Improved Hermetic Grain Storage System for Smallholder Farmers in Tanzania

THESIS

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Abstract

More than 75% of Tanzanians depend on agriculture for their livelihoods. Many smallholder farmers practice subsistence agriculture with maize as the major cereal crop, which is mainly used as food and partly a source of income. However, the maize grains start deteriorating soon after harvesting due to the lack of effective storage, mainly because of insect infestation. Thus, the main objective of this thesis was to develop and test an improved hermetic grain storage system for the smallholder farmers in Tanzania that can effectively store maize grain without addition of any chemicals. The proposed storage system was fabricated using locally available materials in Tanzania. The improved storage structure was tested by comparison with the conventional system using polyethylene sacks for six months using maize grains. Data were collected on the changes in dry matter, moisture content, temperature and relative humidity over the storage period of 6 months. The moisture content and dry matter were determined by sampling maize grains from both types of storage systems, at the beginning and the end of the storage period. Temperature and relative humidity of grains were continuously recorded using data loggers inserted in each storage structure. Initially, the grain moisture contents for the conventional and improved storage systems were 10.5 and 11.4%, respectively, and the final values were 12.0 and 13.2%, respectively. The overall storage dry matter loss for the maize grains stored for 6 months in the conventional and improved storage systems were 30.1 and

10.9%, respectively. The results suggest that the improved hermetic grain storage system stored grain better than polyethylene sacks used in the conventional system. The improved storage system shows the potentials to prolong maize storage period and ensure food security by reducing post-harvest food losses.

Keywords: Grain storage; hermetic; maize grain; smallholder farmers; dry matter loss; food security

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Chapter 1: General Background

Introduction

More than 75% of Tanzania's inhabitants depend on agriculture for their livelihoods (Salami et al., 2010). Many farmers practice subsistence agriculture. Agricultural mechanization level is still very low, thus almost all agricultural practices, including harvest and post-harvest operations, such as transportation and storage, are conducted manually. Most agricultural handling activities, such as drying, dehulling, shelling, winnowing and sorting, are conducted manually (Abass et al., 2014). Around 75% of Tanzania farmers are smallholders, and, normally, they cultivate less that one hectare of land, with some cultivating up to 10 hectares (Salami et al., 2010). Maize is the most common food crop which is seasonally produced and continuously consumed (Nduku et al., 2013).

Usually, maize ears are left on stalks for sun drying and subsequently harvested manually. Typically, corn ears are then detached, de-husked and shelled by hands. Some farmers de-husk and shell the corn ears in their farms, while others do in their homes. The harvested maize is then transported from farm to residence for storage, normally by carrying maize bags on head or using bicycles. Some farmers hire trucks to haul their maize. Maize is

normally stored in jute bags, sacks or traditional cribs and many farmers do not implement any pest control measures. Some practice traditional pest control by mixing with some herbs such as Mexican marigold and hot pepper (Bett and Nguyo, 2007).

Smallholder farmers in Tanzania suffer several challenges, such as getting and paying for pesticides, crop transportation to the market, as well as lack of crop post-harvest storage facilities. The post-harvest quantitative loss is 15% in the field, 13-20% during processing, and 15-25% during storage (Abass et al., 2014). Consequently, large food losses and low food quality occur contributing to food insecurity. Thus, improvement in agricultural practices of smallholder farmers in rural Tanzania is essential to achieve an efficient maize supply chain with increased maize yields, reduced maize grain losses during storage and handling, and reduced time to accomplish the harvest and post-harvest operations.

Problem Identification and Justification

Lack of best management practices and lack of better technology in harvest and post-harvest operations cause huge loss of maize and other crops. The key constraint to improving food and nutritional security in Africa is the poor post-harvest management that leads to maize grain dry matter loss between 16 and 36% (Tefera, 2012). In Tanzania, the post-harvest losses are estimated at an average of US$ 20 per ton for small farms (AFTAR, 2009). There are post-harvest losses at various stages of supply chain. At the storage stage, the post-harvest quantitative loss is between 15 and 25 % (Abass et al., 2014); moreover, the smallholder farmers in Tanzania lack access to capital and are otherwise unable to

invest in high quality storage facilities to combat the storage loss. Most of them continue to store their grains in conventional ways and thus suffer a high storage dry matter loss. Therefore, there is a need to reduce the storage losses as a part of combating the overall agriculture production losses. To address the storage losses, we develop an improved hermetic grain storage structure for smallholder farmers in the developing countries, and tested in Tanzania.

Objective (s)

The main objective of this thesis was to develop and test an improved hermetic grain storage system that could store grains for longer durations without addition of any chemicals for the smallholder farmers in Tanzania. The specific objectives were:

- Design and fabricate an improved hermetic maize grain storage system using locally available materials in Tanzania; and
- Test the performances of improved grain storage system in comparison to the conventional system in terms of storage dry matter loss and the other quality metrics, including changes in moisture, temperature and relative humidity, and visual observations.

Thesis Organization

Chapter 1 describes general background in which introduction, problem identification and justification, objective and thesis organization are explained. Chapter 2 is a literature review which describes various grain storage technologies currently in use. Chapter 3

discusses the storage structure design and fabrication, and storage experiments, which includes experimental design, parameters collected and the statistical analysis used for the study. Results are presented and discussed in the results and discussions section. Chapter 4 discusses the overall conclusions of this thesis research, and recommendations for further studies.

Chapter 2: Literature review

Introduction

Innovations of various technologies to reduce post-harvest losses are considered to be important by the private sector and governments in many African countries. Reducing post-harvest losses improves food security by increasing food availability and accessibility. However, there has been low level of acceptance of different post-harvest loss technologies in various countries in the Sub Saharan Africa. The reasons behind this low level of acceptance are: (i) technology seems to be financially unstable, (ii) lack of cultural acceptability, such as introducing silos where farmers prefer to keep their food within their homes, and (iii) assumptions of the researchers and investors that change can happen within a short timeframe like a three-year project, which usually is not true most of the times as it takes longer time and more money for the farmers to adopt to the technology (Zorya et al., 2011). Some post-harvest grain storage and management practices and technologies intended for storing grains to be used later as seed are not accepted by some societies for cultural reasons (Murdock et al., 2003).

The post-harvest management practices intending to store seed grains include customary techniques, such as hanged cobs over fireplace, gunny bags with cow dung ash, and airtight containers with recent seed protectant (Wambugu et al., 2009). About 30% loss in cowpeas seed weight occurred with on-farm storage, with almost 70% of the grain unfit for human consumption (Singh and Jackai, 1985). The best approach for minimizing storage post-

harvest loss is by modifying or replacing existing storage structures (Zorya et al., 2011). The existing storage structures have to be modified to cost-effectively improve stored grain quality for smallholder farmers in rural areas. Thus, the main objective of this review is to examine the current and potential storage technologies available in order to develop an improved storage structure technology appropriate to the smallholder farmers, especially, in the rural areas of Tanzania as well as the other developing countries.

