Effect of Hermetic Storage Bags and Storage Duration on Occurrence of Storage Insect Pests in Seeds of Cereals and Legumes

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Abstract

Hermetic storage has been introduced and disseminated in some parts of Ethiopia; although their efficacy in protecting seeds has not been studied. Thus, a study was conducted to determine whether different hermetic storage protect or not tef, durum wheat, lentil, and chickpea seeds from damage by storage insect pests over various storage periods. The hermetic storage tested were GrainPro super bag, Purdue Improved Crop Storage (PICS) bag, and fertilizer bag, while polypropylene bag was used as control. In each bag 10 kg of insecticide untreated seeds of tef, durum wheat and chickpea and 4 kg of lentil seed was put and stored for 6, 12, 18 and 24 months. The treatments were arranged in two factor nested design and treatments were replicated three times. Only lentil and chickpea seeds were infested by Adzuki bean beetle (Callosobruchus chinensis). It was found that throughout the tested storage periods, lentil seeds stored in PICS bag and GrainPro super bag had the lowest proportion of seeds with egg or hole; the lowest average number of eggs per seed; and holes per seed than seeds stored either in polypropylene bag or fertilizer bag. Relatively high level of infestation was found on chickpea seeds stored in a single inner layer GrainPro super bag and polypropylene bag. There were no insect infestations in both tef and durum wheat seeds stored in all packaging materials. Therefore, PICS and GrainPro super bags (as double layer) are effective in protecting both cereals and pulses from insect pests in storage.

Keywords: GrainPro super bag, Purdue Improved Crop Storage,

Introduction

Tef (*Eragrostis tef* (Zucc.) Trotter) has tiny seeds that weigh 19 to 34 mg per hundred seeds (Assefa *et al.*, 2011). Because of the smallness of the seeds, it is believed that tef is resistant to storage insect pests. However, McFarlane and Dobie (1972) artificially infested tef grain with different storage insect pests and found that the red flour beetle (*Tribolium castaneum* (Herbst)), flour beetle (*T. destructor* Uyttenb), and flour moth (*Ephestia cautella* (Walk.) (synonym *Cadra cautella*) feed on tef grain and produced fertile progenies. Moreover, Tebkew and Getachew (2011) first reported natural infestation of stored tef grain by the cigarette beetle, *Lasioderma serricorne* F. and the confused flour beetle, *Tribolium confusum* J. du Val. However, the amount of stored grain losses attributable to these storage insect pests in tef has not been quantified.

Similarly, durum wheat (*Triticum turgidum* ssp. *durum*) and other wheat species in Ethiopia are infested by over 25 primary and secondary storage insect pests (Abdurahman and Adugna, 1991). However, only few of the primary storage insect pests, which are the granary weevil (*Sitophilus granarius* L.), rice weevil (*S. oryzae* L.), maize weevil (*S. zeamais* Motsch), lesser grain borer, *Rhyzopertha dominica* (F.), Angoumois grain moth (*Sitotroga cerealella* Oliv.), and flour moth (*E. cautella* (Walk.), are economically important (Abdurahman and Adugna, 1991; Karta *et al*., 2019a). The latter authors also indicated that the majority (91%) of farmers store wheat seed in jute and polypropylene bag and in such storage system seed weight losses attributable to damage by storage insect pests vary between 0.0 and 17%.

In storage, chickpea grain is infested by the Adzuki bean beetle (*Callosobruchus chinensis* L.), *Acanthoscelides obtectus* Say, rice weevil, flour beetle, *Carpophilus dimidiatus* (F.) R.M.D. and *Typhaea stercorea* (L.) J.M.A. (Walker and Boxall, 1974). Similarly, lentil is infested by Adzuki bean beetle and *A. obtectus* Say. However, in recent years only the Adzuki bean beetle causes economic damage in both crops. In stored chickpea, the Adzuki bean beetle can cause up to 50% weight losses within six months of storage (Tebkew and Mohamed, 2006). Similarly, in lentil, grain weight losses due to Adzuki bean beetle infestations and damages range from 1.8 to 4.4% within 13 months of storage (Yemane and Yilma, 1989).

In earlier times, Ethiopian farmers used to store their produce in a variety of storage structures, which includes small baskets, plastic drums, barrels, *dibignt*, *gota (gumbi)*, and *gotera* (Yemane and Yilma, 1989; Teshome, 1990; Esayas *et al*., 2007; Karta *et al*., 2019a). Grains and seeds stored in such storage structures are liable to insect pests, rodents, theft and fire damage. Besides, some of these storage structures are not amenable to apply modern pest management methods in general and fumigation in particularly. Although this is the general truth, chemical control, including fumigation, is commonly practiced by farmers to manage storage insect pests (Tigist *et al.,* 2017), nevertheless, the way chemicals are used, particularly fumigation, is inappropriate. Other storage insect pest management methods includes fire smoke, outdoor storage, periodical winnowing, sun drying, mixing with botanicals, mixing with small grains (such as tef) or ash (Emana and Assefa, 1998; Girma *et al.*, 2000; Blum and Abate, 2001; Tebkew and Geteneh, 2021).

