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Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania

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A B S T R A C T

An assessment of post-harvest handling practices and food losses in a maize-based farming system in semi-arid areas of Central and Northern Tanzania was carried out in 2012. Seventeen crops were mostly cultivated by the farmers in the surveyed areas; maize (32%), sunflower (16%) and pigeon peas (12%) were the most cultivated while maize was the most stored. There are at least 7 months between two harvest seasons of each crop; while farmers sold the crops soon after harvest to cater for household expenditure (54%) and school fees (38%), the market prices increased significantly ($P \leq 0.05$) within six months of storage. Most processing activities (winnowing, dehulling, drying, sorting and shelling) were carried out manually, almost entirely by women, but mechanized processing for maize, sunflower, millet, and sorghum were commonly practiced. Quantitative post-harvest losses of economic importance occur in the field (15%); during processing (13–20%), and during storage (15–25%). The main storage pests responsible for the losses are larger grain borers (*Prostephanus truncatus*), grain weevils (*Sitophilus granarius*) and, the lesser grain borer (*Rhyzopertha dominica*). Most of the farmers considered changes in weather (40%), field damage (33%), and storage pests (16%) as the three most important factors causing poor crop yields and aggravating food losses. However, survey results suggest that the farmers' poor knowledge and skills on post-harvest management are largely responsible for the food losses. 77% of the surveyed farmers reported inadequate household foods and 41% received food aid during the previous year. Increasing farmers' technical know-how on adaptation of the farming systems to climate variability, and training on post-harvest management could reduce food losses, and improve poverty and household food security.

1. Introduction

More than 70% of the sub-Saharan African population is directly involved in agriculture as the primary source of income and food security. Therefore, growth in agriculture production and productivity are critical for eradicating extreme poverty and hunger in the continent. However, sub-Saharan African agriculture productivity and the per capita value of agriculture output is the lowest in the world (FARA, 2006). Despite the low total agricultural productivity, post-harvest losses of the food being produced are significant (World Bank et al., 2011).

Post-harvest and marketing system is a chain of interconnected activities from the time of harvest to the delivery of the food to the consumers. Agricultural commodities produced on the farm have to undergo several procedures like harvesting, drying, threshing, winnowing, processing, bagging, storage, transportation, and exchange before reaching the final consumer. The primary role of an effective post-harvest system is to ensure that the harvested food reaches the consumer, while fulfilling customer satisfaction in terms of quality, volume and safety. Post-harvest losses in the developed countries are lower than in the developing countries because of more efficient farming systems, better transport infrastructure, better farm management, and effective storage and

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processing facilities that ensure a larger proportion of the harvested foods is delivered to the market in the most desired quality and safety. For the low income countries, pre-harvesting management, processing, storage infrastructure and market facilities are either not available or are inadequate (World Bank et al., 2011).

Post-harvest loss in terms of value and consumer quality attributes can occur at any stage between harvest and consumption. The major physiological, physical and environmental causes of post-harvest losses are high crop perishability; mechanical damage; excessive exposure to high ambient temperature, relative humidity and rain; contamination by spoilage fungal and bacteria; invasion by birds, rodents, insects and other pests; and inappropriate handling, storage and processing techniques (World Bank et al., 2011). Losses may be aggravated by poor infrastructure, harvesting methods, post-harvest handling procedures, distribution, sales and marketing policies (World Bank et al., 2011). According to Tyler (1982), the economic importance of the factors leading to high post-harvest losses varies from commodity to commodity, season to season, and the enormous diversity of circumstances under which commodities are grown, harvested, stored, processed and marketed. In Eastern and Southern Africa alone, post-harvest losses are valued at US $1.6 billion per year, or about 13.5% of the US $11 billion total value of grain production (World Bank et al., 2011). Indeed, this calls for more reliable and verifiable data on post-harvest losses (Obeng-Ofori, 2011).

Post-harvest losses in Africa are often estimated to be between 20 and 40% (World Bank et al., 2011). Such losses are a combination of those which occur on the field, in storage, during processing and other marketing activities.

In West Africa, farmers store their crops in homes, on the field, in the open, jute or polypropylene bags, conical structures, raised platforms, clay structures and baskets (Motte et al., 1995, Addo et al., 2002; Ofosu et al., 1995; Hell et al., 2000). In East and Southern Africa, farmers store crops in small bags with cow dung ash, in wood and wire cribs, pits, metal bins, wooden open-air or roofed cribs, and in raised platforms and roofed iron drums enclosed with mud (Wambugu et al., 2009; Kankolongo et al., 2009). The larger grain borer *Prostephanus truncatus* (Horn), grain weevil *Sitophilus granarius* (L.) and the lesser grain borer *Rhyzopertha dominica* (F.) are some of the predominant food grain storage pests in Africa (Bourne, 1977; Dick, 1988; Holst et al., 2000; Hodges, 2012). Unfortunately, farmers and crop handlers, especially women, do not have adequate information on proper crop harvesting and handling methods, resulting in significant damage by insect pests during storage and marketing (Rugumamu, 2009; Kereth et al., 2013). In addition to storage losses, losses during crop processing could be significant. Calverley (1996) showed that losses during harvesting/drying ranged from 6 to 10% for maize in some African countries: about 7% for rice in Madagascar, 4.3% in China and 4% in many Asian countries. Harvesting, drying and threshing losses reported for sorghum and millet were 11.3% and 12.2% respectively, while losses of 3.5% and 4.5% were recorded in Zambia and Zimbabwe respectively, for maize dried on raised platforms (Calverley, 1996). Threshing and shelling losses in smallholder manual methods for Zimbabwe was estimated at 1–2.5%, while it was 3.5%, where mechanized shelling was done (Hodges, 2012). Losses for rice during threshing were 6.5% and 6% in Madagascar and Ethiopia respectively, and were 2.5% and 5% respectively during winnowing in the same countries (Hodges, 2012).

