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ORIGINAL ARTICLE

Evaluation of hermetic storage methods against weight loss, mold growth, and physicochemical properties and germination capacity of maize

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ABSTRACT

Hermetic storage methods reduce post-harvest losses and improve food security. However, little is known about the impact of these methods on maize quality in Ethiopia. Thus, the current study aimed to evaluate Metal silos, Purdue Improved Grain Storage bags, Super Grain Pro bags, plastic drums, and polypropylene bags as control with 2, 4, and 6 months of storage. Analysis of variance was determined using SAS software. The experimental results showed that the storage methods had no significant (p<0.05) effect on fat, protein, and mold growth of stored maize. However, the storage methods had a significant effect (p<0.05) on the moisture content, number of live and dead insects, weight loss, bulk density, and germination test of maize grain. Among the storage methods, Super grain bag storage bags had significantly highest values of germination test (94.67%) at 4 and 6 months of storage and bulk density (755.25kg/m3) at 2 months of storage next to this storage method, Purdue improvement crop storage bags had significantly higher values of germination test (91.3%) at 4 months of storage and bulk density (670.67kg/m3) at 2 months of storage when compared to the polypropylene bag germination test (56.33%) at and bulk density (625.33kg/m3) . Finally, it can be concluded that hermetic storage methods such as Purdue improvement crop storage, Super grain bag, and Metal silo were important to preserve maize grain by reducing insect pest infestation and mold growth.

Keywords: *Hermetic Storage methods, Maize, mold growth, Nutritional properties, Storage Duration.*

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1. Introduction

Maize (*Zea mays L.*) is a member of the grass family, and it is one of the most important cereal crops in the world next to wheat and rice. In many parts of Africa, maize is a staple crop majorly used for household consumption (Revilla et al. 2022). In Ethiopia, maize is an important staple food crop which is widely grown, especially in countryside areas (Dessalegn, Solomon, et al., 2017) and used by over 90 million population of the country (Sector et al.,2017). Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region in terms of production (FAOSTAT, 2019). According to CSA (2017), 20,718,658 quintals of maize were produced during the main crop harvesting season in Amhara region, which is a potential production area in Ethiopia. Among the produce at the Ethiopian level, 76.32% of the maize is used for household consumption and only 12.37% is only used for sales (CSA, 2017). Maize grain is a source of carbohydrates, protein, fat, ash, fiber, vitamins minerals and has some important technological properties such as wet gluten and sedimentation value to make good bread (Saeid, 2017).

In developing countries including Ethiopia, maize grain has been stored using traditional storage methods and about 93.3% farmers used them (Tadeos shiferaw, 2018). These are "*Gotera", "Kefo", Jute* or *Hessian sacks*, *Skin bags* ("*Aqomada/Loqota", "Aybet"*), clay jars, *Gourds*, Wooden boxes, metal drums/barrels, and underground *Pits*. However, traditional storage couldn't protect the stored maize from deterioration (Dubale, 2014) due to its ineffectiveness to prevent from insect pests, mold growth, and rodents (Olorunfemi, et. al, 2021, Dijkink, Broeze, and Vollebregt 2022). The above listed traditional storage methods initiate the post-harvest loss of maize grain in terms of quality and quantity which leads to food insecurity in Ethiopia (Tadeos shiferaw, 2018). According to the African Postharvest Losses Information System (APHLIS), postharvest losses of maize in the country was 16.8% compared to other grains such as teff (12.3%), sorghum (11.6%), and wheat (9.9%) (Anderer, Dumont, and Kolf 2007). Furthermore, according to the report made by Addis Ababa University and the Swiss Agency for Development and Co-operation in two communities in the East Gojam zone of Amhara National Regional State showed that postharvest losses of maize are reached to 30% to 50% (Dubale Befikadu, 2018). To prevent the maize from pests and mold growth, farmers have been using different synthetic chemicals which is not safe for health. Therefore, now a day's hermetic storage methods are launched in the market and used for storage purposes to preserve the grains with little loss without the addition of synthetic chemicals in developed countries and in developing countries. Nonetheless, it is uncommon for Ethiopians to be aware of the need of using alternative hermetic storage. Thus, this research aimed to investigate how hermetic methods of storage and storage time (2, 4, and 6 months) influence the germination capacity, weight loss, mold growth, and physicochemical characteristics of stored maize.

