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Performance of PICS bags under extreme conditions in the sahel zone of Niger

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ABSTRACT

Experiments in Niger assessed whether extreme environmental conditions including sunlight exposure affect the performance of triple-layer PICS bags in protecting cowpea grain against bruchids. Sets of PICS bags and woven polypropylene bags as controls containing 50 kg of naturally infested cowpea grain were held in the laboratory or outside with sun exposure for four and one-half months. PICS bags held either inside or outside exhibited no significant increase in insect damage and no loss in weight after 4.5 months of storage compared to the initial values. By contrast, woven bags stored inside or outside side by side with PICS bags showed several-fold increases in insects present in or on the grain and significant losses in grain weight. Grain stored inside in PICS bags showed no reduction in germination versus the initial value but there was a small but significant drop in germination of grain in PICS bags held outside (7.6%). Germination rates dropped substantially more in grain stored in woven bags inside (16.1%) and still more in woven bags stored outside (60%). PICS bags held inside and outside retained their ability to maintain internal reduced levels of oxygen and elevated levels of carbon dioxide. Exposure to extreme environmental conditions degraded the external polypropylene outer layer of the PICS triple-layer bag. Even so, the internal layers of polyethylene were more slowly degraded. The effects of exposure to sunlight, temperature and humidity variation within the sealed bags are described.

1. Introduction

In West Africa, cowpea (*Vigna unguiculata* Walp) production was estimated to be 4.5 million tons (FAO STAT, 2014). This essential food legume for rural populations is ravaged by insects in the field and during storage after harvest. Losses caused by bruchids are estimated to range from 25 to 95% after 3 to 4 months of storage (Singh et al., 1985). Over the last ten years, post-harvest protection of cowpea grain in the Sahelian zone of Africa has improved considerably thanks to the introduction and dissemination of the hermetic triple-bagging technology called PICS (Purdue Improved Crop Storage) (Baributsa et al., 2010). A PICS bag consists of a woven polypropylene outer bag and two internal polyethylene liners and costs about 2.0–3.0 USD in local markets in the region. The bags are effective in preserving grain quality for at least fourteen different crops. The technology has been directly demonstrated to more than 5 million farmers in 56,000 villages in Africa and at least 10 million bags have been sold by June 2017 (PICS, 2017).

Storage space is a major challenge in many Sub-Saharan African households. Some farmers store their grain-filled PICS bags under a tarpaulin outside but within their household compound. Others store PICS bags inside warehouses such that the bags are exposed to direct sunlight. In addition, the authors have received many inquiries from potential large-scale users asking about the effect of environmental conditions on PICS bags and their effectiveness when kept outside for several days or even weeks. Such large-scale users include development agencies that source food aid from local markers or private processing companies that buy grain from farmers but may not have available warehouse in rural areas to store large amounts of grain. Based on some of these field observations, we have recommended that users not expose their PICS bags to the sunlight in order to avoid the deterioration of the woven bags. The aim is to avoid any potential effect of environmental

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conditions such as temperature on grain quality. Even so, the question of grain quality in PICS bags stored outside under extreme weather conditions has never been systematically investigated.

The present study was conducted to better understand how environmental conditions affect the performance of hermetic storage systems such as PICS bags when the grain-filled bags are stored outside exposed to full sunlight. Given that storage space is sometimes a constraint in many communities in sub-Saharan Africa, the results of this present study will lead to more scientifically-based recommendations for the more efficient use of the technology.

2. Material and methods

Experiments were carried out at the INRAN Entomology laboratory in Maradi, Niger over a period of two seasons (November 26, 2015 to April 7, 2016): (1) The cold dry season extends from November 2015 to January 2016 with a monthly sunshine duration of 203–258 h. The daily average minimum temperature varied between 11.4 and 12.3 °C while the average maximum daily temperature was 30.0–38.0 °C; (2) the warm dry season from March 2016 to May 2016 which has a monthly sunshine duration of 221–288 h, a daily average minimum temperature ranging between 12.4 and 22.1 °C and a maximum daily temperature of 40.5–44.6 °C. (These data were collected from the website http://www.infoclimat.fr/climatologie/annee/2016/maradi/valeurs/61080.html).

The PICS 50 kg triple-bags used in these experiments were manufactured by Lela Agro (Kano, Nigeria). Cowpea grain (1200 kg) was purchased from a local market in Maradi. This grain, already naturally infested with cowpea bruchids, was thoroughly mixed to obtain a homogenous initial infestation. Woven bags and PICS bags in twelve replicates were each filled with 50 kg of the infested grain. Six filled PICS bags and six filled woven bags were stored outside exposed to the sun, and side by side on a raised platform inside a screen cage to avoid damage by animals. The other sets (six filled PICS bags and six filled woven bags) were stored on pallets inside the laboratory.

Data loggers, model EL-USB-2 (Lascar, Whiteparish, Wiltshire, Great Britain), were placed in one bag of each treatment to record temperature and relative humidity over the course of the experiments. Another data logger was placed outside to measure the ambient environmental conditions. Oxygen and carbon dioxide levels were monitored using a Mocon PAC Check Model 325 Headspace analyzer (Mocon, Minneapolis, MN, USA) fitted with a 20-gauge hypodermic needle for sampling through rubber septa or through the walls of the storage bags. We sealed punctures in bag walls with patches of electrician's tape. Oxygen and carbon dioxide data was collected from the second day of the experiment (November 27, 2015) until March 18, 2016 at which point some PICS bags had begun losing their airtightness.

The bags for each treatment were monitored daily to detect any changes in the physical condition of the outer woven polypropylene bags as well as the outer and inner polyethylene liners. This assessment was initially made to the exposed outer polyethylene bag. Next, its surface was touched lightly with a finger. Any crack, breakage or crumbling of the material was judged as degradation. Over time, cracking, crumbling and attendant falling away of the outer woven bag exposed the outer polyethylene bag to the sun and the elements. When this polyethylene layer became exposed it was likewise inspected and touched to determine its physical integrity. The process was repeated when the innermost polyethylene bag had become exposed after the middle bag had degraded and fallen away. In conjunction with inspections of physical integrity, the oxygen and carbon dioxide levels in the bag were determined with the Mocon device, as described above.

The initial bruchid infestation level in the cowpea grain was assessed at the beginning of the experiment by randomly collecting 64 samples of 500 g each. Each 500 g sample was sieved to separate and count dead and live adults. Pupae were counted as adults. Three random samples of 100 seeds were picked from each 500 g sample and soaked in water for 15 min to soften the grains. The water-imbibed seeds were cracked and opened to count the number of living and dead or desiccated larvae, pupae, and adults. At the end of the experiment, 18 samples of 500 g and 54 samples of 100 grains per each treatment were evaluated for dead and live larvae, pupae, and adults.

Data collected was recorded in Excel for calculating mean and standard errors. For temperatures and relative humidity, daily averages were determined as well as the correlations between the treatments and prevailing environmental conditions (temperature and relative humidity). Statistical analysis was done with SPSS software (Statistical Package for the Social Sciences), produced by IBM SPSS, Inc. in Chicago, Illinois. Analysis of Variance (ANOVA) followed by Least Significant Difference (LSD) tests was used to compare parameters related to oxygen and carbon dioxide, infestations and damage per treatments.

3. Results

Daily relative humidity (RH) means ranged from 23.0 ± 0.0 to $35.1 \pm 0.5\%$ in woven bags kept outside, and 27.5 ± 0.0 to $38.7 \pm 0.0\%$ for those kept inside (Fig. 1a). For PICS bags, daily RH varied from 26.6 ± 0.1 to $41.8 \pm 0.3\%$ in bags kept outside and 23.8 ± 0.0 to $31.6 \pm 0.0\%$ for those stored inside. There was an increase in the average daily RH in woven bags (1.5–11.0%) stored inside compared to those kept outside for the period from January to April 2016. For the PICS bag, an average increase in daily RH of 1.89–12.4% was observed in bags stored outside compared to those stored inside. The correlations between the average daily RH and treatments are -12.8% ($p = .12$) and -20.0% ($P = .41$) for woven and PICS bags, respectively, kept outside; and 9.6% ($p = .25$) for PICS bags stored inside the laboratory.

The average daily temperature ranged from 21.3 ± 0.2 to 42.4 ± 0.3 °C and 24.9 ± 0.0 to 41.4 ± 0.0 °C in woven bags kept outside and inside, respectively (Fig. 1b). For PICS bags, temperatures varied from 20.0 ± 0.1 to 39.7 ± 0.2 °C and 23.7 ± 0.0 to 36.0 ± 0.0 °C for the bags stored outside and inside, respectively. From mid-January to mid-March, there was an average daily temperature increase of 2.5–18.1 °C in woven bags compared to PICS bag when stored outside. The correlations with the average daily ambient temperature were 60.3% ($P < .01$) for woven bag kept outside and 71.6% ($P < .01$) for those stored inside the lab and; 96.9% ($P < .01$) and 96.1% ($P < .01$) for PICS kept outside and inside, respectively.

Throughout the experiments, oxygen levels were lower in PICS bag treatments compared to woven bags (Fig. 2a). On the second day of the experiment (27 November 2015), an average oxygen level of $10.6 \pm 0.4\%$ (v/v) was observed in PICS bag treatments and 20.5 ± 0.2 to $20.6 \pm 00\%$ (v/v) in woven bags ($F = 197.00$, $P < .01$) stored inside and outside the laboratory respectively. At day 114 (18 March 2016), the mean oxygen level in PICS bags varied from 10.9 ± 0.4 to $15.00 \pm 0.6\%$ (v/v) and from 19.8 ± 0.3 to $20.7 \pm 0.4\%$ (v/v) in woven bag ($F = 73.77$, $P < .01$) stored inside and outside of the laboratory. The CO_2 levels were higher in PICS bags compared to those in woven bags regardless of whether the bags were stored inside or outside the laboratory (Fig. 2b). Two days after bag closure (27 November 2015), CO_2 levels of 5.7 ± 0.6 to $5.7 \pm 0.2\%$ (v/v) were noted in PICS bag treatments while in woven bags the levels were below detection. At that 114th day (18 March 2016), the average