Hodges (2012) also estimated quantitative grain losses (prior to processing) to be in the range of 10–20%, but losses of over 50% in cereals and up to 100% in pulses have been reported by other investigators (Obeng-Ofori, 2011). In Tanzania, the maize weevil *Sitophilus zeamais* Motshulsky causes significant damage, although new studies showed that some maize varieties are more resistant to attack (Rugumamu, 2012).

Identifying best practices and innovative arrangements for increasing agricultural productivity to improve income and nutrition of farm households is a priority of most African countries. For this reason, improving post-harvest management systems is a priority for farmers and policy-makers (Rugumamu et al., 1997). New technologies and improved post-harvest management knowledge are required by the farmers. However, the report of Kimenju and de Groote, (2010) on the technological and economic implications of new maize storage techniques in Kenya emphasized that economic analysis should be carried out before introducing new techniques to farmers.

The agricultural transformation programs in many African countries give priority to post-harvest processing of crops such as rice, cassava, millet and sorghum, following a value chain approach. The National Strategy for Growth and Reduction of Poverty (NSGRP, 2005) and the current policy on Agriculture First ("*Kilimo Kwanza*") in Tanzania (MAFSC, 2009) underscore the importance of reducing post-harvest losses. However, the financing and actual institutionalization of post-harvest storage and loss prevention strategies are still negligible compared to primary production-related activities. There is an ongoing debate among scientists, policy makers and development agencies about the merits of agricultural intensification, whether it will improve or worsen food security and poverty of the households that lack the capacity to preserve their excess production (Greeley, 2008). A possible higher cost of intensification with possible higher post-harvest losses may reduce the total farm profitability for the smallholders. For this purpose, the extent and causes of post-harvest losses of smallholder farmers need to be established. Additionally, appropriate interventions must be identified for each farming system as part of a broader agriculture intensification program aiming to increase food security, nutrition and rural livelihoods. Therefore, the specific post-harvest characterization of each farming system would be required.

This paper presents the results of an audit of post-harvest practices and constraints in a maize-based farming system in the semi-arid area of Central and Northern Tanzania. The purpose was to identify the factors that contribute to post-harvest losses and the general food insecurity of smallholder farmers, and to propose strategies for improving smallholder food security in similar farming systems in Africa.

2. Material and methods

A cross-sectional survey approach was used to collect data from fifteen communities in the semi-arid areas comprising two regions of central and northern Tanzania; Dodoma and Manyara. These regions constitute one of the most food insecure areas of Tanzania. Questionnaires with open and closed-ended questions were used to elicit responses from 333 households. The data collected included the dominant socio-economic and farming system characteristics; crop importance; methods of processing, storage and marketing practices; farmers' knowledge of the causes of post-harvest losses and loss prevention measures; and perceptions of farmers about the causes of food insecurity. Crop losses were estimated by relying on the traditional knowledge of the farmers to recall the extent and relative losses that occur for each crop and at each stage of post-harvest handling: harvesting, transportation, drying, threshing, processing and storage (Teshome et al., 1999). The individual household interviews were complemented with 15 focus group interviews, one in each village, to validate the loss assessment and other questionnaire survey information. In total, 270 farmers made up of village leaderships, youth, women and village cooperative groups, took part in the focus group discussions.

At the peak of the harvesting season in June/July 2012, and after storage for one and six months, storage areas and structures of 4–5 randomly selected households per village were inspected for physical conditions, prevalence of storage pests, and food stock. A total of 97 storage areas were inspected to further validate the information gathered through questionnaires, check-lists, and focus group discussions. The field data was entered into Microsoft Office Excel 2007, coded and analyzed using SPSS program, version 16.

3. Results and discussion

3.1. Characteristics of the farming system and the farmers

Part of the surveyed area (Dodoma region) is characterized by the savanna vegetation with unimodal rainfall from February–July while the second part (Manyara region) is in the bimodal area, characterized by a long rainy season (*Masika)* from March–May and short rainy season (*Vuli*), occurring sometime between September and December. Fifty-two percent of the sampled farming population in the study area were female, and the average household size was seven. Twenty-two percent of the population, either did not have any formal education, or did not complete primary education, and 39% were above the age of 49 years. Twenty-four percent were engaged in livestock farming and 18% engaged in supply of labor, self-employment or petty business, or were government employees (Table 1).

At least 17 crops were cultivated in the study area. A majority of the crops were those classified as durables, which can be stored or preserved for a very long time without major pre-processing (Appert, 1987). These included maize, sunflower, pigeon peas, beans, groundnuts, millet, sorghum and sesame. Perishable crops such as potato, cassava and vegetables are also grown. The three dominant crops, maize, sunflower and pigeon peas were cultivated by 32%, 16% and 12% of the population respectively (Table 2).

