Maize stored pests control by PICS-bags: Technological and economic evaluation

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Abstract

A trial was conducted in Benin, West Africa to investigate the effectiveness of PICS bags in controlling postharvest pests during maize storage. Sorted and un-sorted maize (25 kg) was stored in either PICS bags (PsB) or polypropylene bags (PPB) as controls with half of the bags being artificially infested with 25 *Prostephanus truncatus* (Pt), and the other half left under natural infestation. Bags were monitored at 0, 3, and 6 months of storage by destructive sampling. Average density of *P. truncatus*/Kg in PsB (0.30 ± 0.11) was significantly different from levels observed in PPB (0.96 ± 0.12) after 6 months of storage. One hundred percent mortality of *P. truncatus* was obtained after 3 months of storage in PsB. Similarly, there were statistical differences in the average density of *Sitophilus zeamais*/Kg between PsB (1.35 ± 0.41) and PPB (238.75 ± 2.38) and 100% of mortality of *S. zeamais* was detected in PsB, whereas PPB showed only 34.05 ± 2.69% of mortality after 6 months of storage. Weight losses were lower in PsB (0.31 ± 0.01) than the control (17.95± 0.51)). After 6 months, at most 0.75 ± 0.47 holes were observed on the inner bag of PsB, whereas 350.75 ± 25.38 holes were observed in the control. In general, PsB showed effective control against the two main postharvest species *P. truncatus* and *S. zeamais* after 6 months of storage, despite the slight increase in moisture content of stored maize in all bags. The effectiveness of storing maize with PICS bags was apparent within the six-month storage period.

Introduction

Maize is the most widely produced and consumed staple crop in Africa with more than 300 million Africans depending on it as their main food source (M'mboyi et al. 2010). Overall food security in sub-Saharan Africa (SSA) is often compromised due to high losses after harvest mainly due to insects and fungi and compounded by inappropriate crop handling and postharvest practices (Kaaya et al. 2005). Losses as high as 36% on stored maize have been recorded in Benin due to the infestation with *Prostephanus truncatus* (Coleoptera, Bostrichidae) (Lamboni and Hell 2009). Such high losses are detrimental to resource-poor farmers leading to poverty and undermining their food security. Most farmers are forced to sell maize early for low prices, since they lack appropriate storage structures for safe grain storage and storage management technologies (Abraham 2003). Prices at harvest are low with price increases after several months (Beyene et al. 1996). Pest problems have been aggravated by the introduction of higher yielding improved varieties which proved to be more susceptible to postharvest insect pests when stored in the traditional stores used by West African farmers (Meikle et al. 1998). There are multiple methods practiced by farmers to reduce postharvest losses, mostly based on good agricultural practices (GAP), use of natural products including botanicals and ash, and use of chemical insecticides. However, access to insecticides in SSA is challenging and use can have an impact on environmental and human health (Obeng-Ofori and Reichmuth 1999). The use of alternative ecologically friendly insect pest control and storage technologies which are economically viable, safe to humans, and can minimize qualitative and quantitative maize grain losses in storage are imperative. One of the available technologies is the use of hermetic grain storage. In hermetic storage oxygen levels are modified by the respiration and metabolism of insects, fungi, and the grain itself to a level of 1–2% O_2, while the CO_2 level rises substantially causing the death of insects and microorganisms by asphyxiation (Moreno et al. 2000). Based on this principle, simple hermetic storage technologies have been developed. These include triple layer bag storage (PICS bags) mainly used for cowpea storage (Murdock et al. 2003) and IRRI Superbag for rice storage (Ben et al. 2006). PICS technology, because of its effectiveness and ease of use, has been quickly adopted by small-scale farmers and other organizations (Baributsa et al. 2010). This technology offers three advantages: reducing direct losses from attack by cowpea weevils; farmers are not obliged to sell at harvest when prices are generally low; and they can sell later at a much higher price and avoid price discounts for cowpeas damaged by weevils (NGI 2009). The hermetic PICS storage bag fits as a liner bag inside a conventional storage bag, they are easy to use, and could be one of the options to reduce maize losses and increase family food security by safeguarding the maize supply for family consumption. Therefore we chose to test the effectiveness of hermetic storage using PICS for controlling postharvest pests and to evaluate the financial profitability of this technology.

