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Grain size and grain depth restrict oxygen movement in leaky hermetic containers and contribute to protective effect

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A B S T R A C T

Postharvest insect pests threaten the nutritional and financial security of smallholder farmers in the developing world. Hermetic storage, a technology that protects grain against insects by blocking their supply of oxygen, alleviates the problem of insect-caused losses. PICS (Purdue Improved Crop Storage) bags represent one hermetic technology that improves food availability and incomes of farmers. The polyethylene liners of PICS bags are sometime damaged during use, acquiring small holes or tears. Observations in the laboratory and field suggest that insect development remains localized around the point where the bag is damaged. We hypothesized that the grain within a hermetic container that has minimal localized damage (such as an insect hole), helps retard leakage of oxygen into the bag and contributes to limiting insect damage and to the overall protective effect. To test this hypothesis, we filled 4 cm dia. by 10 cm long PVC pipes with *Callosobruchus maculatus* (F.) infested cowpeas and sealed them with caps having a single, insect-sized hole in its center. A vertical tube positioned above the cowpea-filled PVC pipe was filled with one of three different grains (sesame, sorghum, and maize) to different depths (0, 5, 15, 30, 50 cm). Seed size and grain barrier depth significantly reduced the level of bruchid damage to the stored cowpea in the PVC container. Smaller sized grains used for the barriers retarded insect development more effectively than larger sized grains, while deeper grain depth was more effective than shallower barriers. The grain held in a hermetic container contributes in a small, but significant, way to the effectiveness of the containers.

1. Introduction

Insect pests that damage grain during postharvest storage are a threat to food security, especially in the developing world. There, postharvest losses to insects can reduce food availability by 20–50% (Keil, 1988; Pantenius, 1988; Boxall, 2002; Mulungu et al., 2007). Lack of access to reliable and affordable pest control methods force many smallholder farmers to sell their grain at harvest when the price is at the low point of the year and buy it back later when food needs demand they purchase it and prices are higher (Boxall, 2002; Jones et al., 2011; Njoroge et al., 2014).

Hermetic storage containers (metal silos, drums, PICS and GrainPro bags, etc.) address the problem of small-scale grain storage (Moussa et al., 2014). Sealed hermetic containers prevent the flow of oxygen from outside into the grain. Any insects present in the grain when it is placed in the hermetic container use up the limited oxygen and create conditions that are unsustainable for them (Oxley and Wickenden, 1963; Quezada et al., 2006; Murdock et al., 2012).

The adoption of PICS bags in Africa has grown steadily since 2007 with 7 million bags having been purchased thus far. Fifty percent of the cowpea not sold at harvest is now stored in these flexible containers or in other types of hermetic containers (Baributsa, 2014; Moussa et al., 2014; Ibro et al., 2014). Farmers who use these bags have enjoyed lower rates of pest damage, higher grain quality, and improved selling prices at the market (Baributsa et al., 2010).

Farmers are encouraged by PICS' promise of better grain storage, as evidenced by the continued sales of the bags (Murdock and Bauoa, 2014). Even so, some farmers have expressed concerns about grain stored in bags that may have small leaks. Handling the bags increases the likelihood of mechanical damage and certain insect species (e.g. *Callosobruchus maculatus* and *Prostephanus*

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truncatus) can chew holes through the liners. This will permit airflow into the bags and raises the possibility of subsequent insect damage to the grain (Baoua et al., 2014; Hell et al., 2014). However, several years of observation in the field indicate that damage to the grain in such bags is minimal (Baoua et al., 2014). In short, despite localized breaks in the airtight seal of the bag, PICS bags continue to be effective in preventing postharvest losses.

Understanding why small holes or tears in the polyethylene liners do not result in failure of the bags' ability to protect grain may provide insight that could lead to making the bags more effective. Here, we hypothesize that the grain itself contributes to the PICS bags' protective action. It is well-known that grain bulk can contribute to the resistance to diffusion of gases through the storage environment (Shunmugam et al., 2005; Haung et al., 2013) and that different grains facilitate different rates of diffusion (Singh et al., 1984). Accordingly, we investigated the role grain may serve in the protective performance of hermetic containers compromised by the presence of small holes or tears.

2. Methods

2.1. Infested grain preparation

Cowpea bruchids (*Callosobruchus maculatus*) were obtained from laboratory colonies maintained on cowpea. Black-eye cowpea, variety #8046 (Wax Co., Armory, MS USA) was used for all trials. The grain was held in a freezer at 0 °C for 5 days prior to each trial to ensure it contained no living insects. Four days before setting up each experiment, 2 L of cowpea were removed from the freezer and divided between two glass jars. One jar was heavily infested with *C. maculatus* adults from the laboratory colony. The second jar, with no insects present, was sealed and returned to the freezer.

