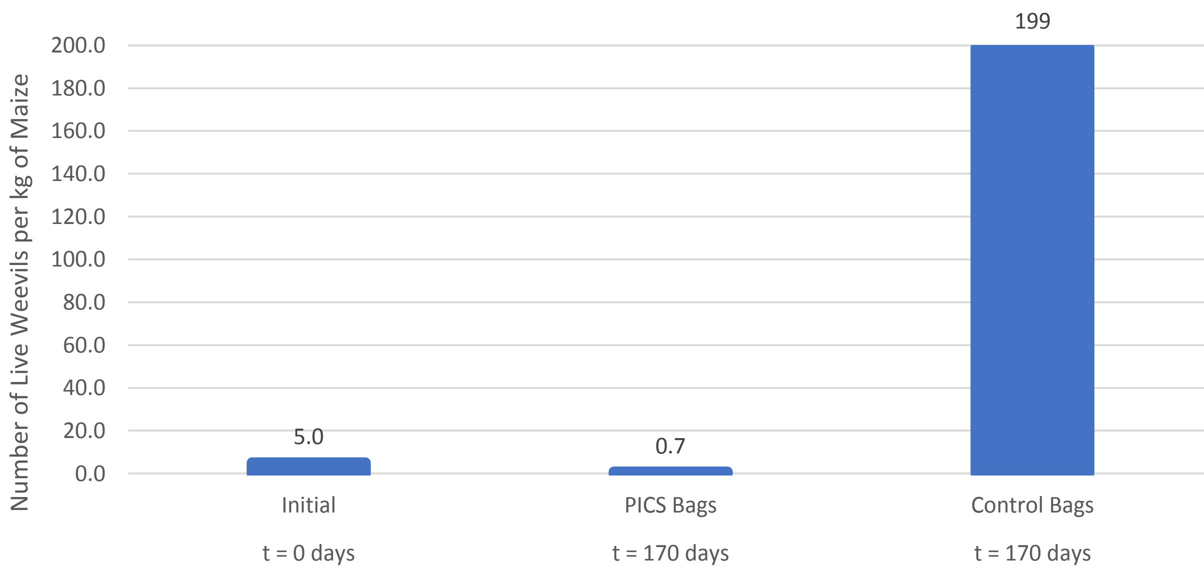

Figure 1. Mean number of live weevils in PICS bags and control bags before and after storage.

Table 1. Initial and final live weevil, moisture content and bag weight means for PICS bags and Haitian (control) bags.

Storage period ►	**Initial (t = 0 d)**	**End of storage (t = 170 d)**	
Parameter ▼	**All bags**	**PICS bags**	**Haitian bags (control)**
Live weevils, weevils/kg	5.0^{A}±2.19	0.67^{A}±1.15	199^{B}±41.8
Moisture content, % wet basis	11.7^{Aa}±0.64	11.4^{A}±1.04	10.9^{A}±0.51
Weight of maize in bag, kg	50.0^{A}±0.07	50.2^{A}±0.26	47.5^{B}±0.17

Means followed by the same uppercase letter within each parameter are not statistically different at the 5% significance level.

out one kernel deep. Live weevils were counted and recorded, and then the sample was returned to its original section on the tarp. Next, a kg sample for aflatoxin testing was drawn from each of the six sections, placed in a Ziplock bag and refrigerated for later testing. Three 50 kg triple-layer PICS bags and three 50 kg single-layer Haitian woven polypropylene control bags were used for the experiment. Each of the six bags was loaded with maize from the experimental lot and weighed using a 300 kg hanging scale (Crane Modern Step, Amazon Prime, USA). A sample for moisture measurement was drawn from each loaded bag using a partitioned dual-tube grain probe (Seedburo Equipment Co., Des Plaines, Illinois, USA). This sample was subsequently returned to its bag. The three PICS bags were tied following the PICS bag tying instructions (PICS, 2015) and the Haitian bags were tied in the traditional Haitian manner. Then, all bags were placed on a wood pallet in a rat-proof, dry indoor location for storage. This location was a bedroom in the Mompremier home. After 170 days of storage, the six experimental bags were opened and a 2 kg sample was drawn from each bag using the partitioned grain probe. A 1kg subsample was spread one kernel deep for a live weevil count and then returned to 2 kg sample. Then a moisture test was conducted and that maize was returned to the 2 kg sample which was placed in a Ziplock bag and refrigerated until further testing. The twelve 2 kg samples (6 initial and 6 final) were tested for aflatoxin using Reveal Q+ MAX for aflatoxin (B_1, B_2, Q_1, Q_2; 3-300 ppb) (Neogen Corporation, Lansing, MI, USA) according to manufacturer instructions.

RESULTS

Figure 1 and Table 1 show mean live weevil counts per kg maize before and after 170 days of storage. Initially, experimental maize averaged five live weevils per kg. According to United States Federal Grain Inspection Service standards, the maize was “infested” since live weevils per kg exceeded two (U. S. Federal Grain Inspection Service, 2013). At the end of the 170-day storage period, PICS bags averaged 0.7 live weevils per kg, a value statistically similar ($p < 0.05$) to the original 5.0 weevils per kg. Maize containing two or less weevils is not “infested” by United States Federal Grain Inspection Service standards. Control bags averaged 199 live weevils per kg, which is significantly greater than in the PICS bags ($p < 0.05$) and nearly 40 times the original population.