Table 1
Demographic and socio-economic characteristics of the farmers.

Background characteristic	Overall sample	Survey area	
		Dodoma	Manyara
	%	%	%
Sex			
Male	48.2	47.6	49.0
Female	51.8	52.4	51.0
Total	100.0	100.0	100.0
Education			
No formal education	6.6	6.3	7.0
Not completed primary school	21.0	23.7	17.5
Completed primary school	68.5	65.8	72.0
Completed secondary school	3.9	4.2	3.5
Total	100.0	100.0	100.0
Household size			
1–3	10.5	11.6	9.1
4–6	41.7	43.7	39.2
>6	47.7	44.7	51.7
Total	100.0	100.0	100.0
Age of respondents			
From 18 to 49 years	61.3	57.9	65.7
Above 49 years	38.7	42.1	34.3
Total	100.0	100.0	100.0
Means of livelihood			
Crop production	55.3	57.8	52.4
Livestock farming	24.1	14.0	36.3
Casual labor, self-employment/ petty business	18.4	26.1	9.1
Charcoal making	1.9	1.5	2.2
Government employee	0.3	0.6	–
Total	100.0	100	100

Table 2
Most cultivated crops.

Type of crop	Overall	Dodoma farmers	Manyara farmers
	%	%	%
Maize (*Zea mays*)	32.3	24.6	43.2
Sunflower (*Helianthus annuus*)	15.9	17.1	14.3
Pigeon peas (*Cajanus cajan*)	12.4	10.4	15.4
Beans (*Phaseolus vulgaris*)	7.4	4.7	11.4
Groundnuts (*Arachis hypogaea*)	6.1	9.8	0.7
Bulrush Millet (*Pennisetum* spp.)	5.2	8.8	–
Sorghum (*Sorghii bicolor*)	5.2	6.7	2.9
Sesame (*Sesamum indicum*)	4.2	0.8	9.2
Cowpeas (*Vigna unguiculata*)	3.8	5.4	1.5
Bambaranuts (*Voandzeia subterranea* or *Vigna subterrannean*)	2.1	3.6	–
Green grams (*Vigna radiata*)	1.8	2.3	1.1
Cassava (*Manihot esculentus*)	1.5	2.3	0.4
Sweet potatoes (*Ipomea batata*)	0.9	1.6	–
Paddy (*Oryza sativa*)	0.3	0.5	–
Banana (*Musa* spp.)	0.3	0.5	–
Onions (*Allium cepa*)	0.3	0.5	–
Tomatoes (*Solanum lycopersicum*)	0.2	0.3	–

About 28% of the population kept poultry, and 26% kept both cattle and goats. The average number of poultry per household was 12, followed by 9 for cattle and 8 for goats (Fig. 1). The farmers kept cattle for land cultivation (ox ploughing), manure, meat, milk and sale for income; while goats were kept as an asset for immediate sale, meat, manure, milk and exchange for other items. Chickens were kept for meat and sale, while donkeys were used as draught animals and for transportation.

3.2. Harvesting periods and price of crops at various cycles of production

Most crops are harvested during May–July (Fig. 2). Maize is harvested from June to July. However, beans, groundnuts and sunflower are harvested over a longer period, from March to July, and pigeon peas, being perennial, are harvested mainly from August to December but continuously throughout the year.

Very few farmers harvested any crops from November to February. In effect, the interval between two harvesting seasons of most crops was about 7–9 months. This might have an implication on food security and food prices from one season to another. Effective storage facilities and sufficient storage capacity are required to maintain household food supplies.

As expected, maize was harvested and stored in the largest amount in the study area compared to other crops (Fig. 3). On average, households harvested 1.2 tonnes maize and stored 75% while 67% of sunflower and groundnuts were stored. But within a month of storage, merely 13% of the households had maize in the store, and stocks were reduced by 63–94% for most crops, with the exception of groundnuts that were reduced by 7% (Fig. 3). The quick reduction of stock may be because maize is grown as a cash crop and therefore the aim is to sell nearly all of it.

The majority of the farmers market their crops: sunflower (82%), sesame (59%), groundnuts (79%), and pigeon peas (74%), soon after harvest to traders who buy them from their homes while the balance is transported to the market for sale, by tractors (27%), motorcycles (23%), head-loads (23%) and by the use of animals (23%). The three crops with the highest average amounts recorded in the survey, maize, pigeon pea and sunflower, in the previous season sold 0.49 tonnes, 0.46 tonnes and 0.5 tonnes, respectively. There were also high amounts of beans (0.51 tonnes), and groundnuts (0.47 tonnes) sold that year.

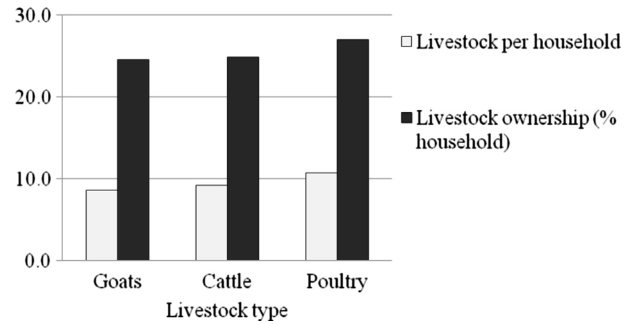

Fig. 1. Livestock ownership.