Materials and Methods

Storage trials

The experiment was set up to determine the effects of PICS bags on stored maize pest population dynamics, grain losses, and moisture content. The improved maize variety QPM (Quality Protein Maize), a 4-month maize variety was grown at the IITA-Station in Southern Benin. At harvest cobs were either sorted or not. All damaged and undersized cobs were put to one side and de-husked. The two categories of maize grains (25 kg) were stored in PICS bags (PsB) or in Polypropylene bags (PPB) used as control. Half of the bags were artificially infested with 25 *P. truncatus*, the rest were left under natural infestation. A total of twelve treatments replicated 3 times were set up. The bags were tightly sealed as recommended by the PsB notice of use and placed on pallets in the storage room where they were monitored 3 and 6 months thereafter, using the destructive sampling method. At sampling, bags were inspected and the number of holes made by insects was counted. Moreover, five samples of 1 kg were taken from each bag to assess insect populations and grain losses. Grains were sieved through a series of sieves (4, 2, 1, and 0.85 mm) to separate insects from grains and flour. Alive and dead adult insects were counted using a manual counter and the loss (on the basis of 1000 grains) was calculated using the count and weigh method described by Boxall (1986). The number of damaged and undamaged kernels were determined through sorting of a 1 kg sample. Grain moisture content was determined by drying in an oven for 2 h 15 min at 130 °C and reweighing using the method of the International Standards Organization (ISO 1980), with 3 replicates per sample.

Data were analyzed using SPSS version 16 (SPSS, Chicago, IL) with the general linear model procedure. The number of insects was log(x + l)-transformed and mortality rate, losses and moisture content arcsine square root (x/100)-transformed to normalize data. The Student -Newman-Keuls (SNK) test was used to separate averages at 5%. Students test for independent samples was used for pairwise comparison of means. ANOVA analysis showed that the effect of sorting cobs had no influence on the different parameters and was not taken into account in the data analysis. No *P. truncatus* was observed under natural infestation, so this parameter was only considered in treatments with artificial infestation.

Economic analysis

The economics of using PsB to store maize grains were evaluated based on data from laboratory trials, socioeconomic surveys in three different markets in Benin (Dantokpa in Cotonou and Dogbo and Ketou, two rural markets), and financial information provided by ONASA (Office National d'Appui à la Sécurité Alimentaire-Benin), the national agency for the collection of price data. Costs and benefits for the maize storage using PsB were calculated over a 6-month storage period.

Generated data were used in the Cost Benefit Analysis (CBA) to monetize the costs and benefits of the new technology over a relevant time period (Hell et al. 2006). The key cost–benefit indicators used were: (1) Present Value of Benefits (PVB), (2) Present Value of Costs (PVC), and (3) Benefit Cost Ratio (BCR) as presented by Laval (2003) and by Nkang et al. (2007). The equations used are:

(1) $PVB = \sum * P_i (Q_0 - Q_1) * k_n$ where

P_i = average monthly maize price, Q_0 quantity of maize losses using polypropylene bag (PPB), Q_1 = quantity of maize losses using ISB or PsB, k_n = discount rate [$k_n = (1+i)^{-n/12}$, i (Interest rate) =12% and n=Number of mouth of storage]

(2) $PVC = (C_1 - C_0) * k_n$ where

C_0 = Cost of old technology (PPB) and C_1 = Cost of the new PsB technology

(3) BCR = PVB /PVC

If BCR >1, the new storage technology (PsB) is considered economically viable as compared to PPB, If BCR<1 the new storage technology (PsB) is not economically viable compared to PPB, and consequently there is no need to introduce the new technology, if BCR is equal to 1, the new storage technology does not make a loss or gives a gain.

Results

Temperature and relative humidity during the trial

Monthly temperatures during storage varied from 23.45 ± 1.01 to 30.16 ± 4.72 °C and relative humidity (rh) from 75.33 ± 5.26 to 84.31 ± 7.59% (Fig. 1). The lowest monthly temperatures were recorded in October and the highest in December. Lowest rh were recorded in November and the highest in January.