As an alternative to chemical and the traditional methods of storage pest management, hermetic grain storage containers such as Purdue Improved Crop Storage (PICS) bag and GrainPro super bag and metal silo were introduced for grain storage in different parts of the country by different organizations such as the International Center for Agricultural Research in Dry Areas (ICARDA), International Maize and Wheat Improvement Center (CIMMYT), Sasakawa Africa Association and others. Hermetic storage containers are air tight and kill insects by asphyxiation. The effects of these hermetic storage containers on storage insect pests of cereals (tef and wheat) and pulses (chickpea and lentil) have not been determined under Ethiopian condition. In this regard, evaluating the performance of these hermetic storage on seed viability and insect infestation is important for smallholder farmers of Ethiopia. Therefore, experiment was conducted jointly by the Technology Multiplication and Seed Research Program and the Entomology Research Program of the Debre Zeit Agricultural Research Center. The effects of these hermetic storage bags on tef -, wheat - and chickpea- seed viability were reported previously by Bekele *et al.* (2021), Tesfaye *et al.* (2021) and Abebe *et al.* (2021), respectively. Therefore, in the present article, the efficacy of PICS, GrainPro super bag, fertilizer bag and polypropylene bag in protecting seeds of cereal and pulse crops from damage by storage insect pests is reported.

Materials and Methods

The type and characteristics of the four hermetic storage bags used in this experiment are described in Table 1. The fertilizer bag was thoroughly washed before use. The fertilizer bag, PICS bag, and the polypropylene bag each has one outer polypropylene bag layer. In the case of GrainPro super bag, although, the recommendation is to use single inner layer with a polypropylene bag as an outer layer, in tef, durum wheat, and chickpea experiments, it was used without an outer layer. But in case of lentil a double layer was used. The conventional polypropylene (PP) woven bags was used as control treatment. The experiment on tef, durum wheat and chickpea was run for 24 months from 2 April 2018 to 3 March 2020. Then, grain samples were collected after 6, 12, 18 and 24 months of storage on 4 October 2018, 6 April 2019, 27 October 2019 and 3 March 2020, respectively. Similarly, the experiment on lentil was conducted for 24 months from 24 March 2020 to 24 March 2022 and grain samples were collected after 6, 12, 18 and 24 months of storage on 24 September 2020, 24 March 2021, 29 September 2021 and 24 March 2022, respectively.

Table 1. Characteristics of six hermetic storage bags tested during this experiment

Hermetic Bags	Inner liner*	Liner Thickness (µm)	Size (cm^2)
PICS bag	2 high density polyethylene liners	80	68 x 118
GrainPro super bag	1 multilayer polyethylene liner	78	75 x 130
Fertilizer bag	1 polyethylene sheet liner	25	55 x 95
PP bags	No liner	-	40 x 70

* Bags with at least one liner are hermetic.

In each bag, 10 kg of insecticide untreated seed of durum wheat (cu. Mangudo), tef (Quncho) and chickpea (cu. Habru) was stored. In case of lentil (cu. Derash), only 4 kg per hermetic storage bag was used. The grain was placed to one of the bottom corners of the bag and then the empty portion was pressed to remove air and then twisted up to the tip and tied with a string. A similar procedure was followed to tie the outer cover of those bags that have an outer cover. Then, all of the bags that were filled with seed were placed on pallets and left for natural infestation up to the end of each storage period. The treatments were arranged in two factor nested design (factor 1 packaging material and factor 2 storage time) and each packaging container was replicated three times. The experiment was conducted at room temperature and relative humidity in a seed storage warehouse (chickpea, tef and wheat) and entomology laboratory (lentil).

Data collection and analysis

Each bag was opened only once when each specified storage month had reached and data were collected by taking 25 seeds per replication from each crop type and hermetic storage bag. Each of the seeds in the samples was examined for the presence or absence of eggs, adults, and exit holes of insect pests. In addition, when there were eggs and insect exit holes, both the number of eggs and holes per seed were recorded. The percentage of seeds with egg and hole was calculated as the number of seeds that had egg and hole, respectively, to the total number of seeds examined.

All the data collected from lentil seed samples were analyzed by PROC NEST of SAS and differences in the proportion of seeds with eggs, holes, average number of eggs per seed and hole per seed were tested at $p = 0.05$ or 0.01. In chickpea seed sample, about 50 to 75% of the values for the different variables were zero and could not be statistically tested. For both crops, however, the data on the proportions of seeds with egg(s) or exit hole(s) were pooled over replication for presentation purposes. Insect infestation was not detected in tef and durum wheat in any of the packaging materials.

Results

In lentil and chickpea seed trials, only the Adzuki bean beetle, *Callosobruchus chinensis* L. (Coleoptera: Chysomelidae) was detected and data are presented separately for each crop type.

