Journal of Stored Products Research 70 (2017) 7–17

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Nutritional deterioration of stored *Zea mays* L. along supply chain in southwestern Ethiopia: Implication for unseen dietary hunger

Chemeda Abedeta Garbaba [a, c, *], Lemlem Gurmu Denboba [a], Fikre Lemessa Ocho [b], Oliver Hensel [c]

[a] Jimma University, College of Agriculture and Veterinary Medicine, P. O. Box 307, Jimma, Ethiopia
[b] Jimma University, P. O. Box 378, Jimma, Ethiopia
[c] Universität Kassel - FG Agrartechnik, Nordbahnhofstr. 1a, 37213, Witzenhausen, Germany

ARTICLE INFO

Article history:
Received 20 June 2016
Accepted 26 October 2016
Available online 11 November 2016

Keywords:
Agro-ecology
Quality loss
Nutrition
Storage duration
Stored maize

ABSTRACT

Maize plays a key role in household food security in southwestern Ethiopia, but its benefits have been negated by high post-harvest losses. Previous loss assessment and management studies have focused mainly on quantity losses. This study was therefore designed to assess nutritional quality losses of stored maize along the supply chain in Jimma Zone, southwestern Ethiopia. Three districts representing potential maize producers and different agro-ecological regimes for maize production were selected for analyses. Sample collection started at harvest and continued for six months at two-month intervals from 21 selected actors along the supply chain. The experiment was conducted for two seasons, and a total of 72 samples were collected during each season. Both nutritional and anti-nutritional analyses were carried out following the international standards of the Association of Official Analytical Chemists. Data were analysed using SAS software (version 9.2) using a general linear model (GLM). The result revealed that moisture content significantly decreases ($P < 0.05$) as storage duration increases under different actors and agro-ecological conditions. But, showed increment during the final months under farmers' storage conditions. In addition, moisture content at the loading stage was not optimal for safe storage. Crude protein, crude fat, carbohydrate, and calorific value content significantly decreased ($P < 0.05$) as the storage duration increased, but fibre, ash, and major mineral (Ca, Zn, and Fe) content increased significantly over the storage period. Phytate and tannin content varied with storage duration and agro-ecological setting. Storing maize under traditional conditions along the supply chain resulted in substantial quality losses. This has great implications for nutrition insecurity and unrecognized undernourishment in the society. Additionally, substantial increases in fibre content above the optimum have important effects on nutrient absorption. There is thus a need to develop and disseminate appropriate storage technologies that minimize quality loss in maize stores.

1. Introduction

Cereal crops are a major agricultural product in Ethiopia and constitute the largest share of domestic food production (EATA, 2013). Of the major cereals produced in the country, maize ranks highest, since it has doubled in both production and productivity within two decades (Demeke, 2012; Abate et al., 2015). In 2010/11, maize accounted 28.07% (4.986 million tonnes) of the total cereal production, as against 22.30% (3.960 million tonnes) for sorghum and 19.61% (3.483 million tonnes) for *teff* which ranked second and third, respectively (Demeke, 2012). Maize consumption's share has increased from 14% in the 1960s to 29% in the 2000s' in Ethiopia, mainly at the expense of *teff*, and at the same time the unit cost of calories from maize is far lower than from all other major cereals produced in the country (Demeke, 2012).

Maize is exposed to high losses during production, but even more significant losses can occur during the post-harvest stage (Golob et al., 2002; Dubale et al., 2012; Tefera, 2012; Befikadu, 2014). Grain preservation is difficult for producers, but post-harvest grain storage is an equally important aspect of food

* Corresponding author. Jimma University, College of Agriculture and Veterinary Medicine, P. O. Box 307, Jimma, Ethiopia.
E-mail addresses: chemedaa@yahoo.com (C.A. Garbaba), lemlem_gurmu@yahoo.com (L.G. Denboba), fikre.lemessa@ju.edu.et (F.L. Ocho), agrartechnik@uni-kassel.de (O. Hensel).

http://dx.doi.org/10.1016/j.jspr.2016.10.004

security in developing countries (IFPRI, 2010; Sori and Ayana, 2012). Grain storage is an important issue since most cereals, including maize, are produced on a seasonal basis (Golob et al., 2002). Seasonal production leads to fluctuations in supply and demand at different stages along the maize supply chain. Storage helps to overcome fluctuations in market supply. As an important post-harvest activity, storage must take into account the bio-deterioration factors that cause quality reduction and consequent nutritional and financial losses (Fourar-belaifa et al., 2011).

Nutritional quality losses during storage are caused by poor post-harvest handling and the natural respiration of grain (Golob et al., 2002), and by damage caused by bio-deterioration (Rehman, 2006; Reed et al., 2007; Farhan et al., 2013; Paraginski et al., 2014). Efficient post-harvest management and quality maintenance of maize depends on the ecological conditions of storage, the storage period, the type of storage structure, and the physical, chemical, and biological characteristics of the grain (Golob et al., 2002; IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Research recommendations also stress the need for nutritional loss assessment of stored products, including maize, and study of the factors that render grain unsuitable for human consumption (Reed et al., 2007; Fourar-belaifa et al., 2011). Furthermore, inappropriate storage and handling of stored grain may lead to the development of fungi, which can result in unacceptable levels of mycotoxin contamination in the tropics (Rashad et al., 2013).

In Ethiopia, maize is usually stored as cobs in traditional storage facilities such as *dibignit, gotera*, and *gombisa* (Tadesse and Basedow, 2004; Abebe and Bekele, 2006; IFPRI, 2010). On-farm storage structures such as *gombisa* make maize susceptible to bio-deterioration in the southwestern part of the country owing to the hot and humid climate, and these structures are not highly protective in general (IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Furthermore, small traders (collectors) and wholesalers use sacks to store shelled maize, and these are not airtight enough to preserve the quality and extend the shelf life of the commodity. Despite the importance of maize storage for food security (availability and nutritional quality), the potential impact of traditional storage structures on stored maize quality has not been well investigated, and there is limited information on the extent of nutritional deterioration during the storage period in southwestern Ethiopia. Furthermore, previous research focused only on the farmers, without considering the other actors along the maize supply chain who play key a role in maize transactions. The current study was therefore designed to investigate the nutritional and anti-nutritional content of stored maize in different agro-ecological settings involving farmers, collectors, and wholesalers in Jimma Zone, southwestern Ethiopia.

2. Materials and methods

2.1. Study site description

The study was conducted in Jimma Zone, which is situated southwest of Addis Ababa, the capital city of Ethiopia. Geographically, it lies between 7°15′ and 8°56′ N latitude and 36°00′ and 38°38′ E longitude. The elevation of the zone ranges from 800 to 3360 m above sea level (m.a.s.l.), and it experiences an average annual rainfall of 1600 mm. The temperature of Jimma Zone varies between a maximum of 25–30 °C and a minimum of 7–12 °C. The agro-ecological setting includes highlands (15%), midlands (67%), and lowlands (18%) (CSA, 2009; Zonal Finance and Economic Development Office of Jimma (ZoFEDO), 2013). In the present study, three districts were purposely selected based on their high maize production potential and their different maize-producing agro-ecologies: Dedo from the highlands, Omo-nada from the midlands, and Sokoru from the lowlands of Jimma Zone (Table 1).

2.2. Sampling procedure and sample collection

Jimma Zone was selected from the southwestern part of Ethiopia specifically for its high maize-producing potential and because nutritional quality losses in maize have been little studied in the region. Three districts were selected that were known to have high maize production and that represented different agro-ecological conditions, according to secondary data from the zonal agricultural office. After discussion with experts and extension agents at each district's agricultural office, three farmers were selected randomly for the current study. These farmers produce the BH-660 variety, dominantly produced in the area and store their maize cobs in *gombisa.* The extensive ventilation of the structure causes moisture leakage into the stored maize cobs from all sides during rainy seasons. High moisture leakage results in mould development and insect pest damage. All maize producers in the area store their maize in *gombisa.*

Three local collectors from each district were selected randomly in order to collect samples for nutritional analyses. To include all actors along the supply chain in Jimma Zone, three wholesalers from Jimma town were also included as they are also participants in maize transactions in the study area. Similar storage structures and the same BH-660 maize variety were used by all traders in the study.

Sample collection was started at the harvesting and loading stage from the farmers' stores and continued every two months for a total six months of storage, as most stored product was depleted by then. From the farmers' stores, twelve cobs were picked from different locations in each *gombisa* (top, centre, and bottom) through a PVC pipe fitted at the middle and bottom of the storage structure that allowed removal of sample cobs; the outside of the PVC pipe was covered with a plastic sheet. Four cobs were removed from each layer, mixed together, shelled on the spot, and maintained in plastic bags for moisture analyses under laboratory conditions. Similarly, 2 kg of grain from the stores of each of the traders (collectors and wholesalers) were sampled through a deep probe into three parts of open-weave sacks and mixed together. The samples were brought to the Post-Harvest Management Department Laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM), for moisture content analyses and

Table 1
Description of study districts and town.

