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Original Research Article

Performance Evaluation of Metal Silo and PICS bag for Maize Grain Storage against Insect Pest Infestation and Grain Quality

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Abstract: Maize is prone to insect pests during grain storage, leading farmers to rely on synthetic insecticides. However, the use of these chemicals has been associated with insect resistance and negative impacts on non-targeted species. The adoption of hermetic principles for pesticide-free grain storage is globally recognized as a sustainable and environmentally friendly alternative to synthetic pesticides. To address losses in stored maize, trials were conducted at Bako, West Ethiopia to compare the effectiveness of pesticide-free hermetic grain storage and traditional polypropylene bags in terms of quantitative losses and seed quality, including germination potential, after three and six months of storage. The on-station trial followed a completely randomized design with three replicates of three treatments: Metal silo, PICS bag, and polypropylene bags without synthetic insecticide. On-farm trials with the same treatments were replicated on four smallholder farms, allowing natural insect infestation. Samples were assessed for total insect count, insect mortality, grain moisture content, grain damage, weight loss, and germination percentage. The results showed that hermetic treatments effectively controlled insect development, grain damage, and weight loss compared to non-hermetic treatments, with significant differences (P<0.05) observed. Seed viability was maintained in hermetic treatments, with high germination percentages (>92%) compared to non-hermetic treatments (<72%). There were no significant differences in grain moisture content among the storage methods. Overall, hermetic storage technologies proved effective in suppressing insect development, reducing losses, and preserving seed viability without the use of insecticides. These findings support the adoption of hermetic storage by small-scale farmers to improve food security and income generation in the country.

Keyword: Maize, Metal Silo, PICS Bags, Polypropylene Bags, Germination, Storage Insect.

1. INTRODUCTION

Maize is a crucial staple food in Ethiopia and forms the basis of the diet for the majority of Ethiopians. The seasonality of grain production, coupled with constant demand throughout the year, highlights the critical role of storage in ensuring household food security and serving as a source of income until the next harvest. Storage insect pests present a significant threat to household food security as they consume stored grain, leading to quantitative, qualitative, and economic losses. These losses manifest as weight reduction, decreased seed viability, and diminished market value, impacting the livelihoods of farmers. To mitigate storage losses, some farmers opt to sell their grain immediately after harvest, despite facing lower prices during the early storage season (Olayemi *et al*., 2012; Tefera and Abass, 2012; Utono, 2013). Consequently, these farmers may later need to purchase grain at higher prices, potentially trapping them in poverty. According to FAO (2012) projections, unless population growth slows, food demand is expected to increase by 38% by 2030 and 60% by 2050. Addressing the food security challenge requires meeting the growing demand for food in environmentally, socially, and economically sustainable ways. Implementing post-harvest handling practices to reduce postharvest losses in commodities and maintain quality and quantity is a more sustainable approach than

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solely focusing on increasing production to offset these losses.

Most smallholder farmers across various regions in Africa, including Ethiopia, rely on synthetic pesticides to protect their grains from storage insect pests (Mvumi *et al*., 1995; Mvumi and Stathers, 2003; Girma, 2006). However, the use of these pesticides has been increasingly associated with negative effects, such as toxic residues in food, effect on non-target species, and the emergence of resistance in targeted pests (Champ and Dyte, 1976; Giga and Mazarura, 1990; Subramanyam and Hagstrum, 1996; Guedes *et al*., 1996; Haines, 2000; Harish *et al*., 2013). While the development of resistance is a natural evolutionary process, it can be accelerated by improper application of these pesticides due to either intentional neglect or a lack of understanding. In Ethiopia and other East African countries, Phostoxin fumigant, Malathion, and Actellic Super are commonly used (Lalah and Wandiga, 2002; Girma *et al*., 2012). Concerns about pests developing resistance and the health risks associated with insecticide-treated grain have prompted the exploration of alternative storage methods, such as inert dusts, wood ash, botanicals, and vegetable oils, as well as biological control. However, none of these alternatives have proven particularly effective or commercially viable in Ethiopia (Girma *et al*., 2008abc; Girma *et al*., 2012).

