Assessing Storage Insect Pests and Faecal dropping of Rodent in Stored Grains in two districts of Southwestern Ethiopia

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Abstract

This study was designed to assess major insects and occurrence of rodent infestation in stored grain in two districts of south western Ethiopia. Omo Neda and Bako Tibe districts were purposively selected supported their potential growing of maize and sorghum grain, and high postharvest losses in these selected areas. A total of 160 farmers' stores from both districts were randomly selected. The grain samples used in the present study were stored for 5 different time periods, ranging from 1 to 5 months and from the same farmers' stores, to identify storage insect pest and to determine grain weight loss and insect damage. The results showed that the dominant insect species in maize and sorghum grains were weevils (Sitophilus spp.) followed by the Angoumois gelechiid (Sitotroga cerealella Olivier) and flour beetles (Tribolium spp.). High numbers of insects were recorded from both plastered and un-plastered gombisa and polypropylene bags. Additionally, the amount of every insect pest in each storage container recorded per 100 g grain increased because the duration of grain storage increased. There have been 0.33–1.29 and 0.44-1g droppings per 100-g sample of maize and sorghum grain, respectively. Grain damage showed significant differences over the storage periods across the study districts. A similar trend was observed for weight loss for each of the grains in all districts. These results indicated that farmers are incurring a substantial grain loss to insects and rodent pests. Hence, there is an urgent need to devise appropriate tactics for protecting the losses in farm-stored maize and sorghum in Ethiopia.

1. Introduction

Grains are the most source of nutrition for one-third of the world's poorest population in Sub-Saharan Africa and South-East Asia. Among the grain crops rice, wheat and maize represent about 85% of total global production (Sofi et al., 2009). In Ethiopia, Cereals constituted 87.3% of the grain production of the country, with 26.8% contribution from maize, 16.1% from sorghum and 15.7% from wheat (CSA, 2015). However, production of cereals and grains are constrained by various biotic and abiotic factors. Post-harvest losses are one among the most constraints affecting food and nutrition security of smallholder farmers within the country (Tefera, 2012; Tesfaye and Tirivayi, 2018). Poor storage systems make grains susceptible to attacks from insect and rodent pests, which cause a substantial amount of losses in quantity and quality of grains.

Losses resulting from poor post-harvest management of grains are among the key constraints to improving food and nutritional security in Africa that results in grain weight losses of 20–30 % (Tefera, 2012). Consistent with Kumar and Kalita (2017), an approximately 50–60% losses of cereal grains occurred during storage thanks to technical inefficiency. In Ethiopia, the typical grain losses thanks to storage insect pests estimated to be 10–30% (Tadesse, 2005; MoARD, 2010). Among many storage insect pests, grain weevils, Sitophilus spp. (Coleoptera: Curculionidae), and therefore the Angoumois gelechiid, angoumois moth (Olivier) (Lepidoptera: Gelechiidae), are major pests of cereal crops in Ethiopia (Tadesse, 1996; Demisse et al., 2008; Tefera, 2016). Consistent with Sori and Ayana (2012), S. zeamais can cause heavy infestation on maize and sorghum grain stored under traditional storage facilities and resulted in weight losses up to 41–80%.

Farmers in Ethiopia, almost like those in other African countries, use traditional storage facilities such are gotera, gumbi, and polypropylene and jute bags. Gotera is an outside storage structure made up of mud or trash plastered basket work covered with thatched roofing and raised off the bottom with stones or wooden platform; Gumbi is an inside grain storage bin made from mud plaster mixed with teff straw (Hengsdijk and De Boer, 2017). Such storage structures often fail to guard the stored grains from insect pests and damage by rodents. Traditional storage structures provide ideal conditions for the multiplication of storage insect pests and rodents. Although most smallholder farmers keep grain for a comparatively shorter period, substantial losses occur to stored grains.

Rodents also are a serious postharvest pest, causing a big amount of losses and contamination of stored grains during storage that affect food security and income of small-holder farmers (Brown et al., 2013; Ognakossan et al., 2016). To style effective postharvest pest management methods, knowledge of major pests and their relative abundances in reference to storage facilities is important. However, little information is out there about storage insect pest infestations in reference to storage facilities. Therefore, the aim of this study was to assess storage insects of stored maize and sorghum and their associated losses of quantity in south western Ethiopia.