2. Materials and methods

2.1. Raw material collection and preparation

Fifty kilogram of maize grain (BH660) which was harvested in November 2019, was collected from the Ethiopian Seed Enterprise, Bahir Dar Center, Ethiopia. Then, it was cleaned to remove foreign matters and stored in hermetic storage methods for different storage times (2, 4, and 6 months) under ambient conditions with (temperature of 24.6±0.6°C and relative humidity of 48.2±10.4%, obtained from Ethiopian Meteorology Agency, Bahir Dar branch) at the food engineering laboratories, Bahir Dar institute of technology, Bahir Dar University, Ethiopia.

2.2. Experimental design

The experiment was employed in a Completely Randomized Design (CRD). The experimental factors are storage methods and storage times. The storage methods were Polypropylene bag (PPB) was used as a control, Super Grain Bag (SGB), Metal

Bin (MB) and Purdue Improvement Crop Storage bag (PICS) and the storage times were 2, 4 and 6 months. The entire experiment was conducted in triplicate.

2.3. Experimental analysis

2.3.1. Sampling

One kilogram of maize sample was taken from each storage methods and storage times at the top, bottom and middle to avoid biasness.

2.3.2. Weight loss

Percent of weight loss was determined by counting damaged and undamaged kernel then weighing them according to the weighing and count method of Ngatia, (2011). A 30 g sieved maize sample was taken, and the damaged and undamaged maize samples were separated and weighed separately. Weight loss percent was calculated using the following equation as described by Demissie et al., 2008.

$$Weight\ Loss\ (\%) = \frac{(WUN \times \mathrm{N}D) - (WDN \times \mathrm{N}U)}{WU \times (ND + NU)} \times 100 - - - - - - - - - - (1)$$

Where: WUN= Weight (gram) of undamaged kernels,

WDN = Weight (gram) of damaged kernels

ND = number of Damaged

NU = Number of undamaged

2.3.3. Bulk density

Bulk density was measured according to the procedure employed by (Kalsa et al., 2019). Each sieved maize grain sample was added to a fixed flask with a 0.4 L volume, and the weight was determined with an analytical balance with a 0.1 g precision.

$$Bulk\ Desnsity\ \left(\frac{kg}{m^3}\right) = \frac{Mass}{Volume}) - (2)$$

The following equation was used to adjust weights to the standard moisture content (13%) to prevent the fluctuation of bulk density (in equation 2) with moisture contents.

$$Adjusted\ Bulk\ Density\ (kg/m3) = \frac{100 - MC}{87} \times Bulk\ Density - - - - (3)$$

Where: MC is the moisture content of maize.

2.3.4. Ash content

Five grams of maize from each sample was weighed into a dry porcelain dish/crucible and then heated in a muffle furnace at 600 ^{0}C for 6 h. It was cooled in desiccators and weighed. The percentage of the ash content was calculated by weighing of the remaining ash after the process (Shaista Qamar and Muhammad Aslam, 2015) as follows:

$$\text{Ash content (\%)} = \frac{\text{M1} - \text{M2}}{\text{M1}} \times 100 - - - - - - - - - - - - - - (4)$$

Where: M_1 weight (gram) of the maize sample

M_2 weight (gram) of ash after burning of maize sample

2.3.5. Number of Live and Dead Insects

The number of live and dead insects was measured according to the method used by (Kalsa et al., 2019). A 500 g sample from each experimental unit was sifted with sieve of mesh sizes of 4 mm (top) and 2 mm (middle and bottom pan were used. Insects which were retained in 2 mm and 4 mm mesh sieve were counted.