In recent years, there has been an increasing interest in using hermetically-sealed containers to manage the Larger Grain Borers (LGB) (Quezada *et al*., 2006). Low oxygen levels lead to insect mortality, prompting the promotion of hermetic storage solutions like Purdue Improved Cowpea Storage (PICS), super grain bags, and cocoons as affordable and effective methods for controlling storage pests in Asia (Quezada *et al*., 2006) and more recently in Africa (Jones *et al*., 2011; Phiri and Otieno, 2008). PICS bags, made of a double layer of high-density polyethylene (HDPE) inside standard polypropylene woven bags, have proven effective in protecting cowpeas from bruchid beetles in West Africa (Baoua *et al*., 2012a, 2012b; Murdock *et al*., 2012). Super grain bags use a single HDPE bag as a liner within standard polypropylene bags and have been widely adopted in Asia (Villers *et al*., 2008). Metal silos, which are also hermetically sealed but more durable, have been actively promoted in Central America (Hellin and Kanampiu, 2008), and their viability is currently being assessed in Sub-Saharan Africa (SSA) (Tefera *et al*., 2011a).

Building on the success of metal silos in Central America and the increasing use of PICS bags, hermetic storage technologies are now being adopted in East and Southern Africa. However, before these new technologies are widely promoted in Ethiopia, they need to be rigorously tested in local conditions. Therefore, the current trials were conducted in Bako, both in simulated farmer storage (on-station) and actual farm settings, to evaluate the effectiveness of metal silos and PICS bags compared to the farmers' existing practice of using polypropylene bags with or without insecticides. The goal is to control major storage pests, reduce storage losses, and maintain grain quality.

2. MATERIAL AND METHODS

2.1. Description of Site

The trials were conducted at Bako, West Shoa Zone of the Oromia National Regional State, western Ethiopia, at an altitude of 1650 meters above sea level. Bako is located at 9°06' north latitude and 37°09' east longitude in the sub-humid ecology of the country, 260 km west of Addis Ababa. Bako represents a mid-altitude sub-humid zone with high potential for maize production. The National Maize Research Coordinating Center is situated here. The average annual rainfall at this location is 1237mm. The rainy season spans from April to October, with the maximum rainfall occurring in July and August. The mean minimum, mean maximum, and average air temperatures are 13.3°C, 27.9°C, and 20.6°C, respectively. The warm humid climate is conducive to storage insect pests such as the maize weevil and Angoumois grain moth.

2.2. Experimental Design and Treatments

On-Station Trial:

An on-station trial was conducted using a completely randomized design with four treatments: Metal Silo, PICS bags, polypropylene bags (the traditional bags used by farmers) treated with 5% Malathion, which is a standard commercial synthetic insecticide (treated positive control), and polypropylene bags without any insecticide (untreated negative control). Each treatment was replicated three times, and the trial lasted for six months.

On-Farm Trial:

An on-farm trial was conducted to assess the effectiveness of two chosen hermetic storage methods, along with one positive control and one negative control, over a period of six months. Four treatments were evaluated, including a Metal Silo, PICS bags, polypropylene bags (traditional farmer's bags) treated with 5% Malathion, and polypropylene bags without any synthetic insecticide. The trial involved four smallholder farmers.

Natural methods of insect infestation were employed, and the hermetic containers were used without any insecticide. Metal silos with a capacity of 200 kg, built according to our specifications, were sourced from local artisans. Hermetic Purdue Improved Crop Storage (PICS) bags with a 100 kg capacity, featuring two inner plastic liners that minimize oxygen permeability and an outer polypropylene bag, were obtained from the Sasakawa Africa Association (SG-2000-Ethiopia). The silos and bags were filled with dried maize grain that had low levels of infestation by storage pests. After loading the grains, a burning candle was placed on the surface in each metal silo to deplete oxygen (Figure 1), and the openings at the top and bottom spout were sealed with a rubber band to achieve a hermetic condition (Figure 2). For the PICS bags, excess air was removed by squeezing the free plastic section above the grain before closing the bags by tightly twisting and securing them with a special strap fastener from the manufacturer. The top of the bag was twisted again, folded back, and sealed with another fastener. In the positive control treatment, Malathion at a concentration of 5% was applied at the recommended rate of 50 grams per 100 kg of grain. Each treatment replicate consisted of 80 kg, which facilitated the creation of a hermetic environment in the PICS bags.