2. Materials And Methods

2.1 Study areas and sample collection methods

Study areas were including the selected zones, woredas and kebele's depend on their potential in maize and sorghum production and selection of farmers was made together with woreda agricultural experts. Its coverers two major maize and sorghum producing zone of south western Oromia, Ethiopia; namely, Jimma and West shawa. A total of 600 g of grain sample of each storage structure were collected. The grain samples taken from the top, middle and bottom of a storage structure were then bulked together to make a composite sample. Samples were collected at monthly intervals for up to five months from the same stores for storage insect pest studies, faecal dropping of rodent studies and grain damage and weight loss assessment. Sample collection was carried out after the grain was stored for one month and samples were enclosed in plastic bags and brought to the Postharvest Management Laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) for laboratory analysis.

2.3. Data to be collected

2.3.1. Identification of major insect pest

100g. of sample was taken from each of the storage for the laboratory insect identification. The grain was sieved through 2 mm mesh sieve (to remove dead and alive insects from the sample taken and to left the grain on the sieve) as method used by (Abraham, 1995). Both live and dead insects removed from each sample were counted, placed individually in a veil containing a 70% ethanol solution and identified using the procedures described by Borror et al. (2005). The collected insects were identified through their morphological characteristics using a dissecting microscope (at magnification x 25-60) for species identification.

2.3.2. Faecal dropping of rodent

100g. of sample was taken from each of the storage for the rodent faecal dropping identification. The sample was spread out on a plastic sheet to separate rodent faecal dropping. Faecal drooping removed from each sample were weighed and the weight of faecal dropping of rodent present in grain was computed (Brown et al., 2013).

$$\text{Fecal dropping} = \frac{(Weight\ of\ fecal\ dropped)}{100g}$$

2.3.3. Grain damage and weight loss assessment

Assessment of grain damaged: Insect damage was recorded by the count and weighing method. Each hundred (100g) grains were taken from initial to last storage periods and from each of the storage types and the number of insect damaged and un-damaged grain were obtained using a hand lens by searching for the presence of hole on the seeds. The percentage of insect damaged grains was calculated according to the methods used by (Wambugu et al., 2009) as follows

$$\text{Insect damaged grain (\%)} = \frac{\text{Number of insect damaged grain x 100}}{\text{Total number of grain}}$$

Grain weight loss: For the assessment of grain weight loss, 100-grain samples were taken from initial to last storage periods and from each of the storage types and the number of insect damaged and un-damaged grain were identified and tallied using a hand lens to inspect for the presence of a hole or burrow. Grain in each portion were then counted and weighed using a digital balance. The percentage of weight loss was then calculated (Gwinner et al., 1996).

$$\text{Weight loss (\%)} = \frac{(\mathbf{WuxNd}) - (\mathbf{WdxNu})\mathbf{x100}}{\mathbf{Wu\ (Wd+\ Nu)}}$$

In the above formula, Wu is the weight of undamaged seeds, Nu is the number of undamaged seeds, Wd is the weight of damaged seeds and Nd is the number of damaged seeds.

2.4. Data analysis

A 2 x 3 factorial design was used for the analysis of damaged grain, weight loss of maize and sorghum kernels stored in the farmers' traditional storage structures with two storage types (Gombisa/Gotera and polypropylene sack) and three storage duration levels (1^{st}, 3^{rd} and 5^{th}) months. The data on the insect count, percent grain damage and weight loss were analysed using one-way analysis of variance (ANOVA) with a generalized linear model. Then the data were arcsine transformed to normalize the variances. Significance level was set at 0.05, and the means were separated by Tukey's Honestly Significant Difference test. All statistical analyses were conducted using MINITAB 16 statistical software

3. Results And Discussion

3.1. Identification of storage insect pests

Maize weevils (*Sitophilus* spp.), Angoumois grain moth (*Sitotroga cerealella*), and flour beetle (*Tribolium* spp.) were the insect species identified from both samples (Table 1). In Omo Nada district, there were significant differences in the number of maize weevil recorded during storage periods of stored maize ($P = 0.05$), but the storage type did not affect the number of insects. However, in Bako Tibe district, the number of maize weevil showed highly significant ($P = 0.005$) differences, with interaction effects of storage duration and storage types. Whereas, in stored sorghum grain there were significant differences in the number of maize weevil recorded during storage periods both in Omo Nada ($P = 0.014$) and Bako Tibe ($P = 0.020$) districts. In both districts the number of Angoumois grain moth and flour beetle recorded in stored maize and sorghum were significantly ($P < 0.05$) affected by storage durations with the exception of flour beetle recorded in stored maize in Bako Tibe district.