2.3.6. Protein, Fat and Starch contents

Proteins, starch and fat content were determined by a NIR Infratech 1241 Grain analyzer (Foss tecator, Sweden) and presented as percent of dry matter (Vesna, Dragičević, 2014).

2.3.7. Mold growth

Mold count was determined according to FAO microbiological analysis manual (FAO, 2006). Ten grams of powder maize grain sample was taken for determination of total number of molds. Serial dilutions were prepared and spread plated on acidified Potato dextrose agar (PDA) (with 10% tartaric acid) to determine the total mold count by counting the colony forming units (CFU).

2.3.8. Germination capacity

The seeds (50 kernels) were kept in petri dish lined with two-layer moistened tissue paper with distilled water in three replications and incubated at 24 ºC for 6 days. Germination test was measured based on the standard procedures of ISTA (2006) as follows:

$$Germination\ percentage(\%) = \frac{\text{TNM} - \text{NNGM}}{\text{TNM}} \times 100 - - - - - - - - - - - (5)$$

Where: TNM total number of maize grains taken from sample

NNGM total number of non-germinated maize

2.3.9. Statistical data analysis

SAS software version 9.1 was used to analyze the ANOVA which was performed using GLM procedure. Pair wise comparison of means was performed using Duncan's multiple range tests to determine significant variations among the means.

The results obtained were expressed as mean ± standard deviation and P < 0.05 was considered as statistical significance for all tests.

3. Results and discussion

3.1. Weight Loss Percentage

The weight loss of stored maize grain was significantly affected by storage methods. The highest mean value (18.08 ± 2.5%) of weight loss was obtained in PPB at 4 months but in PICS, MB and GB had relatively least mean value of weight loss (Table 1). This high percentage of weight loss was primarily a consequence of insect infestation. According to Bezabih et al. (2022), the average weight loss reported was 41-74% on maize stored in traditional farmer storage structures. Hengsdijk and de Boer (2017) also concluded that, the hermetic storage method such as metal bin is better to reduce post-harvest loss of maize grains. Restricted insect multiplication in hermetic treatments helps to control grain damage and consequently suppressing grain weight loss. Purdue improvement crop storage and super grain bag were important to reduce weight loss percentage (Paddy Likhayob, 2013). Dry maize grains (12% moisture content) held well in hermetic bags and lost 1.2% of their weight while losing 35.8% of their weight when stored in polypropylene bags (Likhayo et al. 2018). The highest weigh loss in PPB due to the impact of insect pest damage on the stored maize grain which is directly related to high percentage of weight loss (Kukom et al, 2013). Evidently, the percentage of weight loss of the stored grain rose at different hermetic storage methods as the length of time the maize grain was stored, as the insects had more opportunity to infest the kernels. Though this sort of storage method is best for storing both maize and another grain, the proportion of grain weight loss in the PICS storage method is minimal because insects cannot develop and infest stored grain.

Table 1. The mean ± SD of germination test, weight loss, and bulk density, number of live and dead insect pest per kg of stored maize grain in treatment.