Figure 1: Candle light over the grain of loaded metal silo for oxygen depletion

Figure 2: Hermetic sealing of the spout at the bottom (left) the top opening (right) by tying with rubber band

2.3. Sampling and Data Collection

Grain samples were collected during the trial setup and then at three-month intervals for six months, from January to June 2017. For each treatment, samples were taken twice at three-month intervals using a compartmentalized grain sampling spear. Each container was sampled from the center and edges in all four directions (North, East, South, and West), ensuring samples were collected from the top, middle, and bottom sections. A uniform sample of 0.5 kg was taken from each replicate after three and six months of storage. After sampling from the metal silos, oxygen was removed using the lighted candle method before resealing the silos. For PICS bags, air was squeezed out and the bags were resealed as well. The samples were then sorted into grain, insects, and dust using various sieves.

At the start of the trials, the grain's moisture content and germination rate were analyzed. The collected samples were evaluated for insect mortality, adult insect density (both dead and alive), grain damage, weight loss, and moisture content. The moisture content was measured with a Dickey-John Moisture Meter. Damaged and undamaged grains were separated, counted, and weighed, and the percentage of grain damage and weight loss was calculated. The calculations for percentage grain damage and weight loss were as follows:

$$Grain\ damage(\%) = \frac{Number\ of\ damaged\ grain}{Total\ number\ of\ grain\ used} \times 100$$

Grain weight loss was calculated by using the count and weigh method (Adams and Schulten, 1978).

$$Grain\ weight\ loss(\%) = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

Where:
Wu = weight of undamaged grains,
Nd = number of damaged grains,
Wd = weight of damaged grains and
Nu = number of undamaged grains

2.4. Germination Tests

The tests were conducted in the laboratory at room temperature to assess the impact of the technologies on seed quality and viability. Thirty seeds were randomly selected from each sample, placed on tissue paper in a petri dish, and moistened with distilled water. The seeds were then kept in the laboratory at room temperature, ensuring they remained moist for ten days. The number of germinated and ungerminated seeds was recorded, and the germination percentage was calculated for each treatment. The percentage of seed germination was calculated as follows:

$$Seed\ germiination\ (\%) = \frac{No.\ germiinated}{Total\ No.\ of\ sample\ seed} \times 100$$

2.5. Data Management and Analysis

Microsoft Excel was utilized to compute the percentage of insect mortality, grain damage, weight loss, and germination for each replicate. The data on the number of insects were log-transformed (Log10), while the percentage of grain damage and weight loss were angularly transformed (arcsine √proportion) to stabilize the variance. Analysis of variance (ANOVA) was conducted on the transformed values using SAS (SAS Institute, 2010). When significant differences were detected, the Tukey's Honestly Significant Difference (HSD) test was employed to distinguish the means at a significance level of $p \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1. Grain Moisture and Insect Population

3.1.1. Grain Moisture

The initial moisture content of the grain ranged from 11.96% to 12.30%. After three months of storage, the moisture content increased slightly to between 13.37% and 14.30%, and after six months of storage, it ranged from 13.43% to 15.39%. According to Tukey's test ($P < 0.05$), there were no significant differences in these parameters during storage after three months (Table 1). The same trend was observed in the on-farm trial (Table 2). However, after six months of storage, there were significant differences between treatments, with the untreated control showing slightly higher moisture content. The measured moisture content values remained stable with both traditional and hermetic storage for up to three months and are not considered limiting for insect development.

The moisture content of the grain was unaffected by the type or duration of storage, remaining within acceptable limits for optimal storage conditions (Rickman and Aquino, 2007). However, this study observed a slight increase in moisture levels in both hermetic and traditional bags over time. The frequent temperature fluctuations during the harmattan season caused condensation to form on the sides of the hermetic bags, which then dripped to the bottom. This finding aligns with Obeng-Ofori and Boateng (2008), who noted that condensed water on the walls and bottoms of metal silos is absorbed by grains, raising their moisture content. The moisture content increased from 12.2% to 16.7% after six months of storage, attributed to the inadequate barrier protection of the polypropylene interwoven bags against water, oxygen, and sunlight, which created conditions that heightened insect metabolic activity. The increased metabolic activity of insects in these bags generated heat and moisture, which the grains absorbed, leading to higher moisture levels, the development of 'hot spots,' and subsequent clumping of the grains (Sinha and Sinha, 1992; Obeng-Ofori and Boateng, 2008). In contrast, the superior barrier of the triple-layer hermetic bags against oxygen, moisture, and insects likely contributed to the lower moisture content of maize stored in these bags compared to those in polypropylene interwoven bags. A similar observation was reported by William *et al.*, (2014), where maize in triple-layer hermetic bags maintained moisture levels close to its initial content.