Table 1

Number of insect pests sampled from maize and sorghum grain (100 g^{-1} grain) in the Omo Nada and Bako Tibe districts, south western Ethiopia.

Grain types	Storage duration (Months)	Gombisa			Polypropylene bag		
		Sitophilus spp.	*Tribolium spp.*	*Sitotroga cerealella*	*Sitophilus spp.*	*Tribolium spp.*	*Sitotroga Cerealella*
Omo Nada district							
Maize	1st	6.0 ± 1.53a	2.0 ± 1.53a	2.3 ± 1.20ab	4.7 ± 1.85a	0.7 ± 0.33b	1.3 ± 0.33b
	3rd	31.3 ± 2.68b	3.3 ± 0.88b	4.0 ± 1.76ab	8.0 ± 1.73a	2.0 ± 0.00ab	6.3 ± 2.18ab
	5th	36.3 ± 2.64b	6.0 ± 1.52a	6.0 ± 2.31a	7.3.0 ± 1.73a	4.0 ± 1.00ab	10.0 ± 1.53a
Sorghum	1st	8.7 ± 2.18	0.3 ± 0.33	0.7 ± 0.67	2.0 ± 1.15	0.0 ± 0.00	2.3 ± 0.88
	3rd	9.3 ± 1.20	1.0 ± 0.88	3.7 ± 1.86	8.3 ± 2.53	1.3 ± 0.67	1.7 ± 0.88
	5th	22.7 ± 4.37	5.3 ± 2.85	8.3 ± 1.67	20.3 ± 3.22	7.3 ± 0.84	7.0 ± 4.73
Bako Tibe district							
Maize	1st	2.7 ± 2.18b	0.3 ± 0.33a	0.7 ± 0.33a	2.7 ± 1.45b	0.7 ± 0.67a	1.3 ± 0.33bc
	3rd	17.7 ± 2.17b	1.0 ± 0.58ab	6.3 ± 2.40abc	12.0 ± 1.53b	1.3 ± 1.33a	4.0 ± 2.65abc
	5th	44.3 ± 3.81a	1.3 ± 0.67ab	11.3 ± 2.60a	15.0 ± 3.00b	4.3 ± 1.45b	9.3 ± 0.33ab
Sorghum	1st	5.3 ± 0.67bc	0.3 ± 0.33	0.3 ± 0.11c	1.7 ± 0.88c	0.0 ± 0.00	1.7 ± 0.67c
	3rd	19.3 ± 3.22ab	1.0 ± 0.58	3.0 ± 1.53bc	9.7 ± 0.88abc	1.3 ± 0.88	2.0 ± 1.15c
	5th	25.0 ± 4.00a	2.7 ± 1.33	7.3 ± 0.88ab	21.3 ± 2.41ab	3.7 ± 1.20	7.7 ± 0.88a

Means within a column followed by different letters are significantly different at P < 0.05 (Tukey test)

Note

Unplastered gombisa/gotera in Omo Nada and plastered gombisa/gotera in Bako Tibe district.

3.2. Faecal droppings of rodent

Figure 1 shows result of faecal dropping in maize and sorghum grain stored in gombisa during five consecutive months of storage period. In Omo Nada faecal dropping collected from maize ranged from 0.33–1.29 g droppings/100 g of sample, while in Bako Tibe it was ranged from 0.58-1.13g droppings/100 g of maize. In Omo Nada it was ranged from 0.44-0.92g droppings/100 g of sorghum, while in Bako Tibe it was ranged from 0.58-1g droppings/100 g of sorghum.

3.3. Grain damage and weight loss

The percent damage of stored maize grain was significantly affected by storage type ($F_{1, 12} = 8.92$; $P < 0.01$) and storage duration ($F_{2, 12} = 417.16$; $P < 0.001$) with the highest percent damage (60.5 ± 0.6) was observed in grain stored in *Gombisa/ Gotera* at fifth month of storage duration (Table 2). The percent damage of stored sorghum showed significant differences with storage duration ($F_{2, 12} = 335.73$; $P < 0.001$) (Table 2). In all grain type, damage increased with increase in storage duration (Table 2).

Table 2
Insect damage (% number) of maize and sorghum grains during storage in different storage structures in southwestern Ethiopia.