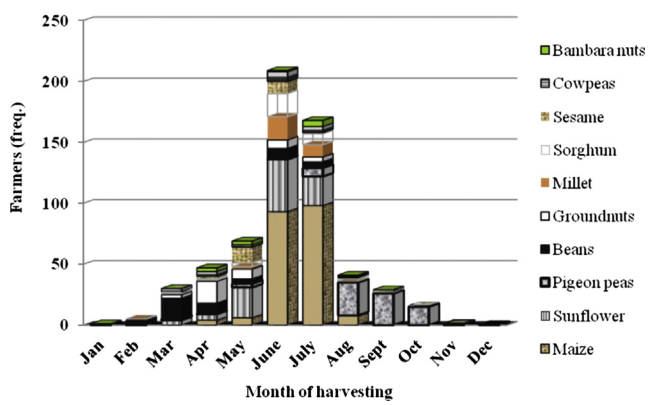

Fig. 2. Harvesting periods for various crops.

Variations in market prices were observed between the peak harvest seasons and at the end of storage period of six months (Table 3). A significant ($P \leq 0.05$) variation in price were observed for most of the crops including beans, sesame, groundnuts, green grams, pigeon peas, and cowpeas. Beans were sold at an average price of US$ 320 and US$ 610 per ton, during the peak season and at the end of the storage period, respectively. The variations in prices of major crops such as maize, sunflower, cowpeas, pearl millet, and sorghum were not significantly different ($P > 0.05$) by the end of the storage period. The price for a ton of sesame, beans, groundnuts and green grams, at the end of storage period was estimated at US$ 579, US$605, US$ 462, and US$ 441, respectively.

Three factors emerged as the key reasons that compelled the farmers to sell their crops soon after harvest. These were household expenditure needs (54%), cash needs for school fees (38%), and perception of surplus produce above storage capability (8%). This confirms the observation of Stathers et al. (2013), that farmers sell off their crops because of financial pressure. In a similar study, Schulten and Westwood (1972) reported that farmers who grew hybrid maize sold the hybrid varieties soon after harvest to keep losses low because the hybrids had low storability compared with the local varieties. The farmers in this current survey did not make a comparison of the storability of local varieties and any improved maize hybrids. However, the implication of early sale of crops soon after harvest is that the farmers miss the opportunity to increase the revenue from sale of the crops. Tefera et al. (2011a,b) had earlier hinted that the smallholder farmers' practice of selling their farm outputs soon after harvesting, only to buy the stocks back at an expensive price, just a few months after harvesting, constitutes a pathway to poverty. Hence, an ability to store the crops until when market prices are much higher provides important income opportunities to the smallholders and can possibly contribute to poverty reduction.

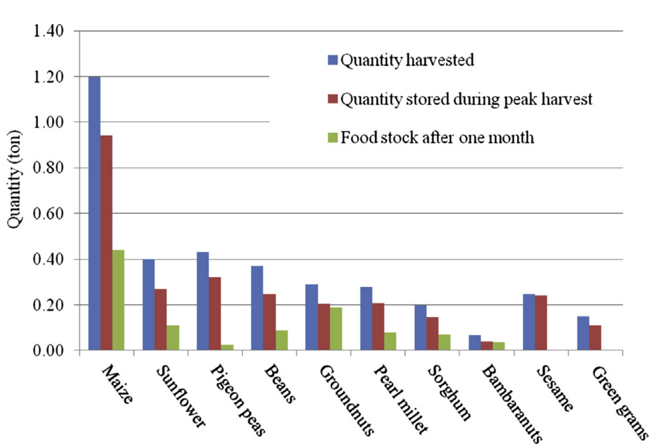

Fig. 3. Food storage and stock balance after one month storage.

3.3. *Pre-harvest handling, post-harvest processing methods and storage practices*

Pre-harvest handling of crops mainly involves leaving the crops on the field to fully mature, ripen and/or dry. After maturity, ripening or field drying, basic harvesting and processing methods are used for shelling, de-hulling, winnowing, sorting, milling and oil extraction. Although every farmer does some cleaning or processing to transform the farm outputs into various products, only 65% of the surveyed farmers claim to be involved in processing. Kernels are processed from pigeon peas (77%, $n = 27$), beans (55%, $n = 12$) and some other crops. Flour is processed from maize (97%, $n = 210$), sorghum (95%, $n = 20$), and pearl millet (91%, $n = 30$). Oils are extracted from sunflower (93%, $n = 93$) and groundnuts (47%, $n = 8$).

Many processing activities in the survey areas (winnowing, dehulling, drying, sorting and shelling) were carried out manually, almost entirely by women. In the case of shelling, pickets are used for beating the maize cobs, heads of sorghum, millet and sometimes rice. The farmers reported that the manual processing methods were tiresome and take considerable time of all the household members. Despite these constraints, the motivation for income seems to sustain the use of indigenous methods of crop processing. Dehulling, milling and oil extraction were the most mechanized cereal and legume post-harvest processing activities in all the surveyed villages (Fig. 4). More women (72%) engage in manual processing activities than men (43%).

Table 3
Price variation from peak harvest season to end of storage.