Storage time (months)	Storage method	Germination (%)	W. L (%)	B. D (kg/m^3)	No. of LI Insect/kg	No. of DI insect/kg
2	GB	83.33±15.01^{a}	7.18±1.87^{a}	755.28±7.09^{a}	0.00±0.00^{a}	3.33±1.53^{a}
	MB	86.00±5.29^{b}	8.52±3.67^{a}	640.41±9.27^{b}	1.33±0.53^{a}	45.00±1.93^{b}
	PICS	91.33±4.16^{c}	5.89± 2.02^{b}	670.67±5.97^{b}	0.33±0.18^{a}	4.67±1.53^{ab}
	PPB	64.67±1.47^{d}	17.39±0.76^{c}	606.91±3.21^{c}	18.33±1.29^{b}	59.67±2.50^{c}
4	GB	94.67±5.03^{e}	1.45±1.7^{d}	694.41±3.9^{a}	1.33±1.53^{a}	10.33±2.08^{a}
	MB	94.00±0.00^{e}	1.18±0.5^{d}	641.37±4.4^{b}	1.00±1.4^{ab}	32.50±1.68^{b}
	PICS	91.33±3.05^{c}	6.48±4.3^{b}	657.67±1.4^{b}	1.00±1.41^{a}	5.33±3.06^{ab}
	PPB	58.67±0.00^{f}	18.08±2.50^{c}	625.50±2.69^{b}	4.00±2.65^{b}	102.67±4.53^{c}
6	GB	94.67±3.06^{e}	3.28±1.05^{e}	659.33±5.63^{a}	1.00±0.00^{a}	10.67±1.45^{a}
	MB	81.33±1.53^{a}	8.59 ±1.23^{a}	639.83±3.34^{b}	2.67± 0.58^{a}	13.00±1.62^{b}
	PICS	83.33±1.53^{a}	2.58 ±0.53^{e}	651.75±4.60^{b}	0.67±1.15^{a}	5.00±3.61^{c}
	PPB	56.33±6.11^{g}	10.21±2.83^{ba}	625.33±2.31^{c}	2.67±2.08^{b}	71.33±2.60^{d}

Where, PICS= Purdue improvement crop storage, GP= super grain bag MB=metal bin, PPB = polypropylene bag, W. L=weight loss, B. D =bulk density, No. of LI= number live insect (pest/kg), No. of DI= number of dead insect (pest/kg). The column value with the same small superscript letter is insignificant between within storage structure and duration before opening time on every quantitative and qualitative parameter of stored maize grain.

3.2. Bulk Density

At two months of storage time, super grain Storage bags with maize grain had the relative highest bulk density (Table 1). The reason for this may be reduced insect and mold damage in that particular storage. The highest bulk density of maize grain (755.29 kg/m^3) was recorded in super pro grain storage bag for two months storage duration, whereas the lowest value (606 kg/m^3) was recorded in PPB. This is because of the hermetic storage structures can prevent pest infestation, mod growth and respiration which results the decline of bulk density of stored grain. The decrease in bulk density during storage is evidence of grain degradation. In addition to the loss of dry mass brought on by grain respiration, these values were decreased by pest insects and storage fungus (Júnior and Dionello 2020) and it was established that during storage, pest insects decreased the precise quantity of corn kernels.

3.3. Live and Dead Insects

Number of live and dead insect pest was significantly affected by storage structure but, storage time did not affect the stored maize. As presented in Table 1, the highest mean (18.33±1.29 pest/kg) value of live insect pest was recorded in the interaction storage structure and duration of PPB at 2 months while, the least mean (3.33±1.53 pest/kg) value of insect pest was obtained in structure of GB at 2 months of storage. Maize grain stored in PICS for 2 months has mean value 0.33±0.58 pest/kg (Table 1). Actually, airtight storage structure reduces the number of live insect pests grown for the duration of storage of maize grain. PPB storage method permits the oxygen into system which provides the infestation of insect pest since there is high respiration of insects and kernel grain. This leads to the development of insect and increases grain damage/dust loss. Previous research conducted by Paddy Likhayob (2013) reported that mean number of insect pest's *P. truncatus* and *S. zeamis* recorded one and zero in PICS at 180 and 90 days, respectively. The second important storage is super grain to protect the maize grains from insect pests. PPB had the maximum insect density (1273 insects/kg grain) compared with hermetic storage methods (7 insects/kg grain) with moisture content 18% (Likhayo et al. 2018). The result showed that the storage methods had significant ($p < 0.0001$) effect on the number of dead insect pests at any storage duration. This is due to insects could be died in hermetic storage methods due to the depletion of gas/oxygen. The number of dead insects in stored maize grain significantly decreased in hermetic methods as compared to non-hermetic PPB. In contrast to live insects, the highest mean value (102.67±4.53 pests/kg) of dead insects of grain was recorded in PPB at 4 months of duration, although the smallest mean value of insects (3.33±1.53 pests/kg) was achieved in GB at 2 and next GB at 4 months (4.67±1.53 pests/kg). In hermetic storage methods there was less growth of insect pests. This provides the prevention of stored grain from weight loss and infestation of insect pests in grain. This is in agreement with Yakubu (2011) who studied the mortality rate of weevils in maize grain on hermetic and non-hermetic storage and the results shows that, high mortality rate and number of insects is created in non-hermetic storage at PPB.