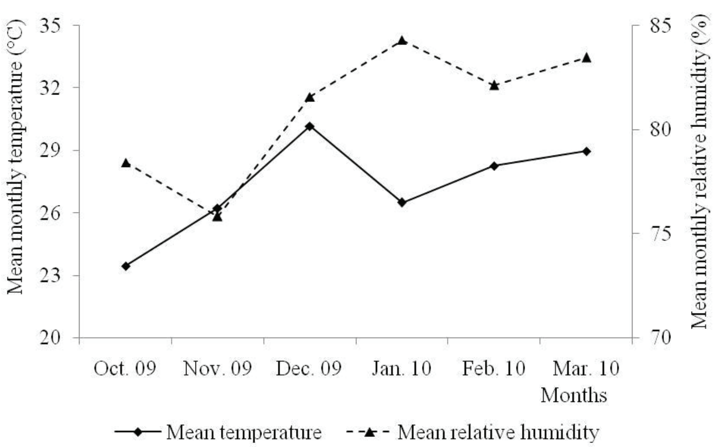

Figure 1. Monthly temperatures and relative humidity recorded in storage room during trial

Maize prices during the storage trial

During the storage period the lowest maize prices were recorded in September (Fig. 2), maize is harvested from the more productive second season during this month and farmers sell a large part of their production at harvest. When comparing maize prices between the three markets it was observed that highest prices were recorded in Dantokpa market, while the lowest were found in Ketou, and the median at Dogbo. This might be due to the different end-users found in these markets with Dantokpa mainly serving consumers, while Ketou and Dogbo are markets in major maize production areas that cater to wholesalers. The highest maize price (235 Fcfa/kg) was observed in May at Dantokpa market, this is when most maize is being planted and there is a shortage of maize.

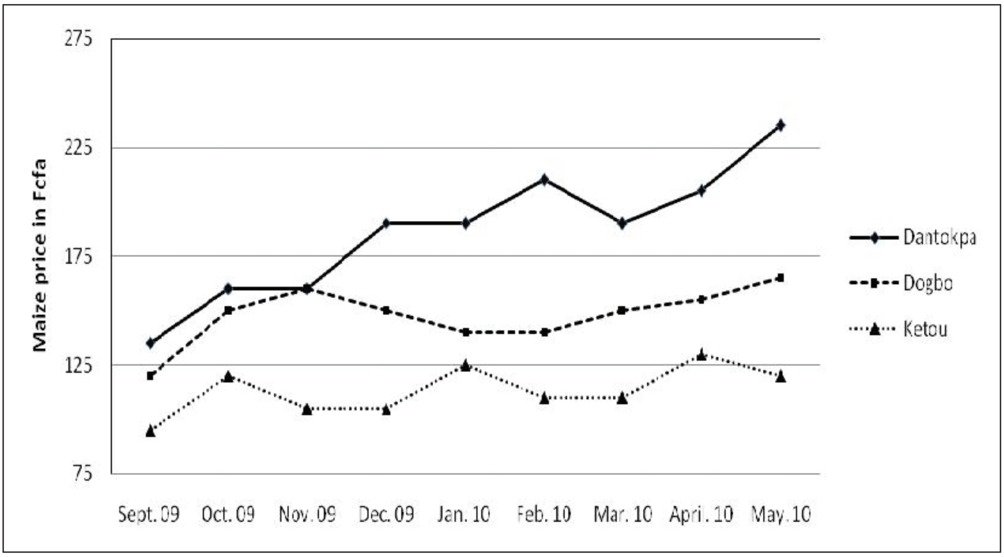

Figure 2. Maize prices (F cfa/kg) during the storage period in three different markets in Benin 2009-2010 (531.82 F cfa=1US$-July 1st 2010). Source: ONASA

Insect bored holes on the storage bags and densities during storage

The type of bags used significantly affected the number of insect holes recorded on the bags, with control bags PPB being more susceptible to insect attack than the other bags (Table 1). The PsB significantly reduced the number of holes bored by insect pests and consequently the insect density. Prior to bagging maize grains, *Mussidia* spp (Lepidoptera, Pyralidae), *Cathartus quadricollis* (Coleoptera: Silvanidae), and *Sitophilus zeamais* (Coleoptera: Curculionidae) were observed in collected samples. During storage, *P. truncatus*, *S. zeamais*, *C. quadricolis*, and *Tribolium* spp. (Coleoptera: Tenebrionidae) were recorded in control bags while only *P. truncatus* and *S. zeamais* were recorded in the PsB (Table 2).