Crop	Peak season		End of storage		*P*-value
	N	Average market price (US$/ton)	*N*	Average market price (US$/ton)	
Beans	35	315.18	36	605.90	0.001
Sesame	34	260.66	25	578.75	0.001
Groundnuts	34	279.96	33	461.74	0.004
Green grams	15	302.92	11	441.48	0.020
Pigeon peas	90	326.39	71	428.79	0.001
Cowpeas	15	260.42	19	402.96	0.220
Sunflower	110	288.86	88	296.91	0.509
Pearl millet	18	259.83	22	295.46	0.415
Sorghum	13	245.19	23	268.48	0.317
Maize	99	237.56	139	247.73	0.211

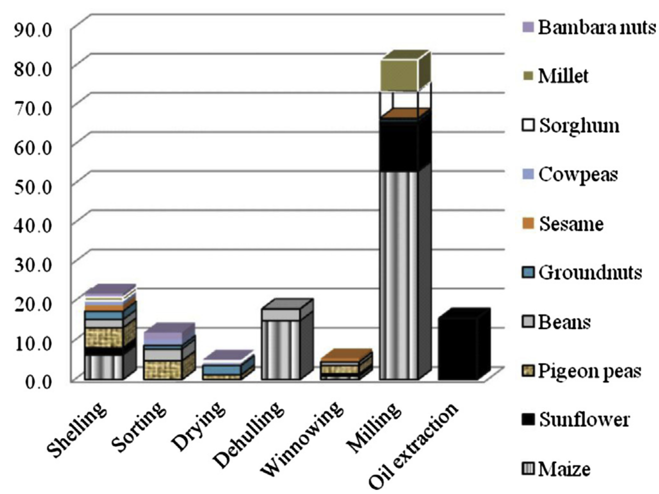

Fig. 4. Unit operations carried out by the farmers during crop processing.

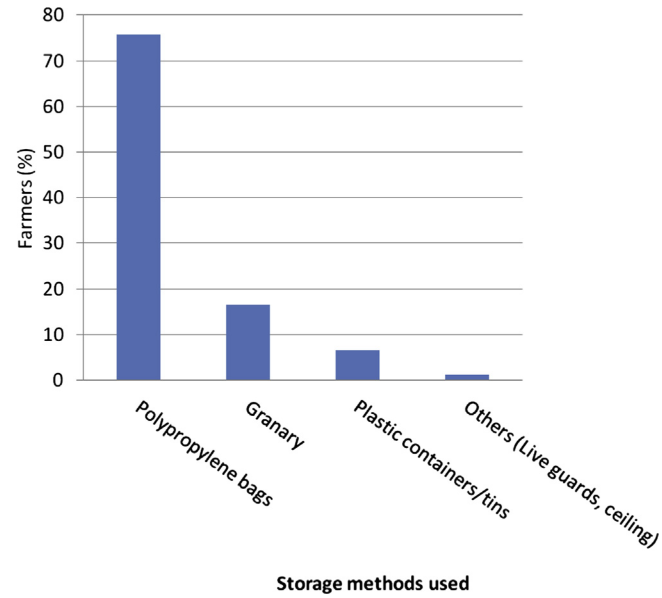

Fig. 5. Storage technologies and materials.

The predominance of mechanized dehulling, milling and oil extraction machines in the villages translate into the observed higher levels of maize, sunflower, and millet processing, implying that mechanization of processing activities could increase utilization of crops and possibly improve household nutrition.

Pigeon peas and sesame, the well known cash crops in these areas, are not mechanically processed, although the farmers reported selling about 86% and 100% of the crops, respectively.

For the livestock farmers, there were no improved technologies for cream separation from milk. Thirty-five percent of the fat in milk is in form of cream. Separating the cream from the milk reduces the rate of deterioration of the milk because the fat degrades quickly and causes off-flavor in full-fat fresh milk. However, when separated from milk, the milk kept longer and the cream serves as an important high value ingredient for cash or household cooking. All the livestock farmers, consisting of 44% of the total surveyed farmers, indicated that indigenous practices of milk storage and processing caused off-flavor, poor color, and contamination by sand as well as poor recovery of cream from milk.

Seventy-six percent of the farmers reported the use of polypropylene sacks for storage of processed and unprocessed crops, while granaries made with mud and plant materials, known as kihenge, were used by 17% of the farmers to store their crops (Fig. 5). Granaries made of traditional mudded bricks, sometimes cemented, were also used by very small number of households.

3.4. Losses associated with pre- and post-harvest handling practices

The study revealed that 70% of the surveyed farmers experience food losses during pre- and post-harvest handling operations, including during manual processing that cause mechanical breakage and spillage of the food, and irksomeness to the processor. Crop losses occur during pre-harvest drying on the field were caused by wild animals, birds and rodents. In worst cases, up to 32% of maize-on-cobs could be lost to birds, monkeys, other rodents before harvest, and through qualitative spoilage by mould and fungi which could be extensive in wet conditions. Similar qualitative loss through aflatoxin contamination of maize and cassava in Tanzania and Congo had been reported (Manjula et al., 2009). In terms of proportion of matured crops, 15% was estimated as pre-harvest field loss for most grain and legume crops. The farmers expressed their inability and skills to effectively prevent or control field losses by pests and rodents. An estimated 1.5% of the maize, millet, sorghum and groundnut outputs were estimated to be lost during harvesting. Losses during transportation of the crops by head-loads, on bicycles and other means were 2.5%. This compares with 2.25% losses recorded during transportation of rice from the field to the store and 1% from the store to the market for maize in Madagascar (Hodges, 2012). An estimated loss of 13.4% for maize ($P = 0.009$), 20% for millet and sunflower, 18% for groundnut, 10% for pigeon pea, 6% for sorghum and 5% for sesame occur when manual methods of processing were used (Table 4). The losses were in form of mechanical damage such as breakage, puncture, compression, rupture, dent bruises, or spillages of the crops.