Lentil

Seeds with egg

The frequency of seeds with eggs was significantly ($p < 0.05$) affected by hermetic storage bag type but not by storage period ($p > 0.05$). Out of the total variance, 32.41% and 3.31%, of the variation in the frequency of seeds with egg was due to hermetic storage bag and storage period, respectively. Thus, in all storage periods, seeds stored in polypropylene bag, followed by that of fertilizer bag, had the highest proportions of seeds with egg (Fig. 1). Depending on duration of storage, the proportion of seeds with egg in polypropylene bags ranged from 40.0 to 80.0%, while 24 to 52% of the seeds that were stored in fertilizer bags had eggs on them; although at the 18th months of storage, seeds stored in fertilizer bag had the lowest proportion of Adzuki bean beetle egg laden seeds.

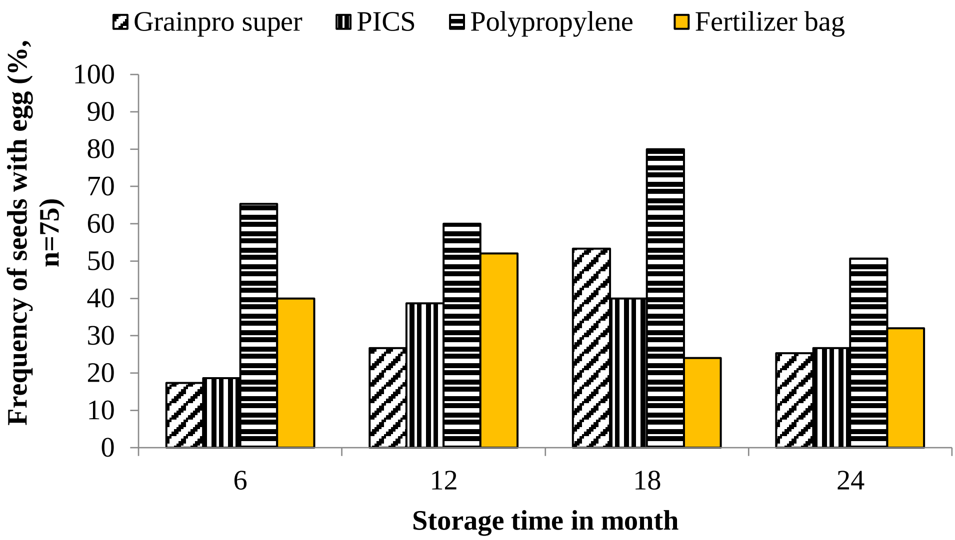

Figure 1. The effect of storage time and hermetic storage bag types on the proportion of lentil seeds with Adzuki bean beetle egg

Number of eggs per seed

The average number of eggs per seed was significantly ($p < 0.01$) affected by hermetic storage bag type but not by storage time. Thus, about 40.4% of the total variation in the average number of eggs per seed was due to the effect of packaging material; whereas only 4.5% of the total variation in the mean number of eggs per seed was ascribed to the storage period. Thus, seeds stored in polypropylene bags had the highest average number of eggs per seed, which was followed by seeds stored in fertilizer bags (Table 2).

Table 2.The effect of hermetic storage bag types on the number of eggs laid by Adzuki bean beetle per seed of lentil stored for different periods

Type of Hermetic storage bag	Storage duration (months)				Mean* ± SE
	6	12	18	24	
Grainpro super	0.26 ± 0.12	0.36 ± 0.18	0.73 ± 0.11	0.37 ± 0.12	0.43 ± 0.08[b]
PICS	0.23 ± 0.02	0.80 ± 0.46	0.52 ± 0.06	0.60 ± 0.38	0.54 ± 0.14[b]
Fertilizer	0.61 ± 0.10	1.15 ± 0.17	0.41 ± 0.17	0.80 ± 0.28	0.74 ± 0.11[b]
Polypropylene	1.19 ± 0.53	1.57 ± 0.41	2.35 ± 0.28	1.12 ± 0.74	1.56 ± 0.26[a]
Mean^{NS} ± SE	0.57 ± 0.17	0.97 ± 0.10	1.00 ± 0.25	0.72 ± 0.21	

* = means within a column followed by same letter are not statistically different at p = 0.05; NS = non- significant

Egg distribution per seed

Egg distribution on lentil seeds by the Adzuki bean beetle is depicted in Fig. 2. Generally, the pattern of egg distribution was similar among seeds that were stored for 6, 12, 18, and 24 months in the different hermetic storage bags. In all hermetic storage bag types and storage periods, the frequency of pristine seeds was greater than the frequency of seeds with one or more eggs. However, at 18 months of storage, the frequency of seeds that had one egg was greater in seeds that were stored in GrainPro super and PICS bags. On the other hand, seeds stored in polypropylene bag had greater proportion of seeds with two or more eggs per seed than seeds stored in GrainPro super, PICS or fertilizer bag. Consequently, seeds stored in polypropylene bags had on the average more than one egg per seed than seeds stored in GrainPro super, PICS or fertilizer bags.