Districts/Town	Annual RF (mm)	Temperature range (°C)	Altitude (m.a.s.l)	Co-ordinates	
				Latitude (N)	Longitude (E)
Dedo	1920	13–22	2500–3360	07°13′–07°39′	36°43′–37°12′
Omo-nada	1880	16–27	1500–2500	07°17′–07°38′	37°00′–37°28′
Sekoru	1467	15–32	1000–1500	07°45′–8°47′	37°20′–37°25′
Jimma town	1600	14–30	1780	07°41′	36°50′

for sample preparation for nutritional and anti-nutritional analyses. The experiment was carried out during the two production seasons of 2013/14 and 2014/15, starting from the end of December until June in each case. Samples collected daily were coded for analysis. In total, 72 samples were collected per season.

2.3. Experimental design

A 3 × 4 factorial design was used for the determination of the nutritional composition of maize kernels stored in the farmers' traditional storage structures. Three agro-ecological levels (highland, midland, and lowland) and four storage duration levels (at harvest, and at two, four, and six months) were used at the farmer level. Three farmers from each agro-ecological setting were used as replicates. Factors such as storage structure, maize variety, and all management practices were kept uniform to overcome bias. For the collectors, a 3 × 3 factorial design was used that included the three agro-ecological levels (highland, midland, and lowland) of the respective districts and three storage duration levels (two, four, and six months). For all collectors, the same maize variety and the same open-weave sacks were used uniformly. As with the farmers, three collectors from each district were used as replicates. For the wholesalers, three actors were included in the study with three level of storage duration. A completely randomized design was used and the samples were collected from Jimma town alone, as there was no wholesaler at the district level. Both collectors and wholesalers store their maize in non-airtight sacks that can hold 100 kg.

2.4. Nutritional and anti-nutritional analyses

The nutritional components of all the stored maize samples, including proximate composition, minerals, carbohydrate (CHO), calorific value, and anti-nutritional content, were determined on a dry-weight basis. And, grain moisture content (m.c.) was measured using the oven method on a dry-weight basis (db). All proximate composition analyses of the grain followed the Association of Official Analytical Chemists (AOAC, 2005) methods for total ash (923.03), crude protein (979.09), crude fat (2003.06), and crude fibre (922.16). Major minerals including calcium, zinc, and iron were analysed with a flame Atomic Absorption Spectrophotometer (AAS) (Autosampler AA 6800, Japan) per AOAC method 985.35, and phosphorus content was measured per AOAC method 965.17 (AOAC, 2005). Condensed tannin and phytate levels were also determined following established methods (Maxson and Rooney, 1972; Vaintraub and Lapteva, 1988). The nutritional and anti-nutritional analyses were carried out at the accredited laboratory of the Ethiopian Public Health Institute (EPHI) in Addis Ababa, Ethiopia. All sample analyses were carried out in triplicate.

2.5. Data processing and analysis

Analyses of proximate composition, minerals, carbohydrate, calorific value, and anti-nutritional factors were done for two production seasons (2013/14 and 2014/15). Means of the values from the two production seasons were used for the analyses (Farhan et al., 2013), which were carried out using SAS version 9.2 after checking the analysis of variance (ANOVA) assumptions. ANOVAs were carried out using a general linear model (GLM). Wherever significant differences were observed, the means were separated using Tukey's Honestly Significant Difference (HSD) test at the 5% probability level. Finally, R software used to draw the graphs and figures.

3. Results

3.1. Nutritional analyses

3.1.1. Moisture content and proximate composition

3.1.1.1. Moisture content. The m.c. of stored maize under the farm storage conditions showed highly significant (P = 0.0003) differences with interaction effects of storage duration and changes in agro-ecology. The highest (24.90%) and lowest (13.00%) means were recorded from the highland and lowland agro-ecologies (Table 2), respectively. Moisture content at the loading stage was not optimum to preserve the shelf life of the product. Likewise, the

Table 2
Moisture, protein and fibre content of stored maize kernels under farm condition.

Quality traits (%)	Agro-ecology	Storage duration (months)				P-Value
		0	2	4	6	
Moisture	Lowland	19.2 ± 0.5^{bc}	$16.4 \pm 0.5^{c-e}$	13.0 ± 0.5^{f}	$15.6 \pm 0.5^{d-f}$	0.0003
	Midland	20.6 ± 0.5^{b}	$16.8 \pm 0.5^{c-d}$	13.4 ± 0.5^{f}	$15.2 \pm 0.5^{d-f}$	
	Highland	24.9 ± 0.5^{a}	$18.0 \pm 0.5^{b-d}$	$13.9 \pm 0.5^{e-f}$	$16.9 \pm 0.5^{c-d}$	
Protein	–	9.1 ± 0.3^{a}	8.6 ± 0.3^{ab}	7.7 ± 0.3^{bc}	7.2 ± 0.3^{c}	0.001
Fibre	–	4.2 ± 0.3^{d}	5.4 ± 0.3^{c}	7.2 ± 0.3^{b}	8.5 ± 0.3^{a}	<0.0001

Means with the same letter(s) are no significantly different from each other at P < 0.05 along the storage duration and agro-ecology for moisture; along the row for protein and fat content. Values are mean ± SEM.

Table 3
Proximate composition of maize kernels sampled from collector store.

Quality traits (%)	Agro-ecology	Storage duration (months)			P-value
		2	4	6	
Moisture	–	16.1 ± 0.2^{a}	14.5 ± 0.2^{b}	14.0 ± 0.2^{b}	<0.0001
Protein	Lowland	9.1 ± 0.2^{b}	9.6 ± 0.2^{b}	7.2 ± 0.2^{c}	0.01
	Midland	8.6 ± 0.2^{b}	9.3 ± 0.2^{b}	7.0 ± 0.2^{c}	
	Highland	11.2 ± 0.2^{a}	9.8 ± 0.2^{b}	8.7 ± 0.2^{b}	
Fibre	–	4.4 ± 0.5^{b}	6.7 ± 0.5^{a}	8.4 ± 0.5^{a}	0.0005
Ash	–	0.7 ± 0.1^{b}	0.9 ± 0.1^{b}	1.1 ± 0.1^{a}	<0.0001

Means with the same letter(s) are no significantly different from each other at P < 0.05 along the storage duration for moisture, fibre and ash; and both along storage duration and agro-ecology for protein. Values are mean ± SEM.

m.c. of maize stored in collector and wholesaler storage was significantly affected by storage duration (Tables 3 and 4).

3.1.1.2. Protein. The protein content of stored maize was significantly affected by storage duration under farm storage conditions (Table 2), but no significant differences were observed across the different agro-ecologies at the producer level. By contrast, significant ($P = 0.01$) interaction effects of storage duration and agro-ecological conditions were observed in the protein content of maize kernels stored under collector conditions (Table 3). In a similar manner, the protein content of maize kernels sampled from wholesaler stores was significantly ($P = 0.001$) affected by storage duration (Table 4). As the storage duration increases, protein content significantly decreases under all actor storage conditions along the maize supply chain.

3.1.1.3. Fibre. The fibre content showed a highly significant increase as storage duration increased under farm storage conditions. At harvest, it was 4.2 ± 0.3%, but it increased to 8.5 ± 0.3% after six months of storage (Table 2). Similar results were obtained in samples taken from collectors and wholesalers (Tables 3 and 4).

3.1.1.4. Fat. The fat content of stored maize was significantly affected by storage duration ($P = 0.0002$) and agro-ecological conditions ($P = 0.0003$) under farm storage conditions. It was 4.5 ± 0.1% at harvest but declined to 3.8 ± 0.1% after six months of storage. Comparing the three agro-ecologies, the highest fat content was recorded in lowland samples (4.5 ± 0.1%), followed by midland (4.3 ± 0.1%) and highland (3.9 ± 0.1%) (Fig. 1). Changes in storage duration ($P < 0.0001$) and agro-ecological conditions ($P < 0.0003$) showed similarly significant differences among the collectors. The highest fat content was recorded from first-round data (5.0 ± 0.1%) but by the end of data collection, it had declined to 4.2 ± 0.1%. A box plot trend for the fat content of stored maize from the collectors is shown in Fig. 2. Likewise, the fat content of maize kernels stored under wholesaler storage conditions was significantly ($P = 0.02$) affected by storage duration (Table 4). Under all storage conditions, the fat content significantly decreased as the storage duration increased.

Table 4
Proximate composition of stored maize under wholesaler condition.