Both bags significantly reduced maize postharvest insect densities when compared to the control polypropylene Bags (PPB) ($P = 0.018$), except for *P. truncatus* after 3 months of storage ($P > 0.05$). While the pest densities remained statistically identical in PsB and ISB, densities of *C. quadricolis* and *Tribolium sp*. increased significantly with sampling date ($P < 0.0001$).

Table 1. Means numbers of holes made by insects at different level of PICS bag (PsB) during storage.

Storage technologies	Number of holes					
	3 months			6 months		
	First plastic bag in contact with grains (PsB)	Second plastic bag containing the first plastic bag (PsB)	PPB (external bag for PsB)	First plastic bag in contact with grains (PsB)	Second plastic bag containing the first plastic bag (PsB)	PPB (external bag for PsB)
PsB with natural infestation	0.00 ± 0.00	0.00 ± 0.00	0.75 ± 0.75	0.00 ± 0.00	0.25 ± 0.25	0.50 ± 0.50
PsB with artificial infestation	0.25 ± 0.25	0.00 ± 0.00	0.00 ± 0.00	0.75 ± 0.47	1.75 ± 0.47	1.25 ± 0.75
PPB with natural infestation	–	–	308.50 ± 36.39	–	–	322.25 ± 19.74
PPB with artificial infestation	–	–	344.25 ± 40.53	–	–	350.75 ± 25.38

Table 2. Effect of PICS Bag (PsB) on maize post–harvest pest populations in 3- and 6-month stored maize grains.

Treatments	Number of adult insects per kg of maize grains (Mean ± SE)[a]							
	P. truncatus		*S. zeamais*		*C. quadricolis*		*Tribolium sp.*	
	3 months of storage	6 months of storage	3 months of storage	6 months of storage	3 months of storage	6 months of storage	3 months of storage	6 months of storage
PsB	0.75 ± 0.38 Aa	0.30 ± 0.11 Aa	2.47 ± 0.69 Aa	1.35 ± 0.41 Aa	0.00 ± 0.00 Aa	0.00 ± 0.00 Aa	0.00 ± 0.00 Aa	0.00 ± 0.00 Aa
PPB (Control)	0.62 ±0.27 Aa	0.96 ± 0.12 Ba	234.37 ± 33.28 Ba	238.75 ± 2.38 Ba	147.05 ± 7.82 Ba	355.05 ± 14.26 Bb	44.77 ± 5.18 Ba	191.65 ± 6.83 Bb

[a]For each species, means within column followed by the same upper case letter and within row followed by lower case letter are not significantly different at *P* < 0.05 (Test SNK).

Table 3. Mean number (±SE) of *Prostephanus truncatus* (adults) per kg of maize grains following artificial and natural infestation of maize grains by the pest.

Treatments	*P. truncatus* density/ Kg			
	3 months of storage		6 months of storage	
	Natural infestation	Artificial infestation	Natural infestation	Artificial infestation
PsB	0.00 ± 0.00 b	1.50 ± 0.55 a	0.00 ± 0.00 b	0.55 ± 0.15 a
PPB (Control)	0.20 ± 0.11 a	1.05 ± 0.47 a	0.80 ± 0.07 a	1.12 ± 0.22 a

Means within rows followed by the same letter(s) are not significantly different at P < 0.05 (Test SNK).