Grain types	Storage types	Storage duration (Months)		
		1st	3rd	5th
Maize	*Gombisa/ Gotera*	10.3 ± 0.6d	37.5 ± 2.6c	60.5 ± 0.6a
	PP sack	9.3 ± 0.8d	34.8 ± 2.3c	52.3 ± 1.6b
Sorghum	*Gombisa/ Gotera*	5.3 ± 0.4c	23.3 ± 1.9b	37.8 ± 0.4a
	PP sack	5.0 ± 0.9c	21.3 ± 2.0b	36.0 ± 0.9a

Means within a column followed by different letter(s) are significantly different at $P < 0.05$ (Tukey test). Values are mean ± SE.

The percent weight loss (WL) of stored maize grain was significantly affected by storage duration ($F_{2, 12} = 310.82$; $P < 0.001$). Similarly, the WL of stored sorghum varied significantly among storage durations ($F_{2, 12} = 198.54$; $P < 0.001$). In all grain type, WL increased with increase in storage duration (Table 3).

Table 3
Mean percentage of weight loss of maize and sorghum grains during storage in different storages structures in southwestern Ethiopia.

Grain types	Storage types	Storage duration (Months)		
		1st	3rd	5th
Maize	*Gombisa/ Gotera*	2.4 ± 0.4c	8.3 ± 0.7b	14.3 ± 0.2a
	PP sack	2.1 ± 0.6c	7.9 ± 0.1b	12.4 ± 0.2a
Sorghum	*Gombisa/ Gotera*	1.9 ± 0.1c	4.9 ± 0.5b	10.3 ± 0.6a
	PP sack	1.8 ± 0.1c	4.6 ± 0.5b	10.2 ± 0.4a

Means within a column followed by different letter(s) are significantly different at $P < 0.05$ (Tukey test). Values are mean ± SE.

4. Discussion

In the present study, Sitophilus spp., S.cerealella, and Tribolium spp. were recorded in maize and sorghum grains stored in gombisa and polypropylene bags storage containers. These species are reported as the main storage insect pests of cereal grains in several parts of Ethiopia (e.g., Mendesil et al. 2007;Demissieet al., 2008; Tadesse et al., 2008; Tefera, 2016) and other African countries (e.g., Tefera, 2012; Midega et al., 2016; Abass et al., 2018). in both study districts and storage types, Sitophilus spp. were the foremost abundant species, which is corroborated by the findings of varied studies, like Mlambo et al. (2017). Angoumois moth was also cosmopolitan and therefore the dominant species attacking different cereal crops in Africa (Mlambo et al., 2017). Consistent with Golob (2002), S. cerealella is especially related to unshelled maize and sorghum soon after harvest. As demonstrated during this study, the amount of every storage insect pest recorded increased because the duration of grain storage increased, leading to considerable losses.

Tefera et al. (2011) observed a rise in grain damage and weight loss due to an increase in densities of storage insects and the duration of the storage period. In earlier studies Dubale et al. (2012) observed a rise in densities of maize weevil and Angoumois gelechiid on maize stored in gombisa and sacks over the storage periods. Dubale et al. (2012) observed an increase in densities of maize weevil and Angoumois grain moth on maize stored in gombisa and sacks over the storage periods.

The presence of faecal dropping in sample grain may be a sign of rodent infestation and it affects the standard attribute of stored grain (Brown et al., 2013). Faecal dropping per 100 g grain increased because the duration of grain storage increased this might flow from to the very fact that gombisa a standard storage structures cannot protect rodent attack. Similar results were reported by Befikadu (2014), that on-farm storage structures like gombisa make grain vulnerable to rodent infestation within the south western a part of the country due to the recent and humid climate, and these structures aren't highly protective generally. Rodents are one among the main postharvest pests causing a substantial amount of losses.

During this study, most farmers considered rodents a significant problem that causes estimated grain losses of 26–50%. A study conducted in Kenya showed that farmers perceived rodents causing up to 43% and 30% of losses of maize stored on cobs and shelled grain, respectively (Ognakossan et al., 2016).

The results presented above show that postharvest insect pests cause severe losses in stored grains for small-holding growers in southwestern Ethiopia. Over 50% and 35% of damaged maize and sorghum grain, respectively, were observed by the fifth month of storage in *Gombisa* and polypropylene sack, which are the most common traditional storage structures in the study areas. Consistent with FAO (2010), an estimated loss of 20–30% occurred in Africa thanks to poor postharvest management practices. For instance, in Ethiopia, the typical grain loss thanks to storage insect pests is estimated to be 10–30% (Tadesse, 2005; MoARD, 2010).