Quality traits (%)	Storage duration (months)			P-value
	2	4	6	
Moisture	15.5 ± 0.2[a]	14.1 ± 0.2[b]	13.5 ± 0.2[b]	0.004
Protein	10.5 ± 0.2[a]	10.3 ± 0.2[a]	8.3 ± 0.2[b]	0.001
Fat	5.2 ± 0.1[a]	5.1 ± 0.1[ab]	4.7 ± 0.1[b]	0.02
Fibre	5.2 ± 0.6[b]	6.6 ± 0.6[ab]	8.1 ± 0.6[a]	0.04
Ash	0.5 ± 0.1[b]	0.8 ± 0.1[ab]	1.1 ± 0.1[a]	0.005

Means with the same letter (s) for each quality trait along the row is not significantly different from each other at $P < 0.05$. Values are mean ± SEM.

3.1.1.5. Ash. The ash content of stored maize was significantly affected by storage duration ($P = 0.003$) and agro-ecology ($P = 0.02$) under farm storage conditions (Fig. 3A and B). Likewise, maize kernels' ash content from collectors was highly and significantly ($P < 0.0001$) affected by storage duration (Table 3), and similar results were recorded from wholesalers (Table 4).

3.1.2. Carbohydrate content

The CHO content of maize stored under farmer and collector conditions was highly and significantly affected by both storage duration and differences in agro-ecology (Fig. 4A–D). The CHO content of maize kernels from wholesalers was also significantly affected by storage duration (Fig. 4E). The mean CHO content of maize showed decrement as storage duration increased under farmer conditions (Fig. 4A). A similar decreasing trend was observed for maize stored under collector (Fig. 4D) and wholesaler (Fig. 4E) conditions.

3.1.3. Calorific value

Significant effects of storage duration ($P < 0.0001$) and agro-ecology ($P = 0.003$) were observed on the calorific value of maize stored under farmer conditions (Fig. 5A and B). Under collectors and wholesaler storage conditions, the calorific value similarly decreased significantly ($P < 0.05$) as storage duration increased (Fig. 5C and D).

3.1.4. Major minerals

Fe, P, and Ca content were significantly affected by interaction effects of storage duration and agro-ecology under farmer and collector conditions (Tables 5 and 6). However, Zn content was significantly affected by both storage duration and agro-ecology for each explanatory variable separately under farm storage conditions ($P < 0.0001$) (Fig. 6A and B). Similar results were observed for storage duration ($P < 0.0001$) and agro-ecology ($P = 0.0006$) under collector conditions (Fig. 6C and D). The mineral content of stored

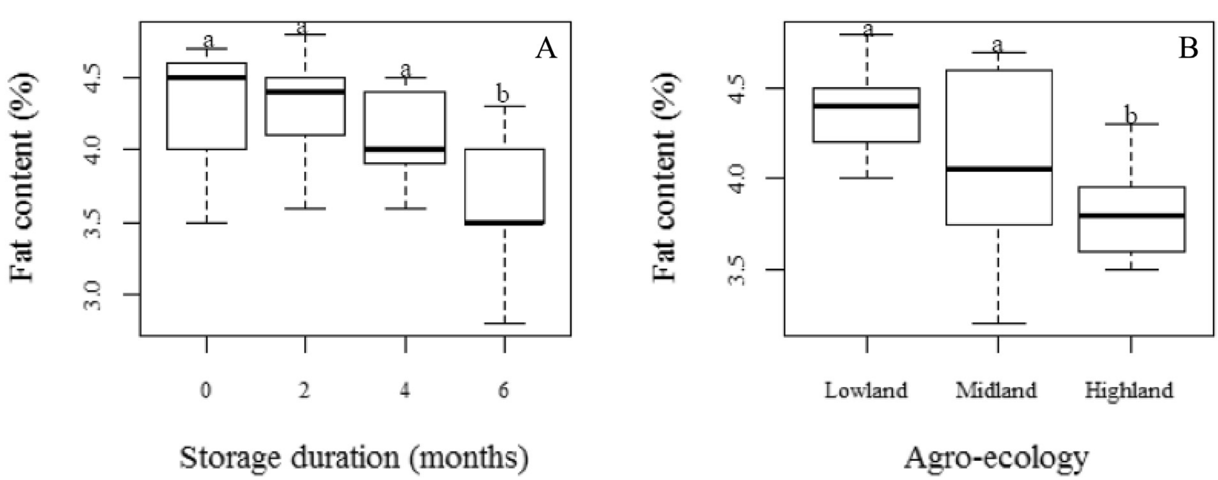

Fig. 1. Box plots for fat content trend of maize kernels collected from farmers store A) across storage duration ($P = 0.0002$) B) under different agro-ecology ($P = 0.0003$). Box plots with the same letter(s) for each figure are not significantly different from each other at $P < 0.05$. Error bars are the range values.

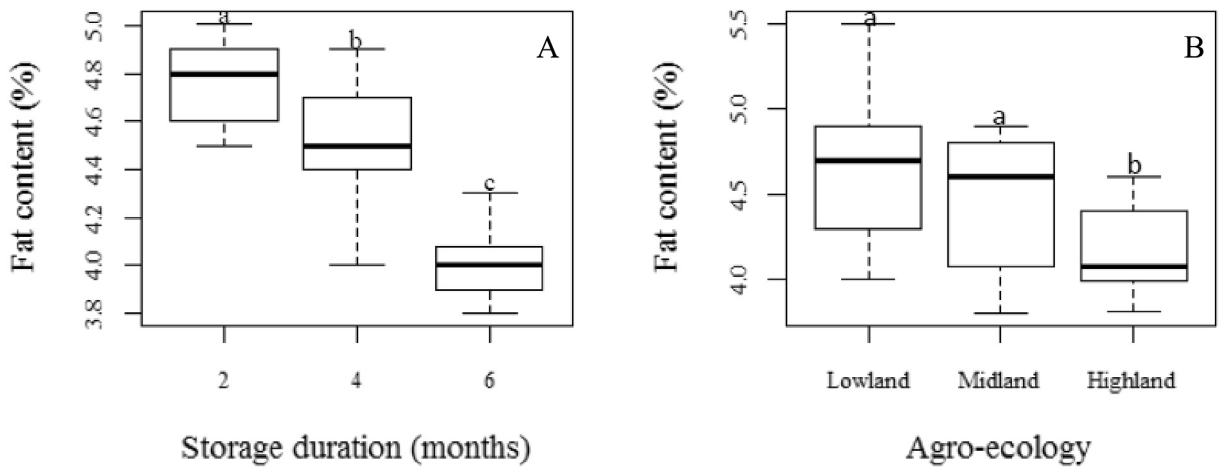

Fig. 2. Box plots of fat content of maize kernels collected from collectors store A) storage duration (P < 0.0001) B) Under different agro-ecology (P < 0.0003). Box plots with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

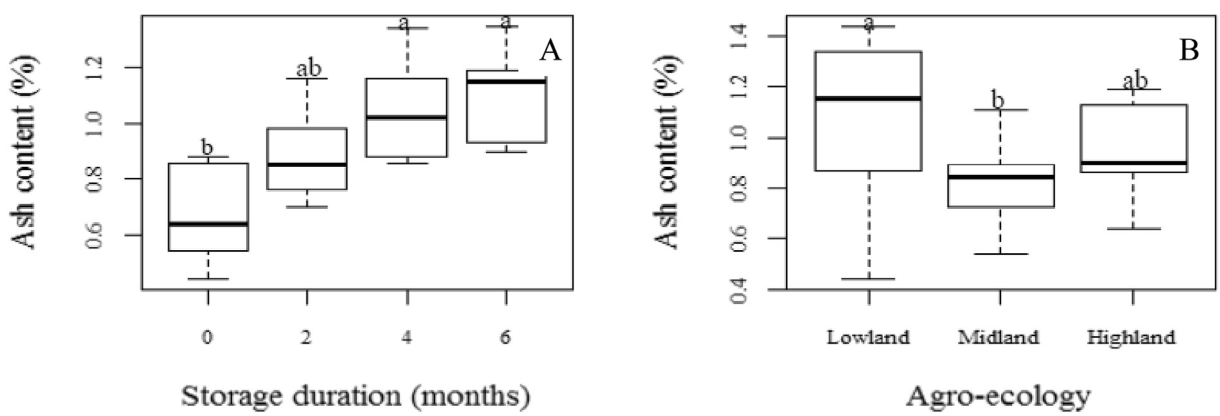

Fig. 3. Box plots for ash content trend of maize kernels collected from farmers store A) across storage duration (P = 0.003) B) under different agro-ecology (P = 0.02). Box plots with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are range values.

maize under wholesaler conditions was also significantly affected by storage duration (Fig. 7A and B).