Pest densities (summarized in Table 2) were significantly reduced in PsB compared to PPB after 3 and 6 months of storage for *S. zeamais*, *C. quadricollis*, and *Tribolium* spp. and after 6 months for *P. truncatus* (Table 3 and *P* = 0.018). Storage time did not affect insect densities in PsB (*P* = 0.111) however, in the control bag densities increased significantly with storage time except for *S. zeamais* (*P* < 0.0001). In PsB, *P. truncatus* was recorded during storage when maize was artificially infested with this species whereas in PPB, it was recorded in all bags with no difference between artificial and natural infestation (Table 3).

Table 4. Effect of PICS Bag (PsB) on insect mortality.

Mortality rate (Mean ± SE)a								
Treatments	*P. truncatus*		*S. zeamais*		*C. quadricolis*		*Tribolium sp.*	
	3 months storage	6 months storage	3 months storage	6 months storage	3 months storage	6 months storage	3 months storage	6 months storage
PsB	100 ± 0.00Aa	100 ± 0.00Aa	95.83 ± 4.16Aa	100 ± 0.00Aa	–	–	–	–
PPB (Control)	100 ± 0.00Aa	96.43 ± 2.33Aa	11.35 ± 1.71Bb	34.05 ± 2.69Ba	7.38 ± 0.51a	10.50 ± 0.73b	4.87 ± 0.56a	7.60 ± 0.29b

[a]For each species, means within column followed by the same upper case letter and within row followed by lower case letter are not significantly different at P < 0.05 (Test SNK).

Table 5. Effects of PICS Bag (PsB) on maize grain losses in 3- and 6-month stored maize grains.

Treatments	Months after storage	
	3 months	6 months
PsB	0.28 ± 0.01 Aa	0.31 ± 0.01 Aa
PPB	9.56 ± 0.34 Ba	17.95± 0.51 Bb

Means within column followed by the same upper case letter and within row followed by lower case letter are not significantly different at *P* < 0.05 (Test SNK)

Effect of PsB on stored insect mortality

In PsB 100% mortality of *P. truncatus* was obtained during the 6 months of storage with no significant differences between the two storage bags (Table 4). *S. zeamais'* mortality was significantly lower in PPB than in PsB at each sampling ($P < 0.0001$) (Table 4), with all individuals lifeless in PsB after 6 months of storage. In PPB mortality rates of *S. zeamais* increased significantly with storage time ($P < 0.0001$). In PPB mortality after 6 months of storage was 34.05 ± 2.69 %. In PsB no significant difference ($P = 0.369$) was found between mortality rate of *S. zeamais* at 3 and 6 months. Mortality rate of *C. quadricollis* ($P = 0.004$) and *Tribolium* spp ($P = 0.001$) in PPB also increased with storage time (Table 4).

Effects of PsB on grain losses

Losses were significantly lower in PsB than in the control bag ($P < 0.0001$) and did not increase in PsB ($P = 0.114$) during storage (Table 5). In the control bag, losses increased significantly with storage time ($P < 0.0001$) and reached 17.95± 0.51 % at the end of storage.

Effect of PsB on grain moisture content during storage

During the 6 months of storage moisture content increased significantly in PsB ranging from 11.21 ± 0.27 % to 13.17± 0.09 % (Fig. 3). The moisture content in control bags (PPB) however did not vary significantly ($P = 0.642$) during the 6-month storage time and remained significantly lower than that in PsB.

Economic evaluation

Figure 4 shows that maximum PVB provided by PsB (3334 CFA) was obtained at Dantokpa market, since the highest prices for maize are found in this market, while the minimum PVB (1930 CFA) was obtained at Ketou market after 6 months of storage.

Table 6 summarized the Benefit–Cost Ratio (BCR) when using PsB as maize storage

Table 6. Benefit Cost Ratio (BCR) of the use of PsB according to markets and storage duration calculated with a discount rate of 12%.

Market	Storage duration		
	3 months	6 months	Re-use bags for 6 months
Ketou	0.9	1.9	3.7
Dogbo	1.3	2.6	5.0
Dantokpa	1.7	3.3	6.3

bags. The BCR was over > in all surveyed markets. The cost–benefit ratio of PsB as compared to PPB, varied between 0.9 and 1.7 over a 3-month period, and 1.9 to 3.3 over a 6-month period dependant of the final market price.