Initial and final aflatoxin levels of each PICS and control bag were under the limit of detection for the assay (3 ppb), except for the initial result from control bag C3 whose value was 9.5 ppb and the final result for PICS bag P1 which was 3.6 ppb. Due to the limited number of observations (17) and characteristically heterogeneous distribution of mycotoxin contamination in grains in general, a statistical analysis was not performed. At the time of bagging, 100% of the PICS bags tested below the limit of detection and 67% of the control bags tested below the limit of detection. After 170 days of storage, 80% of the observations of the PICS bags were below the limit of detection while 100% of the observations of the control bags were below the limit of detection. The initial and final aflatoxin levels of all experimental bags were less than half the 20 ppb FDA action level for grain acceptable for use in general commerce (Aristil et al., 2020).

Initial and final grain moisture contents and bag weights are shown in Table 1. Initial maize moisture content averaged 11.7% with a standard deviation of 0.64% across all six experimental bags. After 170 days of storage, maize moisture did not change significantly ($p < 0.05$) in either the PICS bags or the control bags. Since the PICS bags were hermetically sealed, no change was expected. In the control bags, weevil numbers were rising rapidly and numbered well over 9,000 in each bag at the end of the 170-day storage period. Insect respiration adds moisture and heat to the maize, and air circulation through the mesh bags moves the maize toward moisture equilibrium with atmospheric air. The combination of these effects did not change control bag moisture significantly for the experimental period examined in the current study. These same effects did influence bag weights. PICS bag weights did not change significantly ($p < 0.05$) over 170 days of storage, but control bag weights decreased significantly ($p < 0.05$) by 2.5 kg (5%).

DISCUSSION

Other studies have reported results similar to our results: PICS bags more effectively suppress maize weevils and retain original moisture levels compared to mesh bags. Baributsa et al. (2020) describes a study in Benin comparing six different storage bag models storing 13.4% moisture maize initially containing 26 maize weevils/kg for seven months. The present study as well as the study of Baributsa et al. (2020) was carried out in atmospheric conditions capable of removing moisture from the test maize. At the end of the storage period for the Benin study, lives weevil numbers in the PICS bags had decreased significantly from 26 weevils per kg to zero. Live weevil populations after storage in woven control bags averaged 3.2 weevils per kg, significantly more than in the PICS bags. Maize moisture in the PICS bags did not change, but in the woven bags, it decreased significantly to 9.1%. Our data did not show a significant moisture content decrease in the woven control bags, perhaps because of the limitations of probe sampling. However, final control bag weights did show a significant weight loss from the woven bags. Lane and Woloshuk (2017) stored 14% moisture, weevil free maize in PICS bags and in woven polypropylene bags at a site in Marianna, Arkansas, in the Southern US. After three months storage, the pics bags averaged 2.1 ± 0.5 weevils/ kg and the woven bags contained 589 ± 37 weevils/kg, which was significantly more. Aflatoxin was not detected before or after storage in any of the maize bags. Any storage system using only mesh and/or only hermetic plastic bags are vulnerable to rodents (particularly rats) attacking the bags. As noted earlier, a survey of farmers in the Cul-de-Sac Plains region of Haiti found that nearly 80% of farmers had incurred losses to stored grain due to rodents, a larger portion that reported losses from insects (60%) Quellhorst et al. (2019) and rats penetrated PICS bags being tested by farmers in Grand'Anse during one if the earliest uses of PICS bags in Haiti. When the bags are attacked, penetration through the bag layer(s) is quick and rodents begin to consume and damage kernels and also to contaminate the grain with urine and feces. In addition, holes chewed in the bag allow air to enter hermetic bags, rendering them non-hermetic. This allows insect populations to resume reproduction and to cause storage losses due to insects. Rats are common at UCCC. A recent visitor to the campus reported seeing numerous rats during daytime on a pile of shelled maize stored on the ground in a building that was not rat proof. Workers had to chase away the rats in order to gain access to the maize (Personal communication, Jim Ryken, August 9, 2021). In this case, quantitative losses of maize are invisible and probably unknown to the farmer. Maize is not weighed on the way in or on the way out. Maize just disappears as it is consumed by the rats. As reported earlier, experimental bags for this study were placed in the bedroom of a home for protection from rats. This bedroom has tight doors and windows as well as a tight structural ceiling under the roof and there was no damage from rats during the 170-day storage period. Few such locations are available at UCCC, or would be available on most smallholder farms in Haiti. Some form of rodent protection for loaded hermetic bags is needed that allows them to be stored in less secure locations like buildings that provide protection from rain and sun, but that may not be rat proof. Storage in repurposed steel barrels is a possibility.

Conclusion

The purpose of this research project was to test the effectiveness of using PICS bags as a chemical free postharvest storage method for maize in Haiti. The experimental bags had an initial average of 5 live weevils per kg, 11.7% moisture content, and aflatoxin levels below the limit of quantification except bag C3 which had a level of 9.5 ppb. After 170 days of storage in a secure rat proof location, control bags averaged 199 live weevils per kg maize while the PICS bags averaged 0.7 live weevils per kg maize. Changes in PICS bag maize moisture content and aflatoxin level were minimal. PICS bags were effective in suppressing maize weevils, maintaining maize moisture and low maize aflatoxin levels over 170 days of storage.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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