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Assessment of quantitative and qualitative losses of stored grains due to insect infestation in Ethiopia

Marid Taddese [a], Kumela Dibaba [a], Wakuma Bayissa [a], Debela Hunde [a], Esayas Mendesil [a], Menale Kassie [b], Christopher Mutungi [c], Tadele Tefera [d, *]

[a] Jimma University College of Agriculture and Veterinary Medicine, P. O. Box 307, Jimma, Ethiopia
[b] International Center of Insect Physiology & Ecology (ICIPE), 30772-00100, Nairobi, Kenya
[c] International Institute of Tropical Agriculture Plot No. 25, Mikocheni Light Industrial Area Mwenge, Coca Cola Road, Mikocheni B, 34441, Dar es Salaam, Tanzania
[d] International Centre of Insect Physiology and Ecology, ILRI Campus, Gurd Shola, 5689, Addis Ababa, Ethiopia

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ABSTRACT

This study was designed to determine the quantitative and qualitative losses of stored grains that arise from insect infestation in three districts of southwestern Ethiopia. One district was selected from each zone based on the production potential of the target crops (maize, sorghum, wheat and fababean). A total of 240 farmers' stores from all 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 determine grain weight loss, insect damage, and nutritional losses. 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. The moisture content of the grains decreased along the storage duration. Crude protein and crude fat contents significantly decreased as the storage duration increased in all traditional storage types. Furthermore, the crude fibre and ash contents of the different grain types significantly increased as the storage duration increased in all storage types. These results demonstrated that traditional storage structures have a substantial effect on quantitative and qualitative losses of stored grains. This finding has great implications for food security and hidden nutritional deficits in society. Thus, there is a need to develop and disseminate storage technologies that minimize losses and that are affordable for small farm holders.

1. Introduction

Grains are the main source of nutrition for one-third of the world's poorest population living in Sub-Saharan Africa and South-East Asia. Among the grain crops, rice, wheat and maize are the most important cereals, which contribute more than half of all calories consumed by humans (Awika, 2011). In Ethiopia, grain crops are grown annually on approximately 12.5 million hectares of land; of these, 1.5 million hectares are covered by pulses, of which 443,074.68 ha are dedicated to fababean, with an annual production of approximately 8.4 million quintals (CSA, 2014). Cereals constituted 87.3% of the grain production of the country: 26.8% from maize, 16.1% from sorghum, and 15.7% from wheat (CSA, 2015).

Poor postharvest management, resulting in grain losses, is one of the key constraints to improving food and nutritional security in Africa, including Ethiopia (Midega et al., 2016). In Ethiopia, grain is often stored for less than eight months due to poor storage techniques and inadequate pest management systems (Demissie et al., 2008; Tadesse et al., 2008). Stored grains are damaged by a number of insect pests, leading to qualitative and quantitative losses during storage. Farmers' grain storage losses are further aggravated by poor postharvest handling, inefficient storage facilities and inadequate pest management systems (Demissie et al., 2008; Tefera et al., 2016).

The FAO (2010) estimated a 20–30% loss of grains, with an estimated monetary value of more than US$ 4 billion annually. In Ethiopia, the average grain loss due to storage insect pests is estimated to be 10–30% (Tadesse, 2005; MoARD, 2010). The major postharvest pests of cereal grains in Ethiopia include the maize weevil (*Sitophilus zeamais*), the Angoumois grain moth (*Sitotroga*

* Corresponding author.
E-mail address: ttefera@icipe.org (T. Tefera).

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cerealella), the lesser grain weevil (*Sitophilus oryzae*), and *Callosobruchus* spp. in grain legumes (Demissie et al., 2008; Tefera, 2016). According to Sori and Ayana (2012), *S. zeamais* can cause heavy infestation of maize and sorghum grain stored in traditional storage facilities and result in weight losses of up to 41–80%.

