On-Farm Performance and Assessment of Farmers' Perceptions of Hermetic Bags for Farm-Stored Wheat and Maize in Northwestern Ethiopia

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Abstract. Wheat and maize farmers in Ethiopia seldom adopted hermetic storage technologies which can substantially reduce post-harvest losses. Two on-farm storage experiments and a perception survey were conducted to evaluate the effectiveness of the PICS bag and Super GrainPro bag and to assess farmers' perceptions towards the utility of the technologies in two districts of West Gojjam, Northwest of Ethiopia in the years 2016 and 2017. Results showed that live adult weevil densities in hermetic storage bags such as PICS bag and Super GrainPro bag were below five insects per kg of maize after four months of storage. In wheat, there was no live weevil prevalence in hermetic storage bags after four months of storage. Weight loss wheat and maize stored in airtight bags was maintained at $<1.0\%$. A majority of farmers (95.0%, N = 80) perceived that the hermetic bags are effective against weevils, and 87.3% (N = 80) had the tendency to use airtight bags in the future. Farmers' use of PICS bags in the past had a positive influence on their interest in the future use of hermetic containers. In conclusion, the present study showed that hermetic storage bags are practical under on-farm conditions in Ethiopia. Therefore, we recommend the extensive promotion of the technologies and increasing their local availability.

Keywords: Hermetic bags · Farmers' perception · Wheat · Maize · Ethiopia

1 Introduction

Ethiopia is a leading producer of wheat and the 3rd largest producer of maize in sub-Saharan Africa [1]. Yield increasing technologies such as improved varieties, mineral fertilizer, and increased extension education have all contributed for significant improvement in productivity per unit area of grain crops in the country [2]. In Ethiopia, wheat

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and maize yield increased from below 1.5 metric tons per ha before two decades to about 2.7 metric tons per ha and 3.9 metric tons per ha, respectively, in recent years [3]. Currently, wheat and maize are making about 48% of the total cereals and 43% of the total grain production in the country with a total production of 13 million metric tons. However, poor postharvest storage results in loss of about 6.6% of wheat and 11.2% of maize in the country [4].

The farmers' limited awareness and skills on improved post-harvest management options are largely responsible for the food losses in Ethiopia and elsewhere [5, 6]. Smallholder farmers store their grain until the next successful harvest, which might be a year or more. Grain produced by farmers should be stored to meet home consumption, for sale or seed purpose [8, 9]. However, grain stored in traditional structures is subject to deterioration by biological and physical factors [5, 6].

Wheat and maize farmers rarely adopt hermetic grain storage bags that reduce storage losses in Ethiopia [10, 11]. On the other hands, the adoption of recommended post-harvest handling practices is highly correlated with the lower postharvest loss [5]. Hermetic storage techniques can be recommended to farmers without the use of insecticides provided they are inexpensive, and the farmers are trained on a proper application of the technologies [7]. The present study aimed at (1) participatory evaluation of the effectiveness of hermetic storage bags in farmers' houses, (2) assessment of farmer's perceptions towards the utility of hermetic storage bags, and (3) identification of factors related to farmers' tendency of future use of the hermetic storage bags.

2 Materials and Methods

Two on-farm experiments and a survey were conducted to understand the performance of hermetic bags under farmer's conditions and the perception of farmers towards the utility of the improved storage bags. The study was conducted in two districts (Merawi and Wenberma) of West Gojjam, Amhara Regional State.

2.1 Treatment Set Up and Experimental Design

Hermetic storage bags such as Purdue Improved Crop Storage (PICS) bags and Super GrainPro bags (high-density polyethylene bags reducing gas exchange) were compared with traditional storage system (with polypropylene bags at Wenberma and with *gotta* in Merawi district) under farmers' conditions.

The treatments were set up in a randomized complete block design with nine replications. Farmers served as blocks in both wheat and maize studies. Each farmer stored two types of hermetic bags plus his *gotta* (for maize) and polypropylene bags for wheat. Polypropylene bags were purchased from a local market.