3.5. Germination capacity

The germination ability of stored maize was significantly affected by the interaction of storage methods and storage time. The significance was brought by storage methods but not storage time, there were a similar effect on germination of maize among hermetic storage methods kept at any storage time. In the storage methods of GB, the ability of germination was significantly increased when storage time was increased from 2 month to 6 months. Table 1 indicated that the highest mean value of germination percentage (94.67±5.03 %) was obtained in GB storage container at 4 months while the lowest mean percentage (56.33±6.11) obtained in PPB at 6 months. This could be due to insect pest infestation which reduces the ability of germination of grains; it is inversely proportional to total insect population. But, non-hermetic storage allows the stored grain with the dynamic atmosphere, which results high insect infestation and low seed germination. While in hermetic storage, hermetic containers restrict interaction of grain with external biotic and abiotic factors thus had low insect population and managed to preserve the ability of seed germination (Mvumi and Chigoverah 2018).

3.6. The effect of storage structure and storage time on proximate composition of stored maize

3.6.1. Protein

In Table 2 below, the maize stored in PICS bag identified as insignificantly increased when the storage time increased in terms of protein content. In contrast, maize stored in PPB was decreased when duration was increased; whereas, the maize stored in both MB and GB storage methods, the protein content fluctuates when storage time was raised. As indicated in table 2 the lowest mean value (10.2%) was obtained in PPB stored for 6 months of storage time. According to Stefanello et al., (2015), if the storage time is extended, the protein content of maize culd be decreased.

Table 2. ANOVA Results of protein, starch, oil, ash content and mold growth of stored maize grain in different storage method and storage time (2, 4, and 6) months.

Storage time (months)	Storage methods	Protein (%)	Starch (%)	Oil (%)	Ash (%)	Mold (CFU)
2	GB	10.50±0.26 [a]	68.97±1.07[b]	4.57±0.32[a]	0.93±0.07[a]	9.00±5.57 [a]
	MB	10.50±0.36[a]	69.90±0.36[bc]	4.37±0.15[a]	0.95±0.05[b]	4.33±2.33 [a]
	PICS	10.50±0.20 [a]	68.93±0.12[c]	4.70±0.10[a]	0.80±0.01[c]	10.67±2.17[a]
	PPB	10.57±0.20[a]	70.07±1.10[a]	4.10±0.70[b]	0.85±0.07[b]	1.67±0.33 [a]
4	GB	10.53±0.25[a]	69.10±0.20[b]	4.80±0.17[a]	0.99±0.80[a]	2.67±0.89 [a]
	MB	10.65±0.07[a]	69.30±0.14[bc]	4.45±0.21[a]	1.00±0.00[b]	4.50±2.50 [a]
	PICS	10.53±0.35[a]	68.70±0.52[c]	4.73±0.06[a]	0.80±0.00[c]	9.00±4.16 [a]
	PPB	10.27±0.50 [a]	69.90±0.35[a]	4.07±0.38[b]	0.74±0.10[d]	7.00±1.73 [a]
6	GB	10.47±0.42[a]	68.97±0.35[b]	4.73±0.23[a]	1.00±0.01[a]	4.67±3.28 [a]
	MB	10.33±0.12[a]	69.10±0.35[bc]	4.70±0.26[a]	1.18±0.30[b]	4.67±1.20 [a]
	PICS	10.63±0.21[a]	68.23±0.29[c]	4.77±0.12[a]	0.87±0.42[c]	6.00±4.51 [a]
	PPB	10.20±0.00[a]	70.03±0.32[a]	4.43±0.06[b]	1.07±0.15[d]	4.67±2.33 [a]