3.2. Anti-nutritional content

The phytate content of stored maize under farm storage conditions was significantly affected by storage duration (P = 0.007) and differences in agro-ecology (P < 0.0001), and the trends are indicated in Fig. 8A and B, respectively. The trend in phytate content showed a very slight increment initially but then showed a slight decline during the last sampling period. Both storage duration and agro-ecology showed a highly significant (P < 0.0001) interaction effect on condensed tannin content of maize stored under farmer conditions. The highest tannin content, however, was recorded at harvest (Fig. 8C). Maize sampled from collectors showed a significant (P = 0.01) interaction effect of storage duration and change in agro-ecology on anti-nutritional content (Fig. 9A and B).

4. Discussion

Moisture content is one of the key factors in grain storage. It showed a slight decrement under farm storage conditions, but during the last months of data collection, it showed a percentage increase. As storage duration increases, particularly during last months of data collection it coincides with rainfall and moisture entered into the storage units through the perforated walls of the *gombisa* and so increased grain m.c. Stored maize kernels are hygroscopic in nature which absorb and release moisture from the surrounding external environment, and this affects the biological and biochemical activities of the kernels (Rashad et al., 2013). In contrast, with the present findings, declines in m.c. during storage have also been reported (Dubale et al., 2012; Oladele and Osipitan, 2013). On the other hand, increases in the m.c. of maize grain from 11.3% to 23.9% under traditional farm storage conditions have been reported from Uganda (Costa, 2014). The decline of maize kernel m.c. from 14.0% to 10.6% after eight months of storage, followed by an increase to 13.0% after twelve months of storage due to absorption of moisture from surrounding atmosphere, has also been reported (Bhattacharya and Raha, 2002). Stored maize kernels consist of a constant amount of dry matter but the water content varies (Devereau, 2002).

A higher maize m.c. above safe storage levels are one of the key factors in fungal growth and causes the nutritional quality of the product to deteriorate. It was observed during sample collection that mouldy maize kernels were very common in almost all stores. Higher kernel moisture content resulted in more susceptibility to the mould and insect damage that affects final quality (Rashad et al., 2013). Rainfall usually starts around March and reaches its peak for the year around July in the study region. In addition to moisture leakage into the stored product during the rainy season,

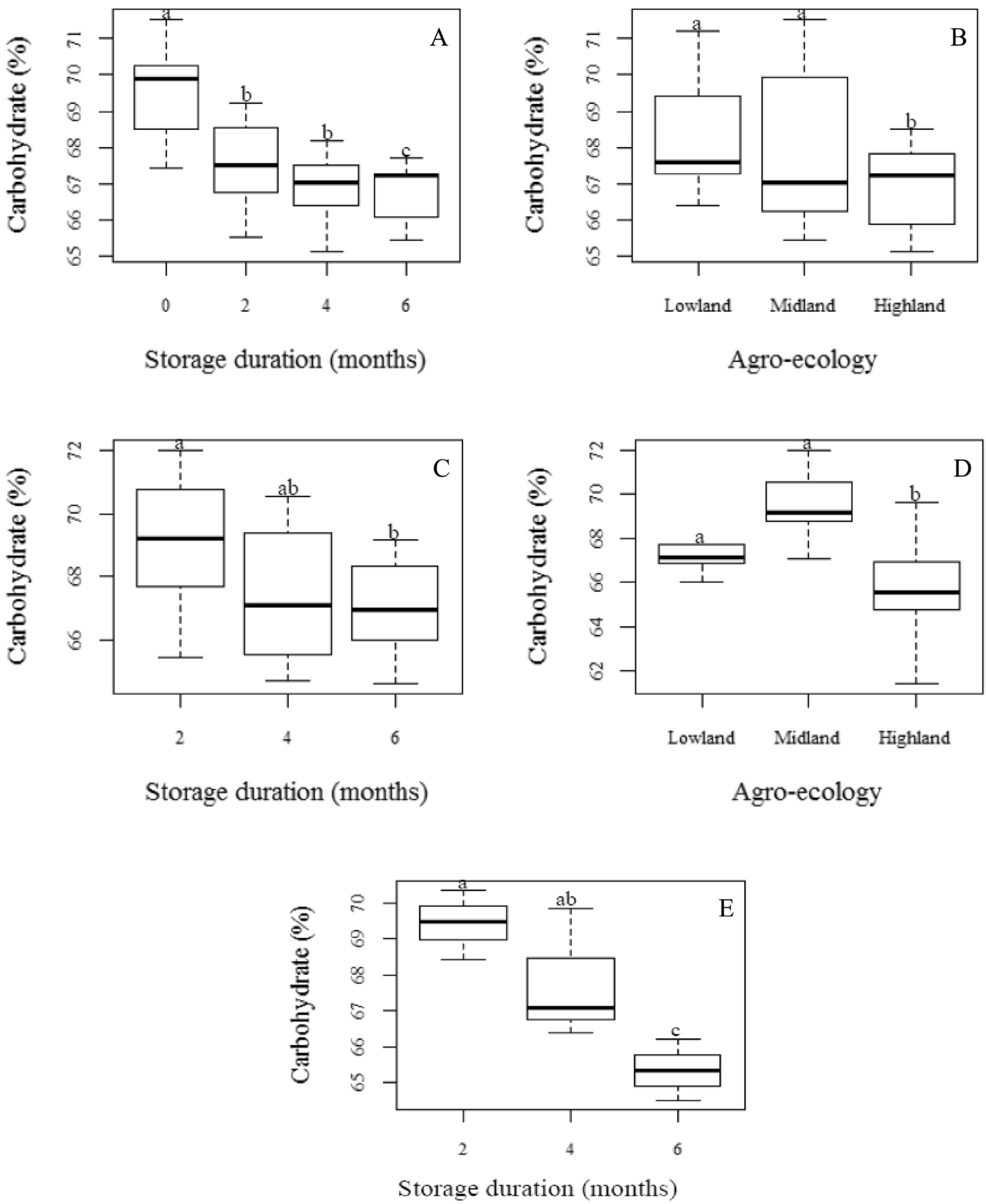

Fig. 4. Box plots for carbohydrate content of stored maize A) under farm conditions for storage duration (P < 0.0001) and B) at different agro-ecology (P = 0.003); C) Under collector conditions along the storage duration (P = 0.002) and D) at different agro-ecology (P < 0.0001); E) Under wholesaler condition along the storage duration (P < 0.0001). Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

m.c. at the loading stage (19%–25% on average) was also not optimum for safe storage. The moisture content of maize kernels for long-term storage should be around 12%–13% (Befikadu, 2014).

The present study found a reduction in protein content of up to 20.8%, 37.5%, and 11.4% for maize kernels stored under farmer, collector, and wholesaler storage conditions, respectively. Previous research reports on seven maize varieties, however, showed that crude protein content of different white maize varieties increased after weevil infestation (Tongjura et al., 2010). Another report, by contrast, found that maize kernels stored for three months showed a 7.1% of protein content reduction due to mite infestation, perhaps because of selective feeding by the mites on the germ part of the grain (Farhan et al., 2013). In a similar manner, fungi also invade and cause damage to the germ and endosperm part of the grain,