3.1.2. Insect Population

The average insect density and notable differences between storage types for both on-station and on-farm methods are presented in Tables 1 and 2. After three and six months of storage, significant differences were noted between hermetic storage and other methods.

Hermetic storage using either metal silos or PICS bags reduced insect population growth by more than 99%. There were no statistically significant differences ($P < 0.05$) in the average number of insects per kilogram of rice between the metal silo and PICS bag methods, indicating that either hermetic storage option should be used depending on availability and cost. Throughout the storage period, hermetic treatments effectively suppressed insect development compared to non-hermetic methods, particularly the PICS bag treatments, which maintained insect populations of less than one insect per kilogram.

Hermetic storage facilities create a barrier against re-infestation, preventing insects from entering during storage. This also contributes to a low live insect population, along with the modified atmospheres created by the respiration of living organisms within the facilities, which negatively affects insect fecundity. Metal silo treatments had a relatively higher insect population density compared to PICS bags due to the larger headspace volume in the silos. The headspace is directly proportional to the amount of oxygen available for use by living organisms within the facilities. A low population of secondary insect pests throughout the storage period can indicate unfavorable conditions for development due to low grain damage and consequently less grain dust, which is their main diet. Interactions within the grain storage ecosystem lead to the ecological succession of insect species as the grain deteriorates, creating a conducive environment for some species while others find the environment unfavorable (Arbogast and Mullen, 1988).

Non-hermetic treatments showed a high insect population and a wide range of insect species. This could be due to the treatments' inability to prevent re-infestation during storage. The malathion 5% D treatments initially had a low insect population, but it increased after about six months. This increase can be attributed to the limited persistence of the pesticide over time and the growing infestation pressure from the untreated control.

Table 1: Mean number of insects population and percentage of moisture content before and after storage (3 and 6 months) under traditional and hermetic conditions (on-station)

Treatments	Moisture content (%)			Mean No. of insects /500gm		
	0	3MAS	6MAS	0	3MAS	6MAS
Metal Silo	12.9	13.93	13.76b			0.00c
PICS bag	12.3	13.93	13.97ab	9.74	0.00c	0.00c
PP bag with malathion 5%D	11.9	13.37	11.43c		4.63b	
PP bag without insecticide	12.1	14.30	15.39a	9.74	73a	
LSD (5%)	NS	NS	1.24	NS	3.76	
CV (%)	1.59	4.70	5.34	23.41	27,53	

Means within a column followed by the same letter are not significantly different ($p<0.05$)

Table 2: Mean number of insects population and percentage of moisture content before and after storage (3 and 6 months) under traditional and hermetic conditions (on-farm)

Treatments	Moisture content (%)			Mean No. of insects /500gm		
	0	3MAS	6MAS	0	3MAS	6MAS
Metal Silo	11.9	13.25	13.20a			3.00c
PICS bag	12.3	13.23	13.53a	8.41	1.50b	0.00c
PP bag with malathion 5%D	11.9	13.20	13.23b		2.50bc	
PP bag without insecticide	12.5	12.23	14.20a	5.74	12.75a	
LSD (5%)	NS	NS	1.12	NS	3.60	
CV (%)	1.59	9.02	5.08	23.41	31.6	

Means within a column followed by the same letter are not significantly different ($p<0.05$)

3.2. Percentage of Insect Mortality, Damaged Gains and Weight Loss

3.2.1. Adult Insect Mortality

These trials demonstrated that both the metal silo and PICS bags resulted in increased mortality among adult insects comparable to standard insecticide treatment. There were significant differences in adult insect mortality between the treated and untreated groups. PICS bags exhibited the highest insect mortality rate (>93.1%), followed by the standard insecticide and metal silo, at 3 and 6 months after storage (refer to Tables 3 and 4). All PICS bags, metal silos, and malathion 5% dust were equally effective against storage insects for up to three months. However, after six months of storage, the standard insecticide malathion 5% dust showed a trend of increasing insect population (refer to Table 2). PICS bags achieved their peak levels of mortality six months after treatment (refer to Tables 3 and 4). The rise in insect population in malathion 5% dust treatments after approximately six months can be attributed to the limited persistence of the malathion 5% dust.