In Ethiopia, Sori and Ayana (2012) reported approximately 64.5% of grain damage in traditional farm stores within three to 6 months. Several factors like storage duration, storage type and management practice may have contributed to high grain damage by storage insect pests (Bounechada et al., 2011; Tefera, 2012). Grain weight loss starting from 10–15% in maize and sorghum were recorded during the fifth month of storage. Hell et al. (2012) observed a 10 to 12% loss of grains stored in traditional storage structures thanks to insect pests in Tanzania. Gonzalez (2013) noted that grain weight loss was found to be hooked in to storage duration, where a rise in storage time results in a big loss in grain weights. Furthermore, Tefera (2012) also reported that storage losses depend on temperature and humidity, which favour the expansion of mould and bug infestation.

In conclusion, no matter storage type, and therefore the traditional storage systems adopted by the farmers within the study areas couldn't effectively protect against storage losses caused by insect and rodent pests. As a result, grains damage consistently increased from the primary to the fifth months of storage. Similarly, grains weight loss increased because the duration of storage increased. This finding indicates the necessity for the development of existing traditional storage facilities and therefore the adoption of improved storage facilities, like hermetic metal silos and PICS bags, which are proven to guard stored grain from insect pest infestation.

Declarations

Availability of Data

The data used to support the results of this study is available upon request from the corresponding author.

Conflicts of Interest

The authors declare that they know the work reported in this paper is not in conflict with financial interests or personal relationships & also no conflicts of interest between the authors.

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References

Abass, A.B., Fischler, M., Schneider, K., Daudi, S., Gaspar, A., Rüst, J., Kabula, E., Ndunguru, G., Madulu, D., Msola, D. 2018. On-farm comparison of different postharvest storage technologies in a maize farming system of Tanzania Central Corridor. Journal of Stored Products Research 77, 55-65.

Abraham T. 995. Insects and other arthropods recorded from stored maize in western Ethiopia. ACSL 4(3):339-343.

AOAC. 2005. Association of Official Analytical Chemists. Official methods of Analysis 4th ed., Washington, DC, USA.

Befikadu, D. 2014. Factors affecting quality of grain stored in Ethiopian traditional storage structures and opportunities for improvement. International Journal of Sciences: Basic and Applied Research 18, 235-257.

Borror, D., De long, D., Triplehorn, C., Norman, F.J. 2005. Introduction to the study of insects. Peter marshal publisher, USA. pp; 377-610.

Bounechada, M., Fenni M., Benia F. 2011. Survey of Insects Pest Stored and Biological Control of Trogoderma Granarium Everts in Setifian Region (North -East of Algeria). Bulletin UASVM Agriculture 68, 70-74.

Brown, P.R., McWilliam, A., Khamphoukeo, K. 2013. Post-harvest damage to stored grain by rodents in village environments in Laos. International Bio deterioration and Biodegradation 82, 104–109

CSA (Central Statistical Agency). 2015. Agricultural Sample Survey, 2011/12 (2004 E.C.), Report on Area and Production of Crops, Volume I, Addis Ababa. Central Statistical Agency of the Federal Democratic Republic of Ethiopia.

Demissie G, Tefera T, Abraham T. 2008. Efficacy of Silicosec, filter cake and wood ash against the maize weevil, Sitophilus zamias Motsch.(Coleoptera: Curculionidae) on three maize genotypes. Journal of Stored Products Research 40, 227-231

Dubale, B., Waktole, S., Solomon, A., Bulitosa, G., Sethu, M.R. 2012. Influence of Agro-ecologies, traditional storage containers, and major insect pests on stored maize (*Zea mays* L.) in selected woredas of Jimma Zone. Asian Journal of Plant Sciences 11, 226-234.

FAO/World Bank. 2010. FAO/World Bank Workshop on Reducing Post-Harvest Losses in Grain Supply Chains in Africa: Lessons learned and practical guidelines. FAO Headquarters, Rome, Italy, 18–19 March 2010, Rome.

Garbaba, C.A., Gurmu, L., Lemessa, F., Hensel, O. 2017. Nutritional deterioration of stored Zea maysL. along supply chain in southwestern Ethiopia: implication for unseen dietary hunger. Journal of Stored Products Research 70, 7-17.