2.2 Wheat On-Farm Storage Experiment

At Wenberma, the experiment consisted of three treatments: two hermetic bags (PICS and Super GrainPro bags) and polypropylene bags (control), replicated on seven smallholder farms. Farmers who have grown the maize variety Kakaba had participated in the study and all the farmers had placed untreated wheat in hermetic bags. In this experiment, wheat in polypropylene bag was not treated with any chemical.

Bags were filled with 50 kg of wheat and sealed 30th January 2017, and they were opened on 10th June 2017, after 130 days of storage. The grains in the hermetic bags were kept for about four months, and sampling was carried out by randomly reaching the top, middle, and bottom sections of the bags. The primary samples from a container were then homogenized, and one kg sample per container was brought to the laboratory.

2.3 Maize On-Farm Storage Experiment

At Merawi, the experiment consisted of three treatments: two hermetic bags (PICS and Super GrainPro bags) and one traditional storage structure (*gushgusha*), replicated on nine smallholder farms. Farmers who have grown the maize variety Jabi (Pioneer 3253) had participated in the study, and all the farmers had placed untreated shelled grains in hermetic bags, while the grains in traditional storage structure were treated with Malathion 5% dust or fumigated with Phosphine gas or in combination.

Bags were filled with a naturally infested grain (2 to 4 insects per kilogram, based on samples collected at the beginning of storage) and sealed on 7th to 10th June 2016; they were opened on 10th to 13th October 2016, after 125 days of storage. The grains in the hermetic bags were kept for about four months, and sampling was carried out by randomly reaching the top, middle, and bottom sections of the bags. The same trend was followed to get samples from traditional storage. The primary samples from a container were then homogenized, and one kg sample per container was brought to the laboratory.

2.4 Data Collection from Storage Experiments

Measurements of gas composition (CO_2 and O_2 levels) (done before the hermetic bags were opened), adult insect abundance (both live and dead), grain damage, weight loss, grain moisture content, grain bulk density, and thousand kernel weights were determined after four months of storage for both experiments.

One kg samples were divided following the use of quartering and coning technique until the final sample of around a 100 g of seed was obtained. From the 100 g of whole seeds, damaged and undamaged kernels were counted and weighed.

2.5 Percentage of Weight Loss and Insect-Damaged Kernels

Each of the maize/wheat samples was divided following the quartering and conning technique until a final sample of around a 100 g of maize/wheat was obtained. From a 100 g of sound maize/wheat, damaged and undamaged kernels were separated, counted, and weighed. Mechanical damages were included in dockages (when it was $<$ 50% of the average size). Insect damaged kernels were visually identified based on holes made by boring insects.

Maize/wheat weight loss was estimated using the equation [11, 12]: maize/wheat Weight Loss (%) $= [(WU * ND) - (WD * NU)] * 100/[WD * (NU + ND)]$, where, WU is weight of undamaged maize/wheat, NU is number of intact maize/wheat, WD is weight of damaged maize/wheat, ND is number of damaged maize/wheat.

Grain damage rates were calculated using the equation Percentage of Insect-Damaged Kernels = Number of Insect-Damaged Kernels*100/Number of Kernels in 100 g of maize/wheat.

2.6 Germination Testing

Wheat seed samples were subject to germination testing using the standard method as prescribed for wheat in Rules of Seed Testing of International Seed Testing Association [13] with modifications. Germination test was carried out in two runs of 100 seeds. Seeds (randomly picked damaged and undamaged seeds) were placed in plastic bowls on top of 15 cm diameter sterile germination papers. The germination papers were soaked in distilled water before sowing the seeds. The bowls, then, were covered with a glass lid and placed in a germination room adjusted at 20 °C temperature. Normal and abnormal seedlings and dead seeds were assessed eight days after sowing, and percentages were calculated.

2.7 Perception Survey

A one-page checklist was prepared to assess farmers' perception towards the utility of hermetic bags they used. A total of six villages were included1: one from Merawi and five from Wenberma districts, West Gojjam, Northwest Ethiopia. A total of 80 households, who were provided with hermetic bags during the year 2016 were included in the survey. To cross validate the survey responses, a focus group discussion with development agents and selected farmers was organized at Merawi.