Despite the severe losses incurred by insect pests in poor storage facilities, many farmers in Ethiopia continue to use traditional storage structures to store their grains, thereby providing an abundant food source for the pests, and aggravating damage. In most cases, farmers store grain in traditional storage facilities such as *Gotera* and *Gombisa* (Haile-Gabriel and Hundie, 2006; Tadesse et al., 2008; Dubale et al., 2012). According to these authors, on-farm storage structures such as *Gombisa* make maize susceptible to bio-deterioration, especially in hot and humid climates. In some instances, farmers are forced to sell their produce immediately after harvest and therefore receive low market prices for any surplus grain produced (Kimenju et al., 2009). *Gotera* (above-ground bin), is a common traditional storage structure in Ethiopia. It is located outdoors and usually cylindrical structure, flat or conical at the base, placed on a raised platform or stones, and covered with a conical thatched roof. The *gombisa* is usually an unplastered structure mostly made from bamboo and its roof is covered with thatched grass. *Gumbi* is smaller than Gotera which has got sections fitted together made from mud reinforced with tef straw, sundried and placed in the house (Tadesse et al., 2008).

Despite the importance of grain storage for food security, the potential impact of insect pests on stored grain quality and quantity have not been well investigated. As described by FAO (2014), Kader (2005), Nega and Semeon (2006) and Haile-Gabriel and Hundie (2006), qualitative and quantitative loss studies are generally sporadic in Africa. The current study was therefore designed to quantify the types and magnitudes of postharvest losses from insects in selected grains (maize, sorghum, wheat and fababean) in different storage structures and over different storage periods in several agro-ecological zones of southwestern Ethiopia. The objectives of the study were to quantify the extent of grain damage and weight loss, and to assess the nutritional value losses caused by insect damage.

2. Material and methods

2.1. Description of the study area

The study was conducted in three selected zones of southwestern Oromia, Ethiopia: Jimma, East Wollega, and West Shoa zones. Omo Nada in Jimma zone, Bako Tibe in West Shoa, and Gudeya Bila district in East Wollega were purposively selected based on their potential for growing target crops (wheat, maize, sorghum, and fababean), and high postharvest losses in these selected areas.

Bako Tibe district is found in West Shoa Zone and it is located at 251 km to the west of Addis Ababa. It has an average rainfall of 886.5 mm and an average temperature of 21.2 °C within a range of 14–29 °C. The altitude of the district ranges from 1650 to 2800 m.a.s.l. (BARC, 2014). Gudeya Bila district is part of the former of Bila Sayo district which is situated in East Wollega Zone 272 km west of Addis Ababa. The annual rainfall of Gudeya Bila district ranges from maximum 1700 mm to minimum 1400 mm and with temperature ranges from 36 °C to 11 °C. The altitude of the district ranges from 1800 to 2400 m.a.s.l. and the district has 43.5% low land, 41.5% midland and 15% high land (GBWOARD, 2017). Omo Nada district is found in Jimma Zone which is located at 300 km to the southwest of Addis Ababa. The altitude of the district range from 1000 to 3340 m.a.s.l. The land coverage of the district is about 56.8% arable or cultivable, 25.2% pasture, 6.3% forest, and the remaining 11.7% is considered swampy, degraded or otherwise unusable. In Jimma zone, in addition to maize, sorghum, and fababean, Teff and wheat are important cash crops. Furthermore, coffee is also an important cash crop in this district (Shumeta, 2012).

2.2. Sampling procedure and sample collection

The focus of this study was on four major grain crops: maize, sorghum, wheat and fababean. According to the production status obtained from the agricultural office, maize and sorghum are categorized as high production status crops in Jimma and West Shoa zones, whereas wheat and fababean are high status in East Wollega zone. A total of 240 farmers' stores from all districts were visited and samples collected. The samples were obtained from four types of local storage facilities, including *Gombisa*, *Gotera*, *Gumbi* and polypropylene sack (PP). Farmer and sample selections were made in such a way that they were representative of the district at random. When a selected store did not have a target grain, the next storage was used as a substitute.

A total of 600 g of target grain 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. Subsequent samples were collected from the same stores in the first, third and fifth month of storage, from March to July 2017. For quantitative loss assessment, grain samples collected at monthly intervals were used. The first sample collection was conducted after the target grain was stored for one month. The grain samples were enclosed in plastic bags and brought to the Post-Harvest Management Laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) for laboratory analysis. For nutritional analysis, the grain samples collected during the first, third, and fifth months' sampling period were used.