3.2.2. Grain Damage and Weight Loss

The percentage values of grains damaged by insects are presented in Tables 3 and 4. The results show significant differences (P < 0.05) between traditional and hermetic storage. However, in line with the mean damage results, no significant differences were observed between Metal silo and PICS bag hermetic storage systems. In both on-station and on-farm trials, polypropylene bags treated with malathion 5% protected the grain for three months. Afterward, a slow increase was observed, reaching 14.06% in the case of on-station and 60.42% in the case of on-farm in the last month. PICS bags and Metal Silo kept damage low for three and six months, respectively. In those without insecticides, the damage reached 54.79% in on-station and 74.06% in on-farm trials.

The results of the grain weight losses were similar to the damage results (Tables 3 and 4). In all trials, the control group of stored grain experienced significant weight losses, ranging from 0.18% to 5.96% in on-station trials and 0.23% to 6.67% in on-farm trials. The peak weight loss of 6.67% was recorded in the on-farm trial at the six-month mark. Both on-station and on-farm trials showed that all pest control treatments effectively minimized losses. Hermetic treatments were more successful in reducing insect damage compared to non-hermetic treatments at both locations. This can be attributed to the protective barrier provided by hermetic storage facilities, which prevent re-infestation and limit interactions between pests and the stored grain. Despite the presence of live insects in the metal silo throughout the storage period, damage remained low after a year of storage. This can be attributed to the antifeedant properties of hypoxic environments and controlled metabolism, which help regulate insect damage (Murdock *et al*., 2012).

Non-hermetic treatments experienced a high percentage of insect damage caused by a large insect population. The damage resulted in weight loss as the insects fed on the stored grain. The level of damage increased significantly over time. The positive control was able to briefly control the infestation but could not sustain the pressure. Non-hermetic treatments, such as the untreated control and malathion 5% treated, allowed the stored grain to interact with the environment, leading to re-infestation that could not be prevented, unlike the screening capabilities of hermetic facilities.

Regardless of the mode of infestation, the damage trend was similar at both sites, with PICS bags showing the least damage and weight loss. This can be attributed to a low insect population throughout the storage period. Metal silos effectively controlled insect damage compared to non-hermetic treatments. The treatments at IAE incurred higher losses compared to those at Makoholi due to a wide range of insect species and favorable weather conditions for insect development in on-farm conditions. Hermetic treatments resulted in low losses (<24% damage) and, according to the VDS by Utono (2013), the grain is suitable for selling, home consumption, and seed. In contrast, grain from non-hermetic treatments with high damage (>57%) cannot be sold or used as seed.

Table 3: Percentage of insect mortality, grain damage level and grain weight loss under different treatments after three and six months of storage (on-station)

Treatments	% insect mortality		% grain damage		% weight losses	
	3MAS	6MAS	3MAS	6MAS	3MAS	6MAS
Metal Silo	87.98a	81.43a	7.91b	6.43c	1.48	0.29
PICS bag	100.00a	97.33a	7.77b	1.09c	0.58	0.18
PP bag with malathion 5%D	100.00a	72.30b	8.14b	14.06b	1.27	0.87
PP bag without insecticide	13.27b	12.60c	11.75a	54.79a	2.85	5.96a
LSD (5%)	19.38	23.45	1.19	6.93	NS	3.66
CV (%)	14.08	19.87	25.83	18.29	34.84	71.35

Means within a column followed by the same letter are not significantly different (p<0.05)

Table 4: Percentage of insect mortality, grain damage level and grain weight loss under different treatments after three and six months of storage (on-farm)

Treatments	% insect mortality		% grain damage		% weight losses	
	3MAS	6MAS	3MAS	6MAS	3MAS	6MAS
Metal Silo	85.32a	83.33a	12.41b	13.65c	1.52b	1.07b
PICS bag	93.25a	100.00a	10.20b	10.43c	1.23b	0.23b
PP bag with malathion 5%D	95.44a	91.67a	13.79b	60.42b	1.51b	2.73b
PP bag without insecticide	25.00b	11.84b	22.49a	74.05a	5.52a	6.67a
LSD (5%)	45.25	21.16	2.81	7.62	3.99	0.88
CV (%)	43.45	18.14	12.11	12.97	61.86	42.25

Means within a column followed by the same letter are not significantly different (p<0.05)

3.3. Germination Capacity

The results for mean germination capacity during the trials are provided in Table 5 for both on-farm and on-station settings. Germination capacity was assessed before and after three or six months of storage. The initial germination capacity ranged from 90% to