2.8 Data Analysis

All data from the on-farm storage experiments were subject to one-way analysis of variance (ANOVA) using the R Software version 5.3.1. All count data were log transformed where required, and the percentage data were square root transformed before analysis of variance. Where the ANOVA showed an overall significance, Tukey's range test was employed to separate significantly different means at 5% level of significance. Survey data were coded, and descriptive analyses were employed using the IBM SPSS statics version 20. Plots were created using the SigmaPlot Software version 12.5 [14].

3 Results

3.1 Maize On-Farm Storage: Weevil Abundance

There was a significant effect ($P < 0.01$) of storage structures on both live weevil count and total weevil specimen counts per kg of maize (Table 1). The abundance of live weevil specimen was significantly higher in the traditional *gotta* structure compared with the hermetic bags. Hermetic bags substantially decreased the population development of weevils in maize (Fig. 1).

Table 1. Analyses of variance for live weevil counts, total weevil counts, the percentage of insect-damaged kernels and grain weight loss of maize stored in farmers' houses between June and September 2016.

Sources of variation	DF	Live weevils (counts per kg)		Total weevils (counts per kg)		Insect-damaged kernels (%)		Grain weight loss (%)	
		F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Storage structures	2	161	0.00	81.4	0.00	30.6	0.00	27.1	0.00
Farmers	8	0.7	0.70	0.5	0.81	0.9	0.55	0.8	0.58
Error variance	16	0.02		0.01		0.17		0.03	

3.2 Maize On-Farm Storage: Grain Weight Loss and Damage

Percentages of insect-damaged kernels and grain weight loss were significantly influenced ($P < 0.01$) by storage structures (Table 1). The proportion of insect-damaged kernels was significantly higher in *gotta* compared to hermetic bags (Fig. 2). Likewise, the grain weight loss percentage was significantly higher in the traditional *gotta* structure compared to hermetic bags. There was a non-significant difference between the PICS bag and Super GrainPro bag about either the percentage of insect-damaged kernels or the grain weight loss percent.

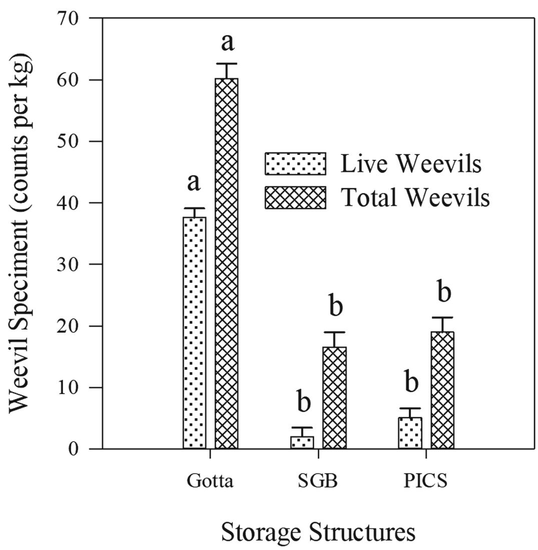

Fig. 1. Mean (±*SE*) of weevil abundance (counts per kg of seed) of maize stored in farmers' houses between June and September, 2016. Means followed by the same letter are not significantly different at Tukey's 5% level of significance, and each mean is based on nine farmers.

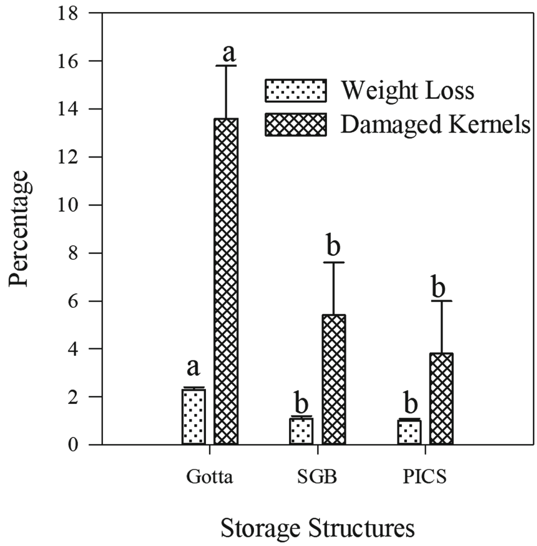

Fig. 2. Mean (±*SE*) percentage of insect-damaged kernels and grain weight loss of maize stored in farmers' houses between June and September 2016. *Note*: Means followed by the same letter are not significantly different at Tukey's 5% level of significance, and each mean is based on nine farmers.