Where, PICS= purdue improvement crop storage, GP= super grain bag MB=metal bin, PPB = polypropylene bag. CFU= colony forming unit.The column value with the same small superscript letter is insignificant between within storage structure and duration before opening time on every quantitative and qualitative parameter of stored maize grain

3.6.2. Starch

The starch content was significantly decreased in maize stored in MB and PICS for storage time of 2 to 6 month, but it fluctuates when stored in PPB and GB storage structure. Table 2 indicated that maximum mean value of starch content (70.07±1.10%) was recorded in PPB at 2 months; whereas, minimum mean value of starch (68.23±0.29%) was observed in maize stored in PICS bags for 6 months.

3.6.3. Fat

By the duration of time increased from 2 to 6 month, the fat content of maize was high in storage method of hermetic (MB, GB and PICS) when compared to that of PPB due to those hermetic storages protect oil loss by storage pests and insects. Table 2 indicated that there was significant decline in fat content observed in maize stored in PPB. The highest fat content (4.80±0.17%) was obtained in maize stored with GB at 4 months, whereas the lowest value of fat content (4.07±0.38%) was obtained in PPB at 4 months sampling duration. However, hermetic storage device was significantly protecting the oil content of maize grain than non-hermetic storage (PPB) during storage because of suppressing effect with the growth of insect pest and microorganism. Insect and microorganism can decompose the fat into simple compound (fatty acid) when they grow in storage structures.

3.6.4 Ash

Table 2 indicated that relatively the highest mean value of ash content (1.18%) was obtained in metal bin. This may be due to the mass transfer that there is migration of metal fragments from metal storage structures to the maize grain during storage time. There is a significant increase of ash content with increasing contact time of metal bin and maize. The highest ash content (1.180±0.3%) was obtained in maize stored with MB at 6 months, whereas the lowest value of ash content (0.74±0.10%) was obtained in PPB at 4 months.

3.7. Mold Growth

Table 2 indicated that the highest mean value of the mold (10.67±2.17 CFU) was obtained at PICS with 2 months. This was happened due to availability of the oxygen at the introduction of the sample in to the hermetic storage. The mold can get enough amount of air and they start infestation of stored maize grain due to absorption of moisture content from surface of grain. But there was a decline in the number molds in hermetic storage methods while the storage time was increased from 2 to 6 months. This is in agreement with Mvumi and Chigoverah (2018) who reported high initial grain moisture content and initial insect infestation might contributed to mold growth. To suppress mold growth, grain should be dry, free from damage and free from insects. According to the Nda-Ayima (2014), there was increase of mold growth with storage time in non-hermetic storage method when compared to that of hermetic storage methods. In this experiment, the same phenomenon happened; that is, 1.67 CFU to 4.67 CFU mold was observed in polypropylene bag when the storage time increased from 2 to 6 months.

Conclusion

The hermetic storage at any periodic time of storage is better than polypropylene bag for reducing the post-harvest loss of maize grain, especially reduction of the infestation of insect pest. The lowest mean values of insect pest infestation (0.0

number) or no insect pest was obtained in hermetic storage of super grain bag at duration time of two months. The weight loss was recorded with minimum mean value (1.18%) at hermetic storage method and with maximum mean value in non-hermetic storage. They can be an alternative to insecticides and pesticides to decrease the infestation and growth of insects than that of polypropylene bag. The metal bin is very important storage structure in protecting grains from the mechanical damage, birds, rodent and other animal, and also airtight bag which reduces the respiration process. The hermetic storage methods were significantly better than non-hermetic storage method for improving the qualitative characteristics of maize grain during storage. Hermetic storages such as super grain and Purdue improvement crop storage bags are critical methods to increase the food security, food availability and reduce the loss of quality attributes of maize grain at any storage time. They are flexible, less weight, and easy to design with less requirement of investment and can be applied on costumer, retailer, and farmer level. Therefore, it is recommended that the farmers can use the hermetic storages during temporary and permanent storage of maize grain rather than the traditional storage method.

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