Calverley (1996) estimated about 7% loss for rice in Madagascar, 4.3% rice loss in China and 4% for many Asian countries, and 6–10% losses during harvesting/drying of maize in Africa. Harvesting, drying and threshing losses reported by the farmers in the current study for sorghum and millet were 11.3% and 12.2% respectively. Losses of 3.5% and 4.5% were recorded for maize dried on raised platforms in Zambia and Zimbabwe respectively (Calverley, 1996). Threshing and shelling losses in smallholder manual method for Zimbabwe was estimated at 1–2.5%, while it was 3.5% where mechanized shelling was used (Hodges, 2012). Losses for rice

Table 4
Percentage losses during manual processing practices.

Crops	*N*	Average processing loss (%)
Maize	119	13.45
Sunflower	57	20.01
Pigeon peas	17	10.20
Pearl millet	11	20.18
Sorghum	10	6.48
Groundnuts	5	18.48
Sesame	4	5.38
Beans	6	2.03
Paddy	2	3.50
Bambara nuts	4	1.28

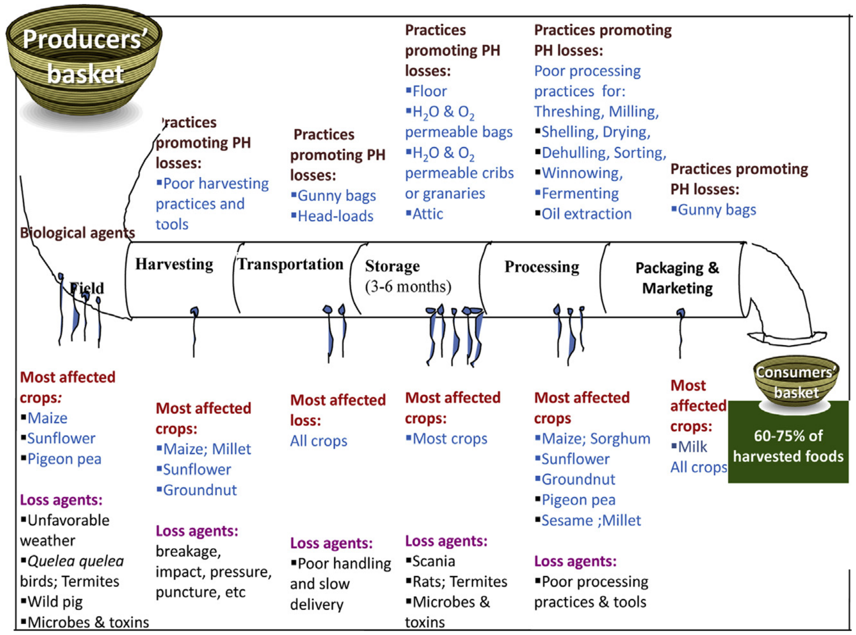

Fig. 6. Post-harvest loss characteristics in the maize-based system.

during threshing were 6.5% and 6% in Madagascar and Ethiopia respectively and were 2.5% and 5% respectively during winnowing (Hodges, 2012).

Following the model of Bourne (1977) and proposal of Obeng-Ofori (2011) the leaky food pipeline with the post-harvest (PH) practices in the study area, loss agents and the most affected crops at each stage of the supply chain are shown in Fig. 6. Indigenous post-harvest practices such as harvesting by hand, head-load transportation, manual processing, and storage on the floor/in the open, or in oxygen and moisture permeable bags, cribs or granaries are the dominant causes of crop losses. Some post-harvest handling practices such as the use of poor harvesting tools, storage in oxygen and moisture permeable bags and reuse of dirty and contaminated gunny bags are either unable to prevent food losses or they exacerbate post-harvest losses.

Although significant variations may exist in the proportions of food lost in the field and during storage, the farmers estimated that the total crop loss from the field until final marketing in the study area was between 25% and 40%. This agrees with the range of 20–30% losses by weight estimated for grains by Tefera et al. (2011b). Hodges (2012) estimated post-harvest loss of grains in Tanzania as 22% (excluding field loss) and 27% for Benin Republic. The Feed the Future (FtF) program of the USAID estimated that as much as 40% of each harvest in Tanzania is lost because of lack of good storage, and poor processing and transportation systems. A study in Tanzania to compare different methods of processing and modes of transporting fish (*Latesniloticus*) from Lake Victoria to Dar-es-Salaam markets by rail or by air revealed that the highest losses occur during processing, but transporting the fish by air gave the best monetary return (Cheke and Ward, 1998). The farmers in the current survey summarized that, in general terms, the losses that occur in the field are of more economic significance than those which occur during any other single activity from harvesting to marketing. Nonetheless, the losses that result from incorrect harvesting methods; poor handling, threshing, shelling, cleaning, sorting or drying practices; and bad transport and loading practices, cannot be ignored. Therefore, access to appropriate storage technology is a critical need for the smallholder producers (Golob et al., 2002; Bokusheva et al., 2012).