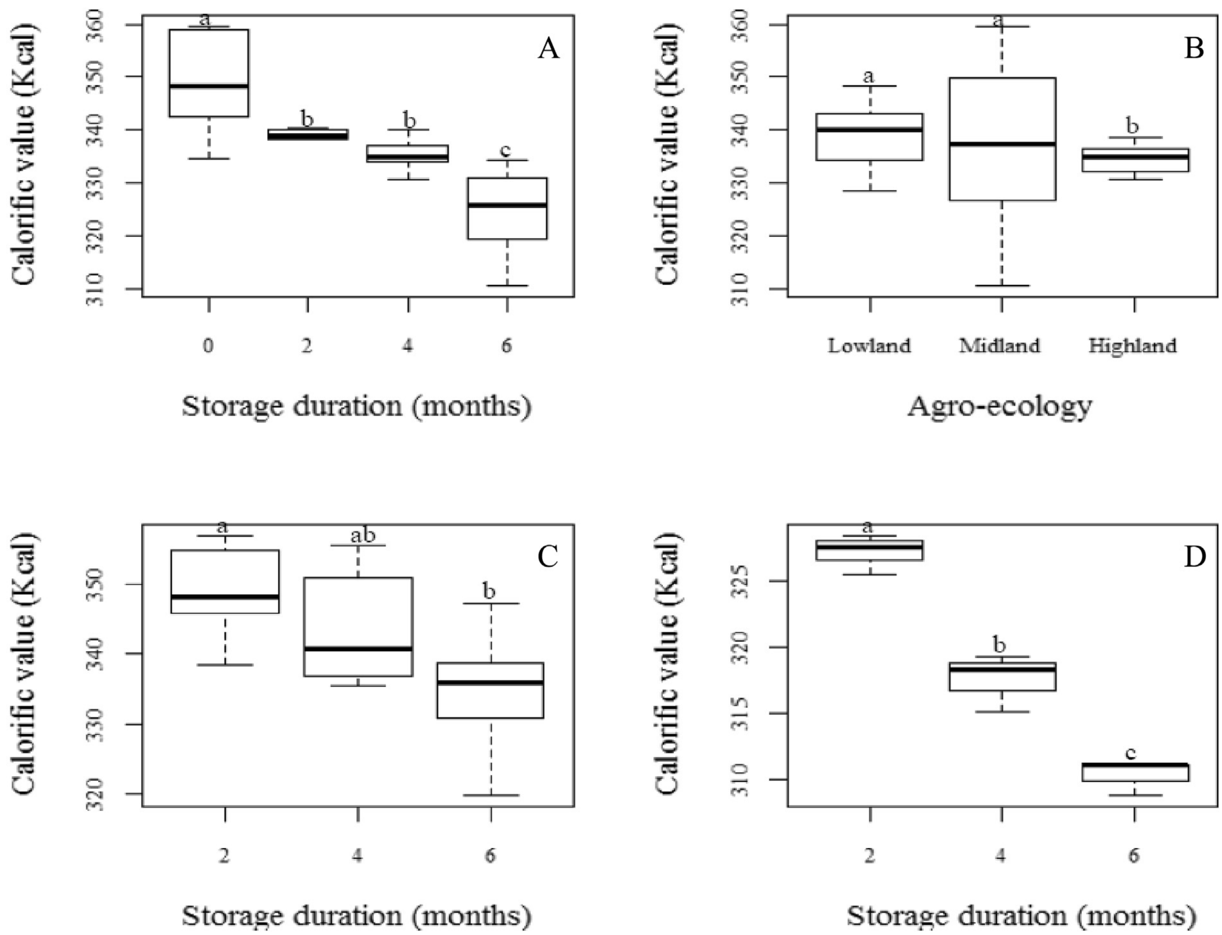

Fig. 5. Box plots for calorific value of stored maize A) farm condition along storage duration ($P < 0.0001$) and B) across agro-ecology ($P = 0.003$); C) collector condition along storage duration ($P = 0.01$); D) wholesaler condition along storage duration ($P < 0.0001$). Means with the same letter(s) for each figure are not significantly different from each other at $P < 0.05$. Error bars are the range values.

Table 5
Major mineral content of maize kernels stored under farm condition.

Minerals (mg/100g)	Agro-ecology	Storage duration (months)				P − Value
		0	2	4	6	
Fe	Lowland	0.6 ± 0.3^{de}	$1.3 \pm 0.3^{c-e}$	$2.9 \pm 0.3^{a-c}$	4.3 ± 0.3^{a}	0.01
	Midland	0.5 ± 0.3^{e}	$1.9 \pm 0.3^{b-e}$	$2.4 \pm 0.3^{b c}$	4.4 ± 0.3^{a}	
	Highland	0.4 ± 0.3^{e}	$2.0 \pm 0.3^{b-e}$	$3.5 \pm 0.3^{a b}$	$4.7 \pm 0.3^{a-c}$	
Ca	Lowland	2.9 ± 2.3^{g}	13.3 ± 2.3^{fg}	43.0 ± 2.3^{c}	77.1 ± 2.3^{a}	<0.0001
	Midland	3.2 ± 2.3^{g}	18.8 ± 2.3^{ef}	30.2 ± 2.3^{de}	60.4 ± 2.3^{b}	
	Highland	6.6 ± 2.3^{g}	23.9 ± 2.3^{ef}	38.5 ± 2.3^{cd}	55.2 ± 2.3^{b}	
P	Lowland	$261.2 \pm 22.6^{a-c}$	$221.1 \pm 22.6^{a-d}$	291.9 ± 22.6^{ab}	107.9 ± 22.6^{de}	0.002
	Midland	$261.5 \pm 22.6^{a-c}$	$230.4 \pm 22.6^{a-c}$	$195.5 \pm 22.6^{b-d}$	57.3 ± 22.6^{e}	
	Highland	316.5 ± 22.6^{a}	$209.6 \pm 22.6^{a-d}$	$167.9 \pm 22.6^{c-e}$	67.4 ± 22.6^{e}	

Means with the same letter(s) are no significantly different from each other at $P < 0.05$ with interaction effect of storage duration and agro-ecology. Values are mean ± SEM.

and this deteriorates quality significantly (Meronuck, 1987). In other studies, only a slight decline in protein content of stored maize kernels was observed, followed by a slight increase after eight months of storage (Bhattacharya and Raha, 2002). Grain respiration, mould, and insect damage are among the key causes of protein content reduction in stored maize (Yakubu et al., 2010). Protein content reduction from 10.1% to 9.4% after nine months of storage in plastic bags under room temperature has also been reported (Stefanello et al., 2015). The high fungal contamination and insect pest damage observed during sample collection is the most probable reason for the high protein content deterioration observed in the present study. The different storage structures used by the different actors along the supply chain are not airtight and do not protect against external environmental conditions and insect pest damage, and this leads to quality deterioration.

Higher m.c. resulting in fungal damage to stored maize was observed in the highland agro-ecological setting under both farmer and collector storage conditions and led to a reduction in fat content. In agreement with these findings, another study reporting high m.c. of maize kernels (28–31%) also revealed a high reduction in fat content (Reed et al., 2007). Similarly, a decline in maize fat content from 5.9% to 5.3% after four months of storage due to damage by storage pests has also been reported (Farhan et al., 2013), as has a decline in fat content from 5.8% to 5.0% after nine

Table 6
Major mineral content of maize kernels stored under collector condition.

Minerals (mg/100g)	Agro-ecology	Storage duration (months)			P-value
		2	4	6	
Fe	Lowland	3.40 ± 0.3 [c d]	4.10 ± 0.3 [b-d]	7.50 ± 0.3 [a]	0.02
	Midland	2.70 ± 0.3 [d]	3.40 ± 0.3[cd]	5.60 ± 0.3 [b]	
	Highland	2.90 ± 0.3[cd]	4.60 ± 0.3 [bc]	5.30 ± 0.3[b]	
Ca	Lowland	23.40 ± 2.5 [ef]	32.90 ± 2.5 [de]	53.90 ± 2.1 [bc]	0.006
	Midland	18.30 ± 2.5 [f]	30.10 ± 2.5[d-f]	67.10 ± 2.5 [a]	
	Highland	23.30 ± 2.5[ef]	41.30 ± 2.5 [cd]	61.00 ± 2.5[ab]	
P	Lowland	167.70 ± 17.7 [c]	257.70 ± 17.7 [b]	373.90 ± 17.7[a]	0.04
	Midland	52.20 ± 17.7 [d]	139.60 ± 17.7[cd]	178.20 ± 17.7 [bc]	
	Highland	67.20 ± 17.7 [d]	206.90 ± 17.7 [b c]	214.3 ± 17.7 [bc]	

Means with the same letter(s) are no significantly different from each other at P < 0.05 with interaction effect of storage duration and agro-ecology. Values are mean ± SEM.

