Identification and Impact of Insects Feeding on the Stored Seeds of *Lagenaria siceraria* Molina (Standl., 1930) and *Citrullus lanatus* Thumb (Matsum & Nakai, 1916), two Oilseed Cucurbits of the Ivory Coast

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Abstract

Storage seeds are exposed to a number of stored product insect pests that cause a major decline in grain quality and contribute to global financial losses. This study aimed to identify insects that feed on two cucurbit seed, *Lagenaria siceraria* and *Citrullus lanatus*, which are endemic to the Ivory Coast. The seeds were placed in jars and bags, and were kept in a modern store or traditional kitchen. Observations were made on (1) insect richness and (2) species diversity, in parallel to a (3) damage assessment (by evaluating the weight loss, moisture content, and germination rate of the seeds). Sixteen insect species were identified, which belonged to 14 families and 5 orders. Species richness and diversity were significantly ($P < 0.001$) higher in the kitchen and bags compared to the store and jars. In both the store and kitchen, seeds in bags had significantly higher ($P < 0.001$) humidity and weight loss rates compared to seeds in jars. Seeds in jars had significantly higher germination rates ($P<0.001$) compared to seeds in bags. Thus, jars reduce insect proliferations and associated damage to seeds (maintaining higher germination rates), and should therefore be preferentially to conserve the seeds of *L. siceraria* and *C. lanatus*.

Keywords: Cucurbit Seeds, stored insect pests, *Lagenaria siceraria, Citrullus lanatus,* conservation

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1. Introduction

Increasing world population numbers make it essential to mobilize resources for the production and storage of food, including cereals and pulses, which are consumed year-round. The oleaginous cucurbit species are cultivated in fields or in home gardens, either in monoculture or in intercropping, on small plots (average 0.74 ha) for their oleaginous seeds (Achigan-Dako et al., 2008). The seeds are packaged in stored equipment (bowls, buckets, bags etc.) inside kitchen, house and granary (Bullen, 2007). The stored seed can lasts 6 to 12 months for seed and consumption. Extracted, cleaned, dried, shelled and roasted, the seeds can be transformed into a paste, similar to the groundnut paste (Arachis hypogaea, Fabaceae). This paste is used to thicken sauces or extract oil in Ivory Coast (Zoro Bi et al., 2003; Zoro Bi, 2005), in Bénin (Vodouhe et al., 2001; Achigan-Dako et al., 2006) and in Congo

(Enzonga-Yoca et al., 2011). The seeds of those cucurbits contain essential nutriments (Loukou et al., 2007; Abiodun & Adeleke, 2010; Anhwange et al., 2010).

The storage of these products results in their being almost permanently available on the market, and guarantees the availability of seeds for future crops (Ngamo & Hance, 2007). Unfortunately, during storage, losses of up to 40 % and 10 % have been observed in hot and humid regions, respectively, as well as in dry regions (Appert, 1985a; Bartali, 1996). Ngamo and Hance (2007) reported that seeds losses between harvest and consumption were up to 30 %. Stored grains are exposed to a number of adverse factors and impacts, including those caused by fungi pathogens (Amin et al., 2009; Butt et al., 2011; Ora et al., 2011; Bhajbhuje, 2014) and by a range of storage pests (Shepard, 1947; Manickavasagan et al., 2008). Stored-product insects can cause postharvest losses, estimated from up to 9 % in developed countries to 20 % or more in developing countries (Phillips & Throne, 2010). About 40 % of losses during storage are attributed to insects (Brabec et al., 2010). Moreover, the uncontrolled proliferation of insects in stocks presents a major risk to food quality, causing deterioration (CEEMAT, 1974). These infestations are caused by a lack of good storage conditions, in parallel to a lack of understanding about the evolution and adaptation mechanisms of these pests (Mills, 1990; Fleurat-Lessard, 1994). The storage methods used in developing countries continue to cause losses (Ratnadass & Sauphanor, 1989; Alzouma et al., 1994). There is much interest in alternatives to conventional insecticides for controlling stored-product insects because of insecticide loss due to regulatory action and insect resistance, and because of increasing consumer demand for product that is free of insects and insecticide residues (Phillips & Throne, 2010).

Therefore, there is a compelling need to reduce these quantitative and qualitative losses during storage (Appert, 1985b). Effective insect management in stored grains requires at least a basic ability to identify the insect species present (Bullen, 2007). To accomplish this objective, it is important study the pests that occur during seed storage. This requirement is not only important for commercially widespread crops, but for neglected and underutilized crops, including endemic cucurbits, which have social, nutritional and economic potential (Zoro Bi et al., 2005; Enzonga-Yoca et al., 2011; Abbah et al., 2014). Indeed, in Ivory Coast, studies about the pests of cucurbits seeds (also commonly called "pistachios") remain absent.

This study aimed to identify the insects associated with the stored seeds of the two main cucurbits grown in Ivory Coast, *Lagenaria siceraria* Molina (Standl.) and *Citrullus lanatus* Thumb (Matsum & Nakai). Insect damage was assessed through the weight loss, moisture content, and germination rates of seeds placed in two types of storage containers (jars versus bags) under two different environmental conditions (store versus kitchen).