95%. After six months of storage, our findings indicate that traditional storage without insecticide led to a significant decrease in seed germination (P < 0.05), with mean values of 66.67% on-station and 72.03% on-farm after the storage period. In contrast, under hermetic conditions, seed germination remained consistent (P < 0.05) throughout the storage period. At the end of the storage period, in the case of on-station storage, the average germination rates were 96.87% and 97.67% for metal silos and PICS bags, respectively. Similarly, under on-farm conditions, the average germination rates were 95.56% and 100% for metal silos and PICS bags, respectively. PICS bags exhibited the highest germination rates at the end of the storage period for both on-station and on-farm trials, followed by metal silos. This can be attributed to the low insect population, resulting in minimal insect damage and, consequently, reduced seed damage. Metal silos treated with Malathion 5% had higher germination percentages than the untreated control. On the other hand, the germination capacity was influenced by the type and duration of storage. Hermetic methods proved to be more effective in maintaining the germination potential compared to traditional methods. Specifically, seeds stored in polypropylene bags without insecticide for six months exhibited germination values below the minimum requirement set in Ethiopia (80% germination).

Germination is a key factor studied in grain storage, as it effectively assesses grain quality and soundness (Pomeranz, 1982). Since many smallholder farmers use grains from previous harvests for planting (Dhliwayo and Pixley, 2003), storage solutions that maintain seed viability can improve productivity by enabling the use of high-quality seeds. Research has shown that rice seeds stored in airtight conditions maintained their moisture levels, remained free from infestations, and were viable for up to seven months, exhibiting a germination index that was 30% to 70% higher than seeds stored in non-airtight environments (IRRI, 2013). Similarly, experiments in Mexico indicate that airtight storage allowed germination potential to remain at or above 85% for more than nine months, whereas traditional storage methods demonstrated a decline in germination rates to between 14% and 76% within three months. In Rwanda, airtight storage for 30 months did not impact the appearance or germination potential of the grain (Villers *et al*., 2008; Navarro, 2012). Additionally, Mantovani *et al*., (1986) noted that when moisture content was below 12%, these storage methods permitted safe storage for up to eight months without harming germination and vigor, making the grain suitable for planting. Hermetic storage also helps maintain germination capacity by effectively managing insect populations that could otherwise cause significant damage during storage (Weber, 2001).

The results corroborate previous studies where both metal silos (De Groote *et al*., 2013) and hermetic bags, namely Purdue Improved Crop Storage (PICS) bags (Murdock *et al*., 2012; Baoua *et al*., 2013; Njoroge *et al*., 2014), IRRI Super bags (Ben *et al*., 2009), and GrainPro bags (Baoua *et al*., 2013), managed to preserve grain quality, reduce grain damage, and weight loss compared to the conventional bag storage system. The majority of smallholder farmers in Ethiopia use bag storage; hence, the hermetic storage facilities used in this study are ideal in terms of capacity and appropriateness of use under existing infrastructure.

Table 5: Percentage of seed germination before and after storage (3 and 6 months) under different treatments at on-station and on-farm conditions

Treatments	Germination (%) (On-station trial)			Germination (%) (On-farm trial)		
	0	3MAS	6MAS	0	3MAS	6MAS
Metal Silo	95.8	92.22	97.87a	93.72	91.67	95.56b
PICS bag	94.6	94.41	96.67a	95.00	94.17	100.00a
PP bag with malathion 5%D	90.6	93.33	88.89ab	92.41	90.00	92.22c
PP bag without insecticide	91.2	91.11	66.67b	90,63	89.16	92.03c
LSD (5%)	NS	NS	20.63	NS	NS	0.27
CV (%)	3.12	2.39	14.53	9.48	5.99	3.06

Means within a column followed by the same letter are not significantly different (p<0.05)

4. CONCLUSION

Reducing postharvest losses boosts the food supply for small scale maize producers, decreasing their need to buy food and lowering household food expenses. It also helps maintain food quality and nutritional value, allowing families to reallocate resources to health, education, and other areas. This study indicates that pesticide-free hermetic storage methods, like PICS bags and Metal Silos, are more effective than non-hermetic options in protecting maize from pests and storage losses while preserving germination rates. These methods support the three pillars of sustainability: economic viability, environmental resilience, and social equity. Thus, promoting the use of Metal Silos and PICS bags is recommended to minimize maize storage losses and improve the livelihoods of smallholder farmers in Ethiopia.

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