Golob, P. 2002. Pest Management. In: Golob, P., Farrell, G., Orchard, J.E. (Eds). Crop Post-Harvest: Science and Technology, Volume 1: Principles and Practice. Wiley-Blackwell.

González-Torralba, J., Arazuri, S., Jarén, C. and Arregui, L.M. 2013. Influence of temperatures and relative humidity during storage on wheat bread making quality. Journal of Stored Products Research55, 134-144.

Gwinner, J., Harnisch, R. and Mück, O. 1996. Manual of the prevention of post-harvest grain losses. Manual of the prevention of post-harvest grain losses.

Haile-Gabriel, A., and Hundie, B., 2006, Farmers' Post-Harvest Grain Management Choices under Liquidity Constraints and Impending Risks: Implications for Achieving Food Security Objectives in Ethiopia. Poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, and August 12-18.

Hell, K., Ognakossan, K., Tonou, A.K., Lamboni, Y., Adabe, K.E. and Coulibaly, O. 2012. Maize stored pests control by PICS-bags: technological and economic evaluation. IITA.

Hengsdijk H and WJ De Boer. 2017. Post-harvest management and post-harvest losses of cereals in Ethiopia. Food Sec., 9:945–958.

Kumar, D., Kalita, P. 2017. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods 2017, 6- 8.

Mali, P.C.,Vir, S. 2000. Quantitative and Qualitative Losses in Green Gram Stored in Different Containers and Temperatures. Annals of Arid Zone 39, 57-63.

Mali, P.C.,Vir, S. 2005. Effect of storage environment and storage material on qualitative and quantitative losses in pearl millet. Annals of Arid Zone 44, 177-184.

Mendesil, E., Abdeta, C., Tesfaye, A., Shumeta, Z., Jifar, H., 2007. Farmers' perceptions and management practices of insect pests on stored sorghum in southwestern Ethiopia. Crop Protection 26, 1817-1825.

Midega, C.A.O., Murage, A.W., Pittchar, J.O., Khan, Z.R. 2016. Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. Crop Protection 90, 142-149.

Mlambo, S., Mvumi, B.M., Stathers, T., Mubayiwa, M., Nyabako, T. 2017. Field efficacy of hermetic and other maize grain storage options under smallholder farmer management. Crop Protection 98, 198-210.

MoARD. 2010. Ethiopia's Agricultural Sector Policy and Investment Framework (PIF): Ten Year Road Map (2010-2.020). Ministry of Agriculture and Rural Development. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia. 182 pp.

Ng'ang'a, J., Mutungi, C., Imathiu, S.M., Affognon, H. 2016. Low permeability triple layer plastic bags prevent losses of maize caused by insects in rural on farm stores. Food Security 8, 621-633.

Ognakossan E, Affognon H, Mutungi C, Sila D, Midingoyi S-K, Owino W. 2016. On-farm maize storage systems and rodent postharvest losses in six maize growing agro-ecological zones of Kenya. Food Security 16, 1-21.

Rehman, Z.U. 2006. Storage effects on nutritional quality of commonly consumed cereal. Food Chemistry 95, 53-57.

Sofi, P.A., Wani, S.A., Rather, A.G. and Wani, S.H. 2009. Quality protein maize (QPM): genetic manipulation for the nutritional fortification of maize. *Journal of Plant Breeding and Crop Science.* ***1*(6):** 244-253.

Sori, W. and Ayana, A. 2012.Storage pests of maize and their status in Jimma Zone, Ethiopia. African Journal of Agricultural Research 4056-4060.

Stefanello, R., Londero, P.M.G., Muniz, M.F.B., Alves, J.S., Fischer, L. 2015. Chemical composition of landrace maize seeds stored under different conditions. International Food Research Journal 22, 918-922.

Tadesse, A. 1996. Insects and other arthropods recorded from stored maize in western Ethiopia. African Crop Science Journal 4, 339-343.

Tadesse, A. 2005. Crop losses due to pre- and post-harvest pests and its attribution to food security. Paper presented at the workshop on prevention and disposal of obsolete pesticide stocks in Ethiopia– Phase II. 23-24 June 2005, CRDA, Addis Ababa. Crop Protection Department, MoARD.

Tadesse, A., A. Ayalew, E. Getu, and T. Tefera. 2008. Review of research on postharvest pests. In Increasing crop production through improved plant protection, volume I, ed. A. Tadesse, 475–562. Plant Protection Society of Ethiopia and EIAR, Addis Ababa, Ethiopia.