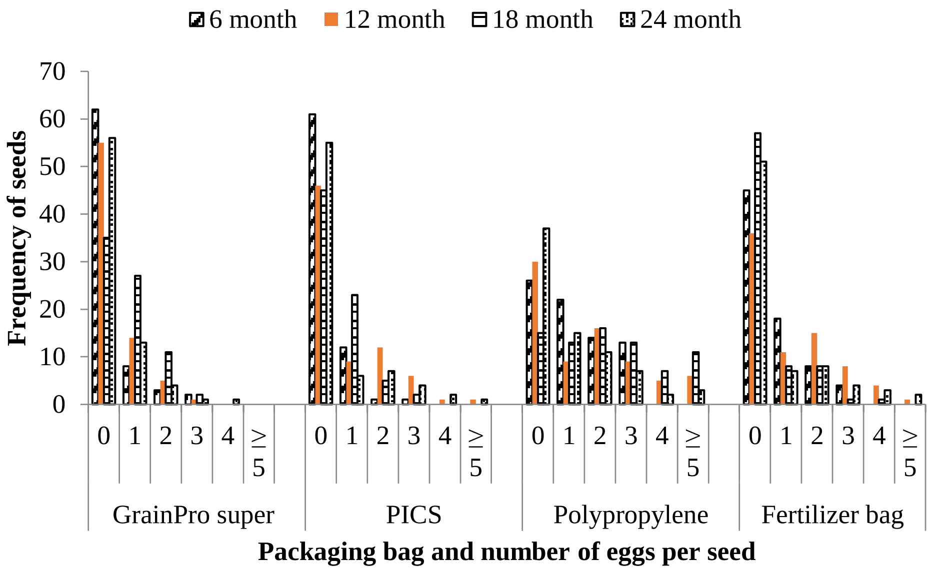

Figure 2. Distribution of Adzuki bean beetle eggs on lentil seeds stored in different hermetic storage bags. Note: the total number of seeds examined per bag per storage month was 75.

Seeds with hole

The number of seeds with insect exit holes was significantly ($p < 0.01$) affected by the type of hermetic storage bag type used but not by storage period. The effect of the hermetic storage bags on the proportion of seeds with holes accounted for 46.38% of the total variation; while the storage period accounted for only 10.01%. Thus, seeds stored in the polypropylene bags had higher proportions (40 to 80%) of exit holes than seeds stored in GrainPro super, PICS or fertilizer bags (Fig. 3). On the other hand, about 4 to 29.33, 6.67 to 38.67 and 8 to 25.33% of the seeds stored in PICS, GrainPro super and fertilizer bags, respectively, had at least one hole on them.

Hole per seed

The average number of insect exit holes per seed was also significantly (P < 0.01) affected by the type of the

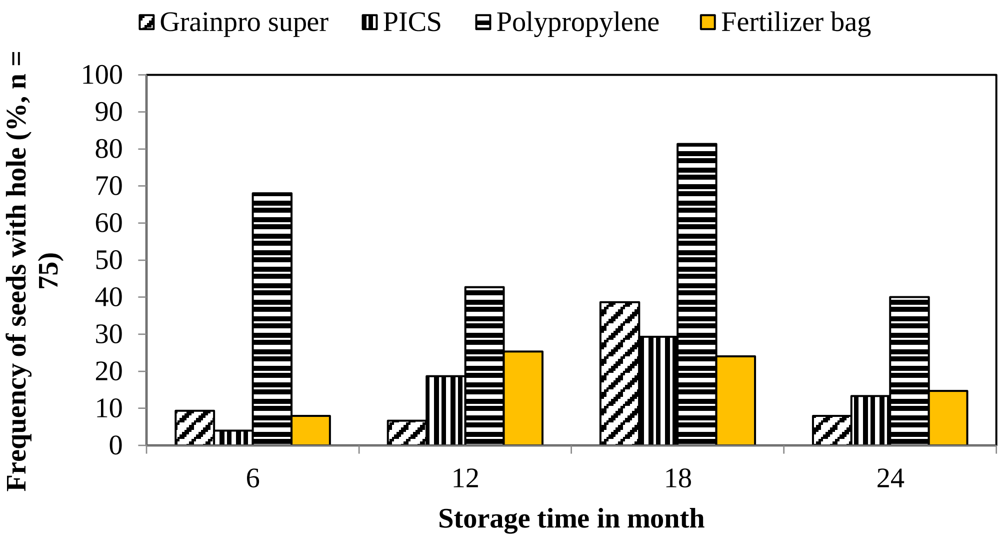

Figure 3. The effects of storage time and hermetic storage bag type on the proportion of lentil seeds with Adzuki bean beetle exit holes

hermetic storage bag used but not by the storage period. About 53.07% and 11.50% of the total variation in the average number of holes per seed was due to the effect of hermetic storage bag type and the storage period, respectively. As it was in the case of eggs per seed, the average number holes per seed in a polypropylene bag was always greater than the average number of holes per seed in seeds stored in PICS, GrainPro super and fertilizer bags (Table 3).