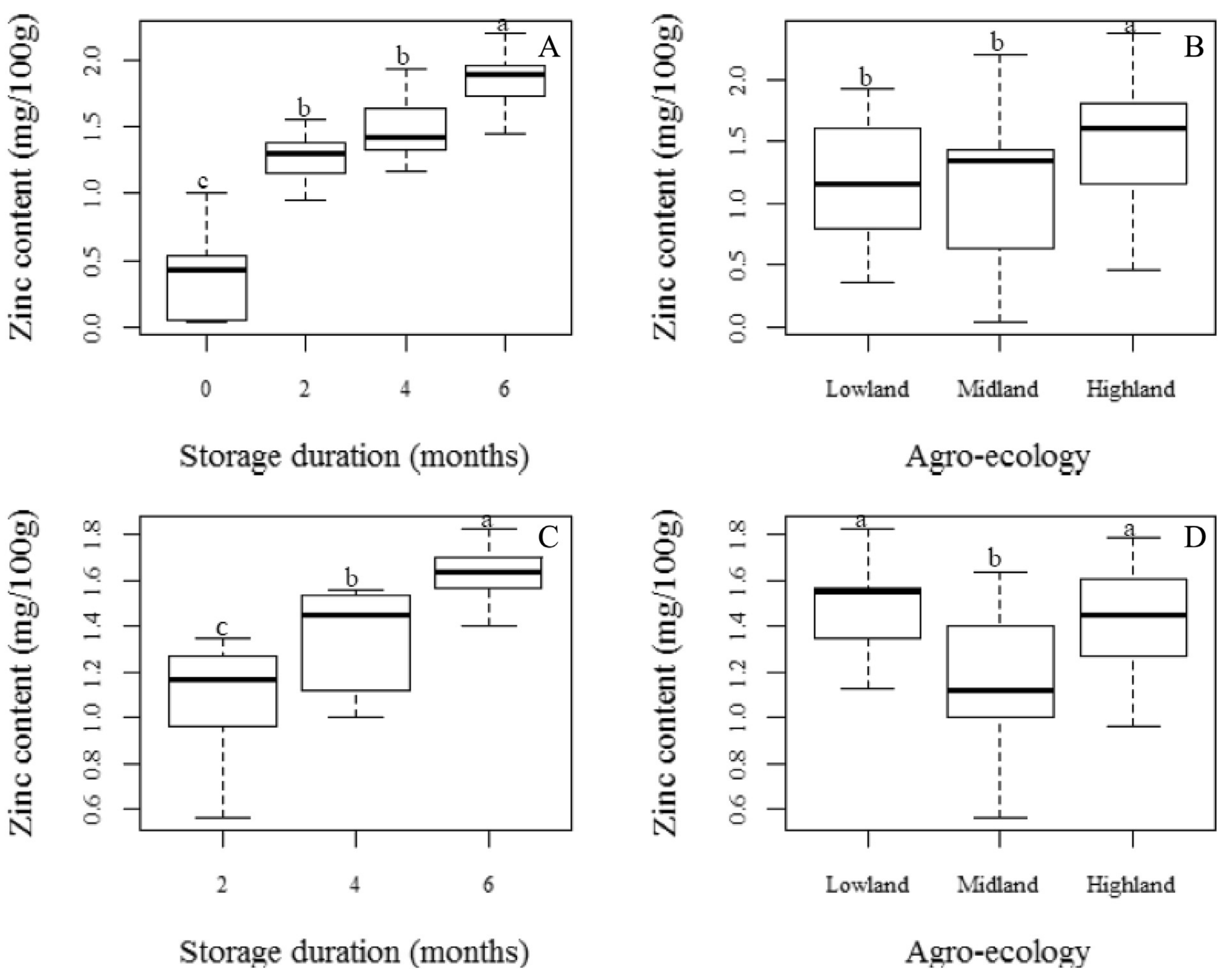

Fig. 6. Box plots showing trend for Zinc content of stored maize kernels A) farm condition across storage duration (P < 0.0001) and B) agro-ecology (P = 0.0001); C) collector condition across storage duration (P < 0.0001) and D) agro-ecology (P = 0.0006). Error bars are the range values. Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05.

months of storage in plastic bags at room temperature (Stefanello et al., 2015). We found a much greater decline in fat content than observed in other studies. This increased decline in fat content is related to the high initial moisture content and traditional storage structures in the study areas, which make it impossible to maintain the intrinsic characteristics of the kernels and protect them from storage pests.

Fibre content significantly increases as storage duration increases. A slight increment in maize fibre content after three months of storage was reported from Pakistan (Farhan et al., 2013). The same authors stated that the fibre content increased as a result of selective feeding by mites on the grain endosperm. The fibre content of maize grain is much higher in the bran than in the endosperm part of the kernel (Golob et al., 2002). Other researchers have also reported an increment in fibre content of maize over the storage period (Rashad et al., 2013). By contrast, Stefanello et al. (2015) reported that dietary soluble and insoluble fibre showed a decrement, but this change was not a significant difference after nine months of storage. The present study showed increments in fibre content of 103.4%, 90.9%, and 55.8% after six months of storage

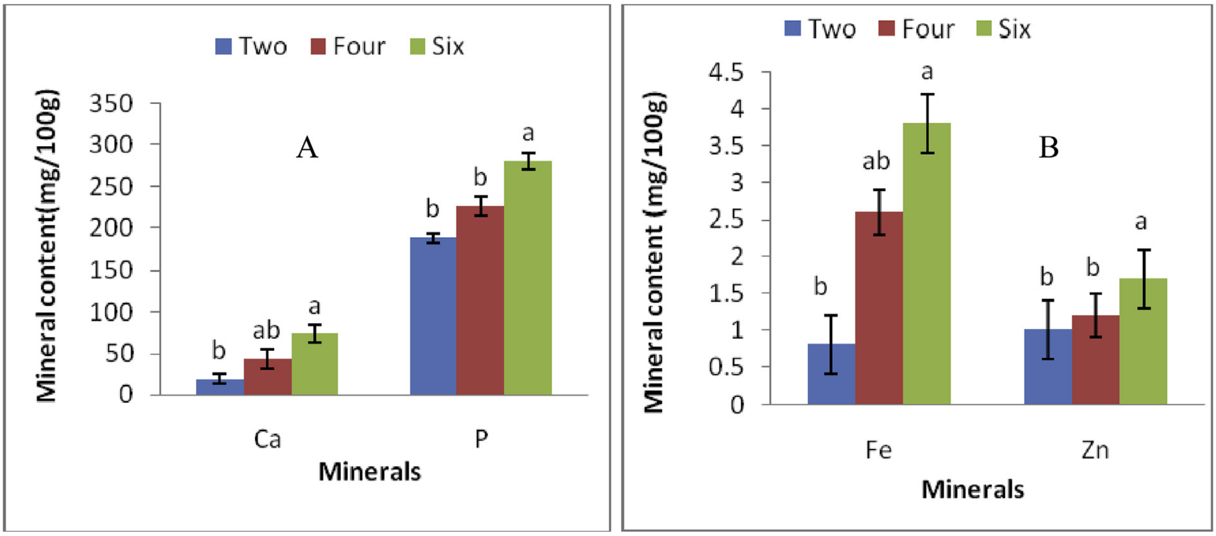

Fig. 7. Mineral content of maize kernels stored under wholesaler condition A) phosphorus and calcium across storage duration in months ($P = 0.001$ for Ca; $P = 0.004$ for P) B) Iron and zinc across storage duration in months ($P = 0.009$ for Fe and $P = 0.007$ for Zn). Means with the same letter(s) for each figure are not significantly different from each other at $P < 0.05$. Values are mean ± SEM.

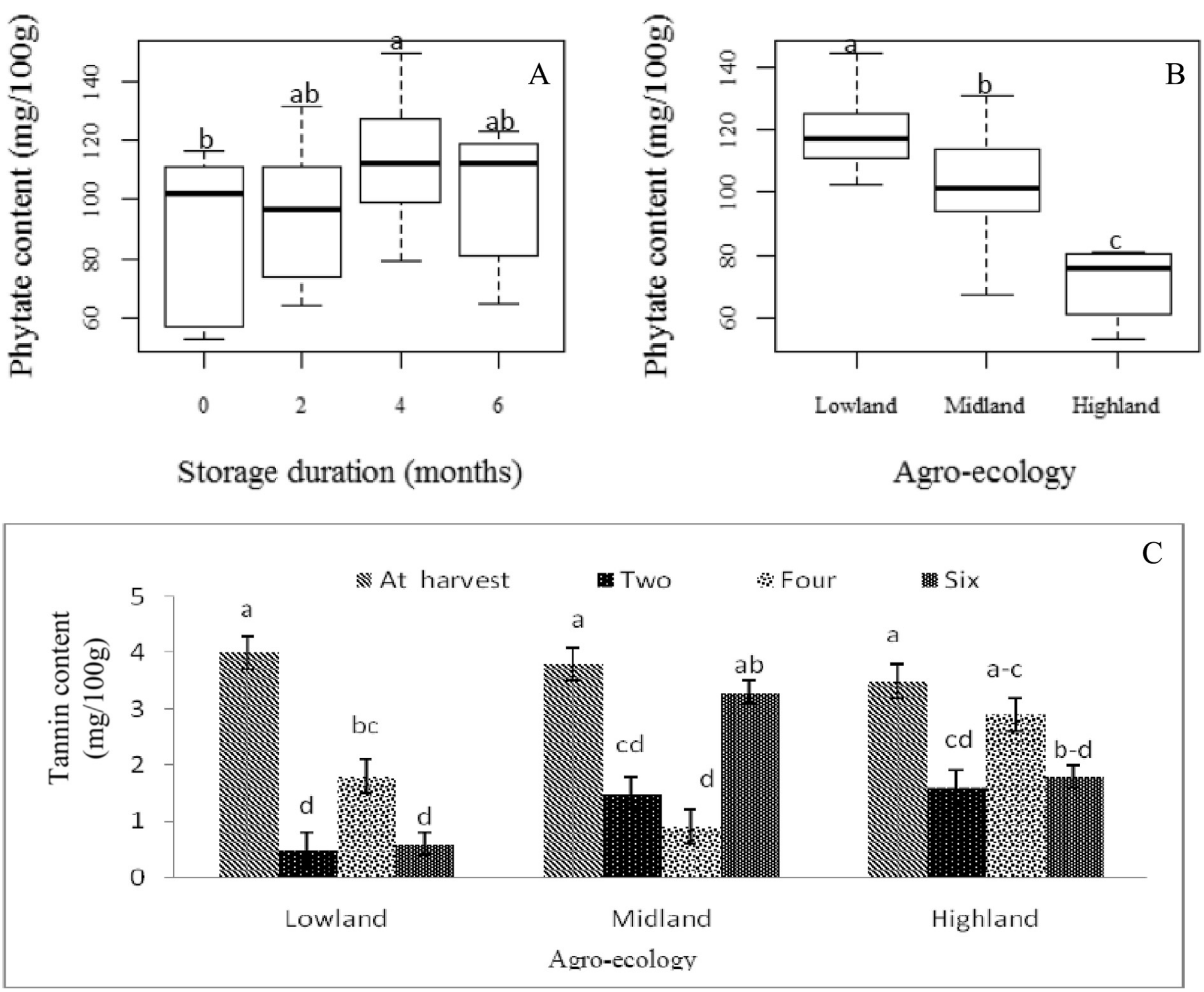

Fig. 8. Anti-nutrient content of maize stored under farm condition A) box plots for Phytate along the storage duration ($P = 0.007$) and B) agro-ecology ($P < 0.0001$) C) Tannin interaction effects of storage duration with different agro-ecology ($P < 0.0001$). Error bars for Phytate are range values. Values are mean ± SEM for Tannin. Means with the same letter(s) for each figure not significantly different from each other at $P < 0.05$.