3.5. Storage structures and incidence of storage pests

The assessment of the farmers' storage areas after six months of storage revealed that crops were damaged in the storage structures by insect pests. As shown in Table 5, the major pests identified in the storage areas of most farmers were larger grain borer (*Prostephanus truncatus*), grain weevil (*Sitophilus granarius*) and lesser grain borer (*Rhizopertha dominica*).

Granaries in the storage area, mostly made of mud and plant materials, were dilapidated and were not able to maintain air tightness required to eliminate insect pests in storage. World Bank et al., (2011) observed that the traditional mud granaries are being abandoned for lack of knowledge of how to construct them, lack of space as they take up a lot of room even when empty compared to sacks, lack of ability to move them rapidly in case of fire or flood and less easy to market the stored grain rapidly in case of emergencies.

The farmers believed that the weevils account for 36% of the total loss for maize while the large grain borers (LGB) account for more than half of the losses recorded for maize. In a similar study, Dick (1988) reported that the LGB alone could increase losses of stored maize and dried cassava to 30%. A similar observation was made in Sudan where 8.34% of sorghum inside non-airtight sweibas (cylindrical mud bins) for 8 months was lost. But, the loss was reduced to 2.23%, when the sweibas were hermetically sealed and raised above the ground (Shazali and Ahmed, 1998).

Table 5
Types of insect pests and contribution to total loss.

Type of insect pest	*N*	%
Larger grain borers (*Prostephanus truncatus*)	55	56.7
Grain weevil (*Sitophilus granaries*)	35	36.1
Lesser grain borer (*Rhizopthera dominica*)	7	7.2
Total	**97**	**100**

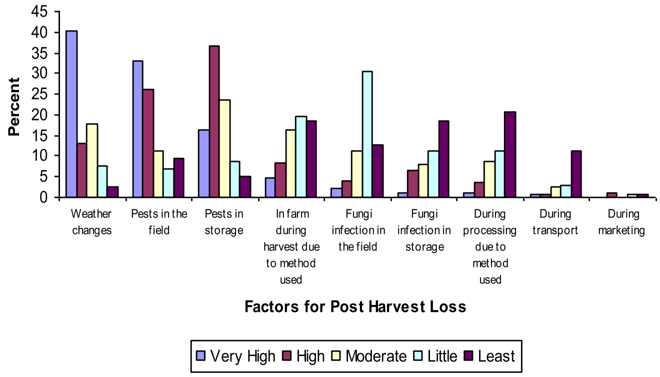

Fig. 7. Farmers' perceptions about the factors responsible for post-harvest losses.

3.6. Farmers' perceptions about post-harvest losses and knowledge on the control measures

Most farmers considered changes in weather (40%), pest damage in the field (33%) and storage pests (16%) as the three major factors that exacerbate post-harvest losses (Fig. 7).

An assessment of the farmers' knowledge of post-harvest loss control revealed high level of awareness of the need for control measures. Farmers reported to have previously applied control measures against post-harvest losses, about 23% using herbs and 20% using wood ash, while 51% of the farmers used commercial chemicals, considered to be a modern pest control method. On the other hand, 94–99% of the surveyed farmers had no appreciation of proper drying, maintenance of hygienic conditions, pre-processing, proper handling and packaging of their crops, or use of metal silos and other hermetic storage devices as control measures against post-harvest losses (Table 6). Many farmers reuse sacks which are often dirty, contaminated with insects or have holes in them, thereby increasing the possibility of damage of the stored crops.

Two challenges emerged as the major stumbling blocks in the consistent use of the control measures. These are higher prices of the artificial chemicals (71%) and the need for large volumes of the chemicals (29%).

Some of the modern technologies for controlling post-harvest loss include contact insecticides and fumigants, botanicals, inert dusts, biological control agents, hermetic storage technologies in form of metal silos and high-density polyethylene that reduces gas exchange (Obeng-Ofori, 2011; Tefera et al., 2011a). De Groote et al. (2013) demonstrated that metal silos were effective in controlling maize weevils and the larger grain borer without the use of pesticides such as Actellic Super and Phostoxin. It was not known during the current study whether the farmers were able to handle or apply the chemical pesticides correctly according to the manufacturers' prescriptions, but Rugumamu (2011) previously highlighted the difficulties faced by farmers in Tanzania regarding the high cost, limited availability, and uncertain genuineness of the available pesticides. Nonetheless, there is sufficient evidence to suggest the need for increasing the skills and capacity of smallholder farmers, traders, transporters, marketers, and other stakeholders in the application of modern pest control measures.

The majority of the farmers (96%) reported that they had limited knowledge in relation to the proper post-harvest management methods, especially for crop storage and pest control, and 55% of them expressed the desire to receive training from agriculture extension officers on management of pest and diseases (Table 6).

Table 6
Application of the control measures, effectiveness and challenges.

