DRYING EFFECTIVENESS AND AFLATOXIN CONTAMINATION OF HOUSEHOLD STORED AGRICULTURAL PRODUCE AT CHAMWINO, DODOMA

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EXTENDED ABSTRACT

In the tropics, agricultural produces experience high post-harvest losses and are prone to mycotoxins contamination. Environmental conditions coupled with inadequate drying and storage practices are the major causes of postharvest loss and contamination. Cereals and oilseeds are more susceptible to aflatoxin contamination. This study aimed at assessing storage practices, awareness of smallholder farmers on aflatoxins, and walk-in solar dryer (WSD) as a drying technique to control aflatoxins contamination in cereals, oil seeds and nuts for improved livelihood of smallholder farmers in Chamwino, Dodoma. Ninety smallholder farmers in Chamwino were interviewed to assess storage practices and awareness of aflatoxins contamination in maize, groundnuts and sunflower seeds.

The majority (95.6%) of smallholder farmers stored grains in plastics or synthetic bags and kept the bags of grains on the floor without pallets. In addition, 88.9% of smallholder farmers had never heard about mycotoxins and thus are not aware of the health consequences of consuming aflatoxin contaminated foods. Moreover, most (96.7%) of farmers interviewed were not aware the fact that feeding animals with contaminated feeds pass on the toxins to animal products such as meat, eggs and milk.

Immune-affinity High Performance Liquid Chromatography (HPLC) and post column derivatization was used to analyse AFB_1, AFB_2, AFG_1, AFG_2 and total aflatoxins of household-stored maize, groundnuts and sunflower seeds samples (n=45). For all samples, the moisture content levels were within the legal limits; maize (9.57%), groundnuts (4.13%) and sunflower seeds (5.70%). However, 38% of samples were highly contaminated with aflatoxins in which mean for maize and groundnuts were 74.91 µg/kg and 268.82 µg/kg, respectively. On contrary, sunflower seeds had the lowest levels (0.23

μg/kg) of total aflatoxins. The maximum level according to Tanzania standards (TZS) or East Africa Community Standards (EAS) is 10 μg/kg. The highest mean levels of AFB_1 was observed in maize (58.36 μg/kg) and groundnuts (233.48 μg/kg), which is beyond the legal limit (5 μg/kg). It further, observed that 31.1% of interviewed smallholder farmers did not sort their grains, and the produces were kept on bare grounds during harvesting and no pallets on storage.

The WSD had higher mean temperature (41°C) and lower relative humidity (31.2%) than open-sun drying (temperature 31°C, relative humidity 43.2%). WSD had lower drying time for all the produce (maize 18 hours, groundnuts 18 hours and sunflower seeds 10 hours) than open-sun drying (maize 20 hours, groundnuts 20 hours and sunflower seeds 16 hours). The final moisture content was statistically significant for all analysed samples. The average mould *Aspergillus flavus* (CFU/g) for maize; freshly harvested, dried in WSD and open sun-drying (OSD) were 4.30, 3.60 and 4.23, respectively (which was within the limits set in EAS 44-2017). In addition, foreign matter for samples dried on OSD was significantly ($p<0.05$) higher (4%) compared to samples dried in WSD (0.65%) which was exceeded the recommended level of foreign matters set in TZS 438-2018 /EAS 2-2017 and TZS 740-2018 /EAS 888-2018.

It was concluded that in the studied villages there is limited knowledge on aflatoxins contamination of stored products and effects of consuming contaminated foods. Training of smallholder farmers on good agricultural and postharvest handling are recommended to reduce postharvest losses and assure food security and safety.

DECLARATION

I, Matrona Emmanuel, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

This dissertation is dedicated to my lovely husband, Dr. Mbonea H. Mrango for his love, support, encouragement, and daily prayer and to my children Herbert, Florence and Clara for their love, prayer and patience during my absence.

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LIST OF ABBREVIATIONS AND SYMBOLS

ADMB	Aspergillus Differential Medium Base
AFB_1	Aflatoxin B_1
AFB_2	Aflatoxin B_2
AFG_1	Aflatoxin G_1
AFG_2	Aflatoxin G_2
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CFU	Colony Forming Unit
EAS	East African Standard
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization
FtLD	Fluorescence Detector
GDP	Gross Domestic Product
GoF	Government of Tanzania
GPHP	Good Post Harvesting Practices
HBV	Hepatitis B Virus
HPLC	High Performance Liquid Chromatography
HSD	Honestly Significant Difference
ISO	International Organization for Standardization
LOD	Limit of Detection
LOQ	Limit of Quantification
MR	Moisture Ratio

MT	Metric Tons
μg/kg	Microgram per Kilogram
MOFP	Ministry of Finance and Planning
NBS	National Bureau of Statistics
PICS	Purdue Improved Crop Storage
PHLs	Post-Harvest Losses
PW	Peptone Water
RPM	Revolution Per Minute
SEM	Standard Error Mean
SSA	Sub-Saharan Africa
SPSS	Statistical Package for Social Sciences
SUA	Sokoine University of Agriculture
TANIPAC	Tanzania Initiative for Preventing Aflatoxin Contamination
TBS	Tanzania Bureau of Standards
TIRDO	Tanzania Industrial Research and Development Organization
TZS	Tanzania Standards
TAF	Total Aflatoxins
USA	United States of America
USAID	United States Agency of International Development
US	United States
UV	Ultra Violet
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Agriculture is the largest and most important sector of Tanzanian economy. It employs 65.31% of the population and accounts for 26.7% of Gross Domestic Product (GDP) (World Bank, 2019; FAO, 2019). Similarly agriculture is the major source of food, industrial raw materials, and foreign earnings. Farmers grow both cash and food crops. The major food crops produced annually include maize (6.3 million MT), cassava (2.8 million MT), paddy (2.2 million MT), beans/legumes (1.8 million MT), sweet potatoes (1.6 million MT), banana (1.1 million MT), sorghum (0.988 million MT) and wheat (0.057 million MT) (MOFP, 2018). Cereals serve as the main staple in Tanzania.

The staple crops, such as maize, sorghum, groundnut, and sunflower common in semi-arid agro-pastoral farming systems of central Tanzania are susceptible to aflatoxins contamination. Consumption of such crop produce, contaminated with high levels of aflatoxin B_1 affects growth and health (Seetha *et al*., 2017). In addition, aflatoxins contamination of agro-produce leads to Postharvest Losses (PHLs) as contaminated produce are discarded or rejected from the market.

Tanzania agricultural sector is experiencing high PHLs due to inadequate postharvest management practices and infrastructure (i.e. drying and storage facilities) along the produce value chain (Shee *et al.*, 2019). In sub-Saharan Africa, PHLs of cereals are estimated to range from 20 to 40% (Kumar and Kalita, 2017). Fungal infection (i.e.

moulds) and pests (insects and rodents) causes high losses of dried food products (Bradford *et al.,* 2018).

Fungal infection of cereals like maize may result in production of secondary metabolites known as mycotoxins when the condition is favourable. These secondary fungal metabolites are mainly produced by *Aspergillus, Penicillium,* and *Fusarium* species. Some fungi species grow in cold weather and hot environments which favour fungal growth and proliferation of mycotoxins which contaminate food and feeds (Kajuna *et al.,* 2013). The most common mycotoxins in agriculture are aflatoxins, deoxynivalenol, zearalenone, fumonisins, OTA, HT-2, T-2 and patulin. Aflatoxins are the most toxic secondary metabolites produced by the fungi *Aspergillus flavus* and *Aspergillus parasiticus,* which commonly infect agricultural produce especially maize, peanuts, sunflower seeds and tree nuts (Mmongoyo *et al.,* 2017). Despite the efforts made by different countries to control aflatoxin contamination in agro-produces, African countries experience higher levels of aflatoxins along the commodities value chains (Kumar *et al.,* 2017; Mahato *et al.,* 2019).

Drying is one of the most common methods to preserve agricultural produces (Kumar *et al.,* 2015). Despite several efforts that have been made to develop different kinds of dryers, the twin problems of aflatoxicosis and of PHLs of agricultural produces are yet to be fully addressed. The traditional method of drying cereals especially after harvesting is open-sun drying. This not only exposes the produce to a high risk of contamination by dust, birds, animals and insects but also takes long time, thus allowing mould growth and subsequent mycotoxin production (Bradford *et al.,* 2018). In this study performance of a walk-through solar dryer was assessed in a view to address aflatoxins contamination of food crops.

1.2 Problem Statement and Study Justification

Aflatoxin contamination in agricultural produce is one of the health global concerns for food safety (Kumar *et al.,* 2017). Aflatoxins contamination occurs naturally in agricultural produces due to inadequate conditions along the produce value chain. The aflatoxins contaminated produces are discarded or rejected on the market resulting into food losses (Negash, 2018). The aflatoxins contaminated produces can result into food losses as food may be discarded or rejected from the market. Limited knowledge and awareness on aflatoxins contamination in food crops and its health and economics consequences and as well poor storage practices of household agricultural produce is among the main constrains in controlling aflatoxicosis in developing countries (Udomkun *et al.,* 2017). Smallholder farmers experience high up to (30-40%) post-harvest losses of cereals, oilseeds due to inadequate handling conditions along the produce value chains (Hodges *et al.*, 2011; Kumar and Kalita, 2017).

Drying is the critical point in postharvest handling of agricultural crops (Kaaya and Kyamuhangire, 2010). This is because inadequate drying may lead to spoilage of products and mould growth with subsequent contamination of agro-produce with mycotoxins. Mycotoxins in food pose health risks to both human and livestock (Mmongoyo *et al.*, 2017). Among more than 400 known mycotoxins, aflatoxins are more toxic and potential carcinogen to human. Other known mycotoxins important to public health include ochratoxin A (OTA), Fusarium toxins, fumonisins (FUM), zearalenone (ZEA), trichothecenes (TCT), and deoxynivalenol/nivalenol (Agriopoulou *et al.,* 2020).-

As mentioned above drying is critical in controlling mycotoxins contamination of agriculture produce. It is important however, that appropriate drying technique is deployed to dry crop produce to ensure timely drying to avoid mould growth and contamination of the produce with dust, sand and other debris. Yet, majority of smallholder farmers in rural areas of Tanzania use direct sun drying to dry their produces (Lamidi *et al.*, 2019). This approach has proved to be inefficient in reducing PHLs (i.e. quality and quantity) and preventing contamination to assure quality and safety of the produce (Sontakke and Salve, 2015). There is a need of developing and optimizing effective drying techniques to ensure proper drying of agricultural produce in order to improve food safety and security, competitive market access and hence improved livelihood of poor resourced smallholder farmers. Therefore, this study aimed at assessing storage practices, awareness of smallholder farmers on aflatoxins, and effectiveness of walk-in solar dryer on controlling aflatoxins contamination in cereals and nuts at Chamwino, in Dodoma region in order to improve the livelihood of smallholder farmers. The area of study was chosen because it has been reported to have high incidences of aflatoxin infection. For example, in 2016 sixty-eight (68) cases of aflatoxicosis was reported which caused 20 deaths and several hospitalizations (Kamala *et al.*, 2018).

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this study was to assess the storage practices, awareness of smallholder farmers on aflatoxins and walk-in solar dryer as a drying technique on controlling aflatoxins contamination in cereals and nuts in order to improve livelihood of smallholder farmers in Chamwino, Dodoma region.

1.3.2 Specific objectives

i. To assess knowledge and current storage practices by smallholder farmers to control aflatoxins contamination of maize, groundnuts and sunflower seeds at Chamwino, Dodoma.

ii. To determine levels of aflatoxins contamination in household-stored maize, groundnuts and sunflower seeds at Chamwino, Dodoma.

iii. To evaluate drying efficiency of a walk-in solar dryer as a technique to control aflatoxin contamination of food crops.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Knowledge and storage practices of maize, groundnuts and sunflower seeds by smallholder farmers in Dodoma region

2.1.1 Knowledge of smallholder farmers on aflatoxins contamination

Aflatoxins occur in agro-produces across the world at various nodes along the food value chain (Battilani *et al.,* 2016). About 80% of food and cash crops are produced by smallholder farmers in developing countries (Manandhar *et al.,* 2018). High aflatoxins contamination of crops like maize and groundnuts is attributed by inadequate knowledge and application of good agricultural practices and post-harvest management by the majority of poor resourced smallholder farmers (Magembe *et al*., 2016; Ayo *et al.*, 2018; Udomkun *et al.*, 2018; Magoke *et al.*, 2019).

It has been reported that training on Good Agricultural Practices (GAPs) such as early planting, application of fertilizers, cleared bushes around the stores, dried cereals properly after harvesting, used of wooden pallets to store maize could reduce possibility of aflatoxin contamination (Mugabi and Driscoll, 2016; Seetha *et al.,* 2017; Marete *et al.*, 2019).

The storage of grains can be done in farmers' field or in large commercial facilities (Pekmez, 2016). Post-harvest operations involve timely harvesting, proper drying, transportation, threshing and cleaning. Grain losses due to storage has been estimated to range between 15 and 25% (Abass *et al.*, 2014). The losses are associated with various factors such as poor storage facilities, temperature, moisture, humidity, insect or pest infestation, rodent and mould growth during grain storage (Swai *et al.*, 2019). In order to ensure food safety along the crop value chain quality assurance system should be adhered. However, the process of identifying crops infected with mycotoxins and their removal could increase PHLs if it leads to dumping of unsafe produces (Sheahan and Barrett, 2017).

Storage condition with temperatures between 20 °C to 40 °C in particular for stored grains could allow growth of toxigenic mould and result into to production of aflatoxins (Manandhar *et al.*, 2018). Smallholder farmers store grains to various facilities such as uncovered wooden granaries, and plastic/polyethylene bags kept on bare ground. The structure of these facilities allows invasion by rodents, insects and pests hence losses and aflatoxins production. To overcome these problems previous research has recommended various storage facilities for example hermetic storage and metal silos which extend period of stored grains (Manandhar *et al.*, 2018; Phokane *et al.*, 2019; Baributsa and Ignacio, 2020).

2.3 Aflatoxins contamination in agricultural produce and health consequences

Aflatoxins contaminate maize in the field and/or during storage (Smith *et al.*, 2016). A study in Tanzania indicated that aflatoxin level increased with storage time; high level was noticed after 3-6 months of storage (Sasamalo *et al.*, 2018). Aflatoxins have been reported in groundnuts (*Arachis hypogaea* L.) and products containing groundnuts like complimentary flours (Maarufu and Kassim, 2018). Another study in Kilosa District (Tanzania) and some of rural villages (Tanzania) revealed higher levels of aflatoxins in groundnut ranging 72.97 to 295.17 µg/kg and maize with levels up to 158 µg/kg (Kimanya *et al.*, 2008; Magembe *et al.*, 2016). Aflatoxin was also reported in seeds and seed cakes in Tanzania (Mmongoyo *et al.*, 2017). Consumption of aflatoxin contaminated food cause serious threat to human and animal health and result to complication such as hepatotoxicity, teratogenicity, and immunotoxicity (Zain, 2011). Also the previous study reported higher levels of aflatoxin B_1 in feeds were 35.8 µg/kg, 15.1 µg/kg, 9.4 µg/kg and 31.6 µg/kg for broilers mash, layers mash, maize bran and sunflower seed cake respectively which exceeded the FAO/WHO level of 5 µg/kg (Kajuna *et al.*, 2013).

2.4 Dietary exposure to aflatoxins contamination of agro-produces in Tanzania

Most tropical countries including Tanzania, have high temperatures and relative humidity, poor aeration in stores, insects and rodents damage which favour accumulation of aflatoxins in agricultural produce. Previous studies observed that poor harvesting and post-harvest handling practices cause high losses of maize and groundnuts in Kilosa District, Tanzania (Magembe, *et al.*, 2016). A recent event of aflatoxicosis reported in Dodoma affected 68 people out of which 20 died due to consumption of home-grown maize grain contaminated aflatoxin (Kamala, *et al.*, 2018). Consumption of foods heavily contaminated with aflatoxins is associated with stunting and underweight (Gong *et al.*, 2002). The central region of Tanzania from which the acute aflatoxicosis was reported in 2016 has one of the highest stunting levels in the country (TFNC 2014). About 1,480 (2.95 per 100,000 persons) new cases of aflatoxin-induced liver cancer is annually reported in Tanzania (Kimanya *et al.*, 2021).

2.5 Tanzania government post-harvest strategies for management of aflatoxins contamination of food crops

Tanzania is a leading producer of maize and groundnuts in the East African region, accounting for 2% of world production (Chapter 1). The crops are the major staple food; maize contributes to around 35% of the average daily calorie intake, making up nearly half of dietary requirements (Wilson and Lewis, 2015). More than 60% of Tanzanians live in the rural areas and depend on subsistence agriculture for their livelihoods (Ramadhani, 2016). However, these crops are highly susceptible to toxigenic fungi infection with subsequent aflatoxin contamination which affects the health of consumers and reduces the country‘s export earning potential. The Government of Tanzania (GoT) has established various initiatives to mitigate aflatoxin problems in the country. For instance, through the Ministry of Agriculture, in 2018 GoT launched a project entitled Tanzania Initiative for Preventing Aflatoxin Contamination (TANIPAC). The main objective of the project is to minimize aflatoxin occurrence in the food system through an integrated approach in the maize and groundnuts value chains with the overall impact of improving food safety and food security, which will ultimately improve the health and nutrition of the communities, improve agricultural productivity, and boost trade.

TANIPAC is rehabilitating the Bio-control Unit, establishing a postharvest centre of excellence for grains at Kibaigwa Dodoma, establishing a central agriculture reference laboratory for enabling mycotoxin control along the food production and supply chain, and constructing and equipping two warehouses in Zanzibar and 12 on the Tanzanian mainland. The project is also carrying out public awareness and education on the subject of food safety, nutrition, and aflatoxin mitigation through mass education as well as sponsoring postgraduate students. The private sector’s role in monitoring and quality control at all segments of the value chains is important. The project is also establishing partnerships with commercial buyers to support advocacy and disseminate new technology on both mainland and Zanzibar. The project expects to benefit about 60,000 farmers in five regions of Tanzania’s mainland and two districts on Zanzibar (Ramadhani, 2016).

2.6 Importance of drying in post-harvesting handling of agro-produces

Post-harvest handling practices are very important since it influence the effect on quality and shelf life of most harvested agro-produces. Smallholder farmers need to know the suitable postharvest handling practices such as harvesting, cleaning, sorting, transportation and storage in order to maintain quality and extend the shelf life of the produce (Arah *et al .,* 2016). Drying of agro-produce is critical to extend shelf life, facilitate storage and transportation, minimize chemical reactions, and maximize nutrients retention and also ensure food security for large population (Guine, 2018). Particularly rapid drying of agricultural products to reduce their moisture content is important, as this can avoid the favourable conditions for the growth of fungi, and thus prevent formation of aflatoxins by toxigenic fungi (Chiewchan *et al.,* 2015). This study has focused on drying evaluated performance of walking-solar dryer in a view to reduce growth of toxigenic fungi which produce aflatoxins. It is a simple and easy to use drying technique which smallholder farmers could apply to reduce aflatoxins contamination of food crops.

2.6.1 Agro-produce drying techniques

Drying is basically vital for protection of agricultural crops purposely for future use. The removal of enough moisture from the crops is of importance as it preserve crops and avoid decay and spoilage (Eze and Agbo, 2011). Most of agricultural produces will need drying to acceptable storage moisture level which do not support growth of fungi. Various drying techniques including air drying which involve sun drying and artificial drying, fluidized bed drying and vacuum drying are used across the world (Gunathilake *et al.,* 2018). The most common applied drying technique is air drying whereby the heat is applied through conventional and vapour is carried out as humidity from the product. Each drying technique has its advantages and disadvantages (Yassen and Al-Kayiem, 2015; Swai *et al.*, 2019). The proper drying of foodstuff can help to prevent food spoilage and losses. High moisture levels during storage can increase aflatoxin contamination and result in food losses. Hence, crops must be stored under optimum condition for longer storage. The maximum drying temperature for agricultural produces such as maize groundnuts and sunflower seeds is ranged from 40 °C to 60 °C (Al-Neama and Farkas, 2018). Proper drying of agricultural produces improve the quality of final produce hence increase consumer acceptability (Swai *et al.*, 2019). The three modes of drying by the sun are (i) open-sun drying, (ii) direct sun drying, and (iii) indirect sun drying. The governing principle of these modes depends on the method of solar energy collection and its conversion into useful thermal energy (Prakash and Kumar, 2013; Sahu *et al.,* 2016).

The most common technique is via air, in which heat is applied by convection, which carries away the vapor as humidity from the product. Examples of this include sun drying and artificial drying. Other drying techniques are vacuum drying and fluidized bed drying, where agricultural products are kept in vacuum conditions and water is used to evaporate and fluidize the material. These methods are suitable for heat sensible crops. Drum drying is another method, where a heated surface is used to provide energy; and spray drying that atomizes the liquid particles to remove moisture, like in milk powders. Special drying and curing techniques are used for preservation of big onion crops

2.6.2 Open-sun drying

This is the one of the most common traditional method used by smallholder farmers in developing countries whereby crops are spreading on the bare soil surfaces, floor or on the surface such as roof and mats (Tomar *et al.,* 2017). Drying by the sun under an open sky for preserving food and agricultural crops has been practiced since ancient times. Conversely, this process has many disadvantages, i.e. products get spoiled due to rain, wind, moisture, and dust; loss of produce due to birds and animals; deterioration in the harvested crops due to putrefaction, insect attacks, and fungi infection which could result to aflatoxin contamination (Chiewchan *et al.,* 2015; Sahu *et al.,* 2016). Apart from the above mentioned disadvantages, the open-sun drying process is labour intensive and time consuming, and requires a large area for spreading the produce out to dry (Dhumne *et al.,* 2015; Tomar *et al.,* 2017). Most farmers use convectional drying like open-sun drying apart from low quality of the products also there are 30-40% losses occurred due to open-sun drying (Kumar *et al.,* 2016).

2.6.3 Solar dryers

Solar dryers are developed to provide ample amount of heat which is more than ambient heat at a given humidity. It increases the vapour pressure of the moisture confined within the produce and decrease the relative humidity of the drying air so that the moisture carrying capacity of the air can be increased. Air is drawn through the dryer either by natural convection or by fan (Tiwari, 2016). There are two types of solar dryers; the passive type (natural convection) dryer and the active type (forced convection) or hybrid solar dryer. These solar dryers can be again sub-grouped under three categories which includes integral type (direct mode), distributed type (indirect type), and mixed mode (Prakash and Kumar, 2013; Johannes and Freddie, 2019; Udomkun *et al.,* 2020). In a direct type, solar drying material is placed in a drying chamber having a transparent cover through which solar radiation enters and heats the food materials to be dried (Sahu *et al.,* 2016). In an indirect mode, solar energy is captured by a solar collector, which in turn heats the air. This heated air is then passed to the drying cabinet/chamber. In mixed mode, solar energy is collected in separate solar collector and heated air is then passed over the drying material. The drying materials absorb the solar energy directly through the transparent cover and walls (Dhumne *et al.,* 2015).

The objective of a solar dryer is to provide ample amount of heat i.e.
more than ambient heat under given humidity. It increases the vapour
pressure of the moisture con•ned within the product and decreases the
relative humidity of the drying air so that the moisture carrying capacity
of the air can be increased. Air is drawn through the dryer by natural
convection or sometimes by a fan. It is heated as it passes through
the collector and then partially cooled as it catches moisture from the

material [24-27]. The material is heated both by the air and sometimes directly by the sun. Warm air can hold more moisture than cold air to maintain relative humidity, so the amount of moisture removed depends on the temperature to which it is heated in the collector as well as the absolute humidity of the air when it entered the collector. The moisture absorption capacity of air is affected by its initial humidity and by the temperature to which it is subsequently heated

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The studies in solar dryer revealed that the introduction of non-open solar dryers in developing countries can reduce crop losses and improve the quality of the dried product significantly when compared to the traditional method of drying such as open-sun or shade drying (El-Sebaii and Shalaby, 2012). Solar dryers offer advantages of shorter periods of drying, resulting into good quality of dried are reduced loss of produce and larger scale of production (Mongi, 2013; Kilanko *et al.*, 2019).

2.6.3.1 Efficiency of solar dryers for drying agro-produces

Drying efficiency refers to the minimum quantity of heat that removes the required water needed to supply the latent heat of evaporation. Therefore efficiency is the ratio of that minimum quantity of heat to the energy actually provided for the process (Billiris *et al.*, 2014). The solar drying process is dependent on different parameters, such as solar radiation, wind speed, ambient air temperature, relative humidity, initial moisture content, amount of initial material and type of dryer (Sahu *et al.*, 2016).

It has been reported that solar dryer efficiency can be predicted based on the type of solar dryer design, shape, fabricated materials, dimensions, layout, absorber material type and paint. The efficiency of drying of the solar dryer is influenced by relative humidity in the air, the moisture content of the materials to be dried and their amount and thickness. The solar radiation intensity on the materials varies with seasons, time of the day, and length of exposure, ambient air temperature, and wind speed, which are important factors (Kassem *et al.*, 2011; Al-Neama and Farkas, 2018).

Previous studies designed and tested a direct type of natural convection solar dryer for banana, mango slice and cassava found that the thermal performance was higher compared to open-sun drying of the same dried foodstuff (Gbaha *et al.*, 2007). Al-Neama and Farkas, (2018) reported that direct solar dryers are mostly commonly used for drying different agricultural crops and the average drying efficiency varies from 20% to 40%.

The study by Sharma *et al.* (1990) evaluated performance of cabinet solar dryer (Indirect solar dryer) and found that the predicted plate temperature for no load reaches a maximum temperature of 80-85°C during noon hours while when the load (i.e. wheat) increased to 20kg the maximum temperature was 45-50°C.

Mohanraj and Chandrasekar, (2008) were involved in designing, fabricating and testing an indirect mode forced dryer for drying copra. The results for moisture content of copra were reduced from 51.8% to 7.8% and 9.7% in 82 hours for trays at the bottom and top, respectively. Bolaji and Olalusi, (2008) constructed a mixed mode solar dryer and reported 74% increase of temperature inside the drying cabinet for about 3 hours immediately after 12:00 hours (noon). The drying efficiency and drying rate were 57.7% and 0.62kg/h, respectively.

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CHAPTER THREE

Paper One

3.0 SMALLHOLDER FARMERS' STORAGE PRACTICES AND AWARENESS OF AFLATOXIN CONTAMINATION OF CEREALS AND OILSEEDS IN CHAMWINO, DODOMA, TANZANIA

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Abstract

Agricultural produces in the tropics are vulnerable to mycotoxins contamination. Hot and humid conditions are favourable conditions for fungal growth and production of mycotoxins. Inadequate drying and storage practices aggravates the susceptibility of produce to mycotoxins contamination. The purpose of this study was to assess the storage practices and awareness of smallholder farmers on mycotoxin contamination of cereals and oilseeds in Chamwino District, Dodoma region. A total of 90 smallholder farmers were interviewed using a structured questionnaire containing closed-ended questions. Smallholder farmers kept their produces on the bare ground during harvesting (42%), used open-sun drying (92%) and rudimentary method to check produce dryness (72% visual assessment and 9% biting), and stored grains in plastics or woven bags which are placed on the floor without pallets (95.6%). Moreover, the majority have neither heard about mycotoxins (88.9%) nor aware on fungal contamination and effects of consuming mycotoxins contaminated products (81.1%). Unfortunately, the overwhelming majority (96.7%) of smallholder farmers involved in this study were not aware that feeding animals with aflatoxins contaminated feeds lead to contaminated animal/poultry products. This indicates that people are exposed to products which are most likely contaminated with mycotoxins. Training of farmers and mass media campaigns are highly recommended to reduce post-harvest losses and mycotoxin contamination along the produces value chains.

+**Keywords:** aflatoxins, storage practices, awareness, smallholder farmers.

3.1 Introduction

Agriculture is the mainstay of Tanzania economy. It employs more than 65.7% of the population and contributes 26.7% of the Gross Domestic Product (GDP). Majority of farmers are smallholder farmers (80%) with less than one acre of land (Mkonda and He, 2018) producing food and/or cash crops. Major food crops are maize (6.3 million MT), cassava (2.8 million MT), paddy (2.2 million MT), beans/legumes (1.8 million MT), sweet potatoes (1.6 million MT), banana (1.1 million MT), sorghum (0.988 million MT) and wheat (0.057 million MT) (MoFP, 2018).The major cash crops include cashew nuts (313.8 million MT), sugar (303.7 million MT), cotton (222.0 million MT), tobacco (50.5 million MT), coffee (45.2 million MT), sisal (40.6 million MT), tea (34.0 million MT) and pyrethrum (2.4 million MT). The major oilseeds include sunflower (768.2 million MT), groundnuts (643.5 million MT) and sesame (133.7 million MT) (MoFP, 2018).

Cereal productivity per acre in Africa, Tanzania inclusive, is (1.8 MT/ha) less than half of the world average (~5 MT/ha). Despite the low productivity, Africa experiences high (30-40%) post-harvest losses of cereals and oilseeds due to inadequate pre-and post-harvest management (Suleiman and Kurt, 2015; Kumar and Kalita, 2017). Poor post-harvest management techniques (including inadequate drying and storage) of the produces are the major contributing factors (Suleiman *et al.,* 2017). Food losses are from farm to fork. Thus, at different nodes (e.g., harvesting, threshing, drying, transportation, processing, storage, distribution and consumption) of the food value chain losses are inevitable. Inadequate drying, pest infestation, fungal infection, and limited knowledge on best handling practices are the major contributing factors to high Post-Harvest Losses (PHLs).

Smallholder farmers in the developing countries practice subsistence farming. They mainly produce for their food uses, and very little surplus is sold for cash. A big proportion of their produces is therefore stored for food until the next harvesting season. However, the majority of smallholder farmers are financially challenged to construct proper storage facilities and have limited knowledge on post-harvest management practices (Muroyiwa *et al.,* 2020). During harvesting and drying, cereals and oilseeds are often heaped on the bare ground. Sun drying is a common method used for drying agricultural produces in the tropics (Likhayo *et al.,* 2018). Although the method has been used from the ancient times, it has several limitations like inadequate drying, contamination, losses, and pest infestation (Suleiman *et al.,* 2017; Mobolade *et al.,* 2019).

Traditional storage techniques (e.g. uncovered wooden granaries, plastic/polyethylene bags) which have proved to be inadequate are the primary means of storage practised by most small-scale farmers in Tanzania. As a consequence, PHLs of cereal grains during storage are estimated to range from 15 to 25% (Mesterhazy *et al.,* 2020). The technical assistance including a public financing for adequate grains storage to smallholder farmers depends on the available new storage technology and whether are cost effective within the local context (Kotu *et al.,* 2019). Mould growth on stored produces dependent on grain moisture content, temperature, gas composition, relative humidity (RH), and fungal contamination during harvesting and storage (Manandhar *et al.,* 2018). Thus, inadequate drying and poor storage conditions aggravate the problem of PHLs.

Unfortunately, mould growth may result into production of secondary metabolites, the mycotoxins. Aflatoxins are the most toxic group of mycotoxins produced by fungal species, *Aspergillus flavus* and *Aspergillus parasiticus*, which commonly infect food crops such as maize, peanuts, sunflower seeds and tree nuts (Kamala *et al.,* 2015; Mmongoyo *et al.,* 2017). Consumption of aflatoxin-contaminated foods and feeds is linked to various adverse health effects like liver cancer in humans and low productivity in animals (Magembe *et al.,* 2016; Benkerroum, 2020).

Good agricultural and post-harvest handling practices (GAP and GPHP) have been recommended as appropriate approaches for reducing both PHLs and aflatoxins contamination of agro-produce (Kumar and Kalita, 2017; Phokane *et al.,* 2019). Limited knowledge on GAP and GPHP by smallholder farmers in Tanzania, exposes agro-produce to aflatoxins contamination during the pre and post-harvesting stages (Magembe *et al.,* 2016; Ayo *et al.,* 2018; Nakavuma *et al.,* 2020). Training and dissemination of information on GAP and GPHP are important strategies to reduce PHLs and aflatoxins contamination of agro-produces along their respective value chains. Therefore, this study aimed at assessing the knowledge, awareness of aflatoxins and storage practices of maize, groundnuts and sunflower seeds by smallholder farmers in Chamwino District, Dodoma region, Tanzania.

3.2 Material and Methods

3.2.1 Study location

The study was conducted in November 2019 in Chamwino District. Chamwino district is among the seven districts in Dodoma region; it is located below the equator between latitude 6° and 10' south and between longitude 35° 46'east. The total population of Chamwino district is approximately 330,543 people (NBS, 2012). The district is considered amongst with high food insecure and mycotoxins contamination (Suleiman *et al.*, 2017). Three villages (Haneti, Mapanga and Zajilwa) from three wards (i.e. Haneti, Itiso and Zajilwa) were involved in this study.

3.2.2 Study design

A cross-sectional survey approach was used to collect data from ninety (90) smallholder farmers producing maize, groundnuts and sunflower seeds. The farmers were randomly selected from three villages at Chamwino District. This design was used to collect data on knowledge, storage practices and awareness of aflatoxins-contamination of maize, groundnuts and sunflower seeds.

3.2.3 Sampling procedure

Multi stage sampling design was adopted in this study (Acharya *et al.*, 2013). In summary, one division (Itiso) was purposively selected among the five divisions of Chamwino district. Three wards, namely, Haneti, Zajilwa and Itiso were also purposively selected based on the production rate of maize, groundnuts and sunflower seeds as advised by the District Agriculture Irrigation and Cooperative Officer (DAICO). Then, one village was randomly selected from each of the chosen wards, as indicated in the sampling plan (Figure 3.1). Finally, 30 households which store all three crops (maize, groundnuts and sunflower seeds) were randomly selected from each village (n=90).

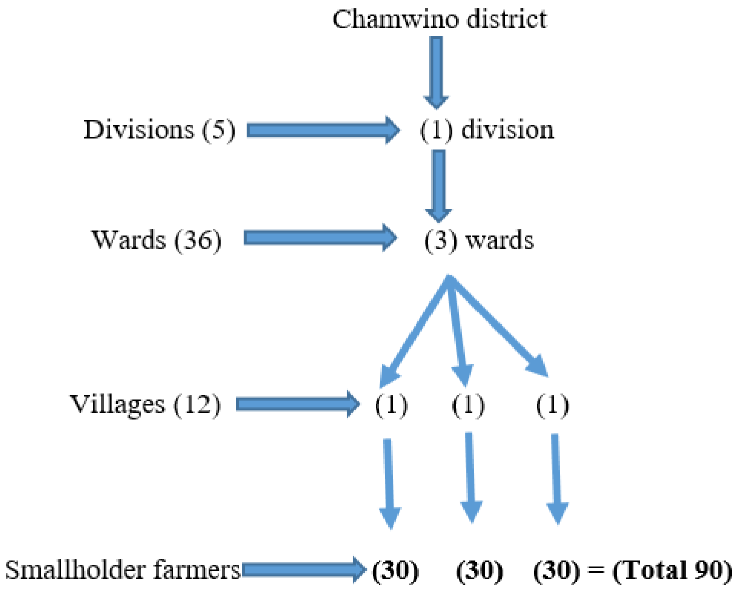

Figure 3. 1: Sampling plan of smallholder farmers from villages of Haneti, Mapanga and Zajilwa in Chamwino district

3.2.4 Assessment of knowledge, storage practices and awareness of aflatoxin contamination of smallholder farmers

A questionnaire containing both closed-ended questions was used to collect data. The questionnaire was designed for smallholder farmers producing maize, groundnuts and sunflower seeds. It contained 40 questions on knowledge, storage practices and awareness of aflatoxins contamination of maize, groundnuts and sunflower seeds. The questionnaire was translated to Swahili and pre-tested using maize traders (n =15) picked randomly in Dar es Salaam. After pre-testing the questionnaire was modified and properly coded.