Discussion

This study shows the effectiveness, economic benefit, and environmental sustainability of PsB for maize storage under Beninese conditions. PICS bags are a tested technology for safeguarding maize, and can be recommended to farmers for use. Their use is cost-effective after just 3 months of storage taking into consideration the prices in Beninese markets. The low insect densities and the high mortality rates recorded in PsB could be attributed to the physiological effect of the PICS bag on insects through lowered oxygen levels and increased levels of CO_2 that result from the natural respiratory rate of insects and grains under hermetic storage. Indeed once the oxygen level in the container falls to a sufficiently low level, the insects cease feeding and become inactive (Margam 2009). According to Bailey and Banks (1980) hermetic conditions delay insect development, leading to impaired metamorphosis and altered fecundity. Our results generally corroborate reports that hermetic storage systems negatively affect insect development during storage (Rickman and Aquino 2004; Ben et al. 2006; Baoua et al. 2008). However, the low density of *P. truncatus* observed (less than 1 *P. truncatus*/kg) in the control bag, might result from the insect exiting from control bags via holes that they bored on the bags; but may also be due to a potential reduction of the insects' reproductive rate. The latter according to Giga and Canhao (1993) could be a consequence of interspecific competition with other stored product pests in these ecosystems. Indeed in the present experiment, we found that before storage, maize showed high infestation rates with *S. zeamais*. Danho et al. (2000) reported that maize previously infested with *S. zeamais* had a deterrent effect on *P. truncatus*, when searching for food or oviposition sites, so that this specie might have avoided maize previously invested with *S. zeamais*. Similarly, studies on the competition between *P. truncatus* and *S. zeamais* showed that the maize weevil was the best competitor and had a suppressive effect on *P. truncatus* (Cowley et al. 1980; Giga and Canhao 1993). The spectrum of insects observed in the PsB without artificial infestation, showed that *P. truncatus* was absent at the beginning of storage prior to bagging. Thus all larger grain borers in PPB might have migrated into this structure. *P. truncatus* are attracted to the odor of starchy crops and also to the aggregation pheromone produced by *P. truncatus* males (Scholz et al. 1997). The absence of *C. quadricollis* and *Tribolium* spp. in PsB could be explained by the low level of losses in this bag and also by the hermetic condition. Indeed these two species are secondary insects which appear on maize only after the grains have been damaged by other pests and their population increases proportionally with losses (Giga and Canhao 1993). The low densities of *S. zeamais* recorded at the end of storage could be due to some individuals exiting from the PPB since the population could have exceeded levels that could be supported by the food source. Meikle et al. (1998) described that insect species would emigrate if the food source would not support the population development. Losses are comparatively lower in PsB than in PPB, due to the hermetic conditions of PICs bags that inhibit insect development as confirmed by the low insect densities and high mortality recorded in PsB.

The results of this study show that in most cases, moisture increased slightly in PsB as compared to the control bag. In PsB, the hermetic structure prevents heat generated by the respiration of insects and grains from being exchanged with the external environment, leading to an increase in moisture content of the grains. The PPB however, is permeable, allowing the exchange with the external environment and cooling the grains.

Holes observed on PsB layers should be attributed to *P. truncatus,* this specie possesses a remarkable ability to tunnel through hard materials and on one occasion an adult was found to have penetrated plastic 35-mm thick (Li 1988). The impact of holes on the efficacy of PsB in this study was negligible, although there is need to determine if this kind of damage could reduce the efficiency of this technology over a longer storage period. In Benin some farmers are known to store maize for periods of 1 to 2 years (K. Hell, pers. comm.).

Economic analysis shows that PVB provided by the use of PsB was cost effective after 6 months of storage. Cost effectiveness of this technology increases through the re-use of PICS bags as elucidated by Baributsa et al. (2010).

Conclusion

Efficient storage of maize with PsB without insecticides was possible, low insect densities and high mortalities were recorded when storing maize with PsB. Consequently, grain losses were significantly reduced in PsB. PICS storage bags are economical when used for maize storage for 6 months and even when storing for only 3 months when maize prices are high.

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