2.3. Determination of physical parameters

2.3.1. Grain damage

Insect damage was assessed by the count method. One hundred seeds were randomly taken from each grain sample and were observed with a hand lens for the presence of a hole or burrow. The number of insect damaged and un-damaged grains were tallied. The percentage of insect damaged seed was then calculated.

2.3.2. Weight loss

For the assessment of percent weight loss, 100-grain samples were taken randomly from each composite sample. Insect damaged and un-damaged grains were identified and tallied using a hand lens to inspect for the presence of a hole or burrow. The grains in each portion were then counted and after damage assessment the grains were weighed using a digital balance. The percentage of weight loss was then calculated (Gwinner et al., 1996).

$$\text{Weight loss } (\%) = \frac{(Wu^{*}Nd) - (Wd^{*}Nu)^{*}100}{Wu\ (Nd + Nu)}$$

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.

2.3.3. Grain moisture content

The grain moisture content of the sample maize (63.03 g), sorghum (57.01 g), wheat (61.23 g) and fababean (61.48 g) was measured using a calibrated moisture meter (Dickey-john corp. Auburn, IL 62615 USA) (Dubale et al., 2012).

2.4. Proximate composition

The standard methods of the Association of Official Analytical Chemists (AOAC, 2005) were used: crude protein (979.09); crude fat (2003.06); crude fiber (922.16); and total ash (923.03). Total carbohydrate was determined by difference. All analyses were carried out in triplicate.

2.5. Data analysis

A 2 × 3 factorial design was used for the analysis of damaged grain, weight loss, and moisture content of maize and sorghum grains stored in the farmers' traditional storage structures with two storage types (*Gombisa*/*Gotera* and polypropylene sack) and three storage duration levels (1st, 3rd, and 5th months). For the nutritional composition, a 2 × 2 factorial design was used with two storage types (*Gombisa*/*Gotera* and polypropylene sack) and two storage duration levels (1st and 5th months). For the analysis of damaged grain, weight loss, and moisture content of wheat and fababean grains, a 3 × 3 factorial design was used with three storage types (*Gotera, Gumbi* and polypropylene sack) and three storage duration levels (1st, 3rd, and 5th months). A 3 × 2 factorial design was used for the analysis of nutritional composition with three storage types (*Gotera, Gumbi* and polypropylene sack) and two storage duration levels (1st and 5th months).

The data on the percent grain damage, weight loss, and nutritional composition were analysed using with a generalized linear model. Percent grain damage and weight losses 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

3.1. Moisture content of stored grain

The moisture content of grains stored in different storage types decreased in the third month of storage and increased slightly thereafter. The moisture content of maize grain varied significantly across storage durations ($F_{2, 12} = 34.24$; $P < 0.001$). Similarly, the moisture content of sorghum grain was significantly affected by storage durations ($F_{2, 12} = 459.55$; $P < 0.001$). There was also a significant difference in grain moisture content of wheat ($F_{2, 18} = 137.04$; $P < 0.001$) and fababeans ($F_{2, 18} = 155.60$; $P < 0.001$) with the storage durations (Table 1).

3.2. 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). Percent grain damage of stored wheat was significant for storage type ($F_{2, 18} = 9.21$; $P < 0.001$) and storage duration ($F_{2, 18} = 316.31$; $P < 0.001$). Highest percent damage (21.6 ± 7.62) was recorded in grain stored in *Gotera*. The percent damage of fababean was significantly affected by storage duration ($F_{2, 18} = 256.39$; $P < 0.001$). In all grain type, damage increased with increase in storage duration (Table 2).

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 ($F_{2, 12} = 198.54$; $P < 0.001$), whereas WL of stored wheat showed significant differences both in storage type ($F_{2, 18} = 19.38$; $P < 0.001$) and storage duration ($F_{2, 18} = 332.36$; $P < 0.001$), with interaction effects of storage types and storage duration ($F_{4, 18} = 3.36$; $P < 0.05$). Furthermore, WL of stored fababean showed significant differences with storage type ($F_{2, 18} = 9.99$; $P < 0.001$), and duration ($F_{2, 18} = 501.34$; $P < 0.001$). In all grain type, WL increased with increase in storage duration (Table 3).