Table 3. The effect of hermetic storage bag types on the number of emergence hole of Adzuki bean beetle per seed of lentil stored for different periods

Type of Hermetic storage bag	Storage duration (months)				
	6	12	18	24	Mean* ± SE
GrainPro super	0.13 ± 0.04	0.12 ± 0.07	0.52 ± 0.07	0.08 ± 0.02	0.21 ± 0.05[b]
PICS	0.05 ± 0.03	0.28 ± 0.19	0.40 ± 0.05	0.15 ± 0.11	0.22 ± 0.05[b]
Fertilizer	0.21 ± 0.03	0.40 ± 0.08	0.36 ± 0.02	0.20 ± 0.16	0.29 ± 0.06[b]
Polypropylene	1.17 ± 0.45	0.95 ± 0.38	1.69 ± 0.15	0.56 ± 0.35	1.10 ± 0.10[a]
Mean ± SE	0.39 ± 0.17	0.44 ± 0.13	0.73 ± 0.17	0.25 ± 0.10	

* = means within a column followed by same letter are not statistically different at p = 0.05

Hole distribution per seed

Except at the 12 and 18 months of storage in which there were as many as four holes per seed in seeds stored in polypropylene bags, the number of holes per seed was at most three in all the packaging materials (Fig. 4). Generally, the seed hole distribution per seed followed the distribution of eggs per seed. Thus, larger proportions of seeds stored in polypropylene bag had two and three holes per seed. As a result, the average number of holes per seed was greater in seeds that were stored in polypropylene bags than seeds stored in other packaging materials.

Chickpea

Seeds with egg

Although data were not statistically analyzed, in all the storage periods, seeds stored in GrainPro super bag and polypropylene bag had greater proportions of seeds with eggs than those seeds stored in PICS bag or fertilizer bag (Fig. 5). It was observed that, depending upon the duration of storage, about 2.67 to 57.33% and 33.33 to 52.0% of the seeds that were stored in polypropylene and GrainPro super bags, respectively, had eggs on them. On the other hand, seeds stored in PICS bag or fertilizer bags had each at most 12% egg laden seeds.

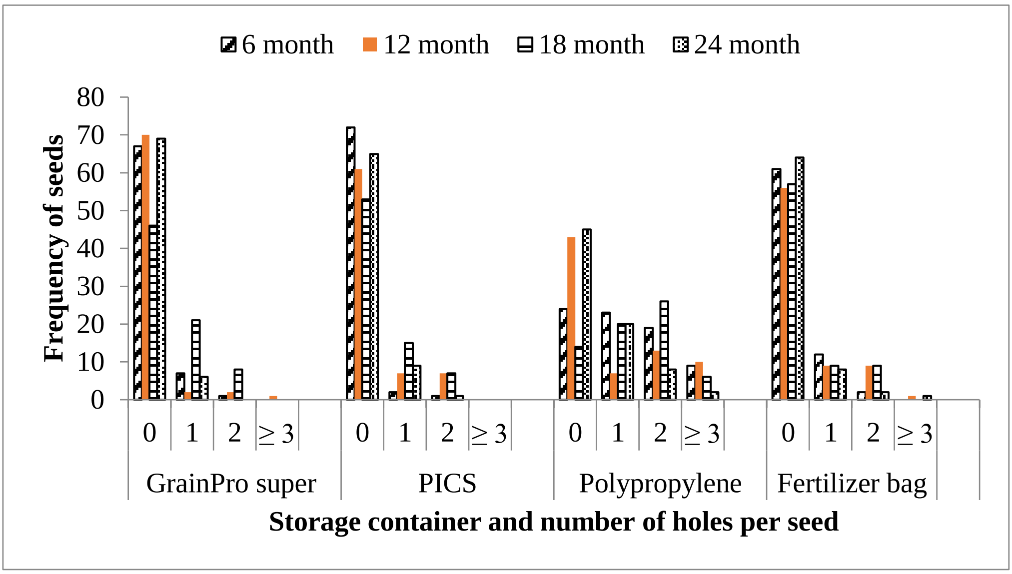

Figure .4. Distribution of Adzuki bean beetle emergence holes on lentil seeds stored in different hermetic storage bags