2. Materials and Methods

2.1 Characteristics of the storage areas and materials studied

Investigations were conducted from April to October over a two-year period (2010 and 2011) at the Institut National Polytechnique Félix Houphouët-Boigny (INP-HB) of Yamoussoukro (6°47’ N ; 5°15’ W) in the Ivory Coast. For each year, observations were conducted during 6 months, twice a month.

Two storage areas (a modern store and a traditional kitchen) with different characteristics were used to store the seeds. The daily temperature was 28.5 ± 2.3 °C in the store and 23.5 ± 3.8 °C in the kitchen. The average daily relative humidity was 83.5 ± 5.8 % in the store and 90.5 ± 8.8 % in the kitchen. The daily average humidity amplitude was 4.5 ± 3.5 % in the store and 7.5 ± 9.0 % in the kitchen.

The seeds of *L. siceraria* and *C. lanatus* (Fig. 1) used in this study were obtained from the Laboratory of Agricultural Zoology and Entomology of the INP-HB. Glass jars with a 1 liter capacity and polypropylene bags with a 5 kg capacity were used for the package of the seeds.

Figure 1. Seeds of Lagenaria siceraria (left) and Citrullus lanatus (right).

2.2 Experimental design

The experiment was based on a Complete Randomized Design with three replications. Specifically, three jars and three bags were used to package the seeds. Each packaging material (one jar or one bag) contained 150 g of *L. siceraria* (730 seeds) in the store and kitchen. The same experimental set up was used for 150 g of *C. lanatus* (3380 seeds) (Fig. 2). Observations were made periodically on the number and species of insects encountered, along with seed weight loss, moisture content, and germination rates.

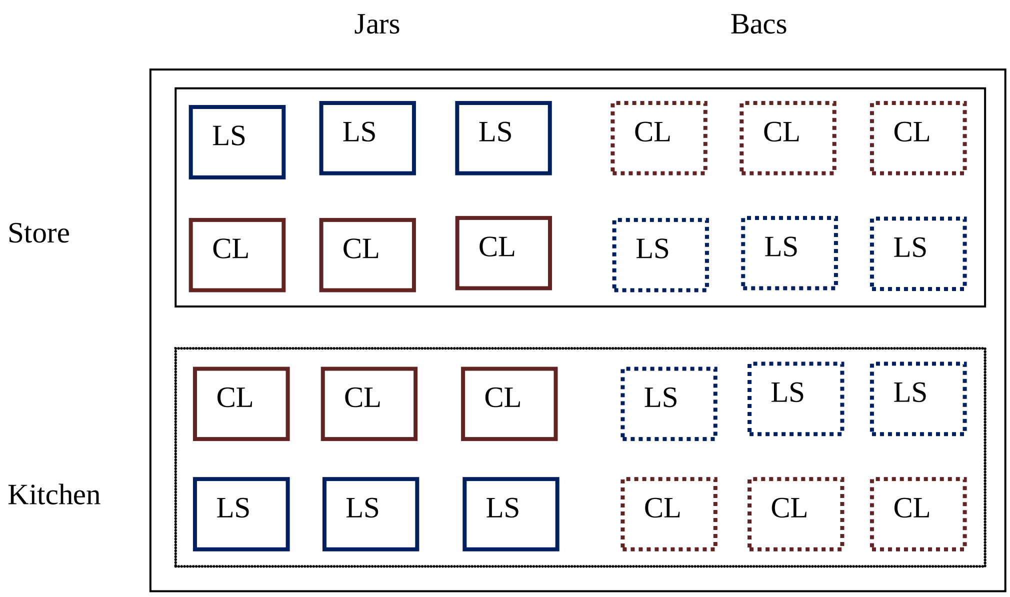


Figure 2. Experimental design (*LS*: *Lagenaria siceraria*; *CL*: *Citrullus lanatus*).

2.2.1 Insect inventory

Every two weeks, the seeds were screened with a sieve (mesh Ø 1.5–2.5 mm) and all visible insects were collected. For the hidden insect forms (i.e., within seeds), 50 seeds were randomly collected and shelled and all of the insects that were found were collected. This activity (observation of the hidden insect forms) was performed once a year, at the end of the six months of storage.

All collected insects were identified through their morphological characteristics by using a binocular microscope (G x 50). The observed characteristics were compared with those of our laboratory collection using several identification keys (Delobel & Tran, 1993; Fleurat-Lessard, 1994; Darracq, 2004; Hölldobler & Wilson, 1996; Detia-Degesch, 2009).

2.2.2 Insect species richness and diversity

After identification, the frequency of occurrence (C) of each insect war determined according to the formula of Dajoz (2000), in which:

$$C(\%) = 100\times {}^{P_i}/_{P} \quad (1)$$

where Pi is the number of occurrence of a species and P the total number of observations.

He identified 5 classes of occurrence:

- Ubiquist species (C = 100 %),
- Constant species (50 % ≤ C < 100 %),
- Commun species (25 % ≤ C < 50 %),
- By-catch species (5 % ≤ C < 25 %),
- Rare species (C < 5 %).

The relative abundance (Ar) was calculated according to the formula of Zaime & Gautier (1989), in which:

$$A_r(\%) = 100\times {}^{N_i}/_{N} \quad (2)$$

where N_i is the number of individuals of a given species and N is the total number of individuals of all species combined. They identified 4 classes of relative abundant:

- Highly abundant species (Ar ≥ 10 %),
- Abundant species (5 % ≤ Ar < 10 %),
- Moderatly abundant species (1 % ≤ Ar < 5 %),
- Scare species (Ar < 1 %).

The Shannon index (H′) takes the number of taxa encountered in an environment into account. It is influenced by specific richness and dominant species. It is calculated according to the following formula (3) (Daget, 1976):

$$H' = \sum_{i=1}^{s}(Ni/N)\times log2(Ni/N) \quad (3)$$

Where Ni is the number of individuals of given species and N is the total number of individuals of all species combined. This index measures the diversity of the insects.

This index is zero when there is only one species, and its value is at a maximum when all species have the same abundance.

The Equitability (E) (or Regularity) measures the equitable distribution of species. This index infers population balance (Daget, 1976).

$$E = H'/H'_{max} = H'/\log 2(S) \quad (4)$$

where S is the total number of species, H' is Shannon diversity index and H'max is the maximum diversity index of Shannon. This index measures the evenness of the insects.

E tends to be zero when a taxon dominates a stand, and is equal to 1 when all taxa have the same abundance.

2.2.3 Seed weight loss

To evaluate weight loss, 100 seeds were randomly selected, and the number and weight of healthy seeds and damaged seeds were recorded. The rate of weight loss is determined by the gravimetric method (Compton et al., 1998), in which:

$$Loss\ of\ weight\ (\%) = \frac{W_h \times N_d - W_d \times N_h}{W_h(N_d + N_h)} \times 100 \quad (5)$$

where W_h is the weight of healthy seeds, N_h is the number of healthy seeds, W_d is the weight of damaged seeds, and N_d, is the number of damaged seeds.

This activity was performed once a year, at the end of the six months of storage.

2.2.4 Moisture content of seeds

At the beginning and end of the study, three batches of 100 g of seeds were placed in an oven at 80 °C for 48 h, and then weighed to determine the moisture content according to Compton et al. (1998).

$$Moisture\ content\ (\%) = (W_i - W_f) \times \frac{100}{W_i} \quad (6)$$

where W_i is the initial weight and W_f is the final weight.

This activity was conducted twice a year (firstly, on all the seed at the beginning and secondly at the end the storage on the seed of each container).

2.2.5 Seed germination rates

Three batches of 100 of seeds were collected at the beginning and at the end of the experiment, and were placed in Petri dishes containing moistened filter paper. The Petri dishes were placed in a room at 28 °C. The seedlings were counted after 3 and 7 days, and the rate of germination was calculated (Compton et al., 1998), in which:

$$Germination\ rate\ (\%) = N_{GS} \times \frac{100}{N_{TS}} \quad (7)$$

where N_{GS} is the number of germinated seeds and N_{TS} is the total number of seeds that germinated. This activity was conducted twice a year (firstly, on all the seed at the beginning and secondly at the end the storage on the seed of each container).

2.3 Data analysis

The collected data were processed using MS Excel 2010, and STATISTICA 7.1 was used for the statistical analysis. Analysis of variance (ANOVA) was used to compare the insect population with the rate of weight loss, moisture content, and germination rate of the seeds.

The Student-Neumann-Keuls (SNK) test of multiple comparisons of means was performed when a significant difference was observed at the 5 % level.

3. Results

3.1 Inventoried insects

Over the two years of study, 16 insect species were identified belonging to 14 families and five orders (Table 1). We collected in boths years (2010 and 2011) 1100 and 1254 individuals respectively, corresponding to 2354 individuals with 55.27 % of Coleoptera, 22.34 % of Hymenoptera, 10.62 % of Psocoptera, 10.58 % of Lepidoptera, and 1.19 % of Dictyoptera. Coleoptera (with 9 species) and Hymenoptera (with 4 species) are the most represented orders. The others orders (Psocoptera, Lepidoptera and Dictyoptera) are represented by a single species.

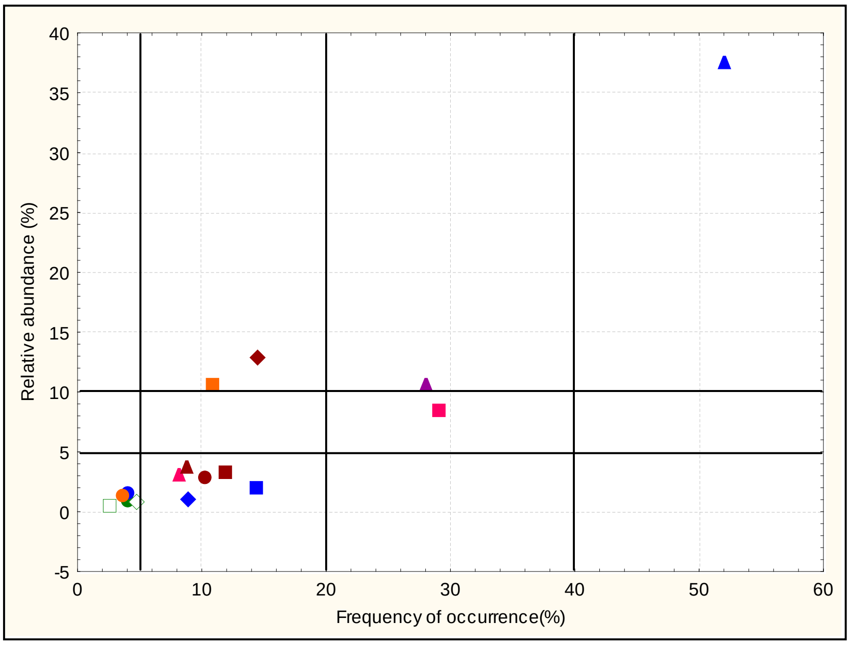
According to the trophic group, we observed that 67.03 % of collected individuals were pests with 13.21 % of primary pests, 52.64 % of secondary pests, and 1.19 % of occasional pests. In addition predator's species represented 16.48 % of individuals, parasitoids, 5.86 % whereas 10.62 % were hyperparasitoids (Table 1). The distribution of these insects, according to their frequency of occurrence and abundance (Fig. 3), showed the constant presence of one species, which was highly abundant (*Lasioderma serricorne*). Two other common species were also found of which one highly abundant (*Ephestia cautella*) and one abundant (*Tribolium castaneum*). Eight by-catch species were observed, of which two were highly abundant (*Monomorium pharaonis* and *Liposcelis divinatorius*) and six were moderately abundant (*Oryzaephilus surinamensis, Cryptolestes ferrugineus, Carpophilus hemipterus, Dimmockia polyconae, Cardiochiles longiceps* and *Lasius niger*). Finally, we observed the presence of five rare species, of which two were moderatly abundant (*Cillaeus* sp. and *Blattella* *germanica*) and three were scarce (*Acanthoscelides Obtectus*, *Rhyzopertha dominica* and *Sitophilus oryzae*).

The major pests found within seeds were *T. castaneum* (50.56 % of individuals), *L. serricorne* (30.56 %), *C. ferrugineus* (7.41 %), *O. surinamensis* (6.02 %), and the larvae of *E. cautella* (5.55 %).

Table 1. Trophic level, occurrence and relative abundance of insects found on the stored seeds of *Citrullus lanatus* and *Lagenaria siceraria.*

Order	Family	Species	Trophic level	Occurence	Relative abundance
Coleoptera	Bruchidae	*Acanthoscelides obtectus*	PP	2.60	0.34
	Bostrichidae	*Rhyzopertha dominica*	PP	4.17	0.85
	Curculionidae	*Sitophilus oryzae*	PP	4.68	0.76
	Tenebrionidae	*Tribolium castaneum*	PP / SP	29.17	8.33
	Cucujidae	*Cryptolestes ferrugineus*	PP / SP	8.33	2.93
	Silvanidae	*Oryzaephilus surinamensis*	SP	14.58	2.00
	Anobiidae	*Lasioderma serricorne*	SP	52.08	37.34
	Nitidulidae	*Carpophilus hemipterus*	SP	8.85	1.15
		Cillaeus sp.	SP	4.17	1.57
Lepidoptera	Pyralidae	*Ephestia cautella*	SP	28.12	10.58
Hymenoptera	Braconidae	*Cardiochiles longiceps*	Pa	11.97	3.19
	Eulophidae	*Dimmockia polyconae*	Pa	10.41	2.68
	Formicidae	*Lasius niger*	Pr	8.85	3.65
		Monomorium pharaonis	Pr	14.58	12.83
Psocoptera	Psocidae	*Liposcelis divinatorius*	HPa	10.94	10.62
Dictyoptera	Blattellidae	*Blattella germanica*	OP	3.64	1.19

PP: Primary Pest ; PS: Secondary Pest ; Pa: Parasitoid ; Pr: Predator ; HPa: Hyperparasitoid ; OP: Occasional Pest.



□	*Acanthoscelides obtectus*	■	*Oryzaephilus surinamensis*	■	*Cardiochiles longiceps*
●	*Rhyzopertha dominica*	▲	*Lasioderma serricorne*	●	*Dimmockia* sp.
◊	*Sitophilus oryzae*	♦	*Carpophilus hemipterus*	▲	*Lasius niger*
■	*Tribolium castaneum*	●	*Cillaeus* sp.	♦	*Monomorium pharaonis*
▲	*Cryptolestes ferrugineus*	▲	*Ephestia cautella*	■	*Liposcelis divinatorius*
				●	*Blattella germanica*

Figure 3. Distribution of species according to the frequency of occurrence (%) and relative abundance (%).

□ *Acanthoscelides obtectus* ■ *Oryzaephilus surinamensis* ■ *Cardiochiles longiceps*

Table 2 Abundance, richness, diversity, and evenness of insects in substratum, environments, and mode of seed preservation

	Year 2010				Year 2011			
Substratum	**Lagenaria siceraria**							
Environment	Store		Kitchen		Store		Kitchen	
Storage device	Jar	Bag	Jar	Bag	Jar	Bag	Jar	Bag
N	8	156	15	431	11	257	7	508
S	3	8	2	14	3	6	3	11
F	2	8	2	12	3	6	3	10
O	1	2	1	5	1	2	1	4
H	1.56	2.24	0.91	3.06	1.49	1.44	1.44	2.23
E	0.98	0.74	0.91	0.80	0.94	0.55	0.91	0.64
Substratum	**Citrullus lanatus**							
Environment	Store		Kitchen		Store		Kitchen	
Storage device	Jar	Bag	Jar	Bag	Jar	Bag	Jar	Bag
N	9	65	11	405	4	129	10	328
S	2	8	3	13	2	6	3	11
F	2	7	3	12	2	6	3	10
O	1	2	1	5	1	2	1	4
H	0.99	2.34	1.43	2.59	1	1.38	1.48	1.97
E	0.99	0.78	0.90	0.70	1	0.53	0.93	0.57

N: Number of individuals ; S: number of species ; F: Number of families ; O: Number of orders ; H': Diversity index of Shannon ; E: index of equitability (evenness)

3.2 Insect species richness and diversity

In general, abundance and species richness was higher in bags kept in the kitchen (N = 328 to 508 and S = 11 to 14), with a greater diversity (H' = 1.97 to 3.06) compared those kept in the store (N = 65 to 257) and (S = 6 to 8; H' = 1.38 to 2.34). The insect population in bags was richer and more diverse (N = 65 to 508 and S = 6 to 14; H' = 1.38 to 3.06) compared to that in jars (N = 4 to 15 and S = 2 to 3; H' = 0.91 to 1.56), regardless of storage area (Table 2). However, the species evenness was higher in jars (E = 0.90 to 1) compared to the bags (S = 0.53 to 0.80) (Table 2). Thus, species diversity appeared to vary according to the environment (kitchen versus store) and method of conservation (jar versus bag).

3.3 Seed weight loss due to insect infestation

At the end of the experiment, the rate of weight loss of *L. siceraria* seeds in jars (6.42 ± 1.43 to 8.76 ± 0.69 %) was significantly lower (F (3.11) = 666.69 and 102.51; P < 0.001) compared to bags (20.73 ± 0.52 to 36.54 ± 3.84 %). The weight loss of seeds in bags in the store (20.73 ± 0.52 to 21.03 ± 2.36 %) was lower compared to those in the kitchen (35.63 ± 0.69 to 36.54 ± 3.84 %) (Fig. 4). The same results were obtained for the seeds of *C. lanatus* in jars (1.41 ± 1.22 to 3.12 ± 1.36 %), in which the rate of weight loss was significantly lower (F (3.11) = 6.63 and 17.71; P < 0.05) compared to bags in the store (4.6 ± 0.95 to 5.21 ± 1.16 %). The rate of weight loss in bags in the store was also lower compared to bags in the kitchen (6.35 ± 2.36 to 9.6 ± 2.5 %) (Fig. 4).

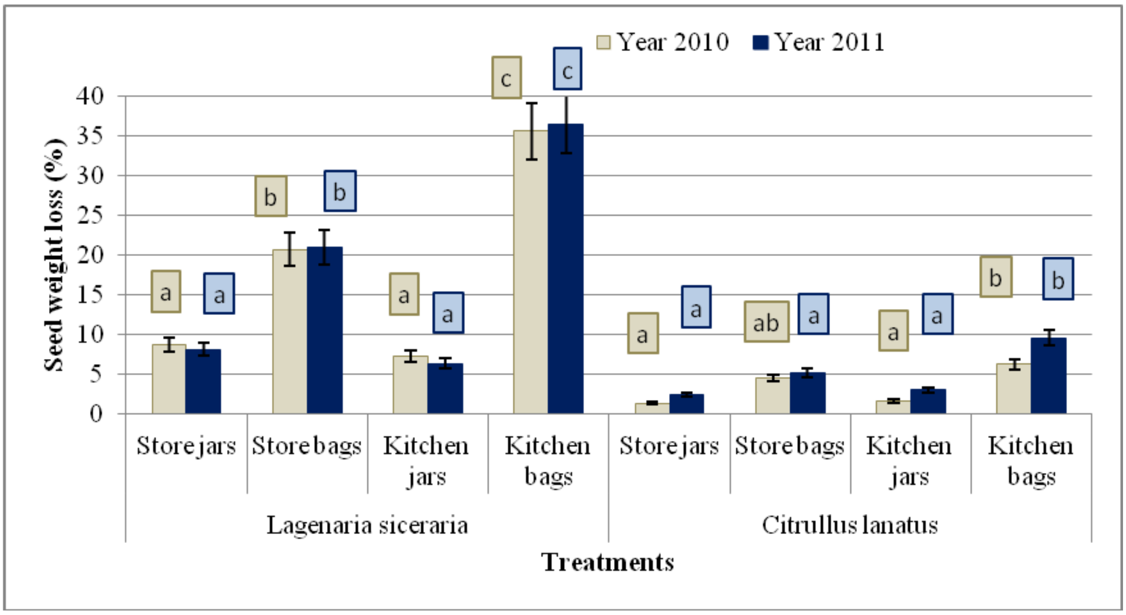


Figure 4. Seed weight loss (%) according to substratum, storage equipment type and environment (For each year, histograms with the same letter(s) for the same substratum are not significantly different according to the SNK test at 5 %).

3.4 Seed moisture content

At the beginning of the experiment, the moisture content of *Lagenaria siceraria* and *Citrullus lanatus* were 6.42 ± 0.48 to 6.46 ± 0.46 % and 4.61 ± 0.25 to 5 ± 0.36 %, respectively. The moisture content of *L. siceraria* in the early part of the experiments (6.42 ± 0.48 to 6.46 ± 0.46 %) was not significantly different to those obtained in the jars (6.79 ± 0.76 to 7.49 ± 0.21 %) and in bags in the store (7.52 ± 0.35 to 7.59 ± 0.53 %). However, these rates were significantly lower ($F (4.14) = 15.02$ and 6.12; $P < 0.05$) compared to bags in the kitchen (8.16 ± 0.67 to 8.62 ± 0.41 %) (Fig. 5). The same results were obtained for *C. lanatus*. The moisture rate at the beginning of experiment (4.61 ± 0.25 to 5 ± 0.36 %) was not significantly different to that obtained in the jars (4.87 ± 0.11 to 5.73 ± 0.6 %). These rates were significantly lower ($F (4.14) = 12.33$ and 86.56; $P < 0.01$) compared to those obtained for the bags kept in store (5.26 ± 0.12 to 6.56 ± 0.15 %). These rates were significantly lower compared to those obtained for the bags kept in the kitchen (6.22 ± 0.28 to 9.66 ± 1.33 %) (Fig. 5). Overall, the humidity recorded at the beginning of the experiments was lower compared to that obtained at the end of the experiment.

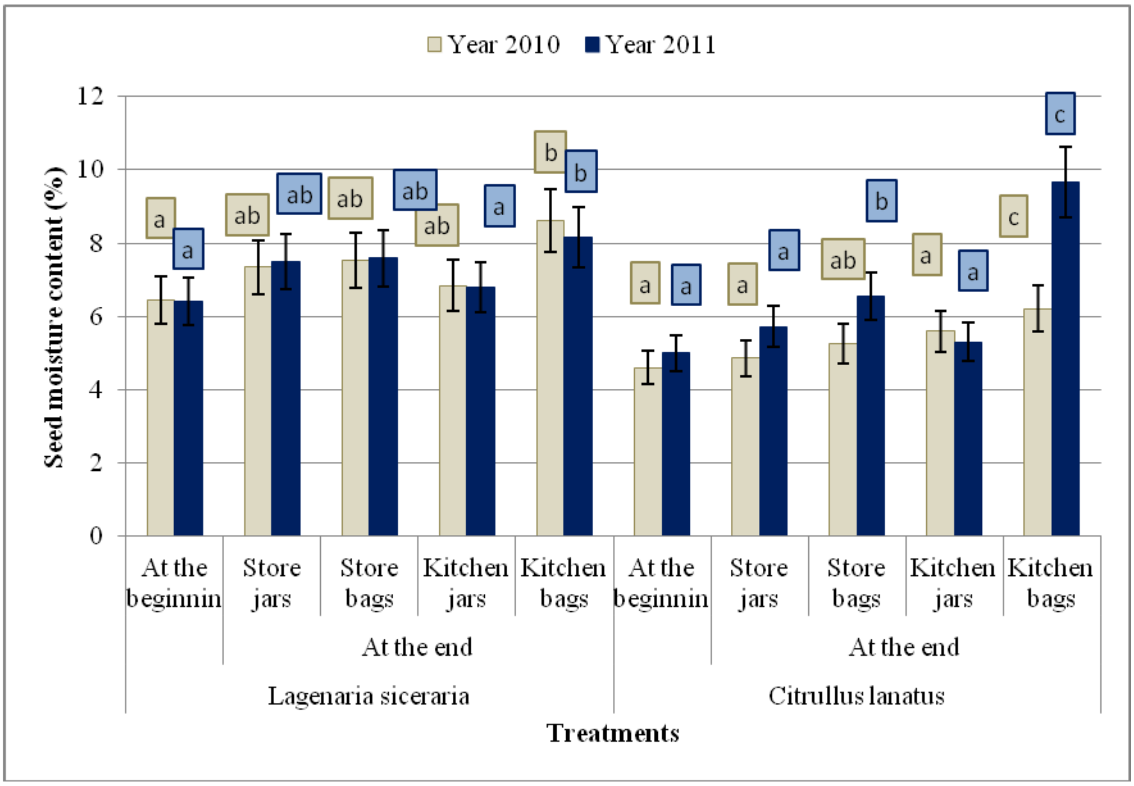


Figure 5. Seed moisture (%) at the beginning and end of the experiment according to storage equipment type and environment (For each year, histograms with the same letter(s) for the same substratum are not significantly different according to the SNK test at 5 %).

3.5 Seed germination rates

At the beginning of the experiment, the germination rate of *Lagenaria siceraria* and *Citrullus lanatus* were 82 ± 6.92 to 86 ± 7.21 % and 90 ± 2 to 98.66 ± 1.15 % respectively. The rate of germination of *L. siceraria* in the early part of the experience (82 ± 6.92 to 86 ± 7.21 %) were significantly higher (F (4.11) = 46.76 and 75.75; P < 0.001) for seeds stored in the jars (60.66 ± 6.43 to 64 ± 5.29 %). These rates were significantly higher compared to those obtained for the bags kept in the store (41.33 ± 4.16 to 43.33 ± 3.51 %), which, in turn, were higher compared to the bags kept in the kitchen (26.66 ± 3.15 to 29.33 ± 3.23 %) (Fig. 6). Similar results were obtained for the rate of seed germination of *C. lanatus*. During the early part of the experiments, the germination rate of *C. lanatus* (90 ± 2.26 to 98.66 ± 1.15 %), did not significantly differ to those obtained to the jars (82.66 ± 3.05 to 94.33 ± 4.04 %). These rates were significantly higher (F (4.14) = 23.87 and 27.24; P < 0.001) to those obtained for the bags kept in the store (79.33 ± 5.12 to 82.66 ± 5.33 %). These rate were also significantly higher compared to those for the bags kept in the kitchen (51.33 ± 9.02 to 56 ± 6.11 %) (Fig. 6). The germination rate recorded at the start of the experiment was higher compared to that at the end of the experiment.

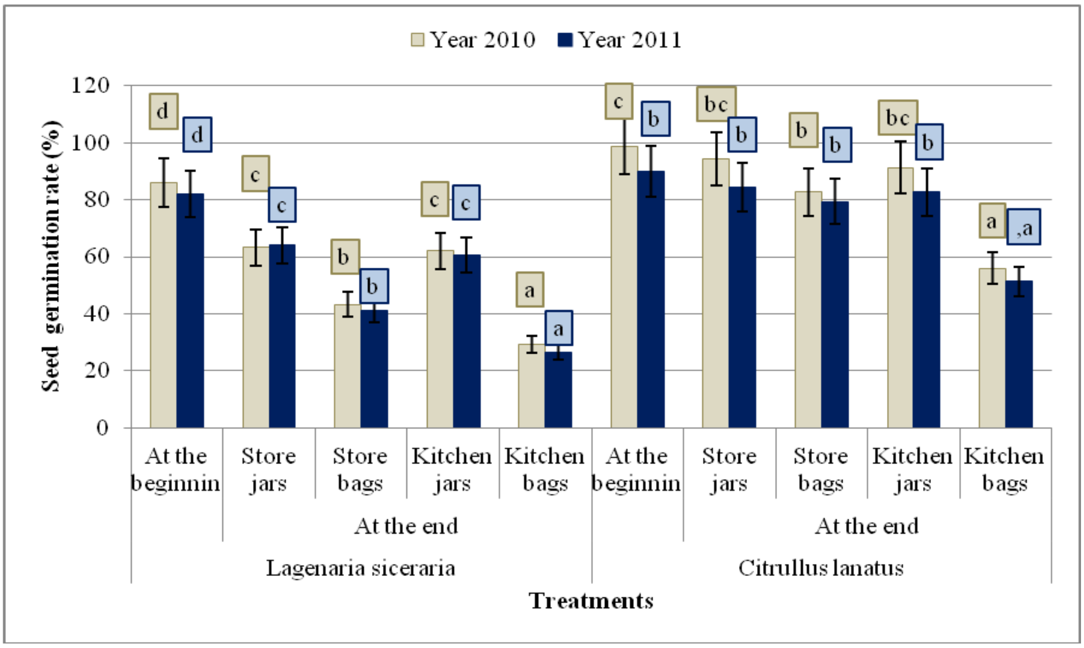


Figure 6. Percentage (%) of seed germination at the beginning and end of the experiment according to storage equipment type and environment (For each year, histograms with the same letter(s) for the same substratum are not significantly different according to the SNK test at 5 %).

4. Discussion

4.1 Inventoried insects

This study revealed that 16 species of insects were encountered on seeds placed in jars and bags and kept in a store and kitchen. Coleoptera were the most represented with 9 species and 55.27 % of the individuals. These results are similar to those obtained by several authors, who reported that the insects of stored grain and seeds mainly belong to the orders of Coleoptera and Lepidoptera, and incidentally to the orders of Hymenoptera, Psocoptera, and Dictyoptera (Schepard, 1947; Appert, 1985a; Ratnadass & Sauphanor, 1989; Alzouma et al., 1994; Ducom 1994; Darracq, 2004; Dauguet, 2004; Detia-Degesch, 2009). The presence of these insects could be explained by their already being present in the storage structures or in infested seeds from the field. Delobel & Tran (1993) reported that the main insects represented by Coleoptera (*T. castaneum, L. serricorne, C. ferrugineus*, and *O. surinamensis*), and Lepidoptera (larvae of *E. cautella*) are primary and secondary pests, which may behave as primary pests. The authors observed that Coleoptera are present in warmer areas and represent insect pests of global economic importance. Similary, Dudu et al. (1996) reported that *Oryzaephilus mercator* develops on oilseeds of *Irvingia gabonensis* (mango), *Citrullus lanatus* (melon), and *Arachis hypogaea* (groundnut). In addition to these listed species, other primary (*A. obtectus, R. dominica,* and *S. oryzae*) and secondary (*C. hemipterus* and *Cillaeus* sp.) pests have been found in the seeds of oleaginous cucurbits "pistachio" (Fleurat-Lessard, 1994), along with various enemies, including parasitoids (*C. longiceps* and *D. polyconae*; Schauff, 1991), predators (*M. pharaonis* and *L. niger* ; Hölldobler & Wilson, 1999), occasional pests (*B. germanica*), and hyperparasitoids (*L. divinatorius* ; Mills, 1990; Anonymous, 2014). The weevil *A. obtectus* infected oil products such as soy beans, groundnut (Alzouma et al., 1994; Papachristos & Stamopoulos, 2002).

4.2 Insect species richness and diversity

At the beginning of experiment, a seeds sieving to remove any available insects was performed. Lower insect species richness and diversity was recorded in the jars compared to the bags. This phenomenon might be explained by the impermeability of jars compared to woven bags, which are easily accessed by insects. Thus, insects that were present in the jars originated from previously infested seeds at the beginning of the study. This could be explained by the presence of hidden forms (eggs) within the seed despite screening. A greater number of insects were encountered in the kitchen compared to the store. This different might be explained by the fact that the kitchen was made of thatch, making it favorable to the proliferation of insects. The outbreak of insects in seeds consequently leads to the presence of various enemies (such as, parasitoids, predators, and hyperparasitoids). Thus, seeds stored in the kitchen contained *L. divinatorius* (Psocoptera), *M. pharaonis*, *L. niger, C. longiceps,* and *D. polyconae* (Hymenoptera), and *B. germanica* (Dictyoptera), which are occasional species that favor poor environmental conditions (Mills, 1990). The Hymenoptera Eulophidae and Braconidae are parasitoids and Formicidae are predators of other insects, including Lepidoptera and Coleoptera (Longstaff, 1981; Varricchio et al., 1999). Psocoptera are hyperparasitoids that grow at the expense of parasitoids (Mills, 1990). Dictyoptera have been reported in stored food in places where light is low or absent and where hygienic conditions are poor (USARS, 1979).

4.3 Effect of the presence of insects on the weight loss, moisture content, and germination rate of seeds

Seed weight loss was higher in the bags compared to the jars. This difference arose because the bags were made in polypropylene; these containers are exposed to ambient air conditions, which had large variations in temperature and humidity with an impact on insect dynamics. In contrast, the seemingly anaerobic conditions of the jars make it difficult for insects to live (Fleurat-Lessard, 1980; Appert, 1985b). According to Bartali (1994), thermal stability prevents water migration, which leads to the poor conservation of stored seeds. Excessive infestation of foodstuffs by insects causes an increase in moisture content, because the biological activity of these insects is accompanied by heat generation (CEEMAT, 1974). In the same idea, Dudu et al. (1996) showed that the moisture content increased in oilseeds stored for nine months, whereas protein content of the seeds decreased during the same period. This moisture causes mildew to grow, leading to seed rot and the release of toxins causing the qualitative loss and depreciation of the market value of foodstuffs (Fleurat-Lessard, 1980; Appert, 1985a). The increasing of moisture increase several fungal pathogens (Aspergillus, Fusarium, Penicillium, Rhizpus, Xanthomonas, Alaternaria, Helminthosporium, Bipolaris, etc.) on seeds, witch decreased germination rate and vigour index (Amin et al., 2009; Butt et al., 2011; Niaz et al., 2011; Ora et al., 2011; Perelló et al., 2011).

The harmful impacts of various insects on seeds resulted in lower germination rates. This phenomenon might explain the very low germination rate obtained in the bags, especially those stored in the kitchen compared to those obtained in jars, despite conditions remaining the same to those at the beginning of the study. In fact, the germination percentage of the damaged seeds decreased with the increase population of the pest and the period of storage (Hailé, 2015).

Several authors revealed the impact of the packaging materials (Morina et al., 2012; Basavegowda, 2013), the atmosphere control (Bullen et al., 2007; Aldawood et al., 2013), the treatment (Arthur, 2015) on seeds health. The initial germination percentage of seeds in tin container, polythene bag and cloth bag was declined after storage. When seed moisture is increasing, the rate of germination is decreases and the deterioration rate was also highest in seeds of cloth bag (Morina et al., 2012). The shoot and root length of seedling was lowest at the end of storage in cloth and the lowest seedling vigour. In case of dry weight of seed decreases in all cases but the rate of deterioration is highest in cloth bag. So, cloth bag is not safe for seed storage for long time compared to tin container and polythene bag. Because the rate of moisture absorbance was higher in cloth bag than tin container and polythene bag. The adults of *Tribolium* (mobile adults and knocked down) increased on untreated arenas 6 week later (Arthur, 2015). Sanitation is perhaps the first line of defense for grain stored at farms or elevators and for food-processing and warehouse facilities. Some of the most promising biorational management tools for farm-stored grain are temperature management and use of natural enemies. New tools for computer-assisted decision-making and insect sampling at grain elevators appear most promising. Processing facilities and warehouses usually rely on trap captures for decision-making, a process that needs further research to optimize (Phillips & Throne, 2010). Basavegowa et al. (2013) reported that the commercial cold storage structures can effectively used for maintaining seed quality during storage. Indeed the seeds stored in cold storage and packed in polylined gunny bag recorded higher seed germination, vigour index, seedling dry weight, lower insect damage, seed infection after 22 months of storage. The essential oils had a repellent action, reduce fecundity, decrease egg hatchability, increase neonate larval mortality and adversely influence offspring emergence of *Achantoscelides obtectus* (Papachristos & Stamopoulos, 2002).

5. Conclusions

The results obtained in this study showed that fewer storage insects were found in the seeds of *L. siceraria* and *C. lanatus* placed in jars in the store compared to the bags and the kitchen. Furthermore, seeds kept in bags had a higher moisture content and weight loss compared to those kept in jars and stored in the store or kitchen. Seeds stored in jars had a higher rate of germination compared to those stored in bags. Thus, jars should be preferentially used to store seeds because they reduce the proliferation of insects and associated damage, allowing seeds to germinate with better success.

High level damages of seeds by pests can be reduced through the storage control. This study provided mounting evidence of proper methods to preserve seeds to damage during conservation, suggesting that African farmers can improve their field incomes.

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