3.3 Wheat On-Farm Storage: Baseline

At the outset of the on-farm storage experiment of wheat, the weevil abundance, test percentage of seed damage and grain weight loss, weight (bulk density), and seed germination and vigor were assessed. There was no live or dead insect specimen detected at the beginning of the storage experiment while a number of insect-damaged seed ranged from 12 to 26 seeds per 100 g with a mean value of 20.1 damaged seeds per 100 g. Likewise, the percentage of insect-damaged kernels ranged from 0.40% to 0.95%, while grain weight loss percentage was between 0.10% and 0.51%. The mean value of percentage insect-damaged kernels and grain weight loss percent were 0.7% and 0.3%, respectively. Test weight (seed bulk density) was between 751 kg m^{-3} and 818 kg m^{-3} with a mean value of 781.8 kg m^{-3}. Percentage seed germination ranged between 87.0% and 99.0% with a mean value of 94.1% whereas the seed vigor index was between 552%.mg to 1786%.mg. The mean value of seedling vigor index at the beginning was 1043.9%.mg.

3.4 Weevil Abundance and Number of Damaged Kernels in Stored Wheat

Significant differences ($P < 0.01$) between hermetic storage bags and the polypropylene bag were detected in both live insect abundance and the number of insect-damaged kernels (Table 2). The highest mean number of live weevils was detected in wheat stored in polypropylene bags. Likewise, the largest mean number of insect-damaged kernels was observed in the same container.

3.5 Weight Loss and Loss of Bulk Density in Stored Wheat

There were significant differences between hermetic bags and the polypropylene bag regarding their effectiveness of containing losses. Grain weight loss was significantly higher ($F = 8.45$; $DF = 2, 32$; $P < 0.01$) in polypropylene bags compared to the hermetic bags (Fig. 3). There was no such difference between the two hermetic bags. Likewise, the percentage of insect-damaged kernels was significantly higher ($F = 16.82$; $DF = 2, 32$; $P < 0.01$) on wheat stored in polypropylene bags. The loss of test weight (bulk density of the seed) was also significantly higher in the polypropylene bags compared to the hermetic bags. Seed bulk density was slightly higher in Super GrainPro bag compared to PICS bag, but the difference was not statistically significant.

Table 2. Mean (±*SE*) of weevil abundance and number of insect-damaged kernels of wheat seed stored in farmers' houses at Wenberma from January to June 2017.

Bag Type	Live Weevils (counts per kg)	Damaged Kernels (counts per 100 g)
Super GrainPro Bag	0.6 b	20.1 a
PICS bag	0.1 b	20.1 a
Polypropylene bag	2.6 a	50.1 b
F (DF = 2, 26)	17.07	21.98
P-value	<0.01	<0.01
SEM	0.3	4.2

Means within the same column and followed by the same letter are not significantly different at Tukey's 5% level of significance. Each mean is based on seven farmers and two replications per farmer.

3.6 Seed Quality in Stored Wheat

Table 3 shows seed quality parameters such as the percentage of seed germination, seedling dry-weight, and seedling vigor index of wheat stored in different bag types. There was a non-significant difference among different types of bags regarding seed germination after four months of storage. However, there seedling vigor parameters of wheat stored in Super GrainPro bags was significantly higher compared to the polypropylene bags. There was no significant difference between PICS bag and polypropylene bag during four months of storage.