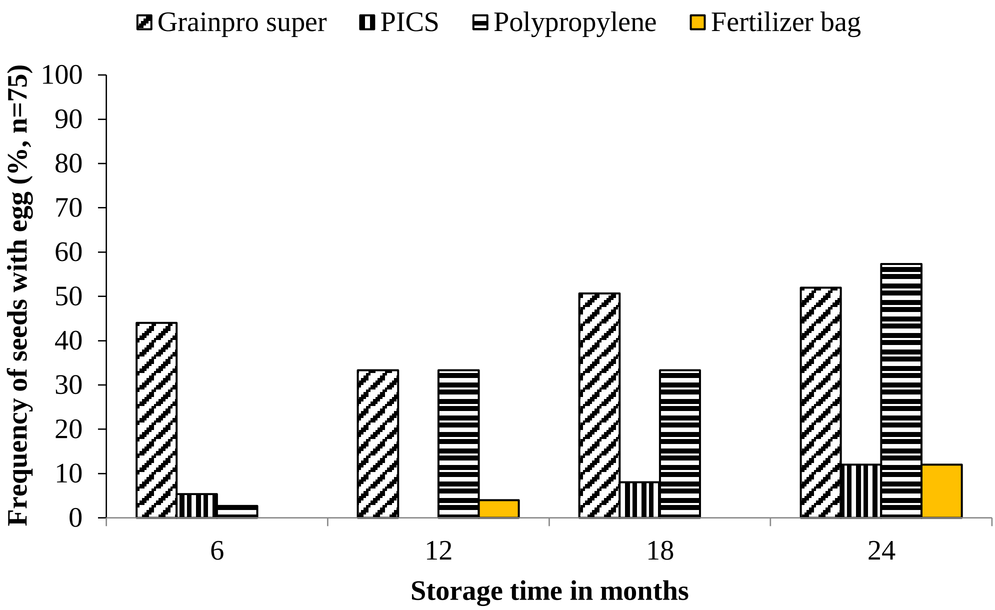

Figure 5. The effects of storage time and hermetic storage bag types on the proportion of chickpea seeds with Adzuki bean beetle eggs

Egg distribution per seed

The majority (95 to 100%) of the seeds that were stored for six months in PICS, polypropylene and fertilizer bags had no eggs on them (Table 4). On the other hand, of those seeds that were stored in GrainPro super bag, only 56% of them had no eggs, 28% had one egg per seed and 8% had each two and three eggs per seed. The average number of eggs per seed was less than one in all seeds stored in any of the packaging materials. However, at 12, 18 and 24 months of storage, seeds stored in GrainPro super bags and polypropylene bags had as many as 14 eggs per seed and as a result the average number of eggs per seed varied between two and four. On the other hand, only 1.3 to 2.6% of the seeds stored in either PICS bags or fertilizer bags had at most two eggs per seed making the average number of eggs per seed less than one.

Table 4. Distribution of Adzuki bean beetle eggs on chickpea seeds stored in different hermetic storage bag types

Storage time (months)	Type of Hermetic storage bag	Frequency of seeds with "x" number of eggs per seed							Number of eggs per seed
		x = 0	x = 1	x = 2	x = 3	x = 4	x = 5	x ≥ 6 (6-14)	($\overline{X} \pm SE$)
6	GrainPro super bag	42	21	6	6	0	0	0	0.68 ± 0.69
	PICS bag	71	4	0	0	0	0	0	0.05 ± 0.09
	Polypropylene bag	73	2	0	0	0	0	0	0.03 ± 0.02
	Fertilizer bag	75	0	0	0	0	0	0	0.00 ± 0.00
12	GrainPro super bag	50	0	0	0	0	0	25	3.63 ± 3.63
	PICS bag	75	0	0	0	0	0	0	0.00 ± 0.00
	Polypropylene bag	50	0	0	0	2	0	23	3.35 ± 3.35
	Fertilizer bag	72	1	0	2	0	0	0	0.04 ± 0.04
18	GrainPro super bag	37	7	6	2	6	2	15	2.32 ± 1.81
	PICS bag	69	5	1	0	0	0	0	0.09 ± 0.09
	Polypropylene bag	50	0	0	1	1	4	19	2.42 ± 2.42
	Fertilizer bag	75	0	0	0	0	0	0	0.00 ± 0.00
24	GrainPro super bag	36	12	2	0	0	6	19	2.55 ± 2.23
	PICS bag	66	9	0	0	0	0	0	0.12 ± 0.12
	Polypropylene bag	33	12	2	3	2	2	21	2.80 ± 2.31
	Fertilizer bag	66	9	0	0	0	0	0	0.24 ± 0.22

Seeds with holes

The effects of hermetic storage bag types on the proprtions of seeds with holes were similar to the effects on the proportions of seeds with eggs (Fig. 5). Seeds stored in either polypropylene or GrainPro super bags had the largest proportion (up to 37%) of seeds with insect exit holes. On the other hand, only ≤ 2.67% and ≤ 13.33% of the seeds stored in PICS and fertlilizer bags, respectively, had Adzuki bean beetle exit holes.