Five storage structures have been identified and discussed in this section. They are: (1) conventional storage structures, i.e., underground pits, woven granary and cribs; (2) metal silos; (3) triple bagging hermetic technology; (4) self-build silos; and (5) on-farm storage structures and condominium storage space technology. Based on these storage structures, a suggested improved storage structure with potentials to reduce post-harvest grain losses is then presented. The suitable storage structure will add value to cereal grains storage by minimizing losses and maintaining quality to improve food security.

Conventional storage structures

Conventionally, cereal grains are stored in the underground pits, woven granary, and cribs (Zorya et al., 2011). Traditional on-farm and domestic storage systems included fire places, local cribs, open fields, roofs and platforms (Nukenine, 2010). The smallholder farmers build these storage technologies using locally available resources such as plant parts and soil (Nukenine, 2010). These storage systems were predominantly used in the past; and, are still used in the societies preferring to store grains traditionally. Other storage structures

include gunny bags and airtight containers with cow dung ash (Wambugu et al., 2009). Polypropylene and sisal bags are mainly used for maize storage; and they have different storage capacities ranging from 25 to 100 kg (Nduku et al., 2013). Most of the smallholder farmers in Tanzania using the conventional storages technologies mix the grains with some materials like tree ashes to prevent early degradation. Farmers in many areas of Sub-Saharan Africa mix their cowpeas with sieved ashes from cooking fires to limit weevil activity. It has been confirmed by scientists in northern Cameroon that smallholder farmers when storing cowpeas commonly use ashes (Murdock et al., 2003).

Wambugu (2009) did a storage experiment to determine the effectiveness of traditional seed treatment and storage in comparison to improved methodologies. After three to six months of storage, it was determined that seed hung above fireplace exhibited more insect damage (99% more) when compared to the seed stored in airtight plastic containers with cow dung ashes. Tables 1 and 2 below summarizes the seed damage caused by insects (%) and increase in the moisture content (%) as determined by Wambugu et al. (2009). In airtight containers, the increase in moisture content of stored seed was attributed to the presence of air in the head space of the containers (Wambugu et al., 2009). The increase in moisture content promotes seeds deterioration, thus shortening the safe storage period. The storage period is reduced by 50% for every 1% increase in moisture content (Harrington, 1972).

Table 1. Insect damaged (%) seeds observed with various methods of seed storage

Treatment	Variety % damage		Mean
	Rachar	Maseno D.C	
Gunny bag + cow dung ash	56.3	37.6	46.9[ab]
Doom + Plastic container	1.1	1.6	1.4[c]
Ash + Plastic container	0.9	0.3	0.6[c]
Fireplace	54.8	54.3	54.5[a]
Mean	28.3a	23.4a	25.8

(Source: Wambugu et al., 2009)

SE 5.8,

P= 0.05, = 17.1

Means followed by the same letter in a column or row are not significantly different according to p=0.05

Rachar = Local maize variety

Maseno DC = Improved maize variety

Table 2. Moisture content increase (%) for various storage methods after 6 months storage

Treatment	Variety change in % moisture		Mean
	Rachar	Maseno D.C	
Gunny bag + cow dung ash	13.8	13.8	13.8[a]
Doom + Plastic container	12.8	12.9	12.8[b]
Ash + Plastic container	12.9	12.4	12.6[b]
Fireplace	13.9	13.9	13.9[a]
Mean	13.3	13.2	13.3

(Source: Wambugu et al., 2009)

SE 0.1,

P= 0.05, = 0.3

Means followed by the same letter in a column or row are not significantly different according to p=0.05

Rachar = Local maize variety

Maseno DC = Improved maize variety

Woven granaries occupy large space indoor whether they have grains or they are empty. Figure 1 below shows an indoor woven granary. For outdoor storage, underground pits and cribs occupy large space, too. Also, the construction skills for conventional woven granaries, underground pits and cribs are disappearing from society. The use of sacks to store cereal grains has increased because they occupy less space when filled with grains,

as well as when empty. In addition, they are portable and can be sold and traded as needed (Zorya et al., 2011).

Figure 1. Woven granary (Source: http://goo.gl/xQ4eUS)

Metal Silos

A hermetically sealed metal silo is a cylindrical structure, which is constructed from galvanized steel sheet (Figure 2) and airtight such that it minimizes oxygen when grains are stored in it, as well as preventing oxygen from entering, thus killing all insects and pests that might be in the stored grain. Hermetic or airtight storage structure work on the principle of depleting oxygen and producing carbon dioxide from the respiration process of living organisms in the sealed storage environment (Anankware et al., 2012). For cereal grains to be stored effectively into a silo, the grain must be dried to a moisture content of less than 14% (Tefera, et al., 2010). Galvanized steel sheet cost, labor and transportation are the main production costs of metal silos. However, these costs vary from one country to another, and depend on some prevailing circumstances. In general, to be cost effective,

seed used for planting in the subsequent years are recommended to be stored in a small metal silo of 100–200 kg capacity, while those for consumption should be stored in a large metal silo of 300–3000 kg capacity (Tefera et al., 2010).

Gitonga et al. (2013) assessed the impacts of adopting metal silos to reduce maize losses during storage in Kenya. The assessment used the propensity score matching method to evaluate the impact of silo structure on maize storage duration, storage losses and costs. The assessment highlighted that the smallholder farmers who adopted the silos lost only 3 kg, worth US$ 2, while those who did not adopt the silos, on an average, lost 157–198 kg, worth US$ 104-132. Furthermore, the smallholder farmers who adopted silos managed to store their maize 1.8 to 2.4 months longer than those who did not; and they also sold their surplus at a good price. However, the initial cost of metal silo is Ksh 20,000/1.8 ton, equal to US$197/1.8 ton, which is very high for smallholder farmers (Gitonga et al., 2013). Even though the construction and uses of metal silos have been promoted by FAO, the adoption of this technology has not been successful because there is a lack of requisite skills and capital among local artisans, and the availability of suitable sheet steel is scarce within local markets (Tivana et al., 2014)

Figure 2. A metal silo (Source: http://goo.gl/YQ9MrV)

Triple bagging hermetic technology

In Africa and Latin America, the Purdue Improved Cowpea Storage (PICS) bag have been used (De Bruin et al., 2012). The PICS bag is also known as triple bagging hermetic technology (Figure 3). It consists of two inner-layers of polyethylene bags acting as oxygen barrier and a third layer that is outer woven polypropylene bag. This layer acts as a case for the two inner polyethylene bags and ensures mechanical strength of the storage structure as a whole (Murdock et al., 2012). The PICS's outer layer is made of woven polypropylene and the two inner-liners are made of 80μ high density polyethylene (Baributsa et al., 2010). The technology has been widely adopted in West and Central

Africa (Baributsa et al., 2012) due to its effectiveness, simplicity, low cost, durability and manufacture within the local context.