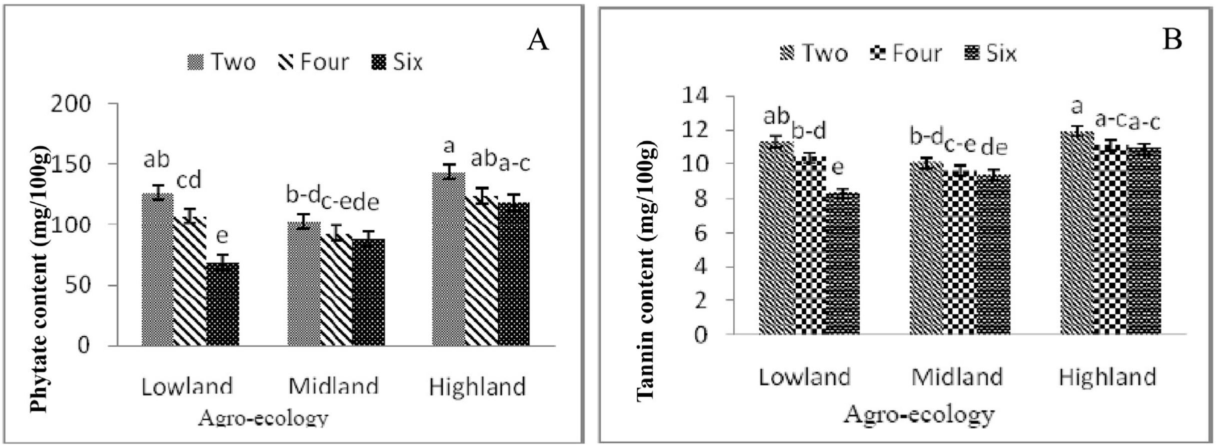

Fig. 9. Anti-nutritional content of maize stored under collector store A) Phytate content and B) Tannin content; P-value = for Phytate P = 0.01 and P = 0.01 for tannin. Means with the same letter(s) for each figure are not significantly different from each other at $P < 0.05$. Values are mean ± SEM.

under farmer, collector, and wholesaler conditions, respectively. This finding clearly illustrates that much fibre is available in the product after six months of storage, but having more than the optimum fibre content in the diet can result in reduced nutrient absorption and other health impacts.

Ash content increased considerably with increasing storage duration across the supply chain. The ash content of different maize varieties is known to range from 1.7 ± 0.2 to 2.4 ± 0.05 mg/100 g (Hassan et al., 2009). As storage duration increased to 90 days, the ash content of stored maize increased from 1.9% to 1.91% (Farhan et al., 2013). For sorghum stored in soil pits an increase from 2.2% to 8.4% after 17 months of storage has also been reported (Dejene et al., 2006). Similarly, Stefanello et al. (2015) reported a maize ash content increment from 1.5% to 2.0% after nine months of storage. As with fibre, the ash content is higher in the maize bran than in the endosperm, and selective feeding on the endosperm by storage pests results in an increment in the ash content (Rashad et al., 2013). The extent of the ash increment in the present study was very high (57.1%–120%) compared with the initial content. This has great implications for nutrient availability in the stored maize.

Significant reductions in CHO content were recorded under all actor storage conditions. This is consistent with the higher m.c. of stored maize, which enhances grain respiration rates and results in a reduction of CHO content (USID, 2011). Similarly, maize with a higher m.c. has higher rates of fungal contamination, and this has negative effects on nutritional content (Kumar and Kweera, 2013). Our findings are in line with these results: CHO declined as storage time increased due to damage caused by the bio-deterioration observed during the study. This agrees with the results reported by Bhattacharya and Raha (2002), who found a decline in CHO content in maize, caused by fungal damage, from 74.7% to 57.0% after twelve months of storage. Maize is one of the principal staple food crops in the study area, and the significant reduction in CHO content along the supply chain means less energy is available from maize for human consumption.

The present study revealed that calorific value, which depends on CHO, fat, protein, and dietary fibre content, declined across the storage period for all actors along the maize supply chain. Kumar and Kweera (2013) reported that maize with higher m.c. had higher fungal contamination and was lower in nutritional quality. A reduction in the energy value of stored maize as a result of mould damage has also been reported (Reed et al., 2007).

During the sample collection period in both production seasons, there was extensive insect infestation, especially in the lowland agro-ecology setting, as well as mould development in the highland maize growing areas, and these may have led to an increase in major minerals. Similarly, Farhan et al. (2013) stated that selective feeding of insects on grain endosperm resulted in an increase in mineral content (Fe, Ca, and Zn). The report by Tongjura et al. (2010) that found increases in calcium from weevil infestations in stored maize also supports our finding. Mineral content is much higher in maize bran, but the CHO content of maize bran is lower and storage pests mainly depend on CHO for their growth (Enyisi et al., 2014). Similarly, selective feeding by fungi on the CHO component of sorghum grain resulted in increases in both ash and mineral content (Dejene et al., 2006). Furthermore, weight loss resulted in an increase in grains per gram, and this may cause an increase in mineral content across the storage period. Weight loss of maize stored for six months under traditional *gombisa* storage structures in Jimma Zone ranged from 41% to 80% due to damage by insect pests (Sori and Ayana, 2012). Similarly, under different traditional farm storage conditions weight losses in maize cob have been reported from Senegal (Gueye et al., 2013). Weight losses of 11.8%–67.1% after three months of storage due to insect damage have been reported from maize in Kenya (Tefera et al., 2011).

Both tannin and phytate content showed a decrement as the storage duration increased. A study conducted in Pakistan showed that the anti-nutrient content of different maize varieties ranged from 30.0 ± 0.03 to 33.3 ± 7.8 mg/100 g (tannin) and 330.6 ± 1.8 to 670.7 ± 5.6 mg/100 g (phytate) under normal conditions (Hassan et al., 2009). Similarly, Hambidge et al. (2004) reported that the phytate content of different maize varieties ranged from 380 ± 0.10 to 750 ± 1.10 mg/100 g based on the dry-weight basis for the samples collected from North America. The concentration of phytate in matured cereal grains largely depends on plant nutrient consumption and the stage of maturity at harvest (Oberleas, 1973). In general, as opposed to the assumption those anti-nutritional components tend to increase during the storage; both phytate and tannin content seem highest at harvest which invites for more research considering maize hybrid currently under production, nature of traditional storage systems and factors during production.

5. Conclusions

This study aimed to determine the nutritional and anti-nutritional content of stored maize under different agro-ecological conditions and different supply chain actors in Jimma Zone, southwestern Ethiopia. The results showed that m.c. at the loading, the stage was not optimum for safe storage. In addition, m.c. decreased as the storage duration increased, except under farm storage conditions, where moisture content increased, mainly due to rainy seasons. Farmers' traditional storage structures are not airtight and not effective in protecting stored maize from external environmental conditions and the bio-deterioration that causes nutritional decline. Our findings also revealed that the nutrient composition of stored maize, especially protein, fat, CHO, and calorific value, significantly declined across the storage period for different actors and their different storage structures. The storing of maize by all actors along the maize supply chain resulted in high-quality losses that have great implications for nutrition insecurity in society. On the other hand, fibre and ash content showed increases over the storage period. Similar trends were observed for major minerals, including Fe, Ca, and Zn.

There is thus a need to develop and/or modify and disseminate appropriate storage technologies that reduce nutrition quality losses. There is a need to determine moisture content at the harvest and loading stages for safe storage. Moreover, there is also need for training and awareness creation at the producer level to promote effective on-farm storage techniques that will minimize quality losses. Attention should also be paid to effective pest management that will help to improve the nutritional quality of stored maize and secondary metabolites produced by fungal pathogens.