3.7 Farmers' Perceptions of the Utility of Hermetic Bags

Table 4 shows the descriptive analysis of farmers' perceptions of the utility of hermetic bags. About 95.0% of 80 household heads included in the study had believed that the bags protected their grains from weevil damages. About 93.8% of respondents ($N = 80$) were indifferent or felt that the price is low, but only 6.3% of all respondents had claimed that

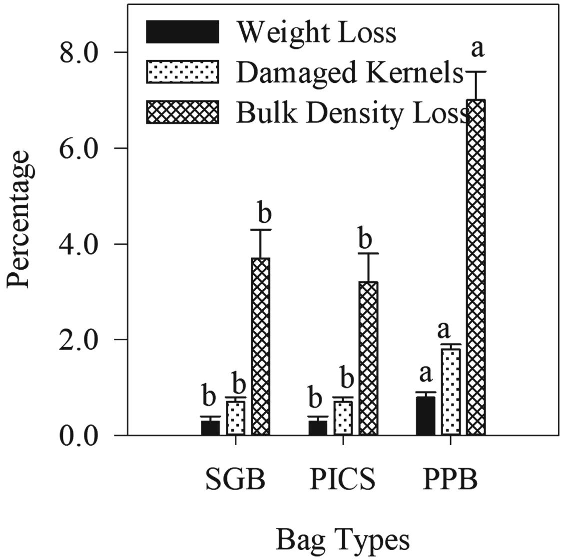

Fig. 3. Mean (±*SE*) of seed weight loss (the %), the percentage of insect-damaged kernels and percentage loss of bulk density (test weight) of wheat seed stored using hermetic bags at farmers' houses in Wenberma from January to June 2017. *Note*: Means followed by the same letter are not significantly different at Tukey's 5% level of significance, and each mean is based on seven farmers and two replications per farmer.

bag prices are costly (the price of PICS bag is ca. $1.47 and that of SuperGrain™ bag is ca. $2.44 at the time of the survey). All farmers who were indifferent about bag price had the likelihood to use the improved bags in the future. However, the possibility of repeated use, reduced amount of loss, and health benefits from reduced/no use of insecticides can be positive drives for future use of hermetic bags by farmers in Ethiopia.

Table 3. Mean (±*SE*) of seed quality characteristics of farm-stored wheat in hermetic bags.

Bag type	Seed germination (%)	Seedling dry weight (mg)	Seedling vigor index (mg. %)
Super GrainPro Bag	94.7	9.4a	885.0a
PICS bag	94.5	8.1ab	763.0ab
Polypropylene bag	94.3	7.3b	687.0b
F (2, 32)	0.10^{NS}	4.88*	4.59*
P-value	0.91	0.01	0.02
SEM	0.8	0.5	46.4

Means within the same column and followed by the same letter are not significantly different at Tukey's 5% level of significance. Each mean is based on seven farmers and two replications per farmer.

There was no significant difference between the ages of those who wanted to use hermetic bags in the future and those who did not want to. However, fishers exact test indicated that there was a significant association ($P < 0.05$) between sex and the tendency to use hermetic bags in the future (odds ratio = 0.238). Farmers' tendency to use hermetic storage bags did not have any significant association with the education status of the household head.

4 Discussion

In our present study, we have observed that the hermetic bags such as PICS bag and Super GrainPro bag have suppressed weevil population development and reduced the rates of grain damage and weight loss both in maize and wheat under farmers' conditions. The germination capacity of wheat seed was also maintained in a better condition.

Adoption of hermetic storage bags has been driven by the effectiveness, simplicity, low cost, durability, and accessibility of the technologies [15]. Studies showed that some form of exposure by farmers to storage practices is related to improved adoption of the hermetic storage technologies [16]. In our on-farm experimentation with farmers, we have observed that farmers' interest in chemical-free storage technology was heightened. Though farmers were so suspicious to store their maize or wheat in hermetic bags without chemical treatment, they were very happy with the outcomes (Box 1). This shows that once farmers have the chance to look at the difference between their traditional storage method and the improved technologies, they show a better tendency towards using hermetic storage bag.