3.3. Proximate composition

3.3.1. Crude protein

The crude protein content of maize was significantly influenced by storage duration ($F_{1, 8} = 99.85$; $P < 0.001$) (Fig. 1A). Similarly, the crude protein content of sorghum was significantly influenced by storage duration ($F_{1, 8} = 106.83$; $P < 0.001$) (Fig. 1B). There were also significant differences in protein content of both stored wheat ($F_{1, 12} = 33.82$; $P < 0.001$) (Fig. 1C) and fababean ($F_{1, 12} = 20.81$; $P < 0.001$) among storage duration (Fig. 1D). Generally lower protein contents were observed in all type of grains from initial month of storage to fifth month after storage. Furthermore, storage types have no effect on the protein contents of all types of grains.

3.3.2. Crude fat

The crude fat content of maize was significantly affected by storage type ($F_{1, 8} = 6.92$; $P < 0.01$) and storage duration ($F_{1, 8} = 53.43$; $P < 0.001$) (Fig. 2A), whereas the crude fat content of sorghum grain was significantly influenced by storage duration ($F_{1, 8} = 53.19$; $P < 0.001$) (Fig. 2B). There were also significant

Table 1
Moisture content of maize, sorghum, wheat and fababean grains during storage in different storage structures in southwestern Ethiopia.

Grain types	Storage types	Storage duration (Months)		
		1st	3rd	5th
Maize	*Gombisa*/*Gotera*	13.0 ± 0.0a	10.5 ± 0.8b	11.4 ± 0.2b
	PP sack	13.0 ± 0.05a	10.5 ± 0.8b	11.5 ± 0.1b
Sorghum	*Gombisa*/*Gotera*	12.9 ± 0.15a	10.5 ± 0.1c	11.4 ± 0.1b
	PP sack	12.9 ± 0.04a	10.4 ± 0.1c	11.6 ± 0.2b
Wheat	*Gotera*	13.1 ± 0.0a	11.3 ± 0.1cd	12.0 ± 0.3bc
	PP sack	13.0 ± 0.0a	11.0 ± 0.01d	12.1 ± 0.2b
	Gumbi	13.1 ± 0.0a	11.2 ± 0.2d	12.1 ± 0.0b
Fababean	*Gotera*	13.6 ± 0.0a	11.4 ± 0.1c	12.5 ± 0.1b
	PP sack	13.4 ± 0.0a	11.4 ± 0.2c	11.9 ± 0.3bc
	Gumbi	13.4 ± 0.0a	11.3 ± 0.2c	11.8 ± 0.0bc

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

Table 2
Insect damage (% number) of maize, sorghum, wheat and fababean 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
Wheat	*Gotera*	7.3 ± 0.6e	24.3 ± 1.4bc	33.3 ± 0.3a
	PP sack	6.7 ± 1.3e	19.7 ± 2.0cd	31.3 ± 0.58a
	Gumbi	5.0 ± 1.2e	18.3 ± 1.4d	28.7 ± 0.9 ab
Fababean	*Gotera*	7.3 ± 0.9c	22.0 ± 1.1b	30.7 ± 1.0a
	PP sack	6.3 ± 1.2c	18.7 ± 2.1b	29.3 ± 0.3a
	Gumbi	4.7 ± 1.4c	18.0 ± 1.4b	28.3 ± 0.9a

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

Table 3
Mean percentage of weight loss of maize, sorghum, wheat and fababean 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
Wheat	*Gotera*	2.0 ± 0.16e	5.7 ± 0.2c	7.9 ± 0.0a
	PP sack	1.8 ± 0.34e	5.4 ± 0.3c	7.2 ± 0.1 ab
	Gumbi	1.7 ± 0.28e	3.8 ± 0.4d	6.3 ± 0.2bc
Fababean	*Gotera*	2.7 ± 0.1d	5.4 ± 0.2b	7.0 ± 0.1a
	PP sack	2.2 ± 0.2d	4.8 ± 0.3bc	6.8 ± 0.1a
	Gumbi	2.1 ± 0.1d	4.4 ± 0.2c	6.8 ± 0.1a

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

differences in crude fat content of wheat ($F_{1, 12} = 7.52$; $P < 0.001$) (Fig. 2C) and fababean ($F_{1, 12} = 14.98$; $P < 0.01$) with storage duration (Fig. 2D). Generally, fat content of all grain types decreased with storage duration.

3.3.3. Crude fibre

The crude fibre content of maize was significantly influenced by storage duration ($F_{1, 8} = 277.81$; $P < 0.001$) (Fig. 3A). Similarly, the crude fibre content of sorghum was significantly influenced by storage duration ($F_{1, 8} = 263.43$; $P < 0.001$) (Fig. 3B). There were also significant differences in crude fibre content of stored wheat with storage duration ($F_{1, 12} = 141.60$; $P < 0.001$) (Fig. 3C), whereas the crude fibre content of fababean was significantly influenced both by storage type ($F_{2, 12} = 15.26$; $P < 0.001$) and storage duration ($F_{1, 12} = 344.62$; $P < 0.001$) (Fig. 3D). Fibre content of all grain types increased significantly from the initial to five months of storage.

3.3.4. Ash

The ash content of stored maize showed significant differences among storage types ($F_{1, 8} = 93.00$; $P < 0.001$), storage duration ($F_{1, 8} = 527.81$; $P < 0.001$) and had interaction effects between duration and storage type ($F_{1, 8} = 43.80$; $P < 0.001$) (Fig. 4A). The ash content of stored sorghum was significantly influenced by storage duration ($F_{1, 8} = 147.65$; $P < 0.001$) (Fig. 4B). The ash content of stored wheat was significantly influenced by storage duration ($F_{1, 12} = 61.46$; $P < 0.001$) (Fig. 4C), whereas significant differences were observed in ash content of fababean among storage type ($F_{2, 12} = 12.12$; $P < 0.01$) and storage duration ($F_{1, 12} = 69.23$; $P < 0.001$) (Fig. 4D). Ash content of all grain types increased significantly along the storage duration.

4. Discussion

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. Postharvest losses in Africa of 20–30% due to poor management practices have been reported (FAO, 2010). In Ethiopia, the average grain loss due to storage insect pests is estimated to be 10–30% (Tadesse, 2005; MoARD, 2010), while in southwestern Ethiopia, Sori and Ayana (2012) reported approximately 64.5% of grain damage in traditional farm stores within three to six months.

Several factors such as 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 ranging from 10 to 15% in maize and sorghum and 6–8% in wheat and fababean were recorded during the fifth month

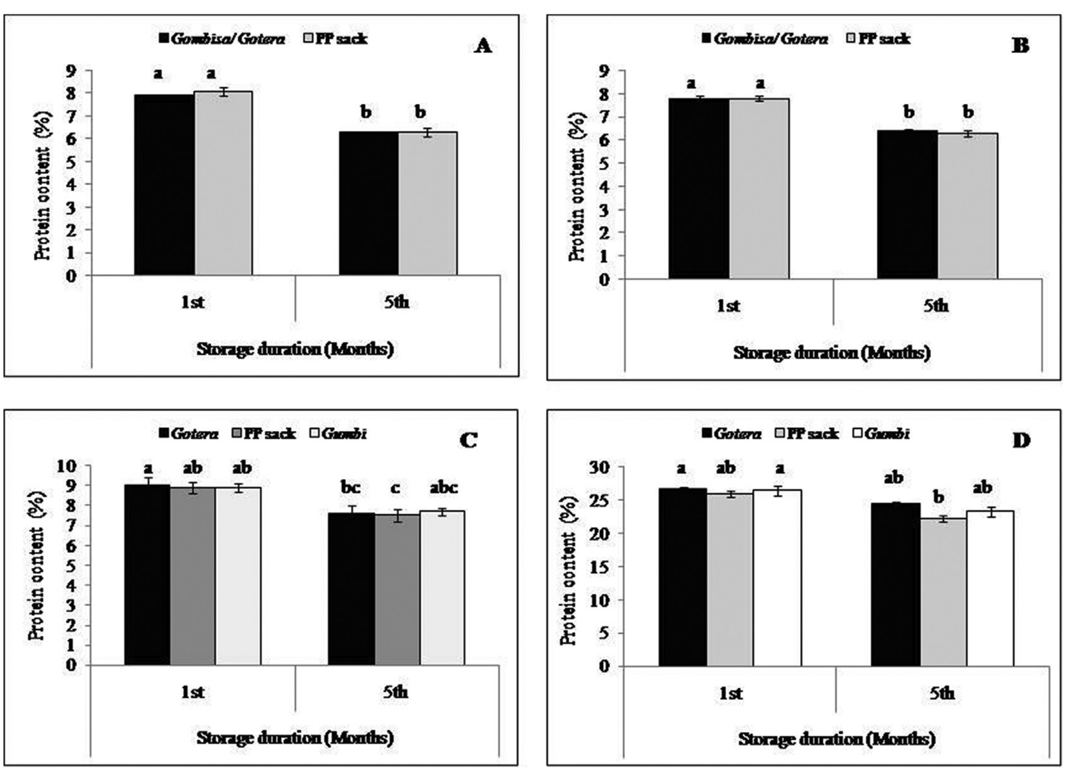

Fig. 1. Crude protein content of maize (A), sorghum (B), wheat (C) and fababean (D) grains during storage in different storage structures in southwestern Ethiopia. Bars with different letter(s) are significantly different at p < 0.05 (LSD test).

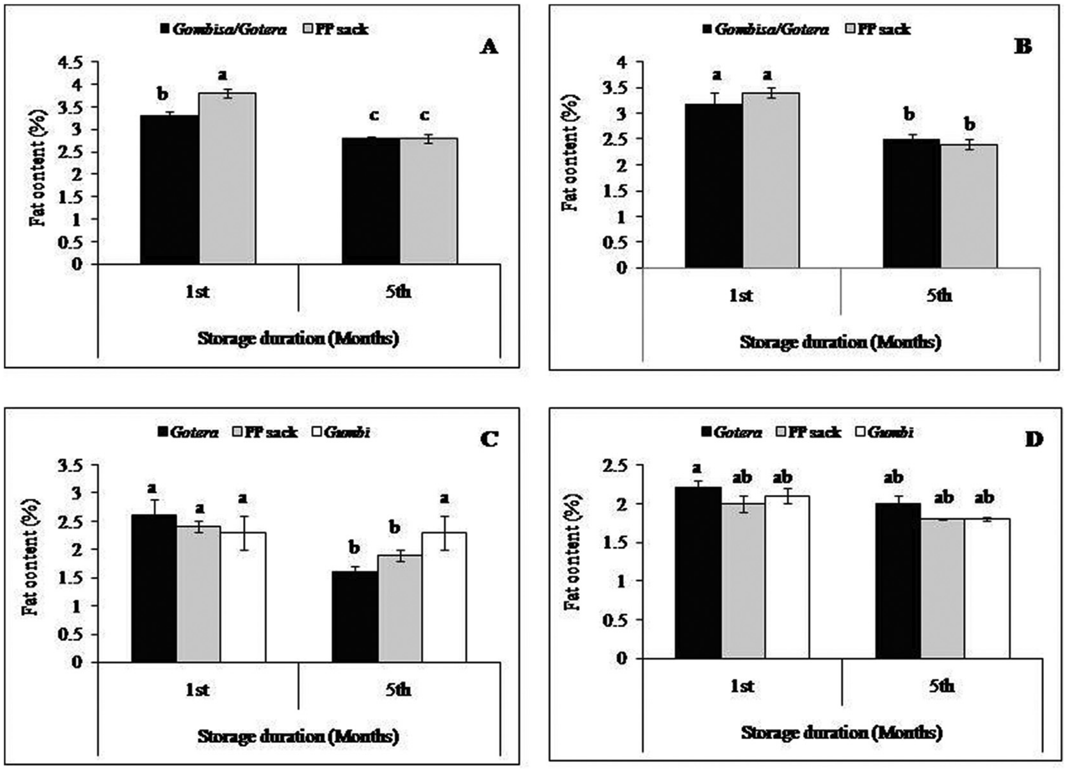

Fig. 2. Crude fat content of maize (A), sorghum (B), wheat (C) and fababean (D) grains during storage in different storage structures in southwestern Ethiopia. Bars with different letter(s) are significantly different at $p < 0.05$ (LSD test).

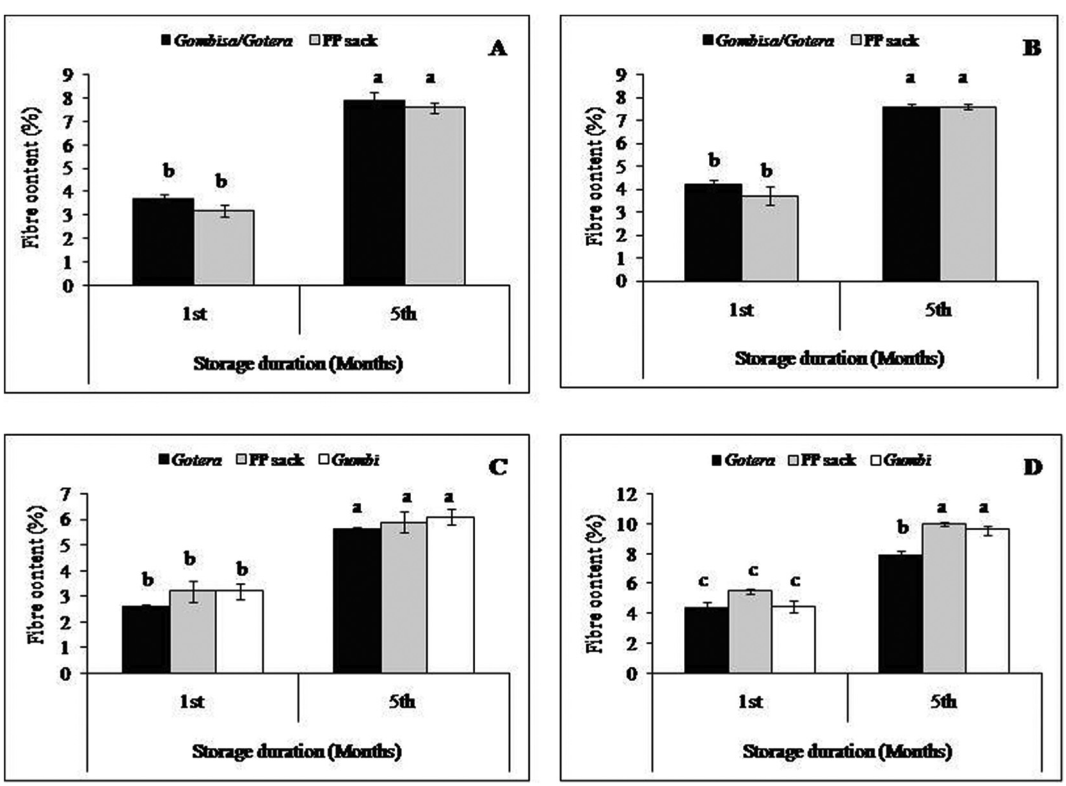

Fig. 3. Crude fibre content of maize (A), sorghum (B), wheat (C) and fababean (D) grains during storage in different storage structures in southwestern Ethiopia. Bars with different letter(s) are significantly different at $p < 0.05$ (LSD test).

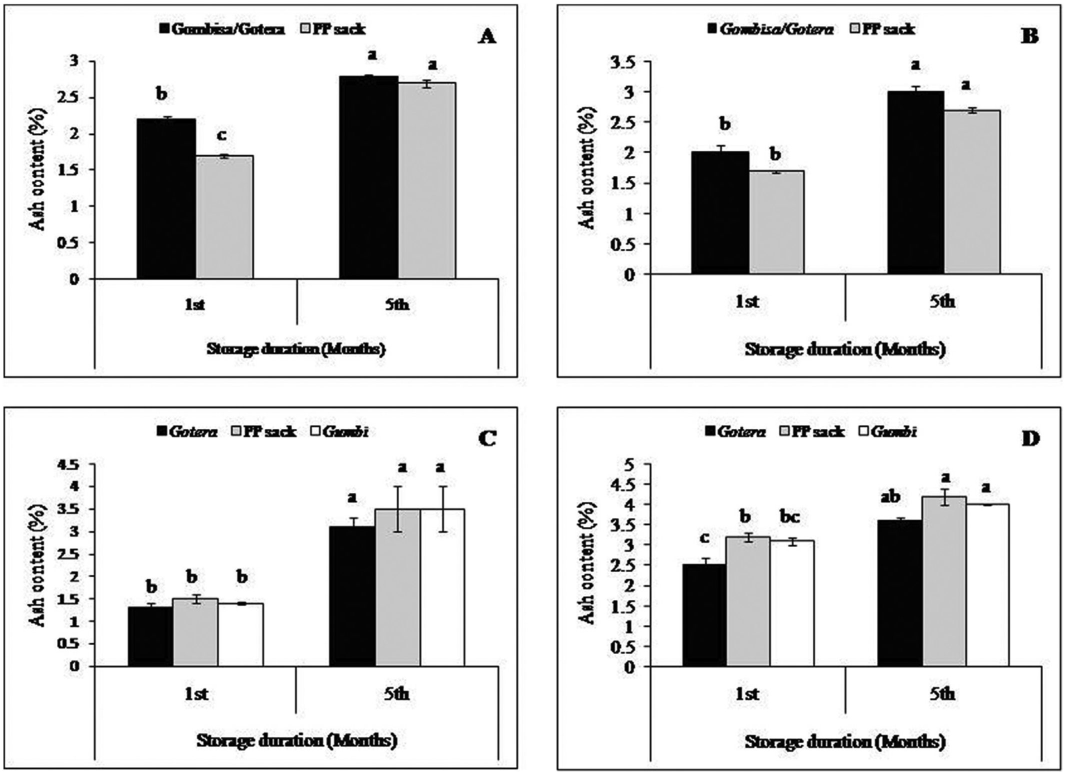

Fig. 4. Ash content of maize (A), sorghum (B), wheat (C) and fababean (D) grains during storage in different storage structures in southwestern Ethiopia. Bars with different letter(s) are significantly different at $p < 0.05$ (LSD test).

of storage. Gonzalez et al. (2013) noted that grain weight loss was found to be dependent on storage duration, where an increase in storage time leads to a significant loss in grain weights. Furthermore, Tefera (2012) also reported that storage losses depend upon temperature and humidity, which favour the growth of mould and insect infestation.

The present study showed a non-significant effect of traditional storage structures on grain moisture content. The hot and humid climate of the southwestern part of the country where this study was conducted coupled with the traditional storage structures which are not hermetic, did not maintain the initial moisture content of the grains and exposed the grains to bio-deterioration (Dubale et al., 2012). In line with this, Abass et al. (2018) recently observed a reduction in moisture content of maize grain stored in non-hermetic containers until 18 weeks of storage, with a slight increase thereafter. Dubale et al. (2012) found reduced moisture content as storage duration increased. Whereas, Garbaba et al. (2017) reported an increased moisture content of maize grains stored in traditional storage structures, whereas fluctuations in grain moisture content may be due to the intermittent opening of storage containers (Abass et al., 2018): grain absorbs or releases moisture from and to the surrounding environment, depending on the moisture content of the environment, due to its hygroscopic nature (Bhattacharya and Raha, 2002; Mlambo et al., 2017). Physical factors such as moisture content play an important role in the storability of grain, where any increment above the safe storage level may affect grain quality and favour fungal growth and insect multiplication (Manandhar et al., 2018).

The present study showed not only losses in quantity of stored grains but also losses of nutritional value including crude protein and crude fat content in traditional storage methods throughout storage. These findings corroborate a number of studies (e.g., Rehman, 2006; Stefanello et al., 2015; Gerbaba et al., 2017). Traditional storage structures expose grains to insect and rodent attack and favour the growth of fungi (Tefera, 2012). Losses in nutritional values, such as protein content, are mainly attributed to storage insect pests, which preferentially feed on grain embryos (Mali and Vir, 2000, 2005). Furthermore, the crude fibre and ash content of the different grains stored in traditional storage structures increased with storage duration, which may be associated with the increase in insect infestation as found by Mali and Vir (2000, 2005) in pearl millet and green gram stored in different containers.

In conclusion, regardless of storage and grain type, the traditional storage systems adopted by the farmers in the study areas could not effectively protect grains against storage losses caused by insect pests. As a result, grain damage consistently increased from the first to the fifth months of storage. Similarly, grain weight loss increased as the duration of storage increased. Furthermore, a loss of nutritional values of stored grains, including crude protein and crude fat content, was observed, mainly due to a poor storage systems coupled with high insect infestation. These findings indicate the need for the improvement of existing traditional storage facilities and the adoption of improved hermetic storage facilities, which have been proven to protect stored grain from insect pest infestation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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