One day before each trial, the sealed jar was removed from the freezer and given time to warm to room temperature. The adult bruchids in the first jar were removed by sifting using a No. 18 sieve. The two quantities of grain, infested and uninfested, were then mixed together in a 17 L bucket to create a 2 L, 50:50 mixture of infested and uninfested cowpea. Four samples of 100 seeds were removed from the mixture and examined under a magnifying lens. The mean number of infested cowpeas-those cowpeas possessing at least one bruchid egg on its surface-out of each sample of 100 was recorded (Table 1).

2.2. Experimental setup

We used experimental containers constructed from 4 cm diameter PVC pipe (Fig. 1). Each unit was divided into two sections: The first (Section A) was 10 cm long and filled with 100 mL of infested cowpea (Fig. 2a). This section was sealed with a cap using vacuum grease. At the center of the cap was a 1.5 mm inlet hole that served as the only entry point for air into the pipe. A small, rectangular piece of 100 μm, steel mesh was placed over the inlet hole to prevent it from being blocked by grain in the pipe above it (Fig. 2b).

The second section of the experimental container (Section B) was 50 cm long and connected to Section A with a PVC coupling unit. Section B pipes were filled with one of three barrier grains depending on the trial (Trial 1- Sesame, Trial 2- Sorghum, Trial 3- Maize). We selected these grains as our barriers due to the clear differences in the average volume of individual kernels. This gave us the opportunity to determine if kernel size influenced the effectiveness of the grain barrier. Seed volumes (Table 2) are estimates based on published measurements of seed dimensions. The amount of grain used to fill these pipes depended on the grain depth we wished to simulate. Greater depths would result in greater separation of the infested cowpea in Section A from the outside air. Treatment depths ranged from 0 cm for controls to 50 cm for the deepest grain group.

All trials lasted 72 d. This period was sufficient for two, full reproductive cycles of the cowpea bruchid. Trials were held inside a Conviron™ environmental chamber in the Purdue Improved Crop Storage (PICS) lab (Fig. 3). Ambient conditions were maintained at 26° C and 30% RH. At the end of the 72 d period, the Section A pipes containing the infested cowpea were placed in a freezer for two weeks. Samples were later removed from each pipe and evaluated.

Table 1
Initial seed infestation for all three trials. Infestation rates are given as the percentage of seeds with at least 1 bruchid egg on its surface out of a 100 seed sample.

Trial	Mean infestation (%)	SE
Trial 1	39.75	1.43
Trial 2	50.25	3.42
Trial 3	28.25	1.75

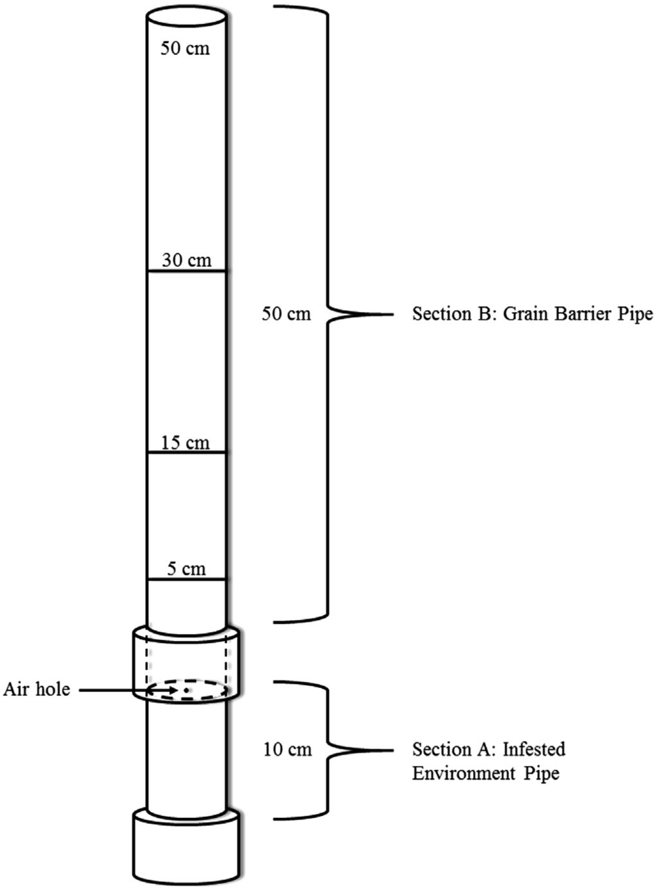

Fig. 1. Schematic of grain barrier pipe system. The 10 cm, Section A pipe was filled with 100 mL of infested cowpea and then sealed with a cap. The cap contained a single inlet hole (1.5 mm diameter) for permitting airflow. The 50 cm, Section B pipe was filled to different depths (0, 5, 15, 30 and 50 cm) with one of our three barrier grains (maize, sorghum, or sesame).

2.3. Evaluation

2.3.1. Seed damage

Two samples of 100 cowpeas each were removed from the 10 cm pipes and evaluated for insect damage. We recorded three values for each sample: 1) the number of adult emergence holes