The main determinants of adoption were household socio-economic characteristics such as age, land ownership, completion of a training course, and quality of basic infrastructure [16]. Our study included only sex, age, and education as a social factor that determined farmers' tendency to use hermetic storage bags. Age and education had no association with farmers' tendency to use hermetic storage bags in the future. Regardless of their age and education status, farmers have applauded the chemical-free hermetic storage technology. The contemporary bag price, with additional awareness of farmers on the reuse of the hermetic bags, does not have a negative influence on farmers' tendency to use the hermetic storage bags in the future. However, the tendency of farmers towards future use of hermetic bags was positively influenced by using PICS bag (Table 5). This might be due to farmers' perception about the triple bagged hermetic technology that it is less susceptible to tears and wears during handling.

Table 4. Farmers' perception of the utility of hermetic bags in Merawi and Wenberma districts

Characters	Frequency (%)	Characters	Frequency (%)
Sex (n = 80)		Level of infestation before bagging (n = 80)	
Male	77.5	High	11.3
Female	22.5	Low	21.3

(*continued*)

Table 4. (*continued*)

Characters	Frequency (%)	Characters	Frequency (%)
Education (n = 80)		None	67.5
No formal education	57.5	Infested with live weevil after opening (n = 80)	
Primary incomplete	38.8	Yes	21.2
Secondary incomplete	3.8	No	78.8
Bags Used (n = 80)		Level of live weevil infestation after (n = 80)	
PICS	78.8	High	1.3
Super GrainPro	15.0	Low	20.0
Both types	6.3	None	78.8
Types of grain stored (n = 80)		Believe bags effective on weevils (n = 80)	
Wheat	25.0	Effective	95.0
Maize	46.3	Not effective	1.2
Both	28.8	Don't know	3.8
Used chemicals in bags (n = 80)		How do you evaluate bag price? (n = 80)	
Yes	14.7	Costly	6.3
No	86.3	Indifferent	33.8
Type of chemicals (n = 80)		Cheap	60.0
Malathion	2.5	Compare new bags to pp bags (n = 80)	
Phosphine	5.0	Better	95.0
Both	6.3	No difference	5.0
None	86.3	Do you plan to use hermetic bags in the future? (n = 80)	
Infested with live weevil before bagging (n = 80)		Yes	87.3
Yes	67.5	No	12.7
No	32.6		

Box 1:
Ato Demeke Mekonen and W/ro Gedene Demelew are residents of Kudmi kebele in Merawi district, West Gojjam, Amhara. They used hermetic storage bags to store their maize grain from May to September 2016. After four months of storage, the bags were opened in the presence of the spouses, and they saw no damage on the grains while the maize which they fumigated with Phosphine and placed in polypropylene bags had live weevils and certain damages. W/ro Gedene (wife) at the end disclosed that she was so suspicious of storing their maize grain in hermetic bags without treating with chemicals. Ato Demeke and Gedene were one of the families who already have recognized the side effects of chemicals they used against weevil. They were so happy to see a chemical-free technology that preserves their maize grain without damage..

In conclusion, hermetic bags are effective under farmers' conditions, and they can be better alternatives to polypropylene bags which are predominantly used by wheat farmers [7, 17]. Besides, there is a high rate of acceptability of hermetic storage technologies by farmers. The type of hermetic bag used by farmers determined the farmers' tendency to the use of hermetic bags in the future. Introduction of the Super GrainPro bag with an external layer of polypropylene bag might increase farmers' tendency to use it. Besides, local availability of hermetic bags should be improved so that farmers can easily access the bags at the time of their need.

Table 5. Probit analysis of factors influencing farmers' tendency for future use of hermetic bags [a,b,c]

Variables	Estimate	SE	β- coefficients	t-value	P-value
Intercept	0.516	0.119		4.343	<0.01
Sex (Male = 1; Female = 0)	0.116	0.086	0.189	1.807	0.075
Use PICS (Yes = 1; No = 0)	0.310	0.100	0.321	3.091	0.003
Insect Damaged Before (Yes = 1; No = 0)	−0.083	0.053	−0.167	−1.595	0.115

[a] Null deviance: 9.49 on 79 degrees of freedom

[b] Residual deviance: 7.71 on 76 degrees of freedom

[c] AIC: 49.84

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