Tadesse, A., Basedow, T. 2004. A survey of insect pest problems and stored product protection in stored maize in Ethiopia in the year 2000. Journal of Plant Disease Protection 111, 257-265.

Tefera T. 2012. Post-harvest losses in African maize in the face of increasing food shortage. Food Security 4, 267-277.

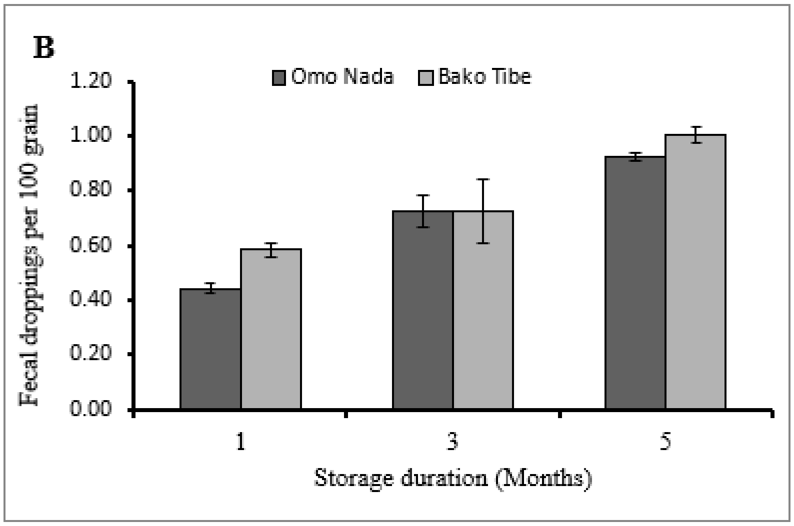
Tefera, T. 2016. Reducing post-harvest losses and increasing food availability. In: Belay Habtegebriel (Ed.), Post-harvest Pest Management Research, Education and Extension in Ethiopia: The Status and Prospects. Proceedings of the 22nd Annual Conference, March 10-420 11, 2016, Addis Ababa, Ethiopia, pp.23-30.

Tefera, T., Mugo, S., Likhayo, P. 2011. Effect of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil, *Sitophilus zeamais*and the larger grain borer, *Prostephanus truncates.* African Journal of Agricultural Research 6, 2249-2254.

Tesfaye, W. and Tirivayi, N., 2018.The impacts of postharvest storage innovations on food security and welfare in Ethiopia. Food Policy 75, 52–67.

Wambugu, P.W., Mathenge, P.W., Auma, E.O. And Van Rheenen, H.A. 2009. Efficacy of traditional maize (Zea mays L.) seed storage methods in western Kenya. African Journal of Food, Agriculture, Nutrition and Development. 9(4): 1110-1128

Figures



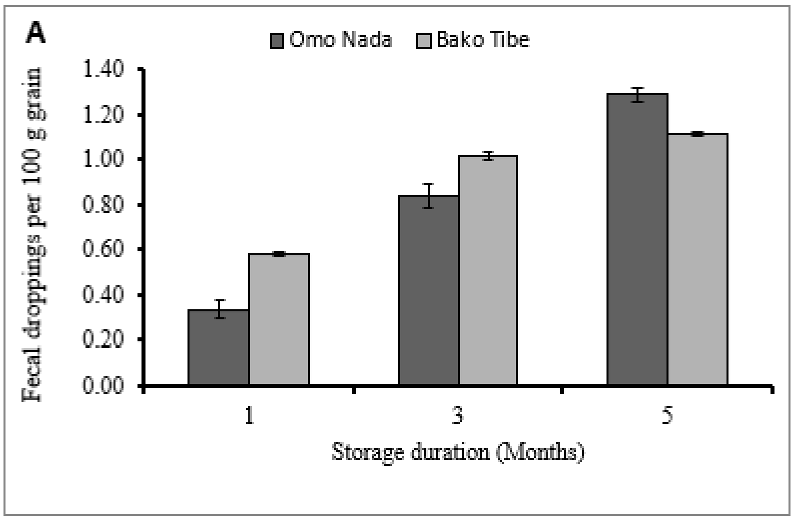


Figure 1

Rodent droppings per 100-g sample (mean ± SE) from maize (A) and sorghum (B) grain sampled over five months in Omo Neda and Bako Tibe district, southwestern Ethiopia.