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Safe storage of maize in alternative hermetic containers

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ABSTRACT

Purdue Improved Crop Storage (PICS) bags have been developed and extended as a way to address grain storage issues faced by smallholder farmers in developing nations. A hermetic technology, PICS bags reduce insect damage to grain significantly while maintaining its quality for many months or longer. Farmers with varying and often small volumes of grain at harvest, may still benefit from alternatives to PICS bags for storing their grain. We evaluated plastic bottles, which may be hermetically sealed, for storing maize grain. Clean maize grain was stored for eight months in sealed and unsealed plastic bottles with half of these bottles being infested by maize weevil (*Sitophilus zemais*, Motschulsky). Oxygen levels in the bottles were monitored throughout the trial and grain was assessed for moisture content, insect damage, germination rate and insect population size when the study was terminated. Sealed bottles preserved grain quality significantly better than unsealed, infested bottles and as well as non-infested unsealed containers. Plastic soda bottles can be used as hermetic containers for safely storing grain.

1. Introduction

Cultivation of maize continues to grow in Africa, eclipsing the traditional grains millet and sorghum. Much of this maize grain is produced by smallholder farmers, who account for 70% of all of Africa's agricultural activity (IAASTD, 2009). Protecting harvested grain in storage is challenging for these farmers, because insect pests such as *Sitophilus zemais* (Motschulsky) can cause substantial losses in the mass and value of the grain after only a few months' time (Keil, 1988; Pantenius, 1988; Boxall, 2002; Mulungu et al., 2007). Hermetic storage containers such as the Purdue Improved Crop Storage (PICS) bags have been developed and disseminated as a preferred method of grain storage for smallholder farmers. By severely restricting the flow of oxygen into the grain bulk, PICS bags can reduce insect population growth in storage by 98% and preserve grain quality (Baoua et al., 2012). This has resulted in greater nutritional and financial security where PICS bags are available (Ibro et al., 2014; Jones et al., 2014; Moussa et al., 2014).

While PICS bags are marketed to smallholder farmers, some individuals may still choose or need to store grain in alternative containers. This need could arise because the farmer's harvest was small or specific needs that require grain be stored as smaller portions, such as setting aside grain for seed. Plastic waste is common in many regions of Africa. Sealable, plastic bottles account for approximately 9% of this waste (King et al., 2013). Farmers may be able to use these cast off, essentially free, bottles for storing grain and seed. There is, however, little empirical evidence on the suitability of these bottles for storing grain. Accordingly, to determine if grain can be stored safely in plastic bottles and maintained their quality, we performed the following experiments.

2. Materials and methods

2.1. Maize storage and sample collection

Sixteen, 2-L soda bottles (approximately 30 cm tall and holding 1.5 kg of maize each) were filled with maize kernels (Yellow Trucker's Favorite Lot#502) purchased from the Wax Seed Company (Armory, Alabama) and stored for eight months. Eight of the bottles were sealed with the plastic, screw-on caps and the other eight were closed with caps that had been punctured with eight, 0.5 mm holes to permit air exchange. Four bottles of each treatment were infested with an initial population of 20 adult *S. zemais*, while the remaining four were not infested. All bottles were stored out in the open in the same room environment except the unsealed, non-infested bottles; these were stored in an adjacent, separate room to prevent infestation by insects that may have escaped from the infested treatments. Both rooms were climate controlled, though the first room bordered an exterior wall and the second room was

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on the interior of the building. At the end of the trial, all of the bottles were frozen for 2 weeks prior to detailed assessment. The following data were collected: (1) Grain moisture content, (2) Percent germination rate, (3) Insect population size, and (3) Relative damage. Methods for collecting these data are described below.

2.2. Oxygen readings

Internal oxygen readings were measured using an Oxysense 5250i® oxygen reader (Oxysense, Dallas, TX). The oxygen data was collected frequently after closing the bottles, with intervals of increasing length as time went on. Intervals for data collection were finally set one week apart and continued for the remainder of the trial. Oxygen data was collected by shining an ultraviolet light on each of two, yellow fluorescent dots glued on the inner surface of each bottle; six and eighteen centimeters from the base. These placements were selected as they were 20 and 60% of the total height of the bottle, giving us a clear idea if different regions of the stored grain had different levels of oxygen. Average readings of both dots were used to estimate the oxygen level within the bottle. Placing the dots at different heights was done to determine if oxygen was distributed evenly within the bottles.

2.3. Moisture content

Grain moisture was measured at the end of the eight-month storage period. Grain moisture was measured using a Dickey-John mini GAC® plus Grain Moisture tester (Dickey-John, Auburn, IL, USA) with a 400 mL basin. Before each measurement, a blank reading of the empty instrument was taken. The instrument cup was then evenly filled to the top with maize from one of the plastic bottles. Grain moisture was recorded as the percentage of the total grain mass.

2.4. Relative damage

Each bottle had four, 50 mL subsamples removed to assess grain damage. The number of damaged and undamaged grains in each subsample was counted visually and the two types of grain separated for further analysis.

Subsamples were dried to 0% moisture by heating in an oven at 60 °C over five days. The resulting dry weight of the damaged and undamaged grain for each subsample was then measured and recorded. Relative percent damage was calculated using the following equation as described by Alonso-Amelot et al. (2011):

$$X_{rel} = \left[\frac{(W_u{*}N_d) - (W_d{*}N_u)}{W_u{*}(N_u + N_d)}\right]{*}100 \tag{1}$$

N_d = Number of damaged grains.

N_u = Number undamaged grains
W_u = Dry weight of undamaged grains
W_d = Dry weight of damaged grains

The equation compares the number of damaged and undamaged grains based on their weighted proportions. Using combined physical grain damage and weight takes into account both visible insect damage and hidden damage caused by insect larvae feeding inside the grain. The equation is an effective way to estimate grain damage without the necessity of collecting and weighing the particles and dust generated by insect feeding (Alonso-Amelot et al., 2011).

2.5. Germination rate

Two samples of 50 kernels were removed from each treatment. The kernels were bathed in a 10% bleach solution for two minutes and then rinsed three times with running tap water. Each sample was wrapped with wet paper towels and stored in a plastic cup and placed within a drawer. Samples were stored at room temperature for one week. After one week, the samples were removed and the number of kernels with at least part of the radical breaking through the seed coat was counted. Data was recorded as the percentage of the number of successfully-germinated kernels out of the total number of grains sampled.

2.6. Insect population growth

At the end of eight months, all bottles were frozen to stop population growth and assessed for the number of individual adult insects present. We did not attempt larval counts as the larvae develop within the kernels of maize and an accurate estimate would have been difficult to make. Maize from all bottles was sifted using a No. 18 mesh sieve (Cole-Parmer, Vernon Hills, IL) and the total number of dead adult weevils present was counted.

2.7. Analysis

The effect of treatment conditions on average oxygen levels in the containers during the study period were compared using Analysis of Variance (ANOVA). Treatment condition effects on grain moisture, relative damage, and germination rates were also assessed using ANOVA. Post hoc comparisons were made between groups using Tukey's HSD. Significant values were reported at the $\alpha = 0.05$ level, unless noted otherwise.

3. Results

3.1. Oxygen

The infested, sealed bottles had the most apparent decline in oxygen out of our four groups. Oxygen levels in these bottles was on average 8.5% lower than the other three treatment groups at nearly all points in time during the study ($F = 329.73$, d.f. = 7, 1535, $P < 0.001$) (Fig. 1). The highest oxygen levels were observed in non-infested, unsealed bottles, where average oxygen levels were close to ambient conditions (~20.4%). Non-infested sealed (~17.8%) and infested unsealed (~18.0%) bottles had slightly lower than normal oxygen levels, suggesting some factor, either the grain (sealed bottles) or *S. zeamais* (unsealed), was removing oxygen from the internal environment.

There was a small, statistical difference between dots placed in different locations of the same bottle for two of the treatment groups (Table 1). Both the non-infested sealed and the infested unsealed bottle groups saw a slight difference in oxygen level from the upper and lower dot placements. These differences only amounted to a few tenths of a percent and could be the product of random variation, but are interesting to note, nonetheless.

3.2. Grain moisture

There was an observable difference in grain moisture between the four treatment groups at the end of eight months of storage ($F = 31.27$; d.f. = 3, 15; $P < 0.001$) (Fig. 2). The infested, unsealed bottles lost almost 2% MC to the environment relative to initial levels, while both the infested and non-infested sealed bottles showed only a small decline in moisture (0.2–0.65%). Maize stored in the non-infested, unsealed bottles were stored in a separate