Figure 3. Triple bagging hermetic storage (Source: Baributsa et al., 2012)

Performance testing of the triple bagging (i.e., PICS) storage technology was conducted whereby four treatments were used (Baoua et al., 2012). The treatments were: 50 kg bags collected from farmers and used for one post-harvest season, new 50 kg bags made in 2007 and stored for one year before use, new 100 kg bags produced in 2008, and a control bag made of woven polypropylene. The bags were filled with infested cowpea and left for more than 5 months in a laboratory room at ambient temperature 28–39 °C and relative humidity ranging from 5-30%.

After the storage period of five months, many cowpea weevils were observed in the control structure (a single woven bag), and less weevils were found in all three PICS bags. 1 kg samples of cowpea grains were used for the observation. The increase in number of

emergence holes in seeds taken from all PICS bags was not significant over the time when contrasted with initially bagged grain. However, for the single woven bag, 100 percent of the seeds had at least one hole. The 100 grains weight was different between treatments. It was 12.6–13.6 g for the 100 kg bags, 12.9–13.7 g for the new 50 kg bags, and 12.9 -13.9 g for the used 50 kg bags. For the single woven bag, the 100 grains weight ranged between 7.6–8.2 g, which when compared to the PICS bags indicated a 40% loss of mass.

The major disadvantages of the PICS bags are that they are very susceptible to puncture from sharp/protruding objects. Not only are these bags susceptible to puncture, but also they are highly susceptible to rodents. Additionally, they can easily burst when they are moved from one location to another, especially when the bag is large. The inner liners are very likely to face physical damage, such as abrasions and perforations, which mostly occurs when the insects are trying to escape from oxygen deficiency (Baoua et al., 2012). Punctures and physical damage reduces the useful life of the bag, and thus adds to the cost of this system.

Self-build silos

The self-build silo is made of corrugated galvanized steel sheet and insulated with earthen walls and is used to store cereals in rural African villages. The rural smallholder farmers can build the silos themselves if trained with few techniques. The silos were constructed in Itigi, one of the rural areas in Tanzania where 1 m^3 and 2 m^3 capacity silos prototypes were designed to be used by individual, smallholder farmers. Figure 4 shows the

construction phases of a self-build silo prototype. Self-build silos are easily constructed within rural villages because the materials used are locally available. To assess the ease of constructing the silo and determining its functionality, tests were constructed whereby a silo was constructed by two unskilled laborers. The unskilled laborers managed to build a small silo prototype by using their local tools and materials (Barbari et al., 2014).

The cost for designing and constructing the self-build silos is relatively low. Material costs are low because are locally available. In addition, advanced technologies are not required to construct the silos so that smallholder farmers can easily fabricate these silos in rural African villages. The corrugated galvanized sheet used to cover houses is less expensive than galvanized steel sheet normally used to make metal bins. The cost of earthen walls for insulating the silos is limited to the cost of labor (Barbari et al., 2014).

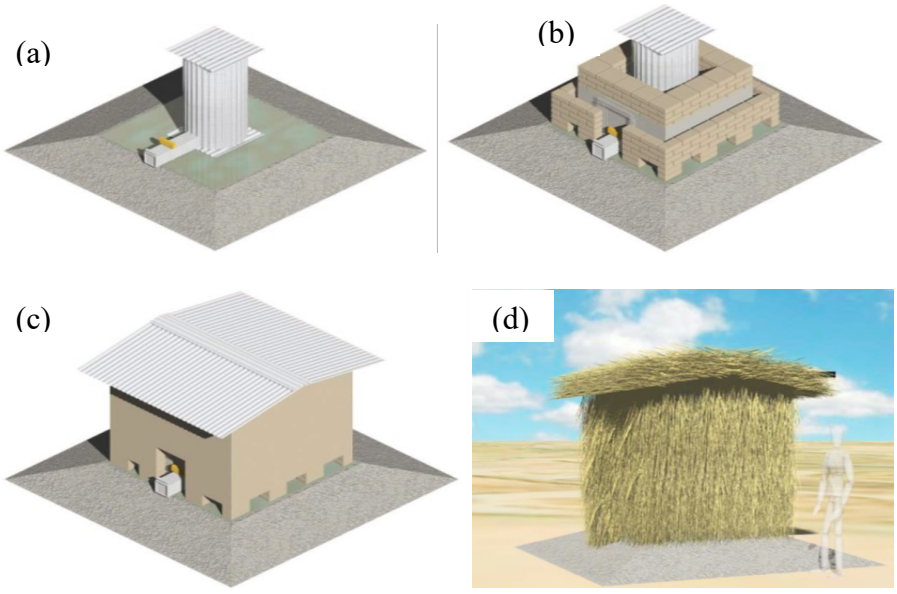

Figure 4. Building phases of the designed silo (Barbari, et al., 2014)

On-Farm Storage Structures and Condominium Storage Space Technologies

The on-farm storage structure is a storage technology whereby farmers build storage bins that provide maximum flexibility and maintain control on their own farmstead. However, it is a challenge for rural farm operators to invest in the on-farm storage structures, unless they unite in groups since it requires high capital (Edward, 2010). Condominium storage refers to a space, which can be owned or leased by a producer within a licensed primary elevator. It consists of a separate facility attached by conveyance to the principal and annex house (Condominium storage policy. (n.d.). The condominium storage space is mostly managed by a commercial elevator, who manages the grain and guarantees quality of the grains throughout the storage period. However, the technologies associated with these storage systems require higher-level technical skills that are difficult for the smallholder farmers in developing countries (Edward, 2010). On-farm storage structures and condominium storage space structures (Figure 5) could be feasible to the rural smallholder farmers in developing countries if they are purposely made for a group of smallholder farmers. However, the technologies are not feasible for individual rural smallholder farmers in developing countries because they require high capital investment (Edward, 2010).

Figure 5. On-farm and or condominium storage structures

Comparison of Different Storage Systems

Triple bagging hermetic technology seems to be easy to use, low cost and readily available. However, the durability of triple bag is questionable as they are vulnerable to simple punctures. The self-build silo seems to be most appropriate because it is very durable compared to the triple bagging technology as it is fabricated from layers of grass and clay soil. However, the self-build silo is permanent. It is constructed to stay outside and it cannot be moved from one place to another. Table 3 summarizes some of the advantages and disadvantages of various storage systems.

Table 3. Advantages and disadvantages of different storage structures

Storage System	Advantages	Disadvantages
Sack	• Simple to use • Available in different storage capacity • Occupy small space	• Do not last long • Easy access by pests and rodents • Susceptible to water
Woven granary	• Simple to make and use • Can be made in different storage capacity.	• Occupy large space all time • Do not last long • Pests, insects and rodents can get into the structure
Metal silo (Figure 2)	• Simple to construct • Easy to use • Durable	• Metal sheets are expensive • High skills required for artisans
Triple bagging system	• Low cost of production • Simple and durable • Easy to use	• Can be destroyed by sharp objects • Pest and Rodents can enter
Self build silo	• Uses local materials • Very durable • Simple to construct	• Several stages to construct it • Remain fixed at one point outside the house
On-farm and Condominium storage structures	• Can be owned or rented by farmers • Cost effective for farmers in developed countries	• Farmer incur both fixed and variable costs • Investment and operations costs are high for smallholder farmers in developing countries

Desirable Features of an Improved Grain Storage System

Investment cost and complexity of the technology are the major constraints on adopting various storage systems being introduced to smallholder farmers in developing countries. Therefore, for the enhanced storage structures appropriate to smallholder farmers should

be simple and easy to manufacture and use, and the materials must be readily available in the local context. It should also ensure enough strength and durability so that it can effectively and efficiently store the cereal grains over a long period.