Variable	*N*	%
Farmers who applied a control measure	265	79.6
Farmers who did not apply any control measures	68	20.4
Total	**333**	**100.0**
Control measures used		
Commercial chemicals	135	50.9
Traditional herbs	60	22.6
Ash	52	19.6
Others (traps, proper drying, maintaining good hygienic conditions, pre-processing, proper handling and packaging	18	6.9
Total	**265**	**100.0**
Farmers' knowledge gap in applying the control measures		
Management of pest and diseases	184	55.3
Proper use of storage facilities	66	19.8
Processing of perishable crops	56	16.8
Sorting and packaging	27	8.1
Total	**333**	**100.0**

3.7. Farmers' perceptions about the causes of food insecurity

The study estimated average crop outputs of the farmers as 1.2 tons of maize, 432 kg of pigeon peas, 401 kg of sunflower and 368 kg of beans. Manyara Region is estimated to have a significantly higher amount of stored maize, sunflower, beans and pigeon peas ($P \leq 0.05$), than Dodoma region. Most of the surveyed farmers (77%) affirmed that their households did not have adequate food during the previous year. The proportion of households with inadequate food was significantly ($P \leq 0.05$) higher in Dodoma (81%) compared to Manyara region (71%). In addition, 41% of the surveyed households reported to have received an average of 42.5 kg of food aid in the previous season (Table 7). During focus group discussions, low crop outputs were identified as a factor responsible for food insecurity. And, 70% of the surveyed households attributed the low crop output to weather changes. Weather changes were described as erratic rainfall and low amount of rain with poor distribution, which negatively affects crop performance. In some occasions, the planting of seeds close to the onset of rainfall did not guarantee good yields because the rainfall was inadequate to support crop growth. Again, weather changes were noted to aggravate post-harvest losses; sometimes when mature crops needed to dry, suddenly rainfall was experienced, causing significant food losses, and reducing both the quantity and quality, in terms of nutrients and taste, and significantly diminishing the market value.

Previous investigators in post-harvest have observed that post-harvest losses are aggravated by climatic variability (Hodges, 2012; Stathers et al., 2013). It was observed in Swaziland that harvesting and drying-losses of 16.3% occurred when maize was harvested

Table 7
Farmers' perception about the causes of food insecurity.

Food security situation	*n*	%
Food insecure households (2011)	*255*	*76.6*
Food insecure households-Dodoma	153	80.5
Food insecure households-Manyara	102	71.3
Households that received food aid in 2011	*137*	*41.1*
Farmers' perception about causes of food insecurity		
Weather change	233	70.0
Poor processing techniques	26	7.8
Pest, disease	23	6.9
Low harvest	18	5.4
Low rainfall	14	4.2
Poor rainfall distribution	8	2.4
Poor weather	4	1.2
Not hard working	4	1.2
Poor infrastructure	3	0.9

under damp conditions compared with 6–10% when maize was harvested during more favorable dry conditions in other locations (Hodges, 2012).

The farmers in the current study believed that the combination of poor crop yields and high post-harvest losses, caused by climate variability, are responsible for widespread food insecurity. Many studies and common opinion is that the negative effect of climate variability on food insecurity of African smallholders is likely to get worse in future (Parry et al., 2009) and more Africans are likely to depend on imported food (Schmidhuber and Tubiello, 2007). As debatable as such projections or observations may be, the farmers' perspective of the role of climate change in their food security status underscores the need for further investigation and understanding of how climate change might impact on post-harvest issues at smallholder level and then develop both institutional and technological changes that will reduce vulnerability in the face of climate variability and even change (Stathers et al., 2013).

4. Conclusion

Climate variability has, at a minimum, twin-consequences on smallholder farmers – low agricultural productivity and high post-harvest losses. The poor state of available post-harvest handling infrastructure and farmers' inadequate knowledge on proper post-harvest handling methods seems to further aggravate the already fragile food insecurity. In addition, losses during manual processing and during storage deprive the farmers the opportunity to gain from increased market prices of processed products, thereby worsening poverty. Processing offers farmers an advantage to diversify their incomes and food by processing their agriculture commodities to different products. However, the current manual processing practices, being labor intensive, time-taking and with low yield, deprive the farmers, particularly women, of the opportunity to diversity the market options and be financially rewarded. Therefore, large farming operations with increased productivity per unit farm area do not appear to be attractive to the smallholders. Increasing productivity whilst the farmers lack the ability to store excess farm outputs may increase post-harvest losses, reduce economic viability and profitability, and may be a disincentive for investment in agriculture.

Any strategies to help smallholders to simultaneously adapt their farming systems to climate variability, improve their capability to use modern farming tools, and improve their ability to use suitable processing and storage methods could be the pathway out of hunger and poverty. Therefore, the dissemination of improved agro-processing technologies and training of the smallholders is necessary in order to achieve food security and improved nutrition.

From the policy perspectives, national agricultural development strategies need to guarantee the availability of effective community-based storage infrastructure. This would have a positive effect on the food security situation and food prices, especially in the scenarios where crop yields are low, total farm outputs are small, or diets are insufficiently diversified in communities with high dependency on a few staple foods. Indeed, targeting of post-harvest technologies based on crop–livestock production systems is likely to improve food security. Appropriate processing machines and tools of varying scales will reduce processing time, labor, and food losses, and will have a significant impact on women since they are chiefly involved in food processing. Finally, increasing the knowledge of farmers on proper use of improved post-harvest storage technologies will have an impact on the ability of smallholder households to reduce food losses but appropriate policies are needed to effect measures that can reduce market imperfections and other market risks.

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