3.2.5 Statistical data analysis

Data collected were summarized and analyzed using Statistical Product and Service Solution software (IBM SPSS® Version 20, Chicago, IL, USA). Descriptive statistics were carried out to obtain frequencies, means and percentages among the variables. The results are presented in tables, graphs and charts.

3.3 Results and Discussion

3.3.1 Demographic characteristics of smallholder farmers

The majority of smallholder farmers interviewed were males (57.8%), aged more than 56 years (35.6%), married (82.2%) and lowly educated (75.6% had primary education and 15.6% had no informal education, Table 3.1). Previous studies also found that smallholder farmers are people with low or informal (11%) level of education (Adekoya *et al.*, 2017) and the farming activity is male dominated (57.7%) (Toma, 2019). However, in the rural areas women are the ones mainly involved with farming activities as compared to males. Most of the households were male headed and were the ones participated in the interview. The study also revealed that 74.4% of smallholder farmers had never attended any training on GAP (Table 3.1). Combination of these aspects may increase PHLs and aflatoxins contamination. Training of smallholder farmers on GAP is critical important to reduce PHLs and aflatoxin contamination along the produces value chains (Stepman, 2018).

Table 3. 1: Demographic characteristics of smallholder farmers (N=90)

Variables	Description	Villages			Total
		Haneti	**Zajilwa**	**Mapanga**	
Gender	Male	26.9	36.5	36.5	57.8
	Female	42.1	28.9	28.9	42.2
Age	15-25	0.0	3.3	0.0	1.1
	26-35	3.3	30.0	20.0	17.8
	36-45	13.3	30.0	36.7	26.7
	46-55	23.3	13.3	20.0	18.9
	56+	60.0	23.3	23.3	35.6
Education level	Primary school	80.0	76.7	70.0	75.6
	Secondary school	10.0	16.7	0.0	8.9
	Informal education	10.0	6.7	30.0	15.6
Marital Status	Married	76.7	90.0	80.0	82.2
	Not married	16.7	10.0	10.0	12.2
	Divorced	0.0	0.0	10.0	3.3
	Widow	6.7	0.0	0.0	2.2
Training on good agricultural practices	Yes	43.3	16.7	16.7	25.6
	No	56.7	83.3	83.3	74.4

3.3.2 Cropping system practised by the smallholder farmers

Ninety-eight (98%) of the interviewed smallholder farmers at Chamwino practised multicropping (Fig.3.2). Out of this, 75% intercropped maize, groundnuts and sunflower seeds, (22%) intercropped maize and sunflower seeds, whereas (1%) intercropped maize and groundnuts (Fig.3.2). The average farm sizes were 9.0±4.58 ha for maize, 8.5±4.98 ha for sunflower, and 1.6±1.34 ha for groundnuts (Table 3.2). Likewise, previous studies observed mixed farming system in Dodoma (Mlay *et al.*, 2017).

The annual production of maize, sunflower seeds and groundnuts for 2018/2019 are presented in Table 3.2. On average maize had higher production (3,203 tones) followed by sunflower seeds (2,904 tones) and lastly groundnuts (53 tones, Table 3.2). Haneti had significantly higher maize and sunflower production (8937 and 7149 tones) than Mapanga (155 and 53 tones, Table 3.2). The low productivity for groundnuts could be contributed by seed recycling practised by the smallholder farmers.

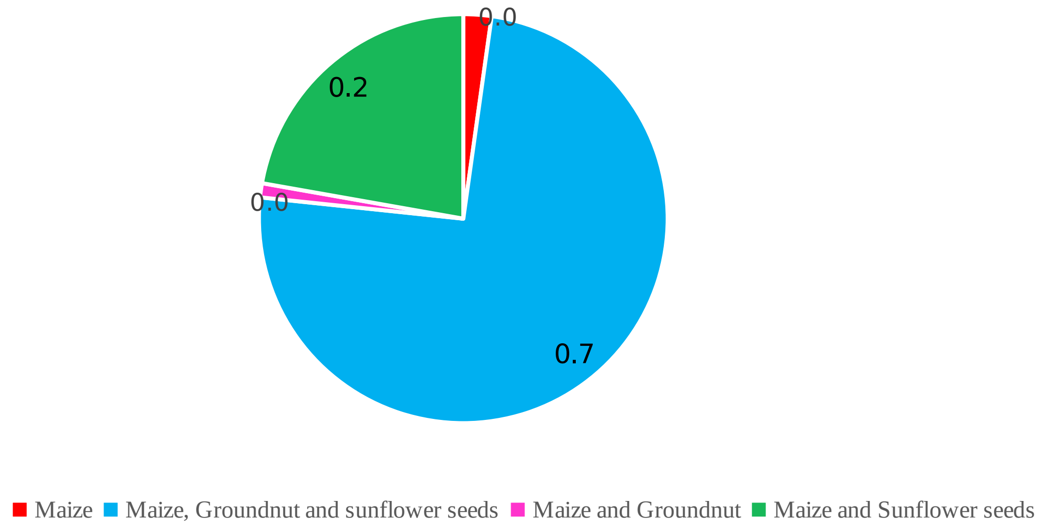

Figure 3. 2: Types of cropping systems in Chamwino

Table 3. 2: Annual production (tones) for maize, groundnuts and sunflower seeds

Villages	**Production (tones) 2018/2019**		
	Maize	**Groundnuts**	**Sunflower**
Haneti	8937	127	7149
Zajilwa	518	53	1510
Mapanga	155	10	53
Average (production)	3,203	63	2,904

Acreage	9.0±4.58	8.5±4.98	1.6±1.34

3.3.3 Postharvest handling and storage practices

Post-harvest handling and storage practices of agricultural produces involve various processes including but not limited to drying, cleaning, transportation and storage.

3.3.3.1 Drying

The study revealed that sun drying is the major method practised by the majority of smallholder farmers (92.2%) to dry maize, groundnuts and sunflower seeds by either leaving matured crops in the field for several weeks (64.1%) or harvesting and drying on the bare ground (42.2%) (Table 3.3). Sun drying is a traditional drying method of crops practised in the tropical countries (Kumar and Kalita, 2017). Similar drying practices have been reported in Malawi (Matumba *et al.,* 2016) and Kenya (Koskei *et al.,* 2020). However, drying practices like leaving crops in the field and drying on bare grounds could increase the chance for fungal growth, aflatoxins and sand contamination (Negash, 2018).

Moreover, 17.8% of the interviewed smallholder farmers physically checked grains for dryness. However, none of them had moisture meter to correctly assess moisture content of the grains. They used traditional practice of chewing grains to determine whether the grains are dried properly (Table 3.3). This practice may not provide the correct moisture content of grains; grains thought to be dry could be wet to develop fungal growth and mycotoxin production on storage. Previous studies have observed the same practice in assessing grains dryness (Magembe *et al.,* 2016). More than 58% of smallholder farmers shelled/threshed their produces manually on farms by beating and/or striking (Table 3.3). During manual threshing grains, spillage and breakage can occur due to excessive striking or beating, resulting in grain losses. Ali and Khalid, (2015) found that manual and mechanical threshing causes 1.12% and 1.09% grain losses, respectively. On contrary, Abass et al., (2014) reported higher manual threshing losses for maize (13.4%), groundnuts (18.0%) and sunflower seeds (20.0%). Use of mechanical thresher could significantly reduce grain losses.

Drying of agro-produces is a key practice to ensure quality and extend shelf-life of agricultural produces. However, drying under a controlled conditions is essential to attain the acceptable moisture level (Chiewchan *et al.,* 2015). Smallholder farmers especially in rural areas dried produces on the bare ground which lead to contamination with aflatoxin producing fungi and foreign matters. Use of other drying techniques like raised platform, concrete floor, tarpaulins and on roofs provide better hygienic conditions (Bauchet *et al.*, 2021). However, when the grains are contaminated with aflatoxins it is not possible to reduce its level of contamination either by drying or heating (Chiewchan *et al.,* 2015).

Table 3. 3: Frequency distribution of smallholder farmers according to postharvest handling and storage practices of stored grains

Variable	Description	Frequency (N=90)	Percentage (%)
Method to dry	Sun drying	83	92.2
	Air drying	7	7.8
Drying time	Maize < 7 days	10	11.1
	Maize above 8 days	80	88.9
	Groundnuts < 7 days	21	23.3
	Groundnuts above 8 days	46	51.1
	Not dry groundnuts	23	25.6
	Sunflower seeds < 7 days	40	44.4
	Sunflower seeds above 8 days	47	52.2
	Not dry sunflower seeds	3	3.3
Shelling/threshing methods	Hand shelling	52	57.8
	Motorised thresher	38	42.2
Where do you kept produces during harvesting?	Bare ground	38	42.2
	Raised platforms	7	7.8
	Tarpaulin	18	20.0
	Jute/Sisal bags	7	7.8
	Plastic/synthetic bags	20	22.2
Testing for dryness	Measure moisture content	16	17.8
	Bite the grains	8	8.9
	Visual assessment	65	72.2
	sound	1	1.1
What action did you take if it rains and produces are at open space?	Cover	61	67.8
	Take to the protected area	17	18.9
	Not cover	9	10.0
	Not rain	3	3.3
Sort/Clean grains	Sort	62	68.9
	Not sort	28	31.1
How do you sort grains?	Colour	28	31.1
	Damage	33	36.7
	Colour and Damage	1	1.1
Which storage facility did you use?	Jute/Sisal bags	4	4.4
	Plastic/synthetic bags	86	95.6
Storage management	Cleaning	56	62.2
	Fumigation	8	8.9
	Cleaning and Fumigation	23	25.6
	No cleaning	3	3.3
Where do you store your produces?	Warehouse	30	33.3
	Under the shed	16	17.8
	In living house	44	48.9
Storage time	Maize < 6 months	73	81.1
	Maize above 7 months	17	18.8
	Groundnuts < 6 months	54	60.0
	Groundnuts above 7 months	15	16.7
	Not store groundnuts	21	23.3
	Sunflower seeds < 6 months	73	81.1
	Sunflower seeds above 7 months	14	15.6
	Not store sunflower seeds	3	3.3
Use of pesticides during storage	Yes	66	73.3
	No	24	26.7
Use of pesticides treated seeds	Yes	41	45.6
	No	49	54.4

3.3.3.2 Cleaning

The smallholder farmers did not clean nor sort grains (31.1%; Table 3.3), and this may increase predisposition of stored produce to aflatoxins contamination. In postharvest handling of agro-produce, cleaning is very important operation as it serves to remove all physical objects such as stones, sands and to separate whole, infected or broken grains. Inadequate cleaning of grains can contribute to insect infestation, poor quality product including adverse health effect to human (Kumar *et al.*, 2017). Also, it increases maintenance costs for milling machine as physical objects may cause damage. Consumption of grains with higher percentage of discoloration is a potential risk to exposure to mycotoxins like aflatoxins (Likhayo *et al.*, 2018). In some cases a very limited cleaning is done through winnowing or use of strainers. This calls for the need of centralized drying, cleaning and storage facilities in rural areas to ensure proper and standardized postharvest handling of cereals and other produce in a view to ensure food safety and competitive market access. It is therefore, vitally important that dirt and impurities be removed as soon as possible to delay the deterioration process and ensure that the product being stored is of high quality for end user. In a nutshell, pre-cleaning of grain before storage add value to the grain through removal of dirt, impurities and damaged particles; and ensure a long life of grain in storage. Clean grain will fetch a better price than dirty grain full of particles.

Factors contributing to on-farm aflatoxin occurrence include erratic rains, drought, high moisture and insect infestation. It is necessary to perform physical cleaning for mold damaged grains to remove intact product and reduce aflatoxin contamination. Sorting could be done manually or mechanically by use of specialised machines like aspirators (Waliyar *et al.*, 2015).

3.3.3.3 Transportation and storage

Transportation is among the post-harvest practices applied by smallholder farmers along the value chains which involve the movement of agricultural produces from one step to another; for example, from field to storage facilities or market place. The primary transportation means of harvested crops are however, by open vehicles (61%) and pushcarts (17%) (Fig. 3.3). Open vehicles and pushcarts could expose the produce to rains and fungal spores' contamination. Poor infrastructure in rural setting accompanied with inadequate handling practices increase the possibilities of contamination and high PHLs (Kumar *et al.,* 2017; Manandhar *et al.,* 2018).

As an essential requirement for grains storage structure should be well ventilated and bags must be placed on treated pallets, and allow free space of about 25% (for movement of people and material). With respect to packaging; the grain is stored on platforms in heaps, in woven baskets or bags. There are also hermetically sealed bags recommended for long term storage (Manandhar *et al.,* 2018). Thoroughly cleaning of grain prior to storage and regular fumigation of store is vital.

In the surveyed areas, basic storage-structures for grain storage are minimal. For instance, in some villages, grains packed in polyethylene bags were found stored in small, poorly ventilated houses or just placed on the floor without pallets. Furthermore, the bags in the stores were poorly arranged worsening air circulation. Poorly ventilated rooms, with poorly arranged bags coupled with uncleaned grains may lead to collection of moisture, high temperature and humidity which are favourable conditions for mould growth and consequently mycotoxins contamination of stored grains. Previous studies have reported high temperature, relative humidity and moisture as major factors to monitor in storage room (Waliyar *et al.,* 2015; Neme and Mohammed, 2017). It was also noted that 48.9% of smallholder farmers stored grains in their living house (Table 3.3). The storage areas had vents without nets/screens to prevent entrance of pests like insects and rats. Unlike result was reported in Eastern region of Kenya that, 55.6% of farmers store harvested grains inside their living house (Njoroge *et al.,* 2019).

This study observed that stores or houses are poorly designed and often made of mud; the walls have chunk and chinks with mud floors which may allow the entrance of pests. Traditional storage structures protect grains from rains and sun, but air and moisture can pass through that and can result to pest infestation of stored grain (Manandhar *et al.,* 2018). These scenarios coupled with high temperature and humidity levels especially in the tropics contribute to high (20-40%) post-harvest losses (Wild *et al.,* 2015). This study revealed that 18.8%, 16.7% and 15.6% of smallholder farmers stored maize, groundnuts and sunflower seeds respectively for longer than seven months (Table 3.3). Storage of grains for such long period under in-appropriate conditions may aggravate spoilage and mycotoxin contamination. Previous studies have reported aflatoxin contamination on grains stored for less than six months due to inadequate post-harvest management practices (Mohamed, 2017). Inadequate post-harvest practices applied by farmers play a significant role on mycotoxin production and contamination (Tola and Kebede, 2016; Kebede *et al.,* 2019)

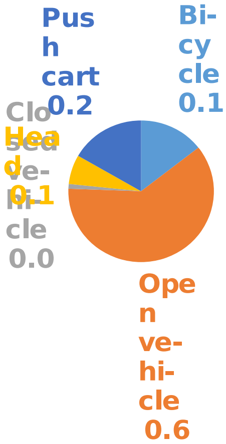

Figure 3. 3: Type of produce transport used by smallholder farmers at Chamwino

About 3.3% of smallholder farmers did not clean their stores when storing new harvest (Table 3.3), which exposes the produce to aflatoxin contamination. The study by Kamala et al., (2016) reported that, farmers clean their storage facility to ensure no mixing of previous harvest and newly harvested ones. Fig. 3.4 shows that, (83%) of smallholder farmers encounter losses of agricultural produces due to insect and rat infestation. Previous studies in the same district observed majority of farmers (60%) experiencing maize losses due to pest infestation (Suleiman *et al.*, 2017. However, minimal losses are likely when storage is done in clean facility and grains are dried properly (Mwangi *et al.*, 2017). The higher losses of grains observed in this study was attributed to poor building structures including storage facilities such as polyethylene bags which allow contamination of stored grains.

This study found that 73.3% of smallholder farmers applied pesticides to stored grains (Table 3.3). However, few farmers (33%) in Kongwa District use pesticides during storage of maize (Seetha *et al.*, 2017). More less, the same level (71%) of farmers in Kenya use pesticides to control pests during grain storage (Koskei *et al.*, 2020). Although use of pesticides is common to smallholder farmers, majority have no skills on proper use of the pesticides. Yet, they may either use single pesticides or coctions of pesticides. The common pesticides applied by majority of farmers assessed in this study include actellic, permethrin and aluminium phosphide (phosphine). Kumar and Kalita, (2017) stated that the most common pesticides applied by farmers in developing countries include permethrin, actellic and phosphine. However, the use of actellic super which is the mixture of actellic and permethrin for grain storage stored in polypropylene bags help to fight against pest infestation for few months of storage (De Groote *et al.*, 2013).

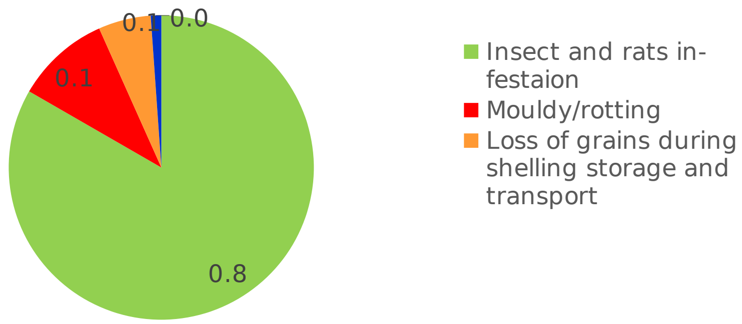

Figure 3. 4: Grains losses encountered by interviewed smallholder farmers at Chamwino

3.3.4 Smallholder farmers knowledge and awareness on use of contaminated crops

The awareness on mycotoxins by smallholder farmers in Chamwino is very low. More than 60% of interviewed farmers used fungal contaminated or rotten produce for food or diverted use to animal feeds (14.4%; Fig.3.5). This implies high potential health risk for most families in the rural areas being exposed to aflatoxicosis. Likewise groundnut farmers (41%, n = 805) in Malawi consumed spoiled groundnuts (Matumba *et al.*, 2016). Previous studies observed use of rotten grains in preparation of animal feeds (Mboya and Kolanisi, 2014; Magembe *et al.*, 2016).

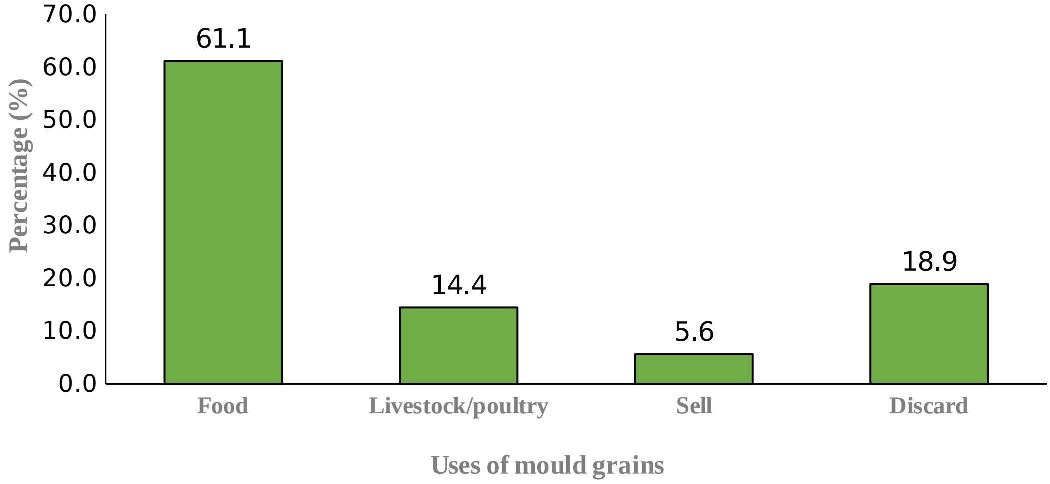

Figure 3. 5: Use of rotten or mouldy grains by the interviewed smallholder farmers

More than half (53.3%) of smallholder famers did not knew about fungi; however, 82.2% indicated that their grains got mouldy and 81.1% were not aware that fungi contamination may cause health problems (Table 3.4). Similarly, a study conducted in Uganda reported that, 88.6% (n=44) of the respondents encountered moulds in grains and feeds during storage (Nakavuma *et al.,* 2020). Another study in Vietnam found that ≥50% (n=551) of the respondents indicated that cereals get mould (Lee *et al.*, 2017).

Moreover, 96.7% of interviewed farmers were not aware that feeding animals with mycotoxin contaminated maize could contaminate milk with a mycotoxin, particularly aflatoxin (Table 3.4). A different study conducted in Kilosa Tanzania found that 66.7% (n=72) of the respondents were not aware of health hazards caused by mycotoxins (Magembe *et al.,* 2016). Also, Matumba et al., (2015) reported a lack of awareness on health effects caused by mould and mycotoxins among the smallholder farmers in Malawi. The difference in the level of awareness can be attributed to the nature of the study population. In general, people from remote areas have low education level and less opportunity to access information on mycotoxins as compared to those in urban areas.

About (10%) of interviewed smallholder farmers had experienced aflatoxicosis cases due to consumption of mouldy food (Table 3.4). For instance, in 2016 Tanzania experienced aflatoxicosis outbreak in Dodoma region. A rapid epidemiological survey was conducted in the affected villages, which reported a total of 68 cases of affected persons with 20 scores of death due to consumption of aflatoxin (2.4-285 µg/kg) contaminated maize Kamala *et al.,* 2018). Surprisingly, this event did not increase the awareness of the farmers on mycotoxins; as most farmers are not aware and could still consume mouldy grains.

Table 3. 4: Smallholder farmer's knowledge and awareness of mycotoxins contamination

Variable	Description	Frequency (N=90)	Percentage (%)
Do you know what fungi are?	Yes	42	46.7
	No	48	53.3
Have you ever observed mouldy grains?	Yes	74	82.2
	No	16	17.8
Are you aware that fungi contamination cause health problem?	Aware	17	18.9
	Not aware	73	81.1
Has any member of your family gotten ill following consumption of mouldy food?	Yes	9	10.0
	No	81	90.0
Do you know that fungi produce toxins?	Yes	12	13.3
	No	78	86.7
Have you ever heard the word mycotoxins?	Yes	10	11.1
	No	80	88.9
Are you aware that feeding animals with aflatoxin-contaminated feeds contaminate animal/poultry products?	Aware	3	3.3
	Not aware	87	96.7

3.4. Conclusions and Recommendations

In general, smallholder farmers at Chamwino district in Dodoma have low level of knowledge on the good postharvest handling practices. Limited knowledge (mouldy grains for food or diverting them to animal feeds) and equipment to properly dry and store agricultural produces increases the risks of aflatoxin contamination along the produce value chains. Since aflatoxins are hardly decontaminated once they get access to foods, intervention measures are needed at nodes where are regarded as hot spots for contamination. Unlike, food products in commercial chains, household-stored maize are consumed by members of such household. Unfortunately, rural households are limited with meal diversification which exacerbates the risks. From the observation made in this study, in order to ensure food safety, improve rural livelihood and the contribution of agriculture to the economy it is recommended that the Government assists smallholders to form farmers groups specifically for cereals and other produce such as beans, groundnuts, sunflower etc. The Cereals and Other Produce Board of Tanzania could coordinate other stakeholders along the produce value chains. The regulatory organs such as Tanzania Bureau of Standards should design and implement a mass awareness campaign (including school children) on mycotoxins contamination of food and its health and economic consequences. However, further studies are recommended to explore, establish and implement real time techniques for the control of mycotoxins along the entire agricultural value chain in Dodoma region.

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CHAPTER FOUR

Paper Two

4.0 AFLATOXIN CONTAMINATION OF HOUSEHOLD STORED MAIZE, GROUNDNUTS AND SUNFLOWER SEEDS IN CHAMWINO, DODOMA REGION

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Abstract

The aim of this study was to determine the level of aflatoxins contamination of household stored maize, groundnuts and sunflower seeds in Dodoma, Tanzania. Immuno-affinity high performance liquid chromatography and post column derivatization was used to analyse aflatoxins (AFB_1, AFB_2, AFG_1 and AFG_2) for 45 samples. Out of all samples, 38% were contaminated with aflatoxins; the highest mean level of aflatoxins were observed in groundnuts (268.82 µg/kg) of total aflatoxins followed by maize (74.91 µg/kg), whereas the least level of aflatoxins (0.23 µg/kg) were observed in sunflower samples. About 27% of maize samples and 67% of groundnuts samples had higher levels of AFB_1 and total aflatoxins contamination beyond the TZS/EAS limits of (5 μg/kg) and (10 μg/kg), respectively. The mean moisture contents were 9.57% in maize, 4.13% in groundnuts and 5.70% in sunflower seeds. The moisture content was within the optimal storage levels of 13.5% in maize, 8% in groundnuts and 10% in sunflower seeds. This indicates that aflatoxin contamination occurred in the field, during harvesting or drying before the acceptable storage moisture levels were not attained. Therefore, farmers need to be trained on the best handling practices along the produces value chain to prevent aflatoxins contamination.

+**Keywords**: aflatoxins, moisture content, grains, maize, groundnuts, sunflower seeds.

4.1 Introduction

Aflatoxins are toxic secondary metabolites produced by toxigenic *Aspergillus* species including *A. flavus*, *A. nomius* and *A. parasiticus* (Mahato *et al.*, 2019). Tropical climate is characterized by high temperature and humidity which favour mould growth and consequently mycotoxins production (Magan *et al.*, 2011; Mahato *et al.*, 2019). Aflatoxins contaminations have been reported in various foods and animal feeds in the developing countries. Previous studies reported aflatoxins contamination of cereals, nuts and oilseeds, milk and milk products as well as animal feeds (Perrone *et al.*, 2014). It is estimated that approximately 25% of the world's agricultural commodities are contaminated with mycotoxins (Eskola *et al.*, 2019).

Consumption of aflatoxins contaminated foods may result into negative health effects like carcinogenicity, hepatogenicity, mutagenicity and immune suppression to both humans and animals (Varga *et al.*, 2011; Pal *et al.*, 2015). Although more than 20 types of aflatoxins are reported the most important ones to public health are aflatoxins B_1 (AFB_1), aflatoxins B_2 (AFB_2,), aflatoxins G_1 (AFG_1) and aflatoxins G_2 (AFG_2) (Kumar *et al.,* 2017). Despite the fact that aflatoxins can be found in array of foods, the most human exposure comes from nuts, cereal grains and their derived products (Eskola *et al.,* 2019; Herrera *et al.,* 2019). Moreover, aflatoxin $M_{1,}$ metabolites of (AFB_1) metabolism can be found in milk and milk products (Marchese *et al.,* 2018). Some studies have reported aflatoxin M_1 in human breast milk and cow's milk (Keskin *et al.,* 2009; Maleki *et al.,* 2015; Diaz and Sanchez, 2015; Daou *et al.,* 2020). Aflatoxin B_1 is the most hepatocarcinogenic compared to other groups of mycotoxins (Fakruddin *et al.,* 2015). It may cause stunting in children due to probable nutrient utilization (Hamid *et al.,* 2013; James and Zikankuba, 2018).

Aflatoxin contamination starts from the fields (pre and during harvesting) and on-storage (Seetha *et al.,* 2017). Hot and humid conditions favour fungal growth and subsequently aflatoxins production. Moreover, soil types such as light sandy with low water retention accelerate growth of the fungi. Keeping or drying produces on bare grounds is a potential source of fungi that produce mycotoxin contamination (Achaglinkame *et al.,* 2017). In general, inadequate pre and post-harvest management practices are the major contributing factors to aflatoxin contamination (Benkerroum, 2020).

Aflatoxins contaminated produces such as maize, groundnuts, and sunflower seeds are frequently consumed and could pose significant health risks. Of recent Tanzania has experienced several incidences of aflatoxin contamination with several scores of death and hospitalisation. For instance, a total of 68 cases of the outbreak were reported in Dodoma, Chemba, Kondoa, Kiteto, and Chamwino districts in 2016 after consuming aflatoxin contaminated maize. These incidences resulted in 17 deaths and hospitalisation of more than 48 people (Kamala *et al.*, 2018). Also in 2017 a total of 8 cases of suspected aflatoxicosis, including four deaths was reported in Kiteto district in Manyara region (WHO, 2017). These incidences not only affect consumers' health but also hamper international trade in food and feeds (Benkerroum, 2020).

Smallholder farmers in developing countries including Tanzania store agricultural produces in primitive structures that do not offer proper protection from pests and agents of spoilage. For instance, majority of smallholder farmers use woven and polyethylene bags to store their grains. Use of pallets and proper storage techniques is not common. Although use of improved techniques like hermetic storage (silo bins and Purdue Improved Crop Storage (PICS) could provide better protection and prevent aflatoxins contamination (Murdock *et al.*, 2003; Sudini *et al.*, 2015; Luoga, 2019), it is limited to medium and commercial farmers. This study aimed to determine the levels of aflatoxins in household-stored maize, groundnuts and sunflower seeds in the study area.

4.2 Material and Methods

4.2.1 Sample Collection

The sample size was estimated using the Kothari equation 4.1 (Kothari and Garg, 2014).

$$n = \frac{Z^2 P(1-P)}{d^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.1$$

Where, n= sample size, z = standard variation at a given confidence level, for this study a 95% confidence level = 1.96, the maximum probability was chosen to be 0.5 and d = allowable error 14.60898% (0.1460898).

Samples of maize, groundnuts and sunflower seeds were collected from 15 households in Chamwino district in Dodoma region from November 2019 to January 2020. A total of 45 samples were collected from 45 randomly selected smallholder farmers in three villages namely Haneti, Mapanga and Zajilwa. Fifteen samples of each produce were collected from each village (Figure 4.1). Two portions (500g each) of household stored maize, groundnuts and sunflower seeds were collected in clean polyethylene bags. The bags containing the samples were sealed, labelled, coded and packed in a cool box (maintained at 4ºC) and transported to Tanzania Bureau of Standards Food Laboratory for analysis. For samples which could not be analysed within the same day were frozen until analysed.

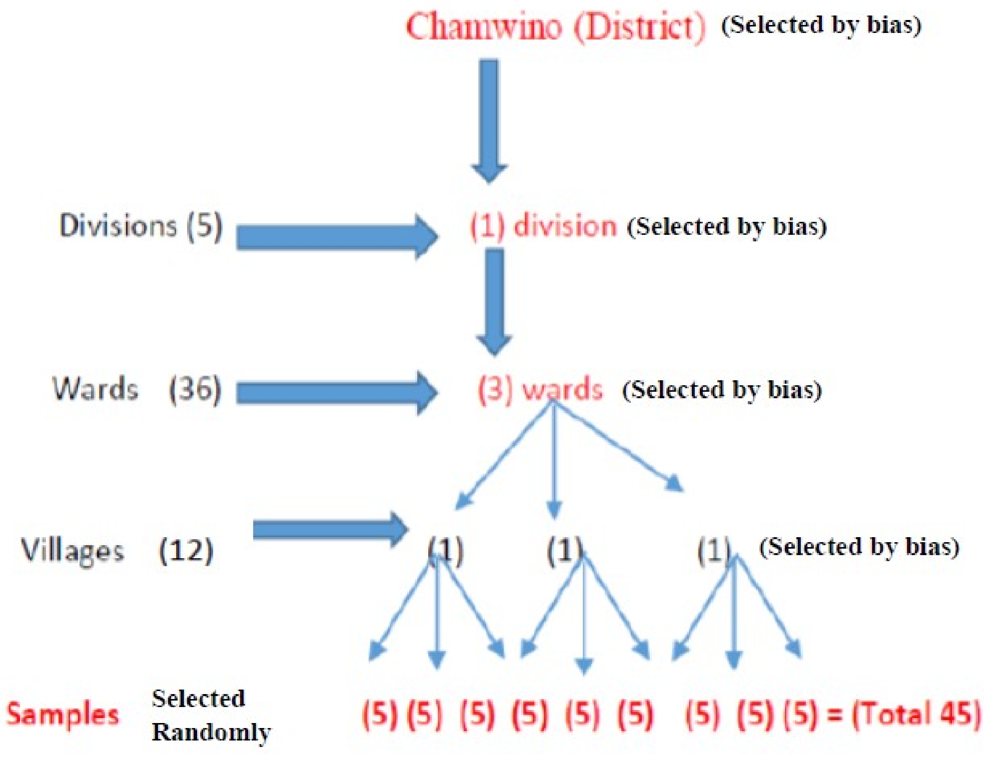

Figure 4. 1: Sampling plan for maize, groundnuts and sunflower seeds from villages of Haneti, Mapanga and Zajilwa at Chamwino district

4.2.2 Moisture analysis

The moisture content in each sample was determined by oven-drying method (AOAC, 2000). The grain samples were ground into powder form with a particle size of 0.2 mm and duplicate samples for each produce about 2.0±0.1g were weighed into a petri dish using analytical balance (Sartorius, Switzerland), and placed into oven set at 105°C± 2 °C for 3 hours. The dried samples were cooled in a desiccator prior to moisture analysis. The moisture content of the grains was determined as indicated in equation 4.2 (Hamdani *et al.*, 2018).

$$Moisture\,content\,\% = \frac{Weight\,of\,wet\,sample - Weight\,of\,dried\,sample}{Weight\,of\,wet\,sample} \times 100 \ldots\ldots \quad (4.2)$$

4.2.3 Determination of aflatoxins contamination

4.2.3.1 Extraction of analytical samples

The aflatoxins contamination was determined by (ISO 16050:2003). The samples for maize, groundnuts and sunflower seeds were ground separately using grinder. About 25 ± 0.1g for each ground sample were weighed into Erlenmeyer flask using calibrated analytical balance. Extraction solvent consisting of methanol: water (70:30 v/v) was prepared. About 100 ml of extraction solvent was added to the 250 ml Erlenmeyer flask containing the sample. Aluminum foil was used to cover the flask and placed on the gyratory shaker (Stuart® Orbital Shaker SSL1, Cole-Parmer LLC, USA) and shake at 250 rpm for 30 min. The extract was filtered into 250 ml Erlenmeyer flask using a filter paper Whatman No. 1.

4.2.3.2 Dilution

The extract was slowly shaken and about 4ml transferred into 12 ml centrifuge tube and 8ml of distilled water was added. The mixture was vortexed (Talboys® Hvy Dty Vortex, Troemner LLC, USA) for about 1 min.

4.2.3.3 Isolation and clean-up of aflatoxin

Solid Phase Extraction (SPE) immuno affinity column (AflaTest from Romer Labs GmbH, Technopark 1, 3430 Tulin, Australia) was loaded with diluted extract and allowed to pass through. Then the column was rinsed twice using 10 ml of HPLC water grade (Fisher Chemical, Bishop Meadow Road, Loughborough, Leicestershire) before eluting the adsorbed aflatoxins. The adsorbed aflatoxins were eluted with 1 ml of methanol-HPLC grade (Fisher Chemical, Bishop Meadow Road, Loughborough, Leicestershire). The eluents were collected in amber vials. Subsequently, slight pressure was applied on top of the column to remove the remaining liquid. About 0.3 ml of the eluent was mixed with 0.6 ml of water and 0.1 ml of acetonitrile and the mixture was vortexed for 30 seconds prior to HPLC analysis.

4.2.3.4 HPLC condition

HPLC coupled with fluorescence detector (FtLD) (Model Agilent ChemStation technology, series 1200, 5301 Stevens Creek Blvd, Santa Clara, CA 95051, USA) was used to analyse the extracted samples. The column C18, (4.6×150mm, 5µm), Eclipse XDB-C18 was used to separate groups of aflatoxins AFB_1, AFB_2, AFG_1 and AFG_2. The column temperature of 30 °C, flow rate of 1.2 mL/min and Water: Methanol: Acetonitrile (60:30:10 v/v) mobile phase were used. The injection volume for both samples and standard solution was 50µL. Derivatization of AFG_1 and AFB_1 was conducted after separation to allow their detection with fluorescence detector at an emission wavelength of 465 nm and an excitation wavelength of 360 nm.

4.2.3.5 Identification and Quantification

Aflatoxin standards solution which contained AFB_1, AFB_2, AFG_1 and AFG_2 was prepared and analysed at different concentrations and four points calibration curve was constructed as indicated in (Figures 4.2 to 4.5). The linearity was established and the correlation coefficients (R^2) ranged from 0.9931 to 0.9976 were used to quantify aflatoxins in the samples. The samples for each produce were analysed in a duplicate. Figure 4.5 shows standard chromatogram for aflatoxins that have been analysed.

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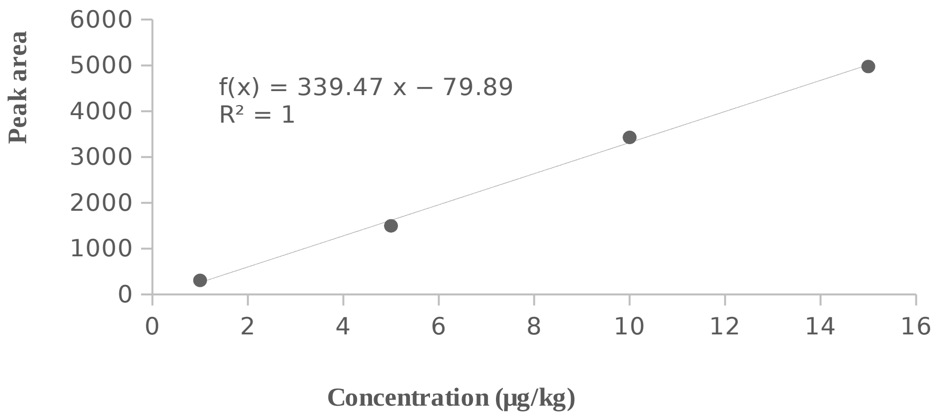

Figure 4. 2: Calibration curve for aflatoxin G_1

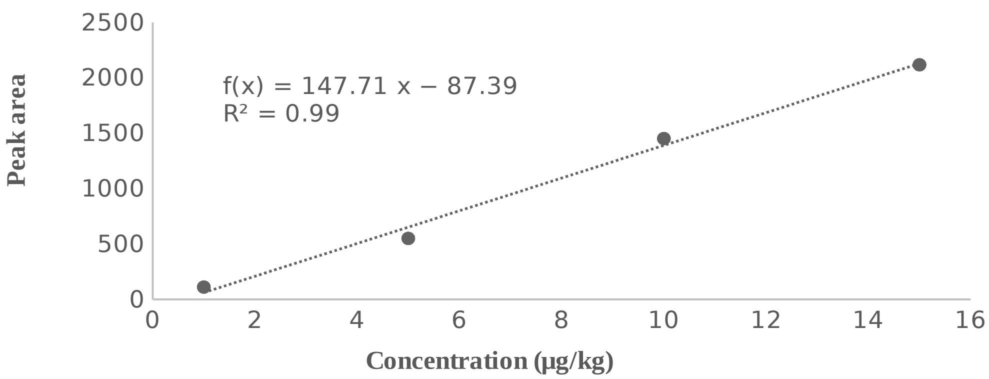

Figure 4. 3: Calibration curve for aflatoxin G_2

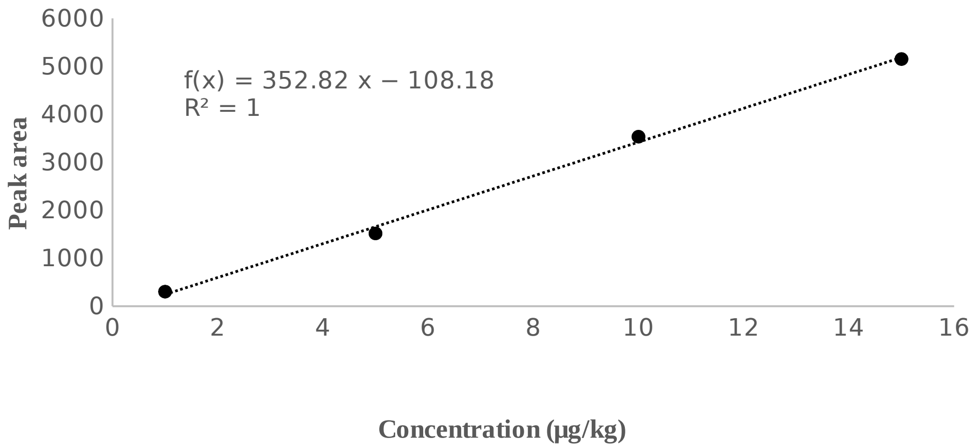

Figure 4. 4: Calibration curve for aflatoxin B_2

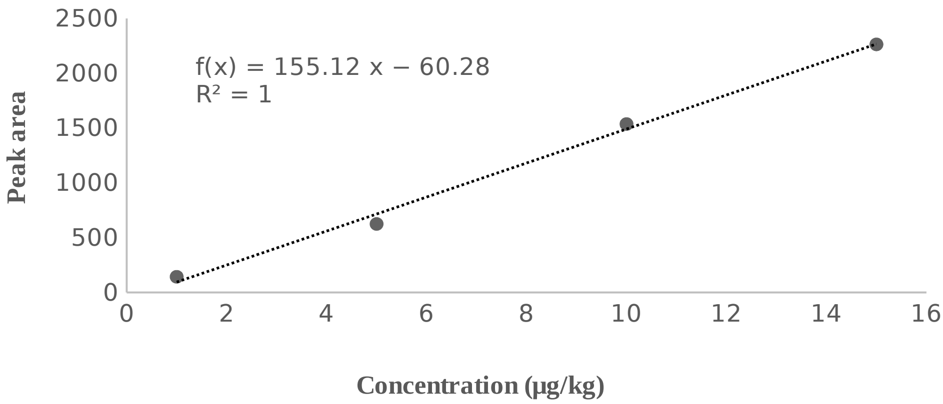

Figure 4. 5: Calibration curve for aflatoxin B_1

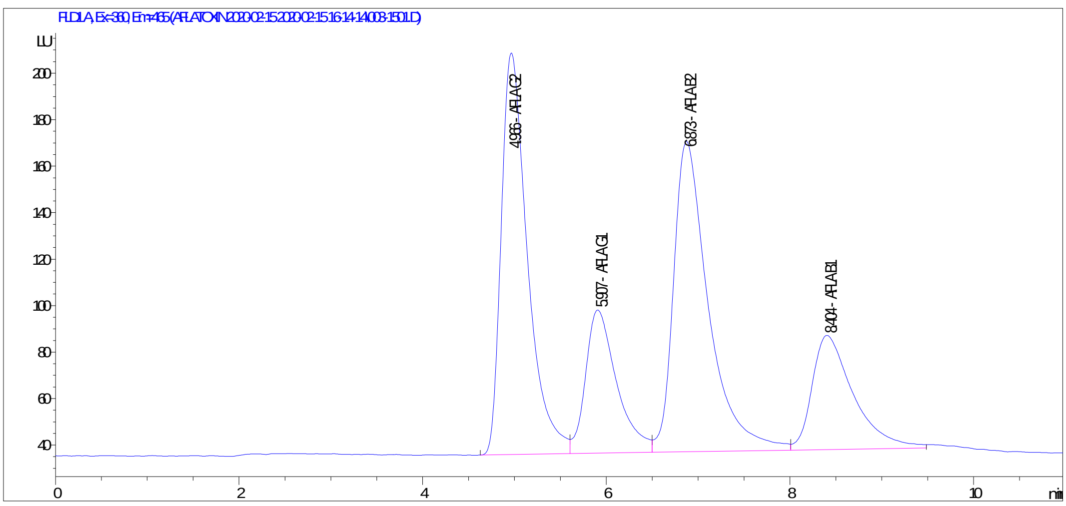

Figure 4. 6: HPLC chromatogram of aflatoxin standards (10 μg/kg)

4.2.3.6 Determination of the limit of detection and limit of quantitation of the HPLC method

The equations 4.2 and 4.3 were used to determine the limit of detection and limit of quantification. Table 4.1 indicates types of aflatoxins analysed in this study and their LOD and LOQ in μg/kg.

LOD = Mean of the lowest concentration + 3 SD……………………………..……… (4.2)

LOQ = Mean of the lowest concentration + 10 SD……………………….……... (4.3)

SD is the standard deviation of the lowest concentration (Armbruster *et al.*, 2008).

Table 4. 1: The Limit of detection (LOD) and limit of quantitation (LOQ) for each analysed aflatoxin

Compound	LOD	LOQ
AFG_2	0.13	0.16
AFG_1	0.13	0.21
AFB_2	0.13	0.18
AFB_1	0.16	0.29

4.2.3.7 Recovery of aflatoxin

Aflatoxin free maize, groundnuts and sunflower seeds were used to determine the recovery rate. The aflatoxin free samples (25±0.1g) were spiked with aflamix (AFB_1, AFB_2, AFG_1 and AFG_2) standard at 5 μg/kg. Due to financial constraints, the aflatoxin free samples were spiked with one concentration of the standard. Extraction of aflatoxins from the spiked samples was carried out as indicated in section 4.2.3.1 above.

4.3 Data Analysis

Data were analysed using R- version 3.6.3 (2020). Two-way analysis of variance (ANOVA) was used to test significant difference on the moisture content or levels of aflatoxin (dependent variable) amongst the type of agricultural produces and study villages (independent variables). The difference between means were separated using Tukey's honestly significant difference (HSD) test in agricolae package, where the p-value less than 0.05 was considered significant. The assumptions for parametric tests including normal distribution, homogeneity of variance and independence of variance were also performed.

4.4 Results and Discussion

4.4.1 Recovery of Aflatoxin

The average recovery of aflatoxin ranged from 97.27±2.98 to 108.33±4.11 % (Table 4.2). According European Commission regulation 401/2006, the recommended recovery range is 70-110% (European Commission 2006). Therefore, this study observed the required recovery range for maize and sunflower seeds; however, higher recovery rate beyond the recommended was reported in groundnuts (Table 4.2). Instrumental failure, matrix interference and errors in the procedure could be the major causes.

Table 4. 2: Percentage mean recovery of aflatoxins from spiked maize, sunflower and groundnuts samples

Type of aflatoxins	Concentration of aflatoxins in blank sample (μg/kg)	Spiked concentration (μg/kg)	Detected concentration (μg/kg)			(%) recovery			Mean (%) recovery
			Maize	Sunflower	Groundnuts	Maize	Sunflower	Groundnuts	
AFG_2	<LOD	5	5.20	5.14	5.98	104	102	119	108.33±4.11
AFG_1	<LOD	5	5.05	5.18	5.98	101	103	119	107.67±4.36
AFB_2	<LOD	5	5.10	5.00	5.38	102	101	107	103.33±1.41
AFB_1	<LOD	5	4.59	4.75	5.27	91.8	95	105	97.27±2.98

4.4.2 Moisture content in maize, groundnuts and sunflower seeds

The moisture content of all produces were within the acceptable storage levels; maize ($\bar{x}$ = 9.57 ± 0.77%), groundnuts ($\bar{x}$ = 4.13 ± 0.67%) and sunflower seeds ($\bar{x}$ = 5.70 ± 0.69%). The recommended moisture content of maize is 13.5% (TZS 438-2018/EAS 2-2017), groundnuts 8% (TZS 740-2018/EAS 888-2018) and sunflower 10% (TZS 1578-2012). In this study the moisture content for maize ranged from 8.25 to 12.75 %, groundnuts ranged from 2.25 to 5.75% and sunflower seeds ranged from 4.25 to 7.00%. (Table 4.3).

Mutegi *et al.* (2013) observed similar levels of moisture (5.2%) in peanuts stored in polyethylene bags. There is a direct relationship between temperature and relative humidity; as the temperature increases the stored grains lose moisture to the surrounding air (Suleiman *et al.*, 2013). Even after drying, maize grain harvested in tropical countries retain a certain amount of moisture and when exposed to air, exchange of moisture between the maize grains and surrounding occurs until the equilibrium is reached (Samuel *et al.*, 2011).

Moisture content is one of the most important parameters to monitor during the grain storage. It influences the physical properties of food during processing as well as the final product. Different grains contain different moisture content during harvesting and storage. In most tropical countries particularly Africa, the moisture content for fresh harvested maize range from 18-20%, groundnuts 40-50% and sunflower seeds about 20% (Ahmad and Mirani, 2012; Likhayo *et al.*, 2018). This moisture content is not safe for storage; therefore, most farmers do dry their grains before storage. However, lack of good drying facilities and equipment to measure moisture, grains are often stored with high moisture content beyond the recommended storage levels (Weinberg *et al.*, 2008).

Maize, groundnuts and sunflower seeds stored at high temperature and beyond the recommended moisture contents are susceptible to bacterial, fungal, pests attack and deterioration (Weinberg *et al.,* 2008; Kaleta and Grnicki, 2013). Conversely, grains stored under appropriate conditions and moisture content (<13.5%) could be stored for long time without spoilage (Kaleta and Grnicki, 2013).

Table 4. 3: The moisture content of each smallholder farmer and mean (Mean + SEM) in maize, groundnuts and sunflower seeds (N=15 for each produce) in Dodoma region

Farmer	Maize	Groundnuts	Sunflower seeds
1	10.00	3.75	7.00
2	9.00	2.25	6.00
3	9.25	4.00	6.00
4	8.50	3.75	6.50
5	9.50	4.75	5.75
6	10.50	5.75	6.50
7	9.50	4.25	5.75
8	9.75	4.25	4.50
9	12.75	4.25	5.00
10	9.75	4.75	6.25
11	9.75	2.25	4.25
12	8.25	5.50	5.25
13	7.75	3.75	4.75
14	9.00	4.25	5.25
15	10.25	4.25	6.75
Mean Moisture Content	**9.60 ± 0.77^{a}**	**4.12 ± 0.67^{c}**	**5.70 ± 0.69^{b}**
Recommended acceptable moisture level	**13.5%**	**8%**	**10%**

Mean within the same row with different superscripts are significant different at p<0.05, Letter N stand for number of samples analysed for each produce.

4.4.3 Aflatoxin levels in maize, groundnuts and sunflower seeds

Table 4.4 shows the mean values of aflatoxin AFB_1, AFB_2, AFG_1, AFG_2 and total aflatoxin of the analysed samples. Compared to maize and sunflower seeds, groundnuts had significantly higher ($p<0.05$) mean values for AFB_1 (233.48±59.99 µg/kg), AFB_2 (9.62±2.28 µg/kg) and total aflatoxin (268.82±61.17 µg/kg) (Table 4.4). Maize had mean levels of AFB_1 beyond the TZS/EAS set limits (5 µg/kg). Out of 45 samples, 31% exceeded Tanzania/East African Standards AFB_1 recommended levels (5 µg/kg) and total aflatoxins set limit (10 µg/kg, Table 4.4). The ranges of AFB_1 contamination were 0.0-574.8 µg/kg in maize, 0.0-790.9 µg/kg in groundnuts and 0.0-2.1 µg/kg in sunflower seeds. Groundnuts had higher prevalence (73.3%) of AFB_1 and total aflatoxins as compared to maize (26.7%) and sunflower seeds (13.3%, Table 4.4).

Previous studies observed that poor postharvest management is the major factor contributing to higher aflatoxin concentration in stored grains (Hell and Mutegi, 2011; Mohammed, 2016; Seetha *et al.*, 2017). Since the samples collected from this study had moisture levels below the recommended limits, it shows that aflatoxin contamination could have occurred while the crops were in the field. Moreover, the samples were collected six months after harvest; proliferation of aflatoxins could happen in the store soon after harvest as normally farmers harvest crops when they have 18-25% moisture content. Therefore, when drying is not done before storage, growth of toxigenic fungi could occur (Seetha *et al.*, 2017). Aflatoxin contamination may occur while the crops are in the field or during storage (Rashid *et al.*, 2013).

During the survey it was observed that significant number of smallholder farmers kept their produces on the bare ground, transport the produces in open vehicles and did not sort their produce (Kimario *et al.*, 2021). Environmental factors such as temperature, relative humidity, poor storage structures and poor aeration in the store are associated with high levels of aflatoxins of stored grains (Sharon *et al.*, 2014). The current study indicated that sunflower seeds had the lowest levels of AFB_1 and total aflatoxins below the set limits (5 µg/kg and 10 µg/kg). Likewise a study by Mariod and Idris, (2015) reported lower aflatoxin contamination in sunflower seeds compared to groundnuts. According to Mmongoyo *et al.* (2017) sunflower seeds collected from Dodoma had highest aflatoxin contamination (1.7–280.6 ng/g). This variation might be contributed with different climatic conditions.

Previous studies reported high levels of aflatoxins in groundnuts in Kilosa (72.97 - 175.49 µg/kg, Magembe *et al.,* 2016), Zambia (361 µg/kg, Kachapulula *et al.,* 2017), East Ethiopia (786 and 3135 ng/g from 2013/2014 and 2014/2015 respectively, Mohammed *et al.*, 2016; 15 ppb to 11,900 ppb, Chala *et al.*, 2013) and Ghana (58 ppb, Agbetiameh *et al.,* 2018). Higher levels of aflatoxins in maize were also reported in Malawi (140 µg/kg, Mwalwayo and Thole, 2016). Also this study revealed low level 26.7% (Table 4.4) of aflatoxin contamination in stored maize samples compared to the study by Kamala *et al.* (2016) who reported higher level (45%) of aflatoxin contamination of maize sample in agro-ecological zones (Northern Highlands, South-western Highlands and Eastern Lowland) of Tanzania. The study by Kamala *et al.* (2015) reported that 87% of the samples collected in three agro-ecological zones of Tanzania were contaminated with more than one mycotoxins. Neme and Mohammed, (2017) reported that maize sampled in Sub-Saharan Africa (SSA) countries always tested positive for aflatoxin by 65%. Another study by Sasamalo *et al.* (2018) conducted in Dodoma reported that 30% of maize samples were contaminated with aflatoxin which is nearly the same to aflatoxin contamination in maize reported in this study.

Aflatoxins contamination of maize and groundnuts are attributed to pests (rodents and insects) attack and pods damage during storage which consequently may expose the grains to fungal infestation. Poor storage practices are among the factors that favour growth of aflatoxigenic fungi for most agricultural produces (Reza *et al.,* 2012).

High level of aflatoxin concentration observed in this study could be attributed to many factors including poor drying, inadequate and poor storage facility. The buildings where grains are stored were poorly designed with roof leakage and had vents which allow rodents, insects and birds to pass through hence increasing the chance for mould growth. The higher levels of aflatoxin pose a high health hazard to the public.

Although good postharvest handling practices including cleaning and sorting may reduce levels of aflatoxin contamination, majority of smallholder farmers lack knowledge and skills to carry out such practices (Kimario *et al.*, 2021). Smallholder farmers kept grains in polyethylene/ plastic bags on the floor which create favourable conditions for growth of toxigenic fungi and grains spoilage.

Aflatoxin B_1 are highly toxic and has been linked with liver cancer and synergistic with hepatitis B virus (HBV) infection hence classified as human carcinogen (Wu *et al.*, 2014). Many studies in African countries reported higher level of aflatoxin contamination in groundnuts which exceeded maximum tolerable limits for European Commission regulation and FAO/WHO (Neme and Mohammed, 2017). Failure to meet the set standards for aflatoxin concentration make a barrier to traders who export grains to international markets hence low income to these nations. A study conducted in Malawi reported aflatoxin B_1 contamination in groundnuts samples higher than the limit set by EC and US standard which was 4 ppb and 20 ppb respectively (Monyo *et al.*, 2012; Waliyar *et al.*, 2015). The exceeded levels of aflatoxin may be contributed with farmers who dried grains on bare ground. These would create more favourable conditions for mould growth and subsequently mycotoxins production. It has been reported that drying food crops on the tarpaulins or raised platform reduce aflatoxin levels (Kamala *et al.*, 2016).

	Maize (N=15)					Groundnuts (N=15)					Sunflower seeds (N=15)				
Farmers	**B_1**	**B_2**	**G_1**	**G_2**	**TAF**	**B_1**	**B_2**	**G_1**	**G_2**	**TAF**	**B_1**	**B_2**	**G_1**	**G_2**	**TAF**
1	**235.7**	19.5	2.0	<LOD	**257.3**	**56.5**	8.3	4.6	1.3	**70.6**	<LOD	<LOD	<LOD	<LOD	<LOD
2	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
3	<LOD	<LOD	<LOD	<LOD	<LOD	**16.3**	2.6	16.5	1.2	**36.7**	<LOD	<LOD	<LOD	<LOD	<LOD
4	<LOD	<LOD	<LOD	<LOD	<LOD	**41.0**	2.3	<LOD	<LOD	**43.3**	<LOD	<LOD	<LOD	<LOD	<LOD
5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
6	<LOD	<LOD	<LOD	<LOD	<LOD	**120.2**	12.7	5.3	1.1	**139.2**	<LOD	<LOD	<LOD	<LOD	<LOD
7	<LOD	<LOD	<LOD	<LOD	<LOD	**789.1**	8.7	31.1	1.2	**830.0**	1.3	<LOD	<LOD	<LOD	1.3
8	<LOD	<LOD	<LOD	<LOD	<LOD	2.0	<LOD	<LOD	<LOD	2.0	<LOD	<LOD	<LOD	<LOD	<LOD
9	<LOD	<LOD	<LOD	<LOD	<LOD	**54.9**	13.5	283.5	60.6	**389.7**	2.1	<LOD	<LOD	<LOD	2.1
10	**37.5**	4.4	5.6	1.1	**48.5**	**790.9**	7.1	<LOD	<LOD	**798.0**	<LOD	<LOD	<LOD	<LOD	<LOD
11	**574.8**	4.0	205.2	1.2	**785.2**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
12	<LOD	<LOD	<LOD	<LOD	<LOD	**784.6**	12.8	<LOD	<LOD	**797.4**	<LOD	<LOD	<LOD	<LOD	<LOD
13	**27.3**	5.4	<LOD	<LOD	**32.7**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
14	<LOD	<LOD	<LOD	<LOD	<LOD	**686.1**	40.7	2.2	<LOD	**728.9**	<LOD	<LOD	<LOD	<LOD	<LOD
15	<LOD	<LOD	<LOD	<LOD	<LOD	**160.7**	35.9	<LOD	<LOD	**196.5**	<LOD	<LOD	<LOD	<LOD	<LOD
Mean	58.36±27.84^{b}	2.22±0.92^{b}	14.18±99.48^{a}	0.14±0.07^{a}	74.91±37.19^{b}	233.48±9.99^{a}	9.62±2.28^{a}	22.87±13.03^{a}	4.34±2.78^{a}	268.82±61.17^{a}	0.23±0.11^{b}	0.00±0.00^{b}	0.00±0.00^{a}	0.00±0.00^{a}	0.23±0.11^{b}
n (%)	4 (26.70)	4 (26.70)	3 (20.00)	2 (13.30)	4 (26.70)	11 (73.30)	10 (66.70)	6 (40.00%)	5 (33.30)	11 (73.30)	2 (13.30)	0 (0.00%)	0 (0.00%)	0 (0.00%)	2 (13.30)
Recommended TZS/EAS standard level	5.0 µg/kg				10.0 µg/kg	5.0 µg/kg				10.0 µg/kg	5.0 µg/kg				10.0 µg/kg

Table 4. 4: Mean aflatoxin concentration (µg/kg) with respect to percentages of contamination in maize, groundnuts and sunflower seeds

Mean within the same row with different superscripts are significant different at $p<0.05$, N is the total number of samples analyzed for maize, groundnuts and sunflower seeds, n is the total number of aflatoxins contaminated maize, groundnuts and sunflower seeds. Bolded number indicated samples that exceeded the EAS regulatory limits and <LOD means less than limit of detection.

4.4.4 Aflatoxins contamination in the studied villages

The grain samples collected from the three villages at the study area had different levels and occurrences of aflatoxin contamination. Zajiliwa village had higher AFB_1 contamination ranged from (0.69±0.295 to 351.40±120.019 µg/kg) than Haneti (0.00±0.000 to 326.27±113.548µg/kg) and Mapanga (0.00±0.000 to 22.77±7.525 µg/kg, Table 4.5).

The mean values for total aflatoxin contamination for the selected stored grains in the three studied villages ranged from 0.00±0.000 to 431.78±112.084 whereby the highest aflatoxin mean value was in Zajilwa village (Table 4.5). A significant difference ($p<0.05$) in total aflatoxin contamination was observed for both villages in groundnuts and maize.

Dodoma is among the regions in Tanzania with favourable climatic condition for mould growth and mycotoxin contamination (Mmongoyo *et al.,* 2017). The majority of farmers had inadequate knowledge of proper post-harvest management. The increase in AFB_1 for stored grains can cause acute and chronic disease. Recently in 2016 there was an outbreak of aflatoxicosis in Dodoma due to consumption of aflatoxin contaminated maize (Kamala *et al.,* 2018).

Table 4. 5: Mean aflatoxin concentration (μg/kg) in villages of Chamwino (Mean +SEM)

Agricultural produce	Type of Aflatoxins	Haneti	Mapanga	Zajilwa
Groundnuts	G_2	0.00 ± 0.000^{c} (0%)	0.50 ± 0.205^{b} (40%)	12.52 ± 7.959^{a} (60%)
Maize	G_2	0.23 ± 0.154^{a} (20%)	0.00 ± 0.000^{b} (0%)	0.21 ± 0.142^{a} (20%)
Sunflower	G_2	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)
Groundnuts	G_1	0.43 ± 0.288^{c} (20%)	4.21 ± 2.127^{b} (40%)	63.97 ± 36.792^{a} (60%)
Maize	G_1	41.04 ± 27.357^{a} (20%)	0.40 ± 0.266^{c} (20%)	1.12 ± 0.745^{b} (20%)
Sunflower	G_1	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)
Groundnuts	B_2	17.86 ± 5.791^{a} (60%)	2.62 ± 1.006^{c} (60%)	8.39 ± 1.610^{b} (80%)
Maize	B_2	1.88 ± 0.782^{b} (40%)	3.91 ± 2.604^{a} (20%)	0.87 ± 0.579^{c} (20%)
Sunflower	B_2	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)	0.00 ± 0.000^{a} (0%)
Groundnuts	B_1	326.27 ± 113.548^{b} (60%)	22.77 ± 7.525^{c} (60%)	351.40 ± 120.019^{a} (100%)
Maize	B_1	120.43 ± 75.814^{a} (40%)	47.15 ± 31.432^{b} (20%)	7.51 ± 5.004^{c} (20%)
Sunflower	B_1	0.00 ± 0.000^{b} (0%)	0.00 ± 0.000^{b} (0%)	0.69 ± 0.295^{a} (40%)
Groundnuts	TAF	344.56 ± 116.666^{b} (60%)	30.10 ± 9.029^{c} (60%)	431.78 ± 112.084^{a} (100%)
Maize	TAF	163.575 ± 103.687^{a} (40%)	51.45 ± 34.303^{b} (20%)	9.71 ± 6.471^{c} (20%)
Sunflower	TAF	0.00 ± 0.000^{b} (0%)	0.00 ± 0.000^{b} (0%)	0.69 ± 0.295^{a} (40%)

Mean within the same row with different superscripts are significant different at $P<0.05$; TAF: total aflatoxins

4.5 Conclusions

The household-stored groundnuts and maize had higher levels of aflatoxins beyond the EAS standard recommended levels which may pose health risks to human and animals. Poor postharvest management practices are the potential causes of aflatoxin contamination in agricultural produces. Thus, aflatoxin contamination of grains can occur at any point along the crop value chains. Although it is very important to dry the agricultural produce soon after harvest to prevent proliferation of toxigenic mould and aflatoxin contamination on storage, smallholder farmers use inadequate storage practices and materials to prevent contamination and spoilage of their harvest. Majority of smallholder farmers lack inadequate knowledge on proper handling and storage of agricultural produces. Farmers dry the grains under the sun on the bare ground however, no assessment of moisture content to check the dryness of the grains. Therefore, these household stored grains are most likely to be exposed to aflatoxins contamination hence increases health risks to the human and animals. Training of smallholder farmers on best storage practices and handling of grains are critical to ensure safety of their produces. Moreover, the regulatory bodies should monitor the household-stored maize and groundnuts prior consumption to reduce aflatoxin contaminated food.

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CHAPTER FIVE

Paper Three

5.0 COMPARISON OF TRADITIONAL OPEN-SUN DRYING AND WALK-IN SOLAR DRYER ON DRYING CEREALS AND OIL SEEDS AT CHAMWINO DISTRICT, DODOMA

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Abstract

Drying is an important process carried out in order to preserve agricultural produce. Various drying methods are employed to dry agricultural produces. This study compared walk-in solar dryer (1000 kg capacity) and traditional open-sun drying methods, and their effectiveness to dry maize, groundnuts and sunflower seeds to acceptable storage moisture levels. During drying, moisture content, temperature and relative humidity were periodically measured and recorded. Toxigenic moulds (*Aspergillus flavus*) were determined before and after drying. Moreover, foreign matters were determined after drying. Walk-in solar dryer had high mean temperature (41°C) and low relative humidity (31.2%) than open-sun drying (31°C, 43.2%). Consequently, walk-in solar dryer had lower drying time for all grains (maize 18 hours, groundnuts 18 hours and sunflower seeds 10 hours) than open-sun drying (maize 20 hours, groundnuts 20 hours and sunflower seeds 16 hours). Unexpectedly, both methods indicated low contamination with moulds. However, open-sun dried grains had higher contamination with other foreign matters (such as stones, plastics and filth) than walk-in solar dried grains. Therefore a walk-in solar dryer could be the best alternative for drying agricultural produces and more effective in term of drying time as compared to open-sun drying.

+**Keywords**: maize, groundnuts, sunflower seeds, drying, walk-in solar dryer, open-sun drying, temperature, relative humidity, mould growth and foreign matter.

5.1 Introduction

Sun-drying is the traditional and common method of drying agricultural produces in the developing countries including Tanzania, where mechanical drying facilities are not often available (Rathore and Panwar, 2010; Kumar *et al.,* 2017). Traditionally, before agricultural produces like maize and sunflower seeds are harvested, they are left for several days in the field to dry. However due to unpredictable weather and change in climatic conditions, agricultural produces are harvested just after they have well matured. Drying to acceptable moisture storage is normally done at the household. High moisture in harvested crops increases vulnerability to bacteria, yeast and toxigenic mould growth that ultimately result into losses (Maisnam *et al.,* 2017).

Although open-sun drying method has been practiced from ancient times, it is associated with various shortcomings including contamination (physical, chemical and microbiological hazards), inadequate drying and high losses (Adelaja and Babatope, 2013; Sontakke and Salve, 2015).

Solar dryers of different types have been developed to overcome the drawbacks from open- sun drying (Neme and Mohammed, 2017). Although this effort has improved quality and safety of dried products, post-harvest losses are still high up to 40% for cereals (Gatea, 2010; Affognon *et al.,* 2015). A walk-in solar dryer is cheap in term of energy and does not require a high skill to operate. Also, the produces are not directly exposed to Ultra Violet (UV) radiations hence, quality and nutritive values are maintained and provides physical barrier to various contaminants including rains (Sontakke and Salve, 2015). However, some studies on solar drying have been especially in fruits and vegetables (Muganyizi, 2013; Mongi, 2013) and very limited in maize, groundnuts and sunflower seeds. This study focused on assessing the effectiveness of traditional open sun-drying and walking-solar dryer as a potential technique to reduce mould infection and pest infestation to ensure food safety and security.

5.2 Material and Methods

5.2.1 Description of the walk-in solar dryer

This study built a walk-in solar dryer of 15 m length, 4 m wide and 4 m high (Figure 5.1). The dryer was built from locally available materials including burnt bricks, clay soil/cement, sand, wood, steel pipes, mesh, visqueen plastic and binding wire. It has three air inlets and outlets and one door used for loading and offloading the produces. The inlets supply fresh unheated air to the dryer while the outlets draw off moist air from the dryer. It has 24 wooden flat trays of 120 cm length, 100 cm width, 7 cm high and each tray can accommodate 42 kg of produce. The dryer has a capacity to dry 1000 kg of produces per round. The detailed design such as floor plan is as indicated in Figure 5.2.

Figure 5. 1: The walk-in solar dryer located at Haneti village in Chamwino district

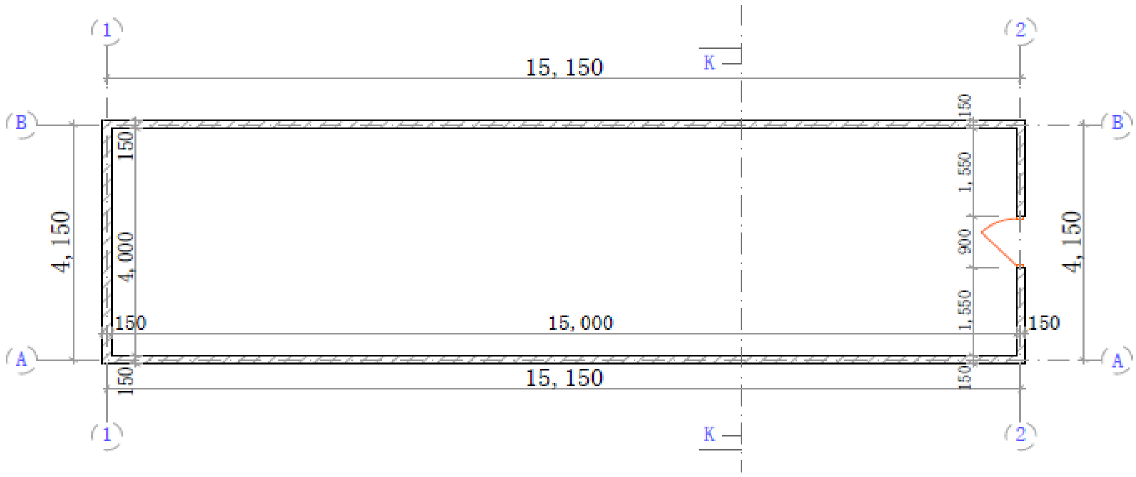

Figure 5. 2: The walk-in solar dryer floor plan

5.2.2 Preparation, collection, storage and transportation of maize, groundnuts and sunflower seed samples

5.2.2.1 Preparation and collection of samples for drying

Samples of maize, groundnuts (unshelled) and sunflower seeds were harvested in July 2020 from Haneti village in Chamwino District. All samples were obtained from one village because at the time of sampling farmers in other villages were done with harvesting. Maize grains (kernels) and groundnuts (unshelled) were separated from cobs and plant by hand shelling to obtain 90 kg of maize and 50 kg of groundnuts, respectively. Ears /heady of sunflower were hand-picked to obtain 80 kg of seeds.

5.2.2.2 Collection and transportation of laboratory samples

The grain samples were cleaned to remove all physical objects. Before drying, three analytical samples for each freshly harvested grains (1kg each) were collected. After drying process, three analytical samples for each grains (1kg each) were collected from walk-in solar dryer and open-sun drying immediately once attained acceptable moisture storage level. Samples were kept in a cool box and transported to TIRDO Food Microbiology Laboratory for analysis. When not immediately analysed, the samples were stored in a freezer around -18°C until analysis.

5.2.3 Drying procedures

Samples for maize grains (kernel), groundnuts (unshelled) and sunflower seeds were dried by open-sun drying and by walk-in solar dryer. The samples were divided into two equal weight and subjected to open-sun drying and walk-in solar dryer. Maize, groundnuts and sunflower seeds (each 5 kg) were distributed evenly in one layer on the tray (1 m length, 1m width and green net hole or mesh size of 1mm). The samples for maize grains (kernel), groundnuts (unshelled) and sunflower seeds were spread on locally made mat (1 m length and 1m width) and open-sun dried until the moisture content of the grains was around 13.5%, 8% and 10% nearly similar to the final moisture content of walk-in solar dried samples, respectively.

All of the samples were dried for about ten hours in a daytime from 07:00 hours to 17:00 hours. Grain samples were dried using open-sun and removed from the drying area at 17:00 hours for every day and stored overnight in a room temperature. The grains samples dried in walk-in solar dryer were not removed during the evening; however, dry salt was spread inside the dryer to capture condensates. The wet salt was dried in daytime (sunshine hours) and reused during night hours until the maize, groundnuts and sunflower seeds attained the safe storage moisture levels (i.e. 13.5% maize, 8% groundnuts and 10% sunflower seeds).

5.2.4 Drying conditions

The drying conditions including air temperature and relative humidity were recorded by wireless temperature and humidity data loggers (Madgetech, USA). The temperature and relative humidity data loggers had readings ranged from (-20 °C to +60 °C) and (0% to 95%) respectively. Three data loggers were placed (one at the bottom of air inlets, second at the top of air outlets and the third at the centre of the dryer) and also one of the data loggers was placed outside the dryer. The temperatures and relative humidity were recorded every 15 minutes.

5.2.5 Determination of moisture content and moisture ratio

The moisture content in each sample was determined directly by grain moisture meter (Dickey-John, USA). During drying, moisture content for each sample was recorded in triplicates at an interval of two hours. The average moisture content was determined for each grain samples. The moisture ratio of the grain is the ratio that indicates moisture content at a given time to its initial moisture content. The moisture removal was determined based on moisture ratio according to (Diamante and Munro, 1993), as shown in simplified equation (5.1).

The moisture ratio (MR) was determined according to (Diamante and Munro, 1993) using a simplified equation (5.1)

$$MR = ¿ \frac{Moisture\,content\,at\,a\,given\,time}{Initial\,Moisture\,content} \text{.......................................} \quad \textbf{(5.1)}$$

5.2.6 Determination of *Aspergillus flavus* infection

The *Aspergillus flavus* was determined according to ISO 21527-1:2008. A selective agar Aspergillus Differentiation Medium Base (ADMB), Peptone water (PW) 0.1% were prepared according to manufacturer's instructions (Himedia, India). The prepared media, glass rods and petri dish were sterilized in autoclave (Panasonic, Japan) at 121°C for 15 minutes at 15 psi. The sterile ADMB was kept in a water bath at 45°C to cool. The cooled ADMB was added with 1 ml of chloramphenicol selective supplement (FD 033) as inhibitor for bacteria growth. About 20 ml of ADMB were poured into a petri dish.

For enumeration of *Aspergillus flavus*; 10 g of each grain samples grounded were weighed by using analytical balance (Sartorius, Switzerland) then, 90ml of peptone water (PW) was added. The mixture was aseptically poured into a sterile stomacher bag and then blended or mixed by the stomacher (Seward STOMACHER ^{R} 3500 Lab System) for 30 seconds to homogenize to obtain 10^{-1} dilution. One ml of mixed samples was pipetted using micropipette (1000 ml) and poured into the test tube marked 10^{-2} dilution. This procedure was repeated up to 10^{-4} dilution. One 1 ml of mixture from each serial dilution was drawn and poured into labelled petri dishes (10^{-1} to 10^{-4}) contained a solidified agar (ADMB), then the mixture was spread by glass rods. The work was performed in a laminar air flow cabinet (Niive, Turkey). All of the petri dishes were kept upright in the incubator (Panasonic, Japan) at 25°C for 5 days and examined for the growth of *Aspergillus flavus*.

5.2.7 Foreign matters determination

Foreign matters in maize, groundnuts and sunflower seeds dried by open-sun and walk-in solar dryer were determined according to EAS 901:2017. About 200 g of each grain samples were measured by weighing balance (Sartorius, Switzerland). From each of weighed samples the foreign matters were picked by hand. Then weight of foreign matter for each grain was recorded. The weight of foreign matter (dust) for each grain samples was passed through the sieve (size 4.5 mm round hole) and its weight was added with foreign matters picked by hand. Two replicates samples were used for foreign matter determination. The foreign matters were calculated and reported in percentage (EAS 901:2017) as indicated in (equation 5.2).

$$Foreign\,matter\,\% = \frac{Mass\,of\,working\,sample}{Mass\,of\,foreign\,matter}\,X\,100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad \textbf{(5.2)}$$

5.2.8 Statistical data analysis

All data were analysed by R (Version 4.0.2; 2020). Two-way analysis of variance (ANOVA) was used to evaluate the effect of independent variables (Drying mode and types of crops) on depend variables (moisture ratio, microbiological data and foreign matter). Drying efficiency was calculated in terms of moisture removal and temperature build-up compared to open-sun in different crops. The p-value less than 0.05 was considered significant. Unpaired student’s t-test was also used to compare statistical different on temperature or humidity between walk-in solar dryer and open-sun drying.

5.3 Result and Discussion

5.3.1 Temperature and relative humidity in walk-in solar dryer and open-sun drying

Results showed that the walk-in solar dryer was found to have higher temperature compared to ambient open-sun. The highest temperature recorded in walk-in solar dryer was 53.5°C while 41.5°C in open-sun (Figure 5.3), that was attained between 13:00 hours and 15:00 hours. The data logger that was located inside the walk-in solar dryer (approximately at the centre) had significantly high temperature than the one located at the point of air inlet and air outlet. As the temperature of the walk-in solar dryer increased the humidity was decreasing (Figure 5.4). The average solar radiation and wind speed during drying was 519.28 Gm.ca/cm^2/day and 5.81 m/s, respectively.

The drying time was observed between 13:00 hours and 15:00 hours both in the walk-in solar dryer and open-sun drying (Figure 5.3 and Figure 5.4), when the temperature was at 53°C and 21% relative humidity. Higher temperature with lower relative humidity indicates fast evaporation of moisture removal from the surface of the grains/seeds. The mean temperature of air entering and exiting the dryer was 24.9°C and 32.7°C, respectively. The mean temperature inside the dryer was 41.09°C and open-sun was 31.92°C (Figure 5.3). Previous studies reported that grain drying air temperature should not exceed 60°C to prevent overheating, cracking and microbial infection (Matis, 2018).

The study revealed significant difference ($p<0.05$) in temperature build-up between the walk-in solar dryer and open-sun drying. Walk-in solar dryer had higher mean drying temperature 41°C than open-sun drying 31°C. Likewise, Kumar and Rai, (2016) observed 10-17°C temperature difference in solar dryer and open-sun drying. Moreover, Mukwangole and Simate (2017) reported a mean drying temperature of 45.6°C of maize in a conventional solar dryer.

The average relative humidity for open-sun drying was 43.2% and for walk-in solar dryer was 31.2% however, this difference in drying methods were statistically significant at ($p<0.05$). The higher percentage of relative humidity in open-sun may be contributed with changes in weather conditions such as cloudy and wind. Also, inside the dryer was warmer compared to the outside which could accelerate drying process than open-sun drying. A study by Mongi, (2013) reported that, drying produces by using solar dryer could shorten the drying time by 65% in open sun drying. However solar drying is highly dependent on the solar radiation intensity and ambient air temperature.

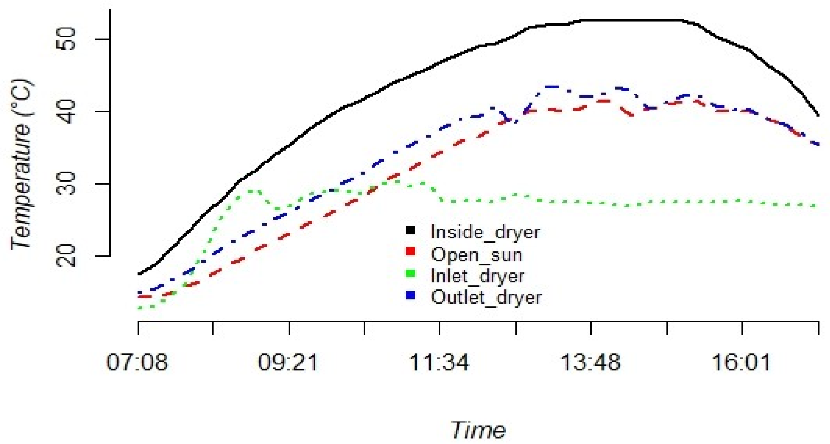

Figure 5. 3: Temperature and time relationship between walk-in solar dryer and open sun drying with regard to (inlet and outlet air temperature from dryer) during the first day of drying

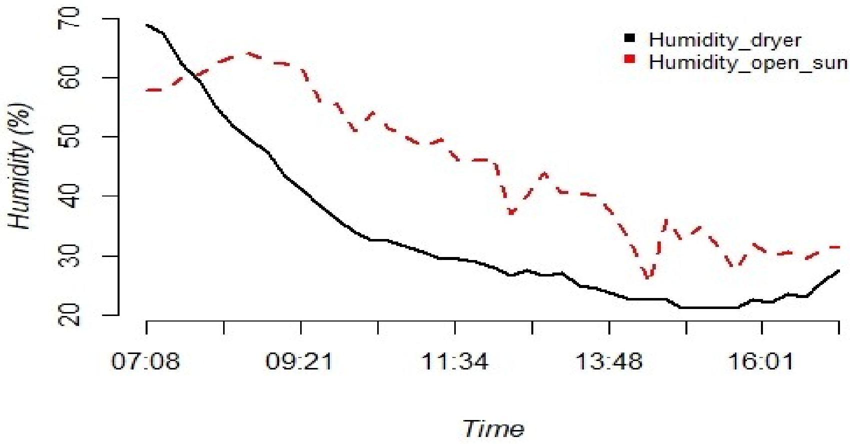

Figure 5. 4: Humidity and time relationship between walk-in solar dryer and open-sun drying during the first day of drying

5.3.2 Moisture removal by walk-in solar dryer and open-sun drying during drying of maize, groundnuts and sunflower seeds

The average initial moisture contents for freshly harvested maize, unshelled groundnuts and sunflower seeds were 19.50%, 17.70% and 24.20%, respectively. The lower initial moisture content observed in freshly harvested groundnuts could be attributed with seasonal variation in temperature and relative humidity of Dodoma region which result to low harvesting moisture content. Drying of produces to the acceptable moisture level inhibit microbial growth and enzymatic reaction (Mugabi and Driscoll, 2016).

The average final moisture content was statistically significant for all analysed samples; sunflower seeds had lower moisture content (9.9%) than groundnuts (10.5%) and maize (12.9%, Fig 5.5.) There was a slight change in moisture ratio for both drying modes during the first day of drying in all grains. Walk-in solar dryer had significantly lower moisture ratio which indicates higher moisture removal compared to open-sun drying. The constant moisture content in sunflower seeds was achieved earlier in walk-in solar dryer

(16 hours) than open-sun drying (18 hours, Figure 5.5). This could be due to increase in temperature during sunny hours and also air velocity. The high temperature generated in solar dryer facilitates ambient air to capture and evaporate moisture from the surface of grains or seeds.

Groundnuts dried by walk-in solar dryer had lower moisture ratio compared to sun drying although during the evening hours the moisture ratio increased and subsequently decreased in the second day of drying (Figure 5.5). The moisture ratio for maize was lower in open-sun drying as compared to walk-in solar dryer during the drying hours between 13.00 - 15.00 hours of day one (Figure 5.5). Within four hours of drying, the walk-in solar dyer with red curves was very low compared to dotted green curves for open-sun during the second day of drying (Figure 5.5). The moisture ratio for maize started to decrease rapidly in walk-in solar dryer compared to open-sun drying during the second day as the drying hours increased. Also there was the rapid decrease in moisture ratio for sunflower seeds in both drying modes.

This study revealed that for the samples dried by walk-in solar dryer there was absorption of moisture in maize and groundnuts at night hours compared to sunflower. This could be attributed with the morphological structure of each grain however, the salt kept inside the dryer was not much effective in groundnuts and maize this can be due to quantity of salt kept. The salt was considered due to its effectiveness of holding water during night hours (Albarracin *et al.,* 2011). Sunflower seeds dried faster compared to maize and groundnuts. This may be contributed to the structure and size of the crop. Likewise the study by Chiewchan *et al.* (2015) reported that solar dryer can create higher drying temperature and low relative humidity resulting into shorter drying time hence lower product moisture content in comparison to open-sun drying.

Furthermore this study revealed that drying time by walk-in solar dryer for maize and groundnuts was 18 hours and for sunflower was 10 hours to attain the acceptable moisture content. The drying time by open-sun drying for maize and groundnuts was 20 hours while 16 hrs for sunflower seeds. The current study indicated low drying time for all grains dried by walk-in solar dryer compared to open-sun drying. The variation in drying time was observed more in sunflower seeds compared to maize and groundnuts. This could be influenced by nature of the crops and changes in climatic conditions. Likewise the study by Janjai and Bala, (2012) reported reduction of drying time for products (fruits and vegetables) dried by solar dryers as compared to natural sun drying.

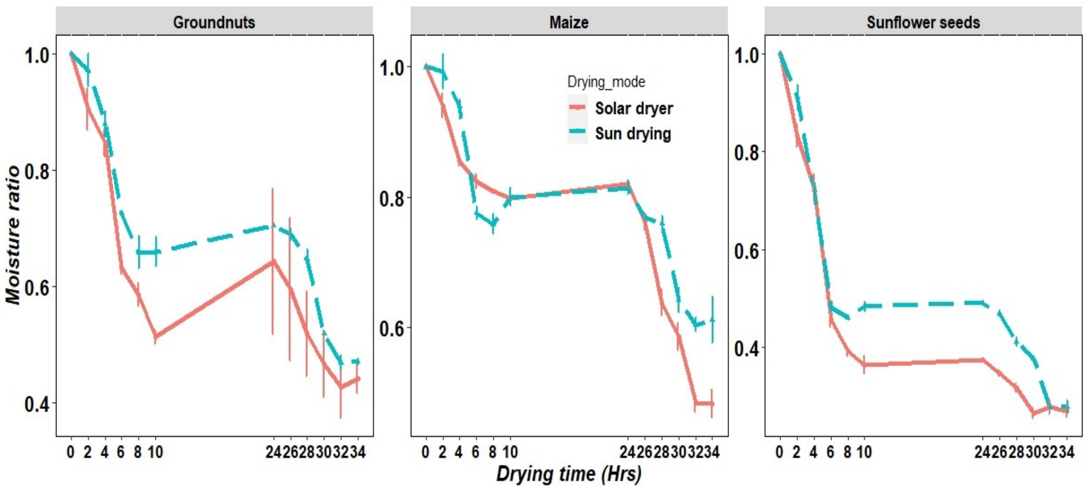

Figure 5. 5: Changes in moisture ratio (± SE, n=3) in walk-in solar dryer compared to open-sun drying for groundnuts, maize and sunflower seeds at different drying time (hours)

5.3.3 Mould (*Aspergillus flavus)* and foreign matters in maize, groundnuts and sunflower seeds

In this study all fresh and dried grain samples were contaminated with *Aspergillus flavus.* The average mould (*Aspergillus flavus)* for fresh groundnuts was 4.5 Log CFU/g, for groundnuts dried by walk-in solar dryer was 3.24 Log CFU/g and groundnuts dried by open-sun drying was 4.45 Log CFU/g. The *A. flavus* for fresh maize was 4.30 Log CFU/g, for walk-in solar dried maize was (3.60 Log CFU/g) and open-sun dried maize was (4.23 Log CFU/g, Table 5.1) respectively. The maximum limits of mould in milled maize is 10^4 CFU/g (EAS 44-2017). All samples analysed were within the EAS limit.

The *A. flavus* detected in the samples could be associated with high moisture content available in freshly harvested grains. Mould infection of grains may occur during the pre and post-harvest periods under suitable conditions such as temperature and humidity (Bensassi *et al.,* 2011). The present study revealed that samples dried by open-sun had higher level of *A. flavus* compared to those dried by walk-in solar dryer except for sunflower seeds. The lower levels of *A. flavus* could be due to effect of ultra violet radiations for both drying modes.

The levels of toxigenic *A. flavus* observed in this study may increase with production of aflatoxins if the dried crops are poorly stored. *A. flavus* produces aflatoxins B_1 and B_2 whereby AFB_1 is the most toxic to human and animal health (Ahmad *et al.,* 2018). It has been reported that *A. flavus* is predominantly a problem in crops such as maize and nuts. Exposure to aflatoxins has been linked to different diseases such as liver cancer, immune suppression and stunting in children (Klich, 2007; Ahmad *et al.,* 2018). However, the presence of *A. flavus* indicates that the produces are contaminated with the toxin. Also not all the fungi strains can be used as a measure of aflatoxins contamination for agro-produces (Benkerroum, 2020).

Maize dried by walk-in solar dryer had low average foreign matters (0.65%) compared to open-sun dried maize (4%, Table 5.2) however, the observed difference in drying modes was statistically significant at (*$p<0.05$*). All of grains dried by solar dryer had lower percent of foreign matters compared to grains dried by open-sun drying. Also all grains exceeded the recommended level of foreign matters (0.5% in maize, 0.1% in groundnuts and sunflower seeds) as per TZS 438-2018 /EAS 2-2017 and TZS 740-2018 /EAS 888-2018 respectively.

The higher levels of foreign matters for samples dried by walk-in solar dryer could be due to poor postharvest handling practices applied by the majority of smallholder farmers in rural area. Grains dried by walk-in solar dryer have better quality in terms of physical appearance compared to those grains dried by open-sun drying. A study by Tiwari *et al.* (2016) revealed that by drying agricultural produce in a solar dryer, the produce could be protected from dust, birds, insect and animals and drying time reduced in comparison to sun drying.

Table 5. 1: Mean mould (*Aspergillus flavus*, Log CFU/g) and foreign matter (%), (±SE, n=2) in different produces between a walk-in solar dryer and open-sun drying

Type of Produces	N		*Aspergillus flavus*		Foreign matter	
		Fresh	**Solar dryer**	**Sun drying**	**Solar dryer**	**Sun drying**
Groundnuts	**3**	4.50±3.18[b]	3.24 ± 2.54[a]	4.45 ± 3.78[a]	0.95 ± 0.05[b]	3.80 ± 0.30[a]
Maize	**3**	4.30±3.00[a]	3.60 ± 2.65[b]	4.23 ± 3.60[ab]	0.65 ± 0.05[b]	4.00 ± 0.30[a]
Sunflower seeds	**3**	2.27±1.74[a]	4.01 ± 3.44[a]	3.83 ± 3.62[a]	0.80 ± 0.20[b]	2.90 ±0.30[a]
Recommended EAS levels for			(Maximum 10^4)			

mould (cfu/g) in grains	

Means within row with different letters within same parameter shows statistical difference at $p<0.05$, n is the number of days for drying and N is the number of samples analysed

5.5 Conclusion

Walk-in solar dyer dried maize, groundnuts and sunflower seeds faster than open-sun drying. Walk-in solar dryer had lower drying time for all grains and are totally protected from pests and rain than open-sun drying. All grains dried by open-sun had higher foreign matters than grains dried by walk-in solar dryer. Smallholder farmers in rural areas depends on open-sun drying which takes long time during the drying process and could increases the chance for contamination. Therefore grains should be dried under the controlled conditions to achieve acceptable moisture level and retain its quality hence increases the shelf life. There is a need to adopt walk-in solar dyers as a best alternative and affordable in drying agro-produces to reduce post-harvest losses, ensure food security, and improve livelihood of smallholder farmers. However, solar intensity and air velocity were not assessed, the study recommends a further comprehensive study that will take into consideration of such important parameters.

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CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A significant number of smallholder farmers have low knowledge on storage practices, low awareness of aflatoxins contamination of cereals and oilseeds. In general household stored maize and groundnuts are heavily contaminated with aflatoxins than sunflower seeds. Any important interventions should be prioritised to aflatoxin prone produces. Since most farmers use aflatoxins contaminated grains for food and feeds, there is high risk of contracting the killer toxin if interventions are not sought. Implementation of good post-harvest management practices such as cleaning, drying and storage are critically important. However, such interventions may be taken aboard when regulatory authorities are involved. Awareness campaigns on the occurrence of aflatoxins and their health effects is highly recommended. Although traditional open sun drying is a common practice by majority of smallholder farmers, it is associated with several shortcomings. Solar drying, like use of walk-in solar dryer could be a potential solution to grains contamination and spoilage. However, building solar dryers could be an expensive endeavour by poor-resourced farmers, communal solar dryers could be a solution. Moreover, training on good agricultural practices and storage practices are highly recommended to reduce contamination and post-harvest losses for improved food security.

6.2 Recommendations

Based on the frequently consumption of staple food such as maize and other oilseeds (groundnuts and sunflower seeds) for majority of smallholder farmers, it is necessary to take action to protect the public from risks of aflatoxins contamination. Despite the efforts that has been made by government and private research institutes on reducing levels of mycotoxins in agricultural produces the following recommendations are put forward for consideration;

i. Remote area should be surveyed regularly in order to determine the level of risk of exposure of the public aflatoxins due consumption of contaminated grains for appropriate measures to be taken.
ii. There should be mass awareness creation campaign using media such as local radio, television and smart phone so as to minimize aflatoxin contamination for stored grains.
iii. The surveillance by regulatory bodies should be conducted for house-hold stored grains in frequently basis to all key stakeholders such as (farmers, traders, processors, consumers) around all villages susceptible to aflatoxin contamination

to monitor the trend of aflatoxin contaminated grains before training and after training.

iv. The Tanzania Bureau of Standard/ East African Standards for seeds and oilseeds to establish aflatoxin acceptable levels for sunflower seeds.

v. Smallholder farmers in rural areas should be provided with regular training and sensitization on good postharvest handling and storage practices.

vi. The designed walk-in solar dryer should be incorporated with heating system as back up for continuous drying during bad weather condition to increase its drying efficiency and reduces postharvest losses.

APPENDICES

Appendix 1. 1 Questionnaire to assess storage practices and awareness of aflatoxins contamination of cereals and oilseeds by smallholder farmers

A. General information

1. Age …………… 2. Sex…………. 3. Marital status

4. Occupation…............. 5. Ward………… 6.Village……………………

7. Education level:

a) Primary ☐ b) Secondary ☐) Not educated ☐

d) Certificate and diploma ☐ e) University ☐

B. Production and Postharvest handling practices

1. Which of the following crops do you produce?

a) Maize ☐ b) Groundnuts ☐ c) Sunflower seeds ☐

d) Others (please mention)…………………………………………………..……….

2. Have you acquired any training that is relating to your farming activities (maize, groundnuts and sunflower seeds? Yes/No

If yes, mention type of training (s) that you have attended
………………………………………………………………………………………

3. What is the size of your farm in (acre)? a) Maize ……………

b) Groundnuts …………c) Sunflower seeds…………. d) Intercropping (mention types of produce) ………….……………………………….,,,,,,,
…………………………………………………
4. How much do you produce in bags (kg) per season? a) Maize
………………………………..

b) Groundnuts …………c) Sunflower seeds ………… d) Others (Please specify)
…………..
5. What time do you normally harvest? a) Any time when crops are ready for harvest

b) Dry season [ ] c) Rain season [ ] d) Others (Please specify)
………………………………………………………………………………………………

6. What method do you use to harvest your produce? a) Ma[ ]

b) Combine harvester [ ] c) Others (Please specify)

……………..,.,,,,,,,…………………

7. What method do you use to shell/ thresh your produce?

a) Hand shelling [ ] b) Hand operated machine [ ]

c) Motorized thresher [ ] d) Others (Please specify)
…………………………………………………………………………………………
8. How do you keep your produce during harvesting? a) Bare ground [ ]

b) Raised platforms [ ] c[ ] d) Jute/Sisal bags

d) Plastic/synthetic bags e) Others (Please specify)
……………………………..

9. How do you transport your produce after harvest? a) Bicycle [ ]

b) Open vehicle [ ] c) Closed vehicles [ ] d) Head [ ]

e) Others (Please specify)
………………………………………………………………………..

10. What action do you take if it rains while your produce is at an open space? a) Cover [ ]

b) Take to the protected area [ ] c) Not cover [ ] d) Others (Please specify)……………………………………………………………………………………

11. For how long do you temporarily store your (maize, groundnuts and sunflower seeds) on farm during harvesting before transporting to a permanent store? a) Maize ………… (days) b) Groundnuts …………… (days) c) Sunflower seeds ………… (days)

12. How do you dry your produces (maize, groundnuts and sunflower seeds)? a) Sun drying

b) Air drying [ ] c) Indirect solar drying [ ] rying [ ]

13. Why do you choose such drying method? ………………………………………… …………………………………………………………………………………………

14. How long does it take to dry your harvest (maize, groundnuts and sunflower seeds)?

a) Maize …………… (days) b) Groundnuts …………….. (days) c) Sunflower seeds………… (days)

15. How do you know that your produces are well dried?

a) Measure moisture content [ ] b) [ ] ins

c) Visual assessment [ ]

d) Others…………………………………………………………………………

16. Do you sort or clean grains before storage? [Yes/No]

If yes, how do you sort? a) Colour [ ] b) Damage [ ]

c) Others………………………………………………………………………….

17. What type of storage/facility do you use to store your produce?

a) Bins /Silo [ ] b) Jute/Sisal bags [ ] c) Plastic/synthetic bags [ ]

d) Granaries ☐ e) Others (Please specify) …………..……..……………............

18. How many bags/kg of produce can you store? a) Maize .... b) Groundnuts...........

c) Sunflower seeds …………

19. Do you think the store can accommodate all of your produce? (Yes/No)

20. If you are using bags to store your produce, where do you keep them?

a) Warehouses ☐ b) Under the shed ☐ c) Outside covered by tarpaulin ☐

d) Others …………………………..

21. How long do you store your produce?

a) Maize …. .(months) b) Groundnuts ……..(months) c)sunflower seeds………… (months)

22. How do you store your produce?

22.1 Maize

a) As cobs ☐ b) As grain ☐

22.2 Groundnuts

a) As Pod ☐ b) As nuts ☐

22.3 Sunflower seeds

a) As grain ☐ b) Others (Please specify) …………………………..

23. Do you conduct the following to your storehouse/warehouse before storing your produces? a) Clea☐ b) Fumig☐

c) Others (Please specify) ……………………………………………………………..

24. Which of the following losses do you encounter? a) Insect and rats infestation ☐ b) Mouldy/rotting ☐ c) Mechanical damage of grainsd) Loss of grains during shelling, storage and transport ☐

e) Others (Please specify) …………………………………………………………

25. Do you use pesticides to store your grain? Yes/No

(If Yes please request to see them and take a photo including expire date)

26. Which are the common pesticides do you apply during grain storage?

a) Pirimiphos methyl (Actellic) ☐ b) Dichlorvos ☐

c) Permethrin ☐ d) Others ……………………………………………..

27. During planting, where do you get your seeds? a) Buying seeds

b) Recycle from the previous harvest ☐ c) Others ………… ☐

28. If you buy seeds during plantation where do you buy them? a) Open market ☐

b) Colleague ☐ c) Official agrovet ☐ d) Others ………………….

29. Do you use pesticides treated seeds during planting? Yes/No

30. What do you do with the fungal or rotten produce? a) Food ☐

b) Livestock/Poultry ☐ c) Sell ☐ d) Mix with fresh harvest ☐

e) Discard ☐ f) Others……………………………………………

31. What do you think are the primary causes of postharvest losses?

a) Poor drying ☐ b) Improper storage ☐ c) Hipping grains on floor ☐

d) Use of expired pesticides ☐ e) Use of poor seeds ☐

f) Other ……………………………………...…………………………………..

32. Do you know what fungi are? Yes/No

33. Do your maize/groundnuts/sunflower ever get mould? Yes/No

34. How can you identify produce with fungi?

34.1 Maize

a) Rotten ☐ b) Discolouration ☐ c) Off smell ☐

d) Others …………………………………………………………………….

34.2 Groundnuts

a) Rotten ☐ b) Discolouration ☐ c) Off smell ☐

d) Others …………………………………………………………………….

34.3 Sunflower seeds

a) Rotten ☐ b) Discolouration ☐ c) Off smell ☐

d) Others …………………………………………………………………….

35. Are you aware that fungi contamination of your produce can cause health problems? Yes/No

36. Has any member of your family gotten ill following consumption of fungi/mouldy food? Yes/No

37. Do you know that fungi produce toxins that can affect human health? Yes/No

38. Have you ever heard the word mycotoxins? Yes/No

39. Which of the following measures reduce fungal contamination and spoilage of produce in store?

a) Dry produces to the safe moisture level ☐

b) Keep out insect and pests from the storage ☐

c) Maintance of container or warehouse at low temperature and humidity ☐

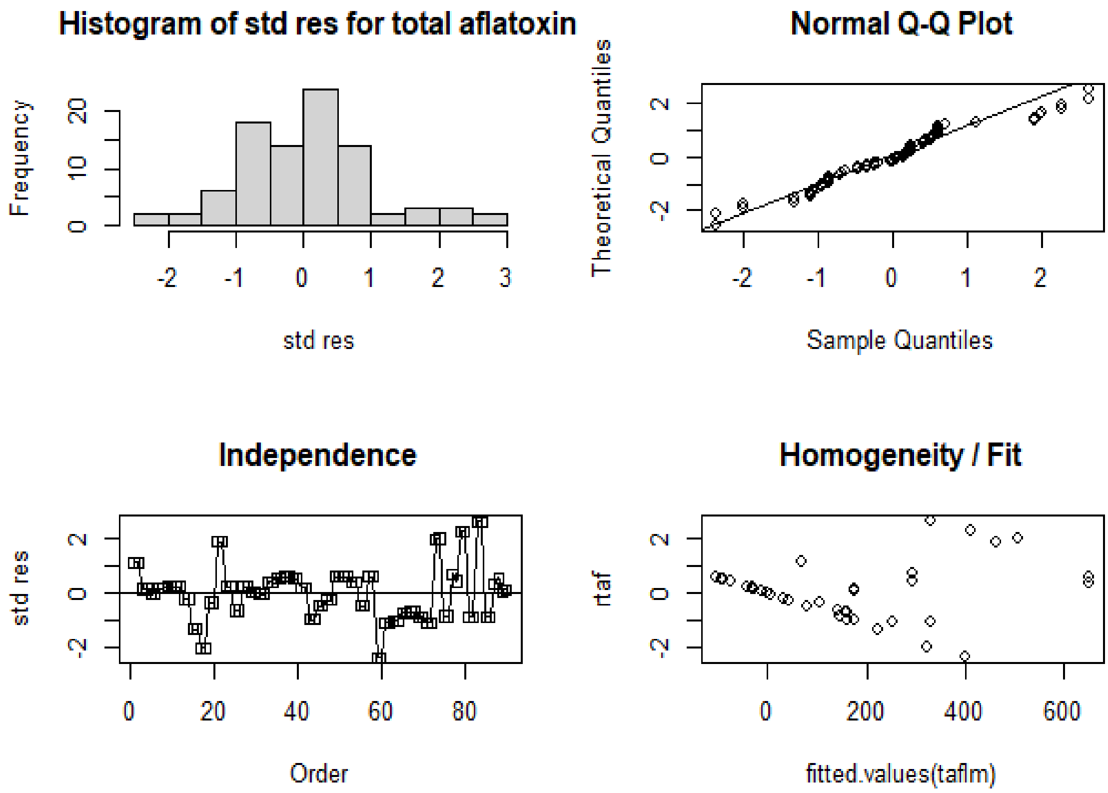
d) Removal of contaminated produce ☐ e) Use of Purdue Improved Crop storage bags (PICS) ☐

f) Others (Please specify) ………………………………………..

40. Do you know that feeding animals with mycotoxin contaminated maize contaminate milk with mycotoxins, particularly aflatoxins? Yes/No

Many thanks for your cooperation

Appendix 1. 2: Validation of ANOVA assumptions



Histogram of std res for total aflatoxin
Frequency
0
10
20
-2
-1
0
1
2
3
std res
Normal Q-Q Plot
Theoretical Quantiles
-2
0
2
-2
-1
0
1
2
Sample Quantiles
Independence
std res
-2
0
2
0
20
40
60
80
Order
Homogeneity / Fit
rtaf
-2
0
2
0
200
400
600
fitted.values(taflm)