Current Maize Production, Postharvest Losses and the Risk of Mycotoxins Contamination in Tanzania

Rashid A. Suleiman
Iowa State University, rashid@iastate.edu

Kurt A. Rosentrater
Iowa State University, karosent@iastate.edu

Follow this and additional works at: http://lib.dr.iastate.edu/abe_eng_conf

Part of the Agriculture Commons, Bioresource and Agricultural Engineering Commons, and the Food Security Commons

The complete bibliographic information for this item can be found at http://lib.dr.iastate.edu/abe_eng_conf/442. For information on how to cite this item, please visit http://lib.dr.iastate.edu/howtocite.html.
Current Maize Production, Postharvest Losses and the Risk of Mycotoxins Contamination in Tanzania

Abstract
Agriculture is the backbone of Tanzanian economy. It accounts for about one-third of the gross domestic product (GDP), provides 85 percent of all exports and saves as a livelihood to over 80 percent of the total population. Maize is the primary staple crop; it’s grown in nearly all agro-ecological zones in the country. Tanzania is a major maize producer in Sub-Saharan Africa. In the last four decades, Tanzania has ranked among the top 25 maize producing countries in the world. In the 2013/14 growing seasons Tanzania produced over half billion metric tons of maize of these maize smallholder farmers produced around 85%. Despite the steady production of maize over the past three decades, post-harvest losses of maize remained significant, up to 30-40 % in some rural areas. Post-harvest handling, poor infrastructure, weather variability, biotic factors such as insects and pests, bacteria, pathogens, viruses, and fungi, often aggravate such losses. Mycotoxin producing fungi pose a major risk. Mycotoxins are toxic secondary metabolites of fungi that frequently contaminate the maize in the field and/or during storage. Mycotoxin contamination of maize poses a health risk to humans and animals if not properly managed. The most important mycotoxins in Tanzania are the aflatoxins, fumonisins and Ochratoxin. The objective of this paper was to review current literature on the production trends, consumption, post-harvest losses, and mycotoxins contamination of maize and to provide strategies to control and prevent postharvest losses and mycotoxins contamination in Tanzania.

Keywords
Tanzania, maize, post-harvest losses, mycotoxins, aflatoxins, fumonisins, Ochratoxin

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Food Security

Comments
CURRENT MAIZE PRODUCTION, POSTHARVEST LOSSES AND THE RISK OF MYCOTOXINS CONTAMINATION IN TANZANIA

Rashid Suleiman and Kurt Rosentrater
Department of Agricultural and Biosystems Engineering
Iowa State University

Written for presentation at the
2015 ASABE Annual International Meeting
Sponsored by ASABE
New Orleans, Louisiana
July 26 – 29, 2015

Abstract.
Agriculture is the backbone of Tanzanian economy. It accounts for about one-third of the gross domestic product (GDP), provides 85 percent of all exports and saves as a livelihood to over 80 percent of the total population. Maize is the primary staple crop; it’s grown in nearly all agro-ecological zones in the country. Tanzania is a major maize producer in Sub-Saharan Africa. In the last four decades, Tanzania has ranked among the top 25 maize producing countries in the world. In the 2013/14 growing seasons Tanzania produced over half billion metric tons of maize of these maize smallholder farmers produced around 85%. Despite the steady production of maize over the past three decades, post-harvest losses of maize remained significant, up to 30-40 % in some rural areas. Post-harvest handling, poor infrastructure, weather variability, biotic factors such as insects and pests, bacteria, pathogens, viruses, and fungi, often aggravate such losses. Mycotoxin producing fungi pose a major risk. Mycotoxins are toxic secondary metabolites of fungi that frequently contaminate the maize in the field and/or during storage. Mycotoxin contamination of maize poses a health risk to humans and animals if not properly managed. The most important mycotoxins in Tanzania are the aflatoxins, fumonisins and Ochratoxin. The objective of this paper was to review current literature on the production trends, consumption, post-harvest losses, and mycotoxins contamination of maize and to provide strategies to control and prevent postharvest losses and mycotoxins contamination in Tanzania.

Keywords. Tanzania; maize; post-harvest losses; mycotoxins; aflatoxins; fumonisins; Ochratoxin.
Introduction

Agriculture is the backbone of the Tanzanian national economy. It accounts about one-third of the gross domestic product (GDP), provides 85 percent of all exports and saves as a livelihood to over 80 percent of the population (CIA World Factbook, 2014). Maize (Zea mays L.) is a primary staple crop; it’s grown in nearly all agro-ecological zones in the country (USAID, 2010). Maize together with wheat and rice are the three most cultivated cereal crops worldwide (Suleiman et al., 2013). Current world maize production is about 10.14 billion metric tons (De Groote et al., 2013). The United States (US) is the largest producer, producing over 30 % followed by China 21 % and Brazil 7.9 % (Table 1). Africa produces around 7 % of the total world production. Two-thirds of all Africa maize come from eastern and southern Africa (Verheye, 2010; FAOSTAT, 2014).

In sub-Saharan Africa, (SSA) maize is the most important cereal crop and staple food for about 1.2 billion people (IITA, 2009) and occupy a third of the cultivated area (Blackie, 1990). Maize accounts for over 30 % lower-house income and contributes 60 % of dietary calories and 50 % of protein intake (IITA, 2009; Amani, 2004). Tanzania is a major maize producer in Sub-Saharan Africa. In the last five decades, Tanzania has ranked among the top 25 maize producing countries in the world (Barreiro-Hurle, J. 2012). Currently ranked 1, 4, and 19 top maize producing countries in East Africa (EA), Africa and in the world (http://www.indexmundi.com, FAOSTAT, 2014; McCann, 2001).
Mycotoxins are toxic secondary metabolites of fungi that frequently contaminate the maize in the field and/or during storage (Smith et al., 2012). Mycotoxins contamination of maize poses a health risk to humans and domesticated animals (Mboya et al., 2012; Suleiman et al., 2013). The most important mycotoxins in maize are the Aflatoxins, Fumonisins, Deoxynivalenol, and Ochratoxin (Kimanya et al., 2012). Aflatoxin is a group of mycotoxin produced as secondary metabolites by the spoilage of two fungi species Aspergillus flavus and A. parasiticus (Marin et al., 2013; Feng et al., 2011).

Fumonisins are mycotoxins synthesized mainly by Fusarium verticilloides and Fusarium proliferatum (Garrido et al., 2012). Deoxynivalenol (DON) is a common type of mycotoxins produced by pink mold F. graminearum (Garrido et al., 2012). Ochratoxin is other types of mycotoxins mostly produced by Penicillium verrucosum, Aspergillus ochraceus, A. niger species (Lai et al., 2014). The objective of this paper was to review current literature on the production and consumption, postharvest losses and mycotoxins contamination of maize and to provide strategies to control and prevent postharvest losses and mycotoxins contamination in Tanzania.

Background

The United Republic of Tanzania is situated on the east coast of Africa and lies longitudes 29º and 41º east and latitude 1º and 12º south of the equator (www.nationsencyclopedia.com). Tanzania consists of mainland and offshore islands of Zanzibar (Unguja and Pemba) and Mafia in the Indian Ocean (Ak’habuhaya and Lodenius, 1988). It is the largest of the East African countries with a total area of 945,078 km² (364,900 sq. mil). Bordered by Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of the Congo to the west, and Zambia, Malawi, and Mozambique to the south. The country’s eastern borders lie on the Indian Ocean. Tanzania is administratively divided into thirty regions.
The population in 2014 was 50.76 million and increasing by an average of about 3% per annum (FAOSTAT, 2015).

Geographically and topographically, Tanzania has diverse and complex climatic and environmental conditions. Tanzania includes both the highest (Mt. Kilimanjaro-5, 895 m high) and lowest (the floor of Lake Tanganyika, 358 m below sea level) parts of the African continent (Ak’habuhaya and Lodenius, 1988). It has a sub-tropical climate with seven agro-ecological zones (BEFS, 2013). Climatic condition varies considerably from tropical at the cost to temperate in the highlands (Rowhani et al., 2011). The coastal areas are warm and humid. They have an average temperature of 25 °C and they receive about 1500 mm of rainfall per year (Ak’habuhaya and Lodenius, 1988). The Country receives two predominant rainfall/precipitation. One is unimodal (December-April) and the other is bimodal (Vuli) October-December and (Masika) March-May (www.tanzaniatrade.co.uk). Average monthly rainfall and temperature from 1900-2009 is shown in Figure 2 (www.worldbank.org).

The history of maize in Tanzania

Maize was introduced to Africa along the western and eastern coasts in the 16th century (Miracle, 1986). As part of global ecological and demographic transformation by the Portuguese and Arab explorers by dint to provide the slave trade (McCann, 2001; Smale and Jayne, 2003). According to Wright (1949) cited by McCann (2001) maize was first received in the coastal area (Pemba Island). The island used by Portuguese planters on 16th century to raise foodstuffs, including maize, to supply their coastal battalion. Maize was introduced in Tanzania mainland (Tanganyika) in the 17th and spread inner parts by mid-19th century (Ashimogo, 1995). It soon established itself as an important cereal crop all over the country and accepted by most of the ethnic groups (Urassa, 2010).
Maize production in Tanzania

Overview of production trends and consumption

Agriculture is the most important economic activity for the majority of the Tanzanian population. Of all staple and cash crops cultivated in Tanzania, maize is the major and most preferred staple crop (USAID, 2010). It has been identified as a key crop to enhance food production, income, poverty alleviation and food security (Homann-Kee et al., 2013). More than half of cultivated land in Tanzania is allocated to cereal crops (FAOSTAT, 2014). Around 45% or over 4.9 million hectares used for maize production (Pauw and Thurlow, 2011). A national yield is oscillating between 1.0 and 1.5 t/h, compared to the estimated potential yields of 4-5 t/h (Barreiro-Hurle, 2012; Mbwanga and Massawe, 2002). Overall maize production has grown at an annual rate of 4.6% over last 25 years.

Compared to other SSA countries, Tanzania produces maize throughout the year thanks to two rainfall seasons (Masika and Vuli) and adaptation of a shorter maize growing season (Verheye, 2010). About 41% is grown during Masika season and around 47% grown on Vuli season. This allows the constant domestic production of maize around the year (WFP, 2010). Figure 3 shows maize cropping seasons in Tanzania. Maize together with rice and sorghum are the three most important cereal crops in Tanzania. Grown on nearly all agro-ecological zones in the country and all twenty-five of Tanzania mainland, although at different levels (Figure 4). For research, management and production purpose. The national maize research program (NMRP) and the ministry of agriculture, food security and cooperatives divide maize production area into three main agro-ecological zones; the southern highlands, the Lake zone and the northern zone (Nkonya et al., 1998).

The southern zones include Iringa, Rukwa, Ruvuma, Njombe, and Mbeya, these regions
Maize production in Tanzania is categorized into four main groups. The first group comprised smallholders farm with less than >10 ha (2-3 ha each), this is the most important group contributes about 85 % of total production. Another group is a community farm with around 50 – 100 ha and donates 5 %. The third group includes large farms with over 100 ha, contributes 5 % and the remaining 5 % produced by large private and public farms (<100 ha) (Croon, 1984). According to FAOSTAT (2014) and ministry of agriculture, food security and cooperatives, total area of maize production has increased gradually from 1630 thousand hectares in 1990 to over 4000 thousand hectares in 2012 (Figure 5).

Generally, cultivated area, per capita production and consumption of maize in Tanzania (Figure 5) have been consistently increasing over the past four decades (CIMMYT, 1990; FAOSTAT, 2014). Nevertheless, maize yields remain very low 1.0-1.5 t/ha, against 12 t/ha, in US or 4 t/ha, in South Africa. The main constraints of low yield and sporadic production are drought stress (shortage of rainfall), infestation by insects, molds, and other pests. Other factors include weeds and diseases, low agricultural inputs such as fertilizer and crop protection chemicals, low levels of technology and poor infrastructure and storage facilities (Cairns et al., 2013; Kaliba et al., 2000; Homann-Kee et al., 2013).

In addition, low price and poor market channels. For instance, crop season 2013/14 farmers enjoying a bumper harvest with total production of around 6 million metric tons, but
government or National Food Reserve Agency (NFRA) afford to buy only 5% of the total output (EABW, 2014). This result the market price to drop approximately 50% below the record level of $27 to $9 for 100 kg sack of maize (EABW, 2014). Furthermore, other constraints include poor agricultural practices, farm size, low fertilizer use, lack of improved seed and inadequate access to information and extension service. Also, inadequate institutional support (credit), lack of credit to purchase inputs and reliance on unpredictable and irregular weather conditions (Lyimo et al., 2001; Otunge et al., 2011; Chauvin et al., 2012).

**Consumption trends**

Worldwide consumption in 2013/14 was around 950 million metric tons (FAOSTAT, 2014), with Africa consumes over 30% and SSA around 21%. Eastern and Southern Africa use larger portions approximately 85% of its production as food (IITA, 2009) and about 5% as animal feed (www.asareca.org). Unlike other cereal crops that are consumed mainly by human as food (wheat and rice), maize is a multipurpose crop used as food, feed, fuel, and as raw materials for industry (Morris and López-Pereira, 1999). Tanzania likes other developing country’s maize mainly used for human consumption. It’s a single most important staple food both in rural and urban areas (Oladejo and Adetunji, 2012).

Maize accounts for 31% of the total food production and constitutes more than 75% of the cereal consumption in the country. It is estimated that the annual per capita consumption of maize is around 128 kg. According to Nyoro et al. (2004) and Peter et al. (2013) nearly 400 grams of maize are consumed per day per person in Tanzania; average national consumption is estimated to be over three million metric tons per year (FAOSTAT, 2014). Maize contributes about 34-36% of the average daily calorie intake (Amani, 2004; BEFS, 2013; Zorya et al., 2011).

According to FAOSTAT, (2014) food balances sheet 60.8% of the total maize produced
in 2013 was used for human consumption with the average waste of around 20.6 %. Feed represents 16.1 % and 0.5 % was used for food manufacturing (Figure 6). Maize is consumed in a variety of forms; ground maize flour is prepared by mixed with water to make thin porridge or stiff porridge (“Ugali”) (Morris et al., 1999). Green (fresh) maize is boiled or roasted on its cob and served as a snack as well as popcorn is also a popular snack (IITA, 2009).

**Postharvest losses of maize**

Post-harvest losses (PHL) is defined “as grain loss which occurs after separation from the site of growth or production to the point where the grain is prepared for consumption” (Boxall, 1986 cited by Nyambo, 1993). Other authors, describe PHL as measurable quantitative, qualitative, and economics of grain loss across the supply chain or the post-harvest system, from the time of harvest till its consumption (Aulakh and Regmi, 2013; Tefera, 2012). The Food and Agriculture Organization (FAO) of the United Nations and World Bank data revealed that PHL of cereal in SSA ranged between 5-40 %, worth around $4 billion (Zorya et al, 2011).

A recent report of a joint FAO/World Bank (Zorya et al, 2011) shown that PHL of cereal in Eastern and Southern Africa account for over 40 % of the total PHL in SSA countries. This represents losses of about $1.6 billion in value each year. Such losses are equivalent to the annual caloric requirement for at least 20 million people (FAO, 2013) or more than half of the value of total food aid received by SSA in a decade (Zorya et al, 2011). Furthermore, it has been reported by Meronuck (1987) that post-harvest losses of maize in various storage facilities in undeveloped tropical countries ranged from 15-25 %.

The PHL of maize can be described by leaky food-pipeline (Figure 7) modified from Bourne (1977) and Abass et al. (2014). As indicated in pipeline losses occur at all stages (field to market). However, higher losses occur at the field/harvest and storage. According to APHLIS, only 60-74 % of the harvested maize reach the final consumer (Abass et al., 2014). Figure 8
shows typical storage condition of maize during bumper harvest.

**Types of losses**

Post-harvest losses are classified into three main categories; quantitative loss, qualitative loss, and economic or commercial loss. Others classified as direct and indirect losses. Quantitative loss indicates the reduction in physical weight, and can be readily quantified and valued, example a portion of grain damage by pests or lost during transportation. A qualitative loss is contamination of grain by molds and includes loss in nutritional quality, edibility, consumer acceptability of the products and the caloric value (Zorya et al., 2011; Kader, 2005). Economic loss is the reduction in monetary value of the product due to a reduction in quality and or/ quantity of food (Tefera, 2012).

**Weight loss**

Weight loss (WL) is the standard international measure of grain loss (De Lima, 1979), generally regarded as a loss of food. WL is expressed as a loss in the dry matter or dry weight basis (Tefera, 2012). According to APHLIS, WL is estimated in two ways; first, scattering of grain due to poor post-harvesting handling practices includes harvesting, threshing, drying, poor packaging and transport. Second, from biodeterioration brought by pest organisms such as insects, molds, and fungi, rodents and birds (Hodges, 2013). Agreed by many researchers that WL is due to the persistent action of pests that can occur along post-harvest activities (De Lucia and Assennato, 1994).

Weight loss is the common way of defining and expresses post-harvest losses of maize in Tanzania. The study conducted by Rugimamu in (2002; 2004) found post-harvest losses of maize is about 20-30 % and as high as 40 % in a traditional storage structure. A similar result has been reported by APHLIS as shown in Figure 9 (APHLIS, 2014). The weight loss can be calculated by the count and weight method (Eqn.1) developed by Adams and Schulten (1978).
Other methods include standard volume and weight method (SVM) equation 2 (Reed, 1987) and by the thousand grain mass (TOM) equation 3 and converted percentage damage method (Dick, 1988).

\[
\text{Percentage (\% weight loss) } = \frac{(W_u \times N_d) - (W_d \times N_u)}{W_u \times (N_d + N_u)} \times 100 \quad \ldots \quad \ldots \quad (1)
\]

Where, \(W_u\) = weight of undamaged grains, \(N_u\) = number of undamaged grains, \(W_d\) = weight of damaged grains, and \(N_d\) = number of damaged grains.

\[
\text{Percentage weight loss (\%)} = \frac{\text{Initial dry weight} - \text{Final dry weight}}{\text{Initial dry weight}} \times 100 \quad \ldots \quad \ldots \quad (2)
\]

\[
\text{Percentage weight loss (\%)} = \frac{M_1 - M_x}{M_1} \times 100 \quad \ldots \quad \ldots \quad \ldots \quad (3)
\]

Where \(M_1\) = grain mass before attack and \(M_x\) = grains mass after attack, mass = dry matter weight.

**Major pests of maize in Tanzania**

In Tanzania, the major constraints to maize production include insect pests, diseases, weeds, rodents, fungi, pathogens, and viruses. Maize is attacked by many insect pests during all stages of growth from seedling to storage (Shiferaw et al., 2011). Insects and other pests are a major threat to maize production (Ak’habuhaya, and Lodenius, 1988) and responsible for direct and indirect losses of maize on the farm and storage (Bankole and Mabekoje, 2004). According to Mihale et al. (2009) insects are responsible for 15-100 % and 10-60 % of the pre- and post-harvest losses of grains in developing countries.

The most economically important insect pests of maize in Tanzania can be categorized into two main groups; (1) field pests such as stalkborer (Busseola fusca), leafhoppers (Cicadulina mbila) and mole crickets (Gryllotalpidae). Others include African bollworm (Helicoverpa armigera), African armyworm (Spodoptera exempta) and cutworms (Agrotis ipsilon) and (2)
storage pests like the maize weevil (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus*) (Hon), red flour beetle (*Tribolium castaneum*) and dried bean beetles (*Callosobruchus maculatus*) and Indian moths (*Plodia interpunctella*) (ASSP, 2004). Table 2 shows common field pests of maize in Tanzania. The major diseases of maize include leaf rusts (*Puccinia sorghi* and *P. polysora*), leaf blights (*Helminthosporium turcicum*). Others include Maydis leaf blight (*Helminthosporium maydis*), maize streak disease (maize streak virus), grey leaf spot (GLS) (*Cercospora zaea-maydis*) and Gibberella Ear Rot (ASSP, 2004).

**Maize stalk borers**

The maize stalk borers, *Busseola fusca* (Fuller) belongs to a group Lepidoptera: Noctuidae. *B. fusca* considered the most damaging field insect pests of maize and sorghum in sub-Saharan Africa (Onyango, 1994). *B. fusca* is an endemic species across the wide geographical distribution (Sezonlin et al., 2006). However, mostly adapted to middle-and high altitude conditions- above 1500 m and annual mean temperature below 30 ºC (Sezonlin et al., 2006).

In Tanzania, the main damage of *B. fusca* occurs during the early stages of plant growth (Katinila et al., 1998). Young larvae cause foliar damage and older larvae feed inside the stem, panicle, and direct damage to grain (Onyango, 1994). Resulting in the production of ‘deadhearts’ and a consequent loss of crop stand (Haile and Hofsvang, 2002). The extent of damage and average yield loss vary considerably from region to region, season, the infestation of the pest and the growth stage of the crop (Haile and Hofsvang, 2002). Reported by Haile and Hofsvang (2002) and Chabi-Olaye et al. (2005) that *B. fusca* can reduce maize yield by 20–100 %. The life cycle of *B. fusca* is about 66 days in the rainy season and as long 200 days during the dry season (Unnithan, 1987).
African armyworm

The African army worms are the caterpillars of the noctuid moth (*Spodoptera exempta*, Walker), is one of the most devastating lepidopteran pest of graminaceous crops and grasses in sub-Saharan African (Tanzubil and McCaffery, 1990). The caterpillar is about 2 to 3 cm long, grey at first then change to greenish black when fully grown (HDR, 2000). It is the larval stage that causes serious damage, voraciously feeding on young stages of maize (Figure 10) and other major cereal crops (Armyworm Network, 2000). “The extent of damage is illustrated by the facts that two larvae can destroy 10 day old maize plant with 6-7 open leaves. A single larva can consume about 200 mg dry mass of maize leaves in the course of the sixth instar” (Odiyo, 1979).

The armyworm outbreaks usually begin in Tanzania or Kenya in November – December and then spread to other countries over a relatively short period. This is achieved by rapid growth of larvae and migratory behaviour of the adult moths. The adult moths are highly mobile, capable of achieving displacement of hundreds of kilometre each generation, flying with the wind at altitudes of several hundred meters (Gun and Gatehouse, 1985; Vilaplana et al., 2010; Boer, 1978). In Tanzania, armyworm outbreaks are usually severe and extensive during the rainy season follow droughts (Gunn and Gatehouse, 1985). According to Rose et al. (1995) “outbreaks of armyworm occur sporadically and caterpillars are generally not noticed until they change color from green to black at their third stars”.

Weed

Weeds are plants that grow where are not wanted or is a plant that is hazardous to crop, peoples and animals (Bubl, 2010). Weed competes with the crops for water, soil nutrients, CO₂, space and light (Rajcan and Swanton, 2001). Besides direct competes with plant for nutrients, weeds also cause indirect damage by harboring insect pests, rodents, diseases, and crop pathogens, as well as reduce wildlife habitat and crop quality (Bubl, 2010). Likewise,
weeds increase the cost of crop production and interfering during harvest and cleaning or the separation of crops (Tetfay et al., 2014).

According to FAO, worldwide, 13% loss of agricultural production is credited to weeds. In Africa, more than 50% of crop losses are due to weeds (Sibuga, 1997). The study conducted by Sibuga (1997) revealed that weeds are the most important crop pests in SSA. Cited by Chikoye et al. (2005) that a significant amount of crop production cost 40% – 80% in SSA is used for weed management. In addition, over 50% of the farming time is devoted to weeds management (Tetfay et al., 2014). The estimated loss due to weeds is higher than the sum of the potential losses due to insect, pathogens, and viruses (Oerke, 2006). The research conducted in Tanzania shows that weeds deny over 1.7 million metric tons of maize per year (Kitabu, 2013). Weed management is an important aspect in crop production. It reduces crop yields and can lead to total crop failures if uncontrolled (Steiner and Twomlow, 2003).

Weed competition greatly reduces crop yields. It is often a greater problem in a single crop or in simple crop associations than in the multi-crop associations. Some report of yield losses in maize due to weeds range between 20 to 100% (Tadious and Bogale, 1994). Furthermore, it has been reported by Chikoye et al. (2005) that in West Africa weeds contributes maize yield losses of about 50% to 90%. Concluded by Tetfay et al. (2014) that proper control of weeds in maize can increase yield up to 96%. The common weeds of maize in Tanzania are summarized in Table 3.

**Striga (witchweeds)**

*Striga* (*Scrophulariaceae*) also known as witchweed is a genus of obligate root parasitic flowering plants. Considered to be one of the serious biotic pests to crop production in sub-Saharan Africa (Menkir et al., 2001). It is estimated over 60% loss in crop production in SSA is due to *Striga* species. This accounts for an annual loss in agricultural revenue of about $7
billion (Robson and Broad, 1989). According to FAO, over 100 million people globally losses over half of their crop production to witchweed (Kanampiu et al., 2004). In addition, revealed by Odongo et al. (2004) that around 21 million hectares of cereals (maize and sorghum) with an estimated yield of nearly 4.1 million metric tons are infested by *Striga* each year in Africa. Yield losses on cereals attributable to infection by *Striga* parasites could be as high 100 % under high infestation season (Lagoke et al., 1991).

Furthermore, the study conducted by Massawe et al. (2002) in Tanzania show that the yield loss due to *Striga* of maize crops ranged around 18 % to 42 %. A major reason that these parasites are so pernicious is their highly efficient mechanism of seed production. Seeds of *Striga* are among the smallest of any known seed, measuring only 0.20–0.50 mm long, and they are often dispersed with planting material of which they are common contaminants (Berner et al., 1994).

Further, in a single growing season, each *Striga* plants can produce 500,000 seeds (Saunders, 1933) which may remain viable for 14 years in the soil (Bebawi et al., 1984). Seed germination requires an exogenous stimulant, that initiates ethylene production within the *Striga* seed (Babiker et al., 1993; Logan and Stewart, 1991) or directly provides ethylene (Eplee, 1975). Without adequate moisture and an external germination stimulant, the seeds remain dormant. Once germinated, the *Striga* seedling must attach to a host root within 3–5 days or the seedling die (Worsham, 1987). The *Striga* species of economic importance in Tanzania include *Striga hermonthica*, *S. asiatica* and *S. forbesii* (Massawe et al., 2002).

Moreover, the problems of *Striga* in sub-Saharan Africa fueled by many factors such as poor farming practices, deterioration of soil fertility, expansion of production to the marginal lands (Menkir et al., 2001). Most studies show the phytotoxic effect of *Striga* to host the main causes of yield losses (Ransom et al., 1990). The recommended approaches to control Striga include hand pull, uses of herbicides, application of high rates of fertilizers, and adopt new
resistant maize cultivars. Other tactics include crop rotation, ethylene gas, mixed cropping of cereals with legumes such as maize and cowpea (Kabambe and Kanampiu, 2002; Massawe et al., 2002).

**Maize diseases in Tanzania**

The major diseases of maize include: leaf rusts (*Puccinia sorghi* and *P. polysora*), leaf blights (*Helminthosporium turcicum* and *maydis*), Maydis leaf blight (*Helminthosporium maydis*), maize streak disease (maize streak virus), grey leaf spot (GLS) (*Cerospora zea-maydis*), and Gibberella Ear Rots (ASSP, 2004). The common diseases of maize in Tanzania are shown in Table 4.

**Maize streak disease**

Maize streak disease (MSD) is a disease caused by maize streak geminivirus. It is recognized as one of the most serious virus diseases of monocotyledonous plants in sub-Saharan Africa (Bock et al., 1974). “Globally, MSD is regarded as the third most serious disease of maize after northern corn leaf and grey leaf spot” (Martin and Shepherd, 2009). MSD causes an annual loss of around $120 to $480 million dollars with estimated yield loss of 6-10% (Martin and Shepherd, 2009). Equivalent to loss of over one million metric tons of maize grain (Karavina, 2014). MSD is spread by several species of leafhoppers that belong to the genus *Cicadulina* (Rose, 1978) but as many by *C. mbila* and *C. storeyi* (Shepherd et al., 2010).

Furthermore, the first symptom of MSD is the appearance of pale, spherical; chlorotic spots 0.5-2.0 mm in diameter on the lowest exposed portions of the youngest leaves (Rose, 1978). Lesion color generated by streak disease varies from whitish to pale yellow (Figure 11). This yellow streaking reduces photosynthesis and increases respiration rate, lead to a reduction in leaf length and plant height (Shepherd et al., 2010). MSD is more severe in younger plants
and irrigated crops (Owor, 2008). The control methods of MSD include cultural control (crop rotation, field hygiene, timely planting, barriers, and cultivar choice), chemical control (systemic insecticides like aldicarb, carbofuran, dimethoate, endosulphan and others), and host plant resistance (plant resistant hybrids) (Karavina, 2014; Shepherd et al., 2010).

**Storage pests**

Insect pests are the principal cause of grain losses in the field and storage (Suleiman et al., 2013). In general, smallholder farmers stored maize for three main purposes: as food until next season; as seed and for selling when prices become available. However, storage pest damage significant portions of their stored maize (Rugumamu, 2004). The most serious insect pests that cause severe economic damage to maize in the storage are the maize weevils, *Sitophilus zeamais*, and the larger grain borer (LGB), *Prostephanus truncatus* (Suleiman et al., 2015). Others important storage insect pests include the Angoumois grain moth (*Sitotroga cerealella*), the lesser grain weevil (*Sitophilus oryzae*), Red flour beetle, and dried bean beetle (Gitonga et al., 2015). Most of the maize grain harvested in Tanzania is traditionally stored on the farm where post-harvest pest management is inadequate (Rugumamu, 2004). Leading to huge amounts of maize grain losses (Sori and Ayana, 2012). Table 5 shows common storage pest of maize in Tanzania.

The larger grain borer (*Prostephanus truncatus*)

The larger grain borer, *Prostephanus truncatus* (Hon) (Coleoptera: Bostrichidae) also termed “Scania beetle”, or “Dumuzi” meaning robber in Tanzania. It is a most destructive pest of farm-stored maize grain and dried cassava roots (Nansen and Meikle, 2002) causing weight losses of 9 % to 45 % after 5- 8 months of storage (Golob, 1988). *P. truncatus* is native to Mesoamerica (Statthers, 2002), where it is found infecting maize grain and wood (Hill et al., 2003). It’s described as dual existence insect as both in storage pest and forest insects.
(Nansen et al., 2004). The adult *P. truncatus* have a cylindrical bostrichid shape (Figure 12), the body is 3 to 4.5 mm long and dark brown in color (Hodges, 1985).

*P. truncatus* was accidentally introduced from Central America to Tanzania in the early 1980’s (Dunstan and Magazini, 1981) and then 1984 in Togo (Harnisch and Krall, 1984). Since then, *P. truncatus* has become a serious threat to stored maize and dried cassava (Key et al., 1994), reducing the storage period of these commodities in the granaries of small-scale farmers. First recognized outbreaks were reported in the western regions of Tanzania (Tabora, Shinyanga, and Mwanza) in 1981 (Dales and Golob, 1997). It has now spread to most of the countries in sub-Saharan Africa, and more recently it has been identified in 17 countries (Figure 13) in Africa (Schneider et al., 2004). This pest can also infest and cause damage to bamboo, plastic, soap, stored timber and timber products (Cabi, 2015).

**Life cycle of *P. truncatus***

Adult *P. truncatus* tunnel through the stored maize grain, dried cassava or other foodstuffs, creating large quantities of dust (Cabi, 2015). *P. truncatus* is a long-lived species—the life cycle in about 4-6.5 weeks, female, live 16 days longer than male (Shires, 1980). Adult females lay small yellow ovoid (ellipsoidal) shape eggs in chambers at right angles to the main tunnels (BioNet-Earfinet, 2011). Larvae hatch from eggs after 3 to 7 days at 27-32 ºC and about 50-80 % R.H (Cabi, 2015).

The control strategies of *P. truncatus* include good store hygiene, clean the warehouse or store between harvest and burning infested maize grain. Other include harvest maize soon after mature, the use of resistant varieties, and traps-chemical attractant (pheromone) produced by the male beetle to attract females (Cabi, 2015; www.infonet-biovision.org; Bergvinson and Garcia-Lara, 2011). Other methods include; immerse used sacks in boiling water to eliminate residual infestations, addition of inert dusts (ash and clay), store the grain in a hermetic seal container and removing any wood materials from stores (Markham et al., 2004).
1994; Schneider et al., 2004; Bergvinson and Garcia-Lara, 2011; www.infonet-biovision.org). In addition, fumigation with phosphine and application of synthetic pyrethroid insecticides such as permethrin and deltamethrin (Golob, 1988) show positive results against *P. truncatus*.

**The maize weevil (Sitophilus zeamais)**

The maize weevil (Figure 14) *Sitophilus zeamais* Motschulsky, is a small reddish-brown to black snout beetle (Suleiman and Abdulkarim, 2014). It is described as one of the most destructive stored and primary grain pests of maize and grain in tropical and subtropical regions (Suleiman et al., 2015). *S. zeamais* is so devastating and capable of multiplying to large populations, causing tremendous damage to the stored grain (Cosmas et al., 2012). It has been estimated that 5-30 % of the total grain weight of the stored product is lost due to infection by *S. zeamais* (Ojo and Omoloye, 2012). Other studies cite as high as 80 % loss may occur in untreated maize grain stored in traditional structures (Tefera et al., 2011). Infestation by *S. zeamais* often begins in the field, but serious damage is done in storage (Fikremariam et al., 2009; Suleiman et al., 2015).

**Life cycle of S. zeamais**

*Sitophilus zeamais* is regarded as internal feeders of grains, with typically range from 2.5-4.5 mm in length (Kasozi, 2013). The average life span of *S. zeamais* ranging from 3 to 6 months up to one year (Rees, 2003; Kranz et al., 1997). Female weevil release sex pheromones to attract the males (Mason, 2003). Once fertilized the female uses the snout to excavate a small hole in a maize kernel and laying eggs (ovipositing) and plugs the hole with a waxy secretion (Kasozi, 2013). At optimal conditions, each female can lay up to 150 eggs in her lifetime (Gewinner et al., 1996). Eggs hatch into small larvae in about 6 days; the larva feed (Figure 15) and develops inside the maize kernels for about 25 days (Kasozi, 2013; Throne 1994; Kossou and Bosque-perez, 1998). Total development periods on environmental
conditions but normal range from 35 to 110 days (Kossou and Bosque-perez, 1998). The adults emerge by eating their way towards the testa causing rugged exit holes resulting in a damaged kernel and reduced grain weight (Mwangangi and Mutisya, 2013; Suleiman et al., 2015).

**Rodents**

Rodents are a significant pest problem worldwide. Rodents are major pests in cereal grains, causing both qualitative and quantitative damage (Mdangi et al., 2013). Qualitative losses occur through the decreased value of grain due to spoilage caused by grain discolouration, physical contamination and spillage such as faeces, hairs, and urine (Brown et al., 2013c). Quantitative losses arise through grain wastage between farmer and to the end-user (Brown et al., 2013c).

In the literature, estimates damage losses vary widely. The data show between 5-15 % yield loss of maize in Tanzania (Makundi et al., 1991) and 20 % of annual maize loss in Kenya (Oguge et., 1997). Likewise, 10-20 % annual loss of rice in Indonesia, 6-7 % in Thailand, 5-10 % in India and over 10 % in Vietnam (Leirs, 2003). The average rodent damage to stored maize in developing countries is around 35 %, even higher in certain cropping seasons during rodent outbreaks (Mdangi et al., 2013; Mulungu et al., 2011). This is equal to an annual loss of about $141 million ($11.1/100 kg bag of maize), corresponding to food grain to feed approximately 7 million people (0.5 kg/day/person) per year (Mulungu, 2003).

Rodents are known to cause damage at all stages of crop production. By digging up newly sawing seed, by attacking the developing grain maize in the field, matured grain just before harvesting and in storage (Segerbäck, 2009; Brown et al., 2007b). Besides crop damage, rodents also have serious implications for public health and animal husbandry. Act as a vector carrying numerous zoonotic diseases, including Lassa fever, hemorrhagic fever, Lymphocytic choriomeningitis, Leptospira, Scrub typhus, Toxoplasmosis, Murine typhus and Lyme disease
In addition, rodents also transmit and plague diseases by carrying several protozoa and bacteria like *Salmonella* spp., *Listeria* spp., *E. coli* O157: H7, *Campylobacter*, *Giardia* spp and others (Meerburg, et al., 2009). An excellent review of various diseases associated with rodents explained by Meerburg and others (Meerburg, et al., 2009). Moreover, rodents cause spoilage and contamination of food with hair, urine, and faeces, biting people, killing chicks and lead to storage structural damage in developing countries (Makundi, 2009).

**Rodent in Tanzania**

The most destructive rodent pests in Tanzania and another sub-Saharan Africa is multimammate shamba rat, *Mastomys natalensis* (Makundi et al. 1991; Leirs et al., 1996). Damage due to *M. natalensis* in Tanzania causes an estimated annual yield loss of 5-15 % of maize, equivalent to about $45 million or 400,000 tons of maize. To put into context, such losses are estimated to be equal to the annual caloric requirement to feed about 2 million people (Odhiambo et al., 2005; Leirs et al., 1996; and Makundi et al. 1991). The main characteristics of *M. natalensis* are an enormous breeding capacity and coexist both as field and house rats (Sluydts et al., 2009; Brooks and Fielder, 2013). Thus, make it huge challenges to managing (Odhiambo et al., 2005) and remains a chronic problem for many countries in sub-Saharan Africa (Mwanjabe et al., 2002). Revealed by Keener (2007) *M. natalensis* are very smart and once a population is established may be difficult to control.

*M. natalensis* is a small rat, the body length measures 1.0-1.5 cm, with a tail approximately the same length. They weigh about 50-120 g (Brooks and Fielder, 2013). “The dorsum is grey to brownish-grey, brown, or reddish-buff, the venter is lighter coloured” (Brooks and Fielder, 2013). Females, having up to 8-12 pairs of mammies or about twice that of most rodents (Fiedler, 1994). Have a mean gestation period of around 23 days and females mate multiple
times during the year breeding season and litter size of 9-13 (Figure 16) (Fiedler, 1994; Kennis et al., 2008). The young are weaned for about 3 weeks and siblings reach sexual maturity after 3.0-3.5 months (Brooks and Fielder, 2013; Fiedler, 1994). The maximum life span ranged between 339-487 days (Coetzee, 1975). The population dynamics depends on food availability and rainfall (Julliard et al., 1999; Massawe et al., 2011).

**Strategies to reduce postharvest losses**

Reducing PHL has positive consequences for poverty alleviation, food security, nutrition status, and increases household income for the smallholder farmer in developing countries (Shiferaw et al., 2011; Affognon et al., 2015). Also, has significant impacts on the environment, increases the amount of food available for consumer and reduces utilization of production resources (Affognon et al., 2015; Zorya et al., 2011). Figure 17, show repaired postharvest losses leaky pipeline for maize. For instance, by introducing simple strategies like to improve varieties, harvest at the right time, improve storage structures, and improve drying efficiency. As well as uses of moisture and temperature meters, proper hygiene and sanitation, and access to market information save a significant portion of maize harvested.

According to Affognon et al. (2015) likely strategies to mitigate PHL in developing countries is to look each stage rather than concentrate all effort on the storage activities. Other potential strategies include better government policies like reduction of taxes for materials, a public-private partnership that enable dissemination of new technologies, and extension services such as farm field school and precision agriculture. As well as promotion of newly innovated technologies, communication and market information and investments in infrastructure (Shiferaw et al., 2011).
Technology and Infrastructure

Multidisciplinary approaches and several technologies have been developed to reduce PHL in developing countries. However, the potential gains from adopting these technologies have challenged, particularly in rural areas (Rosegrant et al., 2015). Cited by Greely (1982) the main constraints of the PHL reduction in developing countries are mostly smallholder farmers are reluctant to change unless the losses are considerably higher than average. In addition, these technologies turn up to be inappropriate for smallholder farmers, and unavailable at the right price and the right time. Also, inadequate knowledge of the biological and environmental factors on product deterioration and adopt technology only when are offered free of charge (Shiferaw et al., 2011).

Further, quoted by Meena et al. (2009) the main setback of PHL reduction in less developed countries is a huge gap between agricultural technologies developed at research institutions and its adoption by smallholder farmers. Gamon et al. (1994) the limited adoption of technologies in rural areas is due to the lack of disseminating information. He continued and add most of the technologies offered or developed by researchers and development patterns are unsuited and perceived as irrelevant by most smallholder farmers. Moreover, the factors such as socioeconomic status, education background, economic motivation, and training received have a positive correction with technology adoption (Atibioke et al., 2012). Nevertheless, hermetic storage technology is considered the best solution to combat PHL in developing countries.

Hermetic Storage Technology (HST)

Hