Effects of PICS bags on insect pests of sorghum during long-term storage in Burkina Faso

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The PICS bags, originally developed for cowpea storage, were evaluated for sorghum (Sorghum bicolor) preservation. Batches of 25 kg of sorghum grain were stored in 50 kg PICS or polypropylene (PP) bags under ambient conditions for 12 months and assessed for the presence of insect pests and their damage, seed viability and, oxygen and carbon dioxide variations. The grain was incubated for 35 days to assess whether any insects would emerge. After six months of storage, oxygen levels decreased in the PICS bags compared to polypropylene bags. After 12 months of storage, only two pests, Rhyzopertha dominica and Sitophilus zeamais were found in the PICS bags. However, in PP bags there were additional pests including Tribolium castaneum and Oryzophillus mercator and Xylocoris flavipes. Grain weight loss and damage caused by these insects in the PP bags were significantly higher compared to those stored in PICS bags. Germination rates of sorghum grains stored in PP bags decreased significantly while no changes were observed in grains stored in PICS bags when compared to the initial germination. After the incubation post storage period, there was a resurgence of R. dominica in sorghum grains from PICS bags but the population levels were significantly lower compared to polypropylene bags. PICS bags preserved the quality and viability of stored sorghum grains and protected it from key insect pests. The PICS technology is effective for long-term sorghum storage but the potential resurgence of insects in low-oxygen environment calls for further research.

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1. Introduction

Agriculture in the Sahel is dominated by the production of traditional grains such as millet [Pennisetum glaucum (L.)] and sorghum [Sorghum bicolor (L.) Moench] (World Bank, 2011). In Burkina Faso, sorghum is the predominant cereal. In 2015, Burkina Faso produced 1,707,613 tons on 1,548,404 ha; representing 38.21% of total cereal production and 42% of the total cereal production area (DGESS, 2015). In addition to its high nutritional value, sorghum grain is also a source of diverse compounds including tannins, phenolic acids, anthocyanins, phytosterols and policosanols (Dykes and Rooney, 2006; Dlamini et al., 2007).

Traditionally, sorghum is stored as panicles in straw or mud granaries (Waongo et al., 2013). In traditional storage conditions, in Burkina Faso, sorghum grains are attacked by several insect pests, with the lesser grain borer Rhyzopertha dominica (F.) (Coleoptera: Bostrichidae) being the most important (Waongo et al., 2015). Infestation of stored grains by R. dominica is known to cause losses in both quality (Williams et al., 1981) and quantity (Brower and Tilton, 1973). In Burkina Faso, losses during sorghum storage are estimated to be 6.8% (Loada et al., 2015). Damage to seed and residue produced insect feeding reduce grain quality and decreases the essential amino acid contents (Jood et al., 1995). Damage caused by R. dominica also reduce seed viability and seedling vigor (Jilani et al., 1989). Improved storage is needed because traditional storage is largely ineffective.

Hermetic storage of grain using Purdue Improved Crop Storage (PICS) bags represents a promising way of post-harvest grain storage in Burkina Faso, sorghum grains are attacked by several insect pests, with the lesser grain borer Rhyzopertha dominica (F.) (Coleoptera: Bostrichidae) being the most important (Waongo et al., 2015). Infestation of stored grains by R. dominica is known to cause losses in both quality (Williams et al., 1981) and quantity (Brower and Tilton, 1973). In Burkina Faso, losses during sorghum storage are estimated to be 6.8% (Loada et al., 2015). Damage to seed and residue produced insect feeding reduce grain quality and decreases the essential amino acid contents (Jood et al., 1995). Damage caused by R. dominica also reduce seed viability and seedling vigor (Jilani et al., 1989). Improved storage is needed because traditional storage is largely ineffective.

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storage. This technology has the advantage of being easy to use, affordable, and does not require the use of chemicals that may be harmful to human health (references). The effectiveness of PICS bags for controlling storage insect pests has been demonstrated on different legume crops including cowpea, bambara groundnut, groundnut, pigeonpea, mungbean and common bean (Sanon et al., 2011; Baoua et al., 2012, 2014; Affognon et al., 2014; Baoua et al., 2014a; Mutungi et al., 2015; Sudini et al., 2015). Likewise, PICS bags are effective in protecting cereal grain against different insect species feeding on rice, maize, wheat, sorghum, cassava, and Hibiscus seeds (Baoua et al., 2014b; Njoroge et al., 2014; Hell et al., 2014; Martin et al., 2015; Amadou et al., 2016; Baoua et al., 2016b; Williams et al., 2017a, b).

A recent study by Williams et al. (2017a) focused on the effectiveness of PICS bags for preservation of sorghum seeds viability but they did not investigate the preservation from insect pest damage. Moreover, they only covered six months’ storage period while the average storage time of sorghum grains in Burkina Faso extend to nine months (Waongo et al., 2013). Therefore, the present study assessed the effectiveness of PICS bags for long-term storage of sorghum grains infested by insect pest over a period of 12 months.

2. Material and methods

2.1. Source of sorghum grains, packaging and storage conditions

Naturally infested sorghum grain (150 kg) was purchased from a local market (Sankaryare) in Ouagadougou (12°21′58″ North; 1°31′05″ West), Burkina Faso. The grain was divided into 6 batches of 25 kg and transferred into two types of 50 kg capacity bags: Treatment 1- control polypropylene (PP) bag which were standard woven bags of 25 mm thick; Treatment 2: PICS bag made of two liners fitted inside a woven bag. The PICS bags were closed tightly in accordance with the method described by Baributsa et al. (2010, 2013, 2015). All bags of both treatments were tightly sealed with a rubber cord. The bags were kept on pallets for a period of 12 months (March 2016 to February 2017) in a room with an average temperature of 29.29 ± 2.68 °C and relative humidity of 53 ± 20%. Rodent traps were placed in the room and bags were checked each week to ensure no damage.

2.2. Monitoring of oxygen and carbon dioxide concentrations

During the first eight months of storage, oxygen (O₂) and carbon dioxide (CO₂) levels in the bags were measured using a Mocon PAC Check® Model 325 Headspace analyzer (Mocon, Minneapolis, MN, USA) at 12:00 local time.

2.3. Evaluation of insect infestation, grain damage and loss, and grain viability

Before tying the bags filled with sorghum, three samples of 500 g were collected randomly from each of the six bags to assess the initial insect infestation level, the number of grains with holes, and the initial weight of grains. Germination tests were carried out with four subsamples of 100 grains randomly collected from each 500 g sample. The same parameters were determined again at the end of the 12-months storage period. The infestation was assessed by counting the number of insects in the grain sample after sieving the grain through a 3 mm mesh sieve. Insects collected were sorted and counted according to their species to determine their abundance. However, grain damage was assessed from a subsample of 1000 grains from which we counted the number of damaged (with holes) grains; and the weight of damaged and undamaged grains.

The percentage grain weight loss was calculated using the following formula (Boxall, 1986; Alonso-Amelot and Avila-Núñez, 2011):

\[
\text{Weight loss (\%) = } \left[ \frac{(a \times d) - (c \times b)}{a \times (d + b)} \right] \times 100
\]

with: \(a\) = Dry weight of undamaged grains, \(b\) = number of undamaged grains, \(c\) = Dry weight of damaged grains and \(d\) = number of damaged grains.

2.4. Re-emergence of insects after storage time

Resurgence of insects was determined only after 12-months storage period. After the determination of the parameters aforementioned, each sample of 500 g was placed in a plastic jar of 1-L capacity covered with a mosquito net, and observed for 35 days. At the end of the observation period, the samples were sifted and the insects counted and grouped according to species.

2.5. Data analysis

The verification of the data distribution of each measured variables was performed using Shapiro-Wilk test. Data on number of insect pests after 12-months storage of sorghum grains were separated with the student’s t-test. For other variables, when data were found normally distributed, we performed a Linear Model Analysis of Variance (ANOVA). When the p-value was significant, means comparisons were done using the Tukey’s test. In contrast, when the data were not normally distributed, an analysis of variance following the model of Kruskal-Wallis. In this case, when the p-value was significant, means comparisons were made using the Dunn’s test. All tests were performed with R software version 3.4.3 (2017-11-30) at the probability level of 5%.

3. Results

3.1. Oxygen and carbon dioxide concentrations

Over the months, the O₂ concentration decreased steadily in the PICS bags while the CO₂ concentration increased. In the meantime the CO₂ concentration increased by about 8% compared with a 2% decrease in the PP bags (Fig. 1a). In the 8-months period, the O₂ concentration in the PICS bags decreased by about 8% compared with a 2% decrease in the PP bags (Fig. 1a). In the meantime the CO₂ concentration increased by more than 6% in PICS bags compared to only 0.7% increase in the PP bags (Fig. 1b).

3.2. Insect infestation of sorghum grains

At the beginning of the storage period, four insect species were identified in the grains, namely R. dominica, Sitophilus zeamais Motschulsky (Coleoptera: Curculionidae), Tribolium castaneum Herbst. (Coleoptera: Tenebrionidae) and Orzyaephilus mercator Fauvel (Coleoptera: Silvanidae) (Table 1). At the end of the 12-months storage, only two insect species, R. dominica and S. zeamais were present in the PICS bags. In the PP bags, all four species were still present in addition to a predator species, Xylocoris flavipes (Reuter) (Hemiptera: Anthocoridae) not found at the outset of the experiment (Table 1).

3.3. Levels of insect pests after 12-months storage of sorghum grains in PICS and PP bags

After 12 months of storage, R. dominica was the only species that emerged from sorghum grains stored in the PICS bags but with a population 15 times less than that observed in the PP bags (Table 2).
In addition to *R. dominica*, *T. castaneum*, *O. mercator*, *X. flavipes* and *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) emerged from grain stored in the PP bags but not from grain held in PICS bags. (Table 2).

### Table 1

<table>
<thead>
<tr>
<th>Species</th>
<th>Initial number of insects (Means ± S.E.)</th>
<th>Number of insects after 12-months (Means ± S.E.)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PICS bags</td>
<td>Polypropylene bags</td>
<td></td>
</tr>
<tr>
<td><em>Rhyzopertha dominica</em></td>
<td>2.33 ± 0.73b</td>
<td>12.67 ± 5.70b</td>
<td>$\chi^2 = 7.2, \text{df} = 2, P = 0.027$</td>
</tr>
<tr>
<td><em>Sitophilus zeamais</em></td>
<td>2.66 ± 0.33b</td>
<td>2.33 ± 0.90b</td>
<td>$F_{2, 6} = 7.125, P = 0.026$</td>
</tr>
<tr>
<td><em>Tribolium castatum</em></td>
<td>0.17 ± 0.16b</td>
<td>0.0 ± 0.0b</td>
<td>$\chi^2 = 7.7143, \text{df} = 2, P = 0.021$</td>
</tr>
<tr>
<td><em>Oryzeaphilus mercator</em></td>
<td>0.17 ± 0.17b</td>
<td>0.0 ± 0.0b</td>
<td>$\chi^2 = 6.7879, \text{df} = 2, P = 0.033$</td>
</tr>
<tr>
<td><em>Xylocoris flavipes</em></td>
<td>0.0 ± 0.0b</td>
<td>0.0 ± 0.0b</td>
<td>$\chi^2 = 7.6235, \text{df} = 2, P = 0.022$</td>
</tr>
</tbody>
</table>

Within a row, means followed by different letters were significantly different (Dunn test or Tukey test, $\alpha = 0.05$).

In addition to *R. dominica*, *T. castaneum*, *O. mercator*, *X. flavipes* and *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae) emerged from grain stored in the PP bags but not from grain held in PICS bags. (Table 2).

### 3.4. Grain damage and weight loss of sorghum stored for 12 months in PP and PICS bags

The percentage of damaged grains after 12-months of storage was nearly 30 times higher in polypropylene bags than in the PICS bags. In the PICS bags the final grain weight did not differ significantly from the initial weight (Table 3). Weight loss in the PP bags was fourteen times higher than that observed in the PICS bags (Table 3).

### 3.5. Seed viability after storage of sorghum grain in PP and PICS bags

Sorghum grains stored in the PICS bags for 12 months germinated as well as it did at the start of the experiment. While the
The germination rate was slightly lower in PICS bags, the difference was not statistically significant. By contrast, germination decreased significantly when the grain was stored in PP bags ($F_{2,9} = 17.85, P = 0.0007$, Fig. 2).

### 4. Discussion

The present results revealed changes in the concentration of CO2 and O2 during the storage period for both PICS bags and PP bags. But in PP bags, which are permeable to air, only slight variation in O2/CO2 concentration was observed. However, in the confined atmosphere of the PICS bags, there was a significant decrease in the O2 content and a simultaneous increase in CO2 concentration. Similar trends in gas concentrations have been reported for PICS bags by several authors (Mutungi et al., 2015; Amadou et al., 2016).

However, in the present study, the O2 and CO2 concentration decreased by 8% and increased by 6% respectively. Amadou et al. (2016) observed a decrease of 17% and an increase of 8%, respectively. Mutungi et al. (2015) observed a decrease in O2 and an increase in CO2 of about 15%. These differences in the variation in gases may be explained by the species present and numbers of insects present in the confined atmosphere of the PICS bags. In fact, in the present studies we observed four insect species initially present in the PICS bags while some studies observed only one insect species. According to Murdock et al. (2012), the respiratory activity of insects present in the confined atmosphere of the PICS bags, through inhalation of O2 and expiration of CO2, may explain the variation of respiratory gases in the storage bags.

Sorghum used in this experiment (purchased in a local market) was infested with four insect species including *R. dominica*, *S. oryzaeaphilus*, *Tribolium castaneum*, and *Xylocoris flavipes*.

### Table 2

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of insect after 12-months (Means ± S.E.)</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rhyzopertha dominica</em></td>
<td>12.67 ± 6.01b</td>
<td>$t_{1,4} = 2.808, P = 0.048$</td>
</tr>
<tr>
<td><em>Tribolium castaneum</em></td>
<td>0.0 ± 0.0b</td>
<td>$t_{1,4} = 2.882, P = 0.045$</td>
</tr>
<tr>
<td><em>Oryzaphilus mercator</em></td>
<td>0.0 ± 0.0a</td>
<td>$t_{1,4} = 1, P = 0.374$</td>
</tr>
<tr>
<td><em>Xylocoris flavipes</em></td>
<td>0.0 ± 0.0b</td>
<td>$t_{1,4} = 4.490, P = 0.011$</td>
</tr>
<tr>
<td><em>Corcyra cephalonica</em></td>
<td>0.0 ± 0.0b</td>
<td>$t_{1,4} = 4.064, P = 0.015$</td>
</tr>
</tbody>
</table>

Within a row, means followed by different letters were significantly different (independent $t$-test, $a = 0.05$).

### Table 3

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Grains with holes (%Means ± S.E.)</th>
<th>Grain weight loss (%Means ± S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial level</td>
<td>0.50 ± 0.10b</td>
<td>0.08 ± 0.05b</td>
</tr>
<tr>
<td>PICS bags</td>
<td>0.57 ± 0.15b</td>
<td>0.35 ± 0.17b</td>
</tr>
<tr>
<td>Polypropylene bags</td>
<td>16.83 ± 5.32a</td>
<td>4.25 ± 1.26a</td>
</tr>
<tr>
<td>Statistics</td>
<td>$F_{2,6} = 28.18; P = 0.0009$</td>
<td>$F_{2,6} = 30.45; P = 0.0007$</td>
</tr>
</tbody>
</table>

Means bearing different letters within a column were significantly different (Tukey test, $a = 0.05$).
primary pest of stored sorghum was able to sustain its population during the storage period. In conclusion PICS bags can be recommended for safely storing sorghum grains over a 12-months period but investigations should be carried out to understand survival of *R. dominica* immature stages under low-oxygen conditions.

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**References**