Therefore, we suggest that the appropriate grain storage for smallholder farmers in Tanzania should be an improved storage structure that is simple to construct by using locally available material and can be stored inside the living house and could be moved from one point to another easily. Such an improved grain storage system will reduce losses and maintain quality to ensure food security. The improved storage system should be designed for in-home use because most small-scale farmers in Africa like to store their harvested cereals within their living space to ensure security (Zorya et al., 2011).

Insects (weevils) Activity and Mold Growth in Grain Storage

Insects utilizes oxygen during metabolism, in the meantime, raising carbon dioxide concentrations through respiration. The insects feeding activity drop progressively in proportion to the varying gas concentrations and stops nearly at 3-6% (v/v) oxygen and 15-18% carbon dioxide. Some insects can recover their feeding activity after some days of deficiency of oxygen and presence of high carbon dioxide. (Chi et al., 2011)

Insect multiplication and mold formation in stored maize are rapidly stimulated by tropical heat, moisture and open air. For most storage insects, the rapid insect growth occurs when the temperature is in the range of 25°C to 35°C (Proctor, 1994). Maize weevil (*Sitophilus*

zeamais) is the main deterioration insect for stored maize, sorghum and other grains in tropics (Jacobs and Calvin, 2001). Around 18% of shelled maize were found with weevil damage in research involving stored maize in Tanzania conducted by Mulungu et al. (2007).

An experiment was conducted by Yakubu et al. (2011) with the objective of determining the effects of oxygen level, storage temperature, maize moisture, and their interaction on the survivability of maize weevils over time in hermetic containers.

According to the results of this study, weevil mortality in hermetic storage reached 100% in six days at 27°C for both maize with 6.3 and 16% moisture. The weevil mortality increased over time at 10°C whereby the mortality rate reached 28% for maize with 6.3% moisture, and 5% for maize with 16% moisture. Therefore, as temperature rises mortality rate increases very rapidly. For non-hermetic treatments, the mortality rates ranged from 0 to 5% after 10 days, which were much lower compared to hermetic treatments. For hermetic storage, the weevil mortality was affected by maize temperature and moisture content, especially for 27°C where the mortality was 100%. For non-hermetic, weevil mortality was not affected by maize temperature or moisture content.

Molds can produce different mycotoxins, which are secondary toxic metabolites that can grow on crops and different feed and food stuff. Based on difference in their chemical structure, mycotoxins are categorized into numerous cluster, such as Aflatoxins, Ochratoxins, Trichothecenes, Zearalenone and Fumonisins. Molds are able to develop on

the crop in the field, likewise during storage, hence creating two bases of mycotoxins owing to mold formation. During storage, contamination risks from molds, insects, and other non-food substances must be disallowed. For molds and its related mycotoxins, obtainability of water is the key causes of spoilage. The conditions like temperature and humidity offers favorable atmosphere to microbial stability of the grain during storage. Furthermore, the prevailing temperature during storage has effects on the mold growth and activity. When cereal grains are stored in a silo or warehouse, there is an immobilized volume of air whereby, temperature at the center of the grain volume remains relatively the same to that during harvest, and, the grains far from the center are in contact with the storage walls. Thus when the outside temperature decreases, the walls cool faster which causes condensation and wet spots to occur, thus mold growth occurs. A temperature increase of 2 to 3°C can indicate mold growth or insect infestation. Additionally, the growth optima for the majority molds is between 25 and 30°C (Eeckhout et al., 2013).

Conclusion

From the review conducted, it can be concluded that although there has been advancement in improving the storage structures, more improvements to the available structures are still needed. The focus should be on how to ensure maximum air-tightness while taking into account a solution to restrict free air space on top of the storage structure when removing grain from the structure. This will eliminate the oxygen that is available in the free top space in the structure, thus shortening the life of insects by eliminating oxygen in the storage space. However, depletion of oxygen is accompanied with the formation of other

gases such as carbon dioxide from the respiration process of living organisms in the sealed environment of the storage structure. The respiration process also produces moisture that condenses within the structure. This leads to heat production that causes the generated moisture to evaporate, and raise humidity levels within the storage structure. Thus, another focus must be on finding a solution to remove and restrict moisture increase within the storage structure so that the grains within it can be stored longer without deterioration or mold formation. Such solutions could include using desiccant materials that do not contaminate food.

Therefore, the suggested improved grain storage structure to be constructed must also address to eliminate the head-space formed during grain removal from the hermetically storage structure. In addition, the structure should minimize moisture production from respiration processes.

Chapter 3: Developing and Evaluating an Improved Hermetic Grain Storage System for Smallholder Farmers in Developing Countries

Abstract

There has been a low level of acceptance of different post-harvest technologies in various countries in the Sub-Saharan Africa. Some societies do not accept the storage technologies for cultural reasons. Because of the low acceptance level of storage technologies, there are high post-harvest losses. The best approach of minimizing storage post-harvest loss is by modifying existing storage structures to work more effectively and efficiently. This study aims to design, fabricate, and test an improved storage structure for improved acceptance by smallholder farmers in Tanzania and other Sub-Sahara African countries. The storage system was designed and fabricated using locally available materials in Tanzania. It was then compared with conventional system using polyethylene sacks for its effectiveness by storing maize for 6 months. Data were collected on the changes in dry matter, moisture content, temperature and relative humidity over the storage period of 6 months starting in October 2015. The moisture content and dry matter were determined by sampling maize grains from the storage structures at the beginning and the end of the storage experiment. The temperature and relative humidity results were continuously recorded using data loggers inserted in each storage structure. At the end of experiment, maize stored in the conventional storage structure experienced a dry matter loss of 30% while the loss for the improved storage system was around 10%. Therefore, the improved storage structure

seems to work better than the conventional structure for reducing post-harvest losses thereby improving food security.

Keywords: Grain storage structure; cereal grain; post-harvest losses; smallholder farmers; food security.

Introduction

Storage is an important post-harvest step since better storage can preserve grain quality for a longer duration, thus enhancing food security. For the developing countries, different storage structures have been used for storing grains as discussed in Chapter 2. The financial status and the obtainability of fabrication materials are key drivers for the acceptance of storage technology (Gueye et al., 2013). In Tanzania, maize is the main cereal crop. Most rural Tanzanians' smallholder farmers have maize farms between 1 to 10 hectares (Salami et al., 2010). After harvesting the maize, transporting to the storage sites (usually homes), drying and shelling; maize grains are usually stored in sacks, traditional cribs, or jute bags; all with limited pest control measures. Insects are the main threat to maize storage, causing losses that range from 18% for shelled maize, to 20% for ear maize and 27% for stored and shelled maize in local granaries (Gueye et al., 2013). Thus, maize stored in the traditional storage structures is widely exposed to external temperature and moisture variability as well as pest infestations. As a result, maize shelf life is reduced resulting in an increased grain loss and low food quality, as well as adding to food insecurity.

Limited mechanization is a major constraint for all agricultural practices, including harvest and post-harvest operations, such as transportation and storage. The mechanization is limited in developing countries because of limited access to electricity and fossil fuels, limited access to capital to purchase machineries limited technology and limited know-how on the use of the systems. In addition, smallholder farmers have less land area to cultivate which become favors continuation of labor-intensive production systems (Ashburner and Kienzle, 2011). The lack of appropriate storage facilities contributes to the post-harvest losses. Maize post-harvest losses are estimated to reach 20% (Rugumamu et al., 2012). Improvement of agricultural practices of farm operators in rural Tanzania is essential to achieve an efficient maize supply chain with increased maize yields and reduced maize grain losses. Improvements in storage structures should aim at reducing storage losses and prolonging the storage durations while minimizing the use of chemicals.

Thus, the main objective of this thesis was to develop and test an improved hermetic grain storage system that could store grains for longer durations without addition of any chemicals for the smallholder farmers in Tanzania while allowing user to continuously remove grain. Specific objectives were:

- To design and fabricate an improved hermetic maize grain storage system using locally available materials in Tanzania; and
- To test the performances of improved grain storage system in comparison to the conventional system in terms of storage dry matter loss and the other quality

metrics, including changes in moisture, temperature and relative humidity, and the visual observations.

Materials and Methods

Case Study Area and Storage Conditions

The improved hermetic grain storage system was developed in the Department of Food, Agricultural and Biological Engineering of The Ohio State University in Wooster, OH, USA, and the experiments were conducted in the department of Agricultural Engineering and Land Planning of Sokoine University of Agriculture (SUA) in Morogoro region of Tanzania. A room with enough space was used to store the improved storage system and sacks with maize as shown in Figure 6. Grains stored were harvested on August 3, 2015 from a SUA farm to ensure grain uniformity. Maize grain with mass of 504 kg was collected and made available for storage. Each storage structure, both improved and conventional, stored 126 kg of maize. Prior to storage, the moisture content of the maize grains were 16% (wet basis), thus the grains were sun-dried for a day. The moisture content dropped to 12% (wet basis), which is within the recommended moisture content range for maize storage. For cereal grains to be stored effectively in a silo, it must be dried to a moisture content below 14% (Tefera, et al., 2010).

Storage Structure Design

The improved storage system was developed at The Ohio State University with a design storage capacity of 150 kg, and was fabricated from the locally available materials in rural

Tanzania. Steel barrels were used with modifications to develop the improved storage system. The barrels are primarily used as containers for transporting fuel to Tanzania and thus are available in surplus quantities. These are used for storing local alcohol. Thus, the barrels were selected as the design material and were modified to secure the hermetic conditions required for maize storage over a long period of time while enabling the continuous removal of the stored grains without allowing air to enter the structure.

Experimental Design and Statistical Analyses

The experimental design was a "completely randomized design with sub-sampling". The experiment consisted of two treatments, which were "conventional" and "improved" storage structures, each having two replicates (Figure 6). From each replicate, three sub-samples were collected to determine grain moisture content, dry weight, and dry matter loss. Data loggers were installed in each storage structure to continuously record temperature and relative humidity of the environment within storage structures at 15 minutes intervals over the six months storage period. The storage period began in October 2015 and ended in April 2016.

Figure 6. Conventional storage structure (two sacks) and improved storage structure (only a part of one structure shown, though there are two)

The average dry weight for each three sub-samples of a structure provided a dry matter measure for a particular structure. The statistical significance of findings was performed using a one way ANOVA (analysis of variance) at 5% level of significance. The p-values were used to check if the differences in initial moisture content, initial dry matter, final moisture content, final dry matter, and dry matter loss between conventional and improved storage structures, respectively, are significant.

Sampling

Sampling was done by assuming uniformity among maize grains, both at the top, and all the way to the bottom for all storage structures. For each storage structure, three sub-samples were taken, each with 300 maize grain kernels. The samples were collected before

storage, while storing and after storage. The sample after storage were obtained by proper mixing of all maize grains, separately from the improved and conventional storage structures.

Measurements and Outcomes

Moisture content

The moisture content was determined by collecting samples from all storage structure to the lab, where they were weighed and then dried in the oven for 24 hours at 105°C and then weighed again after drying. The oven drying method moisture determination is classified as a basic method, but results depend on applied temperature and drying time. The Seed Analysis Rule (SAR) of Brazil revised in 1992 maintained using the oven method without forced ventilation, at 105°C during 24 hours, using whole seeds, as the official method to determine moisture for seeds of all species (Tillmann and Cicero, 1996). The weighing balance measures weight in grams (g), and has two decimal places. The oven drying temperature was recorded in degrees Celsius with precision of ± 0.5°C. Equation (i) was used to determine the moisture content of the maize samples.

$$Moisture\ Content\ (\ \%, wet\ basis) = \frac{Wet\ weight\ - Dry\ weight}{Wet\ weight} * 100\ \% \ldots\ldots\ldots (i)$$

Dry Matter

Dry matter was determined based on the dry mass of 300 maize kernels after the samples were dried in the oven for 24 hours at a temperature of 105 °C. The average dry mass for

each three sub-samples of a structure provided a dry matter measure for a particular structure.

Dry Matter Loss

Equation (ii) was used to determine the dry matter loss at the end of the storage experiment.

$$Dry\ Matter\ Loss\ = \frac{Initial\ dry\ weight - Final\ dry\ weight}{Initial\ dry\ weight} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

Temperature and Relative Humidity

Data loggers were used to record the temperature and relative humidity in each storage structure after every 12 hours for a six–month storage period. The data loggers set up on personal computer to record temperature and relative humidity after every 15 minutes for six months. Then at the end of the experiment, the data were averaged based on 12 hours, day and night, to reduce the size of the data set. The temperature and relative humidity were recorded to study how the internal temperature and relative humidity varied with respect to the external environment.

Quality Analysis Based on Visual Inspection

Main quality analysis was conducted by visual inspection whereby grain structure appearance, color, odor, and mold formation were visually observed and recorded.

Results and Discussions

Moisture Contents

Figure 7 presents moisture content results for conventional and improved storage structures, at the beginning and the end of the storage periods. At the beginning, the moisture content of the conventional storage structure was 10.5% while that of the improved structure was 11.5%. The ANOVA results for initial moisture contents give p-value of 0.10 which is greater than 0.05, thus, the initial moisture content among storage structures do not differ significantly (Table 4). Also, at the end, the moisture content of the conventional structure was 12% while the final moisture content of the improved one was 13.5%. The ANOVA results for final moisture contents give p-value of 0.05 <= 0.05, thus, the final moisture content between storage structures is significantly different (Table 5). Therefore, at the end of experiment, the final moisture content of improved structure is 1.5% more than that of the conventional structure. Generally, the moisture content of an improved storage structure was higher than that of the conventional storage structure.

From the data analysis, it can be inferred that the moisture contents in the conventional and improved storage structures are both increasing. The moisture from ambient environment is contributing to the increase of the moisture content in the storage structures, especially in the conventional storage structure. Even though the moisture contents in both the cases were increasing, the moisture content of an improved storage structure is greater than that of the conventional structure. The improved storage structure grains have a higher moisture

content due to the trapped water generated from the grains and living organisms during respiration. Respiration produces heat, water and carbondioxide. When the grains and living organisms in the sealed environment of the storage structure respire, they deplete the oxygen and produce carbon dioxide (Anankware et al., 2012)**.** The moisture formed in the improved storage structure remains within the improved storage structure, causing moisture content to increase. On the other hand, the moisture content of the grains within conventional structure seems to be lower than that of the improved storage structure because of the environmental interactions. Even though, there was moisture content increase for both cases, the moisture content remained in the allowable moisture content range recommended for long term maize grain storage. . To prevent fungi growth, the corn must be dried to 14% or less (Bern et al., 2013)

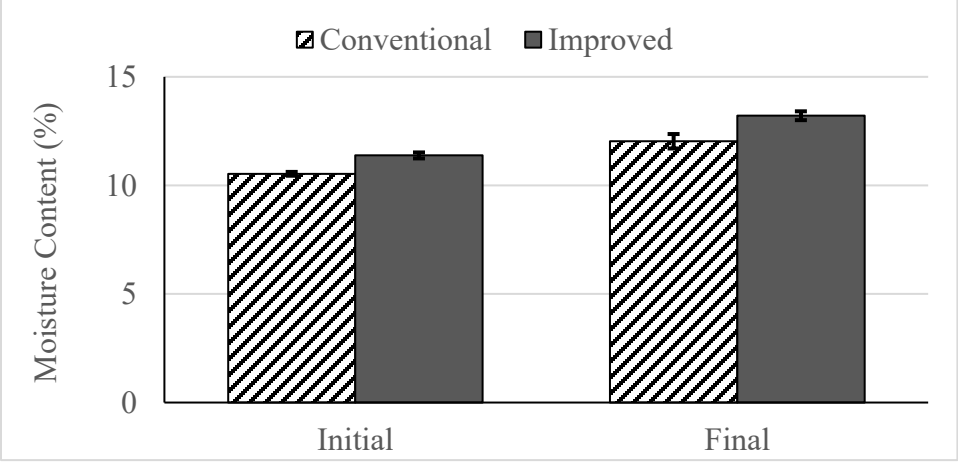

Figure 7. Moisture content (%) in conventional and improved storage structures.

Table 4. ANOVA table for initial moisture content in conventional and improved storage structures

Source of Variation	df	SSE	MSE	F Ratio	P > F
Storage Structure	1	1.84	1.84	9.0	0.10
Experimental Error	2	0.41	0.20	5.2	
Sub-Sampling Error	8	0.31	0.04		
Total	11	2.56			

Table 5. ANOVA table for final moisture content in conventional and improved storage structures

Source of Variation	df	SSE	MSE	F Ratio	P > F
Storage Structure	1	4.2	4.2	18.7	0.05
Experimental Error	2	0.4	0.2	0.6	
Sub-Sampling Error	8	3.2	0.4		
Total	11	7.8			

Dry Matter (DM) and Dry Matter Loss (DML)

The initial dry matter for conventional structure was 79.9 g/300 grains, while that of the improved storage structures was 82.0 g/300 grains (Figure 8). The ANOVA table for initial dry matter gives p-value of 0.22 which is greater than 0.05, thus, suggesting that the initial dry matter of the conventional storage structure do not differ significantly with that of the improved storage structure (Table 6). Finally, at the end of the 6-month storage period, the dry matter for conventional structure was 55.5 g/300 grains, and the dry matter for improved structure was 73 g/300 grains. The ANOVA results for final dry matter give a p-value of 0.004 which is less than 0.05, thus, suggesting that the final dry matter between

storage structures is significantly different (Table 7). Therefore, the final dry matter for conventional storage structure is less than that for the improved structure. The difference was reasonably high by 17.5 g/300 grains.

DML of the maize stored in the conventional storage structure was higher than that stored in the improved storage structure (Figure 9). There was 30% DML for conventional structure, and 10% dry matter loss for improved storage structure. ANOVA results for DML give a p-value of $0.003 < 0.05$, thus, the DML between the storage structures differ significantly (Table 8).

From the statistical analysis, the initial dry matter (g/300 kernels) of the maize grains in conventional storage structure do not differ significantly with that of the grains in improved storage structure (p-value = $0.22 > 0.05$). However, the final dry matter (g/300 kernels) of the maize grains in conventional storage structure differ significantly with the final dry matter of the maize grains in the improved storage structure (p-value = $0.004 < 0.05$). In the conventional storage structures, maize deterioration was very high because weevils were having enough oxygen supplied from the external environment, thus surviving and consuming grains, leading to its deterioration. Therefore, that was the cause of the dry weight of conventional storage to dramatically decrease by approximately 25.0 g/300 grains by the completion of the 6-month storage period, in contrast to the improved structure that had a decrease of only 9.0 g/300 grains. For the improved structure, survival of the weevils was minimal because the barrels were airtight so that oxygen did not enter

the structure from the outside environment. There were 30% DML of maize stored in conventional way (sacks), while there was only 10% DML for grains stored in the improved barrels. Based on cited post-harvest quantitative loss at storage stage of between 15 and 25% (Abass et al., 2014) as well as found in this study (~30%), the improved storage structure worked much better with only 10% measured loss.

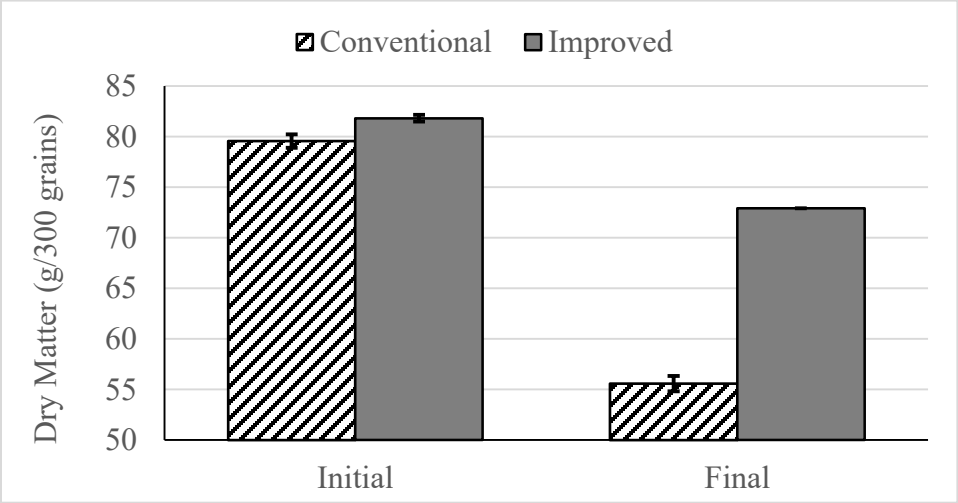

Figure 8. Pre- and post-storage dry matter (g/300 grains) in conventional and improved storage structures

Table 6. ANOVA table for initial dry matter in conventional and improved storage structures

Source of Variation	df	SSE	MSE	F Ratio	P > F
Treatment	1	6.0	6.0	3.2	0.22
Experimental Error	2	3.7	1.9	0.4	
Sub-sampling error	8	42.2	5.3		
Total	11	52.0			

Table 7. ANOVA table for final dry matter in conventional and improved storage structure

Source of Variation	df	SSE	MSE	F Ratio	P > F
Treatment	1	903.1	903.1	256.5	0.004
Experimental Error	2	7.0	3.5	2.5	
Sub-sampling error	8	11.2	1.4		
Total	11	921.3			

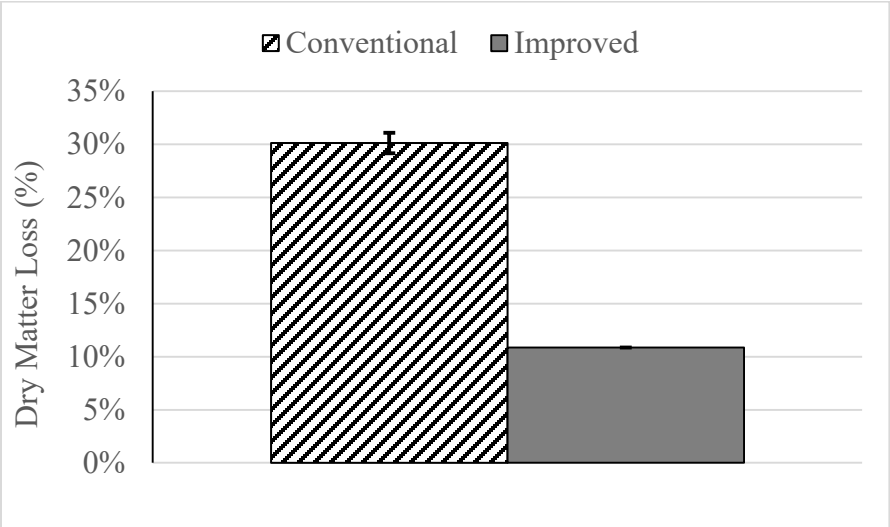

Figure 9. Dry matter loss (%) in conventional and improved storage structures

Table 8. ANOVA table for dry matter loss (DML) in conventional and improved storage structures

Source of Variation	df	SSE	MSE	F Ratio	P > F
Treatment	1	1083.0	1083.0	305.8	0.003
Experimental Error	2	7.1	3.5	0.4	
Sub-Sampling Error	8	69.7	8.7		
Total	11	1159.8			

Temperature and Relative Humidity

Temperature

Figure 10 shows the temperature trends within the storage structures over the storage period of six months. One logger was inserted in each of the improved and conventional storage systems. The loggers were set to record data after every 15 minutes, then later the data were converted into day and night, based on 12 day hours and 12 night hours. Temperature in the improved storage structure was generally lower than the temperature in the conventional storage structure for the duration of the six-month storage period. The temperature recorded within conventional storage structures is higher than that recorded in the improved structure because ambient air can flow in and out of the sacks, thus it depends much on the external temperature from the surrounding environments. Furthermore, weevil activity in the conventional storage structures also generates heat. For the improved structures, the temperature was lower because the lowered gas exchange rates tended to insulate the grain mass making it less susceptible to local environmental conditions and reduced weevil activity.

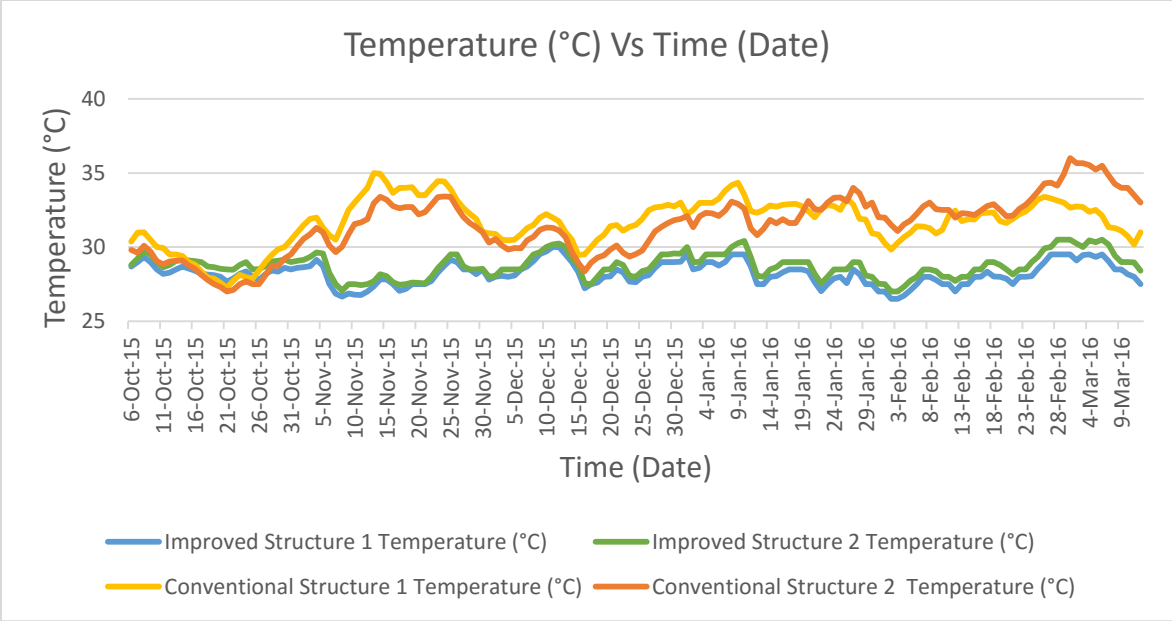

Figure 10. Temperature of grains in improved and conventional storage structures vs time

Relative humidity

Figure 11 indicates how relative humidity within different storage systems varied from October 2015 to April 2016. At the beginning, the overall relative humidity was around 70%; and kept on increasing gradually for all loggers up to the mid November 2015. Then, the relative humidity in conventional storage structure started to decrease through December 2015, and then remained constant up to the end of storage period (March 2016). The relative humidity in the two improved storage structures kept on increasing slightly and gradually up to the end of the storage period of six months. One possible reason for this relative humidity trend could have been the varying relative humidity of the external environment because of the high incidence of rain from September 2015 to February 2016, followed by the dry season through the end of storage period.

When relative humidity is more than 75% during grain storage, mold development occurs at high rate and heat production increases resulting in grain quality deterioration, thus causing significant post-harvest losses (Pixton and Warburton, 1970). Therefore, from the line graphs displayed in the figure 11, it can be inferred that there was neither rapid development of mold nor much heat production during the storage period. The initial relative humidity was approximately 70% for all storage structures. The relative humidity for the improved storage increased slightly through the end of the storage period to approximately 75%. For the conventional storage structures, the relative humidity decreased slightly to 68%. Therefore, finally the relative humidity in conventional storage structure was lower than the relative humidity in the improved storage structures. The reason for this difference between the improved and conventional structures could have been that the latter structures allows generated moisture to escape to the atmosphere through the woven sack. Conversely, moisture remains trapped in the improved storage structure.

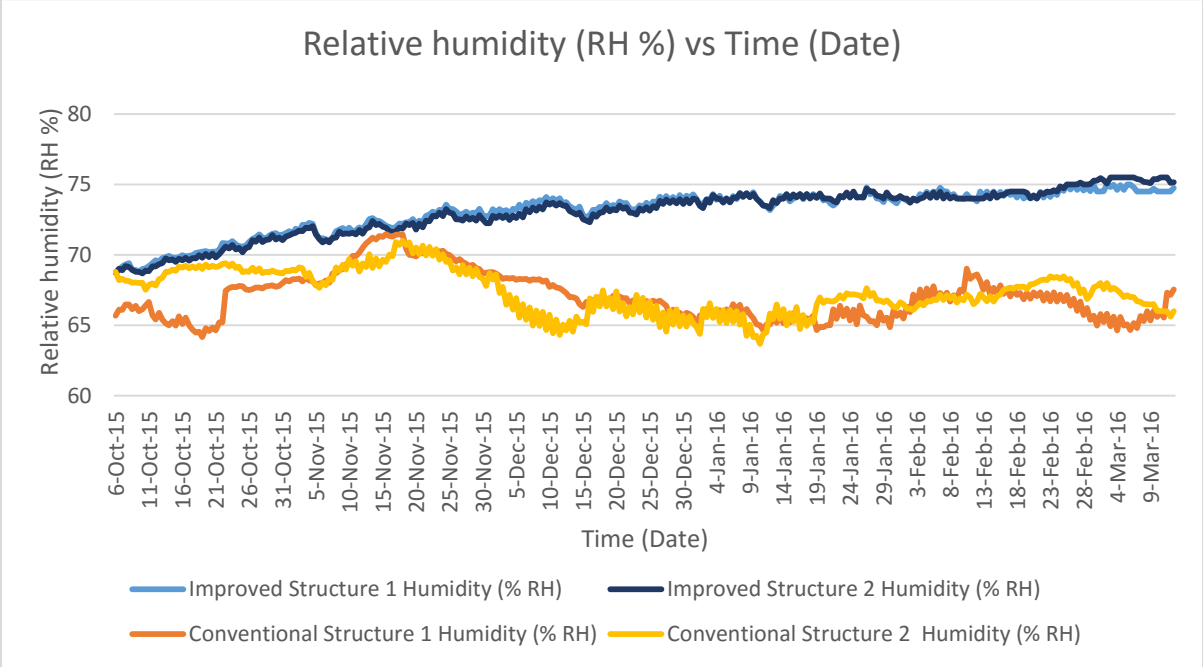

Figure 11. Relative humidity (RH %) for improved and conventional storage structures vs time

Quality Analysis: Visual Inspection Based

A visual analysis was done to evaluate grain quality by spreading stored maize on mats. As shown in figure 12, maize grains stored in the improved storage structure appeared to be of high quality when compared to grains stored in the conventional storage structures. Grains from the conventional structures contained numerous weevils, and exhibited high weevil damage and mold formation. Grains from the improved storage structures contained minimum numbers of weevils, little weevil damage and no mold formation. Weevils survived longer in the conventional storage structures because of the availability of oxygen

from the external environment, and thus, accelerated the deterioration. In the improved storage structures, access to oxygen was limited, and therefore the weevils did not survive.

A

B

Figure 12. Maize stored in conventional (A) and improved (B) storage structure

Conclusion

The improved hermetic grain storage structure provided very promising results for the effective storage of cereal grains. The maize grains moisture content remained within the acceptable range for maize grain storage, and thus prevented fungi growth. At the end of a six-month storage period, the moisture content was 13.5%, denoting an increase of 2.0% moisture content. The 2.0% moisture content increase highlights that before storage, the grains must be as dry as possible so that when stored for six or more months the grains moisture content remains below 14.0% for safe storage. In addition, relative humidity of air within the grain mass remained below 75%, which is threshold level for the initiation of mold growth accompanied by heat production and grains deterioration. Therefore, storage structures should be placed in locations where they are not directly affected by the external environment temperature and relative humidity variations. The improved storage structures effectively reduced storage dry matter losses to around 10% while losses for the conventional storage structure approached around 30%. According to literatures, the storage losses range between 15 and 25%, therefore the improved storage structure minimized storage loss effectively reducing overall post-harvest losses.

Chapter 4: Conclusions and Recommendations

Conclusions

The improved hermetic grain storage system designed and tested shows promise for addressing storage losses. The technology is promising as it utilizes locally available materials, which are more durable than other storage technologies or structures currently in use. Other metal silos are constructed using galvanized steel sheets, thus increasing overall storage costs. The use of surplus metal barrels, an underutilized resource, minimizes fabrication costs leading to broad adoption of this storage technology. Fabrication of the improved storage structure is easy and time effective compared to the construction of other structures such as metal or self-build silos. Furthermore, the improved storage structure can easily be moved within and outside of the family home when compared to the other structures, which are built outside of the home and are stationary. In terms of strength or durability, the improve storage structure are similar to metal and self-build silos, but stronger than triple bagging system. Grain quality for the improved storage structure was found to be superior to that of the grains stored in the conventional structure at the conclusion of the six-month storage period.

Recommendations

Because the improved structure exhibited promising result, it should be promoted as an alternative to conventional storage structures for adoption and use by smallholder farmers. If needed, it can be scaled up for use by medium and large-scale farmers, too. Further, we

recommend that the improved storage structure should be filled up to the top to ensure that no top space is left free inside the structure in order to limit oxygen availability. However, grain stored in the improved structure must be discharged from time to time, thus head-space creation is inevitable. Therefore, we recommend that a mechanism to eliminate any oxygen present in the head-space should be considered for improving the structure. Based on our improved storage structure, future study of grain storage should focus on finding a way to remove moisture formed within the hermetic storage structure. Because the hermetic storage structure is sealed, moisture formed inside the structure cannot escape to external environment. Therefore, finding a way to remove such moisture while maintaining the airtightness of the structure could improve grain quality and/or extend the safe storage period.

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