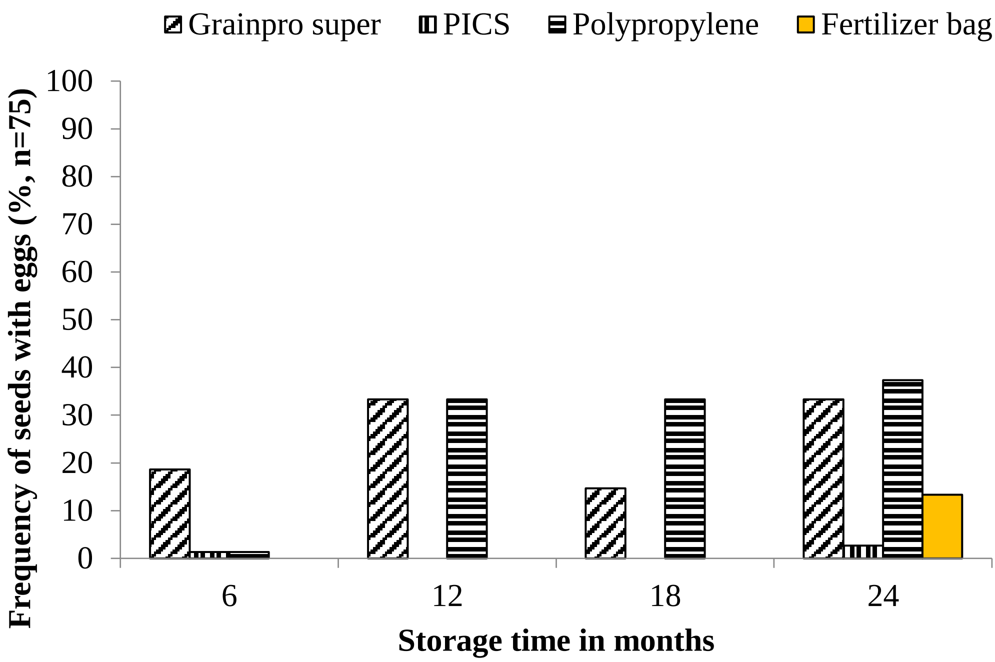

Figure 5. The effect of storage time and packaging materials on the proportion of chickpea seeds with Adzuki bean beetle exit holes

Distribution of hole per seed

Similar to the egg distribution per seed, the majority (98.8 to 100%) of seeds stored in PICS and fertilizer bags for 6, 12, and 18 months had no Adzuki bean beetle emergence holes (Table 5). However, after 24 months of storage, about 4.0 and 9.3% of the seeds stored in fertilizer bags had one and two eggs per seed, respectively. But only a small proportion (2.67%) of seeds in PICS bag had Adzuki bean beetle emergence holes. Consequently, the average number of emergence holes per seed was less than one during the entire storage period.

Only a few (1.3%) seeds that were stored in polypropylene bags for six months had one Adzuki bean beetle emergence hole per seed (Table 5). However, about 32% of the seeds, in each of the remaining storage periods had as many as 14 Adzuki bean beetle emergence holes per seed. Similarly, in seeds stored in GrainPro super bag, the maximum proportion of seeds that had at most three holes per seed was 18.66% and 14.67% after 6 and 18 months of storage, respectively, whereas 32% and 28% of the seeds that were stored for 12 and 24 months, respectively, had up to 14 holes per seed. The average number of holes per seed in both packaging materials ranged from two to four.

Table 5. Distribution of Adzuki bean beetle emergence holes on chickpea seeds stored in different hermetic storage bag types

storage time (months)	Hermetic storage bag	Frequency of seeds with "x" number of holes per seed					Number of holes per seed ($\bar{X} \pm SE$)
		x = 0	x = 1	x = 2	x = 3	x ≥ 4 (4-14)	
6	GrainPro super bag	61	6	7	1	0	0.31 ± 0.12
	PICS bag	74	1	0	0	0	0.01 ± 0.02
	Polypropylene bag	74	1	0	0	0	0.01 ± 0.02
	Fertilizer bag	75	0	0	0	0	0.00 ± 0.00
12	GrainPro super bag	50	0	0	1	24	3.96 ± 3.96
	PICS	75	0	0	0	0	0.00 ± 0.00
	Polypropylene bag	50	0	0	1	24	3.31 ± 3.31
	Fertilizer bag	75	0	0	0	0	0.00 ± 0.00
18	GrainPro super bag	64	7	3	1	0	0.21 ± 0.21
	PICS bag	75	0	0	0	0	0.00 ± 0.00
	Polypropylene bag	50	0	1	0	24	2.24 ± 2.24
	Fertilizer bag	75	0	0	0	0	0.00 ± 0.00
24	GrainPro super bag	50	1	1	2	21	2.11 ± 2.11
	PICS bag	73	2	0	0	0	0.02 ± 0.02
	Polypropylene bag	47	2	1	1	24	2.99 ± 2.91
	Fertilizer bag	65	7	3	0	0	0.17 ± 0.17

Cereal crops

Regarding cereal crops, both tef and durum wheat seeds stored in the different packing materials were not infested with insects during the entire storage duration.