Acknowledgements

The authors gratefully thank the Federal Ministry of Education and Research (BMBF), Germany, for their financial support (No. 031A247A-D) under the Reduction of Post-Harvest Losses and Value Addition in East African Food Value Chains (RELOAD) project administered by the University of Kassel. We also thank Jimma University for continued help and facilitation during the implementation of this work, and the Ethiopian Public Health Institute (EPHI) for many sample analyses.

References

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B., Keno, T., 2015. Factors that transformed maize productivity in Ethiopia. Food Secur. 7, 965–981.

Abebe, H.G., Bekele, H., 2006. Farmers' post-harvest grain management choices under liquidity constraints and impending risks: implications for achieving food security Ethiopia. In: International Association of Agricultural Economists Conference August 12-18, 2006, GoldCoast, Australia. Accessed on 13 February 2016. http://ageconsearch.umn.edu/bitstream/25716/1/pp060120.pdf.

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. Int. J. Sci. Basic Appl. Res. 18, 235–257.

Bhattacharya, K., Raha, S., 2002. Deteriorative changes of maize, groundnut and soybean seeds by fungi in storage. Mycopathologcia 155, 135–141.

Costa, S., 2014. Reducing Food Losses in Sub-Saharan Africa (Improving Post-Harvest Management and Storage Technologies of Smallholder Farmers.) An “Action Research” Evaluation Trial from Uganda and Burkina Faso. World Food Program. Accessed 17 February 2016. http://documents.wfp.org/stellent/groups/public/documents/special_initiatives/WFP265205.pdf.

CSA, 2009. Report on Area and Production of Crops (Private Peasant Holdings, Meher Season). The Federal Democratic Republic of Ethiopia Central Statistica Agency, vol. IV. Agricultural Sample Survey, Addis Ababa, 60pp.

Dejene, M., Yuen, J., Sigvald, R., 2006. Effects of storage methods, storage time and different agro-ecological zones on chemical components of stored sorghum grain in Hararghe, Ethiopia. J. Stored Prod. Res. 42, 445–456.

Demeke, M., 2012. Analysis of Incentives and Disincentives for Maize in Ethiopia. Technical Notes Series. MAFAP, FAO, Rome. Accessed 29 February 2016. http://www.fao.org/3/a-at472e.pdf.

Devereau, A.D., 2002. Physical factors in post-harvest quality. In: Golob, P., Farrell, G., Orchard, J.E. (Eds.), Crop Post-Harvest: Science and Technology, Volume 1 Principles and Practice. Blackwell Publishing Company, UK, pp. 62–92.

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 J. Plant Sci. 11, 226–234.

EATA, 2013. Maize Sector Development Strategy (Working Document 2013-2017). Addis Ababa, Ethiopia, 70pp. http://www.ata.gov.et/download/maize-sector-development-strategy-working-document-2013-2017/. Accessed 20 March 2016.

Enyisi, S.I., Umoh, V.J., Whong, C.M.Z., Abdullahi, I.O., Alabi, O., 2014. Chemical and nutritional value of maize and maize products obtained from selected markets in Kaduna. Afr. J. Food Sci. Technol. 5, 100–104.

Farhan, M., Afza, M., Hamid, M.B., Ahmad, T., Ramzan, M.A., 2013. Changes in the nutritional value of stored maize grains infested with mites (*rhizoglyphus tritici*) under different storage time. Int. J. Agric. Appl. Sci. 5, 47–52.

Fourar-belaifa, R., Fleurat-Lessard, F., Bouznad, Z., 2011. A systemic approach to qualitative changes in the stored wheat ecosystem: prediction of deterioration risks in unsafe storage conditions in relation to relative humidity level, infestation by *Sitophilus oryzae* (L.), and wheat variety. J. Stored Prod. Res. 47, 48–61.

Golob, P., Farrell, G., Orchard, J.E., 2002. Crop Post-Harvest: Science and Technology Volume 1 Principles and Practice. Blackwell Publishing Company, UK.

Gueye, M.T., Goergen, G., Ndiaye, S., Asiedu, E.A., Wathelet, J.-P., Lognay, G., Seck, D., 2013. Efficiency of traditional maize storage and control methods in rural grain granaries: a case study from Senegal. Tropicultura 31, 39–46.

Hambidge, K.M., Huffer, J.W., Raboy, V., Grunwald, G.K., Westcott, J.L., Sian, L., Miller, L.V., Dorsch, J.A., Krebs, N.F., 2004. Zinc absorption from low-phytate hybrids of maize and their wild-type iso hybrids. Am. J. Clin. Nutr. 79, 1053–1059.

Hassan, A.B., Osman, G.A.M., Rushdi, M.A.H., 2009. Effect of gamma irradiation on the nutritional quality of maize cultivars (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) grains. Pak. J. Nutr. 8, 167–171.

IFPRI, 2010. Maize Value Chain Potential in Ethiopia: Constraints and Opportunities for Enhancing the System, Sustainable Solutions for Ending Hunger and Poverty Supported by the CGIAR, 42pp. http://www.ifpri.org/publication/maize-value-chain-potential-ethiopia. Accessed 20 February 2016.

Kumar, U., Kweera, B., 2013. Comparative analysis of nutritional value and aflatoxin level of maize grain from different sites of Rajasthan. Int. J. Sci. Technol. Res. 2, 333–335.

Maxson, E.D., Rooney, L.W., 1972. Two Methods of tannin analysis for *Sorghum bicolor* L. Moenchgrain. Crop Sci. 12, 253–254.

Meronuck, R.A., 1987. The significance of fungi in cereal grains. Plant Dis. 71, 287–292.

Oberleas, D., 1973. Phytates. In: Committee on Food Protection, Food and Nutrition Board and National Research Council Editors. Toxicants Occurring Naturally in Food. Chapter 17. National Academy of Sciences presses, Washington, DC, USA, pp. 363–371.

Oladele, O., Osipitan, A., 2013. Deterioration of dried maize (*Zea mays* L.) stored under different temperatures by fungi. J. Biol. Sci. Bioconservation 3, 253–260.

Paraginski, R.T., Vanier, N.L., Moomand, K., de Oliveira, M., Zavareze, E.R., Silva, R.M., Ferreira, C.D., Elias, M.C., 2014. Characteristics of starch isolated from maize as a function of grain storage temperature. Carbohydr. Polym. 102, 88–94.

Rashad, A.S., Kurt, A., Rosentrater, C., Bern, J., 2013. Effects of deterioration parameters on storage of maize a Review. J. Nat. Sci. Res. 3, 147–165.

Reed, C., Doyungan, S., Ioerger, B., Getchell, A., 2007. Response of storage molds to different initial moisture contents of maize (corn) stored at 25 1 C, and effect on respiration rate and nutrient composition. J. Stored Prod. Res. 43, 443–458.

Rehman, Z., 2006. Storage effects on nutritional quality of commonly consumed cereal. Pak. J. Food Chem. 95, 53–57.

Sori, W., Ayana, A., 2012. Storage pests of maize and their status in Jimma Zone. Afr. J. Agric. Res. 7, 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. Int. Food Res. J. 22, 918–922.

Tadesse, A., Basedow, T., 2004. A survey of insect pest problems and stored product protection in stored maize in Ethiopia in the year 2000. J. Plant Dis. Prot. 111, 257–265.

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

Tefera, T., Mugo, S., Likhayo, P., 2011. Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus Zea mays* and the larger grain borer *Prostephanus truncatus*. Afr. J. Agric. Res. 6, 2249–2254.

Tongjura, J.D.C., Amuga, G.A., Mafuyai, H.B., 2010. Laboratory assessment of the susceptibility of some varieties of *Zea mays* infested with *Sitophilus zeamais*, Motsch. (Coleoptera, Curculionidae) in Jos, plateau state, Nigeria. Sci. World J. 5, 55–57.

USID, 2011. Staple Crops Storage Handbook. http://acdivoca.org/sites/default/files/attach/legacy/site/Lookup/StorageHandbook/$file/StorageHandbook.pdf. Accessed on 21 February 2015.

Vaintraub, I.A., Lapteva, N.A., 1988. Colorimetric determination of phytate in unpurified extracts of seeds and the products of their processing. Anal. Biochem. 175, 227–230.

Yakubu, A., Bern, C.J., Coats, J.R., Bailey, T.B., 2010. Non-chemical on-farm hermetic maize storage in east Africa. Proc. In: 10th International Working Conference on Stored Product Protection, pp. 338–345. http://dx.doi.org/10.5073/jka.2010.425.440.

Zonal Office of Finance and Economic Development Office of Jimma (ZoFEDO), 2013. Physical and Socio-Economic Profile of Jimma Zone. Jimma. Unpublished report.