Discussion

Throughout the experimental period, both live insects and damaged seeds were not detected in both tef and durum wheat seeds in any of the storage containers. In the case of tef seed, it is apparent that so far there are no reports of infestation of tef grains by primary storage insect pests perhaps because of the smallness of the grain. Besides, secondary storage insect pests are unable to breed if clean (i.e. dust and chaff-free) tef seed is stored (Tebkew and Getachew 2011). Therefore, both seed size and cleanness of the seed might have contributed to the absence of infestation on tef seed in the current study. However, the absence of infestation on durum wheat seed does not imply resistance of the hermetic storage bag types and the control – polypropylene bags, to storage insect pests. For instance, according to Kalsa *et al.* (2019a) the majority of Ethiopian farmers store wheat in polypropylene or jute bags and wheat stored in these types of bags is commonly infested by

Sitophilus spp. Moreover, Karta *et al.* (2019b) detected live insects (*R. dominica*) in wheat seeds that were stored in PICS and GrainPro super bags for six months although there was no sign of infestation at the beginning of the storage. It is also known that true storage insect pests do not infest standing wheat. Therefore, one of the reasons for the absence of insect infestation in durum wheat seed in all the tested packaging materials could be the absence of sources of infestation. Thus, it is recommended to evaluate the hermetic storage bags under simulated farm storage conditions in the presence of naturally infested old stock grains/seeds that guarantee infestation by the major storage insect pests.

In chickpea seeds, the contribution of hermetic storage bags to the total variations for all variables ranged from 9 to 23%. On the other hand, for the same insect pest in lentil seed, the type of hermetic storage bag had significant effects on all the variables considered in the study. This is because, at the 12 and 24 months for seeds stored in GrainPro super bags, and at the 12, 18 and 24 months of storage for seeds stored in polypropylene bags, only one of the replications was severely infested by Adzuki bean beetle, which is corroborated by the larger standard error of means for eggs per seed and hole per seeds (Tables 4 and 5). The infestation in GrainPro super bag was partly due to mechanical damage on the bag as the bag was used without an outer cover that protects it from puncture and damage. This suggests that GrainPro super bag should be used as described by the manufacturer.

During the experimental period, rats preferentially attacked only the polypropylene bag probably because of the diffusion of beany odor easily from the woven polypropylene bag. On the other hand, at least the PICS bag and GrainPro super bag are known to limit air movement into and out of the stored grain. As a result, rats might not have the chemical cues that trigger them to attack the bag.

Seed germination is not affected by asphyxiation rather it is affected by insect damage and seed age. For example, the germination rate of tef seed, which was used in this experiment, was 94% and 90% at the beginning of the experiment and 24 months later, respectively (Bekele *et al.,* 2021). On the other hand, when tef seed is infested by storage insect pests, it loses germination by more than 50% (Tebkew and Getachew 2011). Similarly, germination of durum wheat, which was about 91%, decreased as the duration of storage increased. Thus, the germination rates of seeds stored in GrainPro super, PICS, polypropylene and fertilizer bags were 78, 81, 63, and 69%, respectively, after 24 months of storage (Tesfaye *et al.*, 2021). A similar result was reported by Karta *et al.* (2019b) who found that wheat seeds that were stored in PICS, GrainPro super bag and metal silo for six months had 92 to 98% germination rate. The effect of packaging materials on chickpea and lentil seeds germination rate was similar to the effect on seeds of tef and durum wheat (Abebe *et al*., 2021).

In the current study, the effect of bag reopening frequencies on the occurrence of storage insect pests or fungus has not been investigated. However, it is known that farmers will open bags and remove grains/ seeds for consumption and sale. Moreover, the existing literature corroborates high risk of pest occurrence in stored commodities with frequent openings of bags. For instance, according to Baoua *et al.* (2013) opening bags for a short period does not affect the occurrence of cowpea weevil (*C. maculatus*), whereas bags left open for several days have a high risk of insect's infestation. Similarly, Tubbs *et al.* (2016) stated that frequent opening of PICS bags leads to increased *Aspergillus flavus* infection and spread in stored maize.

Conclusion and Recommendation

In the presence of insect infestation in lentil and chickpea seeds, the efficacy of the PICS bag in preventing Adzuki bean beetle was significantly greater than the efficacy of polypropylene and fertilizer bags. Consequently, the proportion of seeds with eggs or holes, and the average number of eggs or holes per seed were significantly less in seeds stored in PICS bags than those seeds that were stored in polypropylene and fertilizer bags. The efficacy of GrainPro super bag was variable depending on the way the bag was used. Thus, it significantly reduced insect infestation when used as a double layer but it did not prevent infestation when used as a single inner layer. In other parts of the world, hermetic storage bags are recommended for use by small-scale producers provided that the seeds are dry enough to the safe storage moisture content; storage's relative humidity and temperature are high; and the bags are kept sealed throughout the storage period. Therefore, PICS and GrainPro super bags (double layered/ with outer polypropylene layer) can be used to store seeds under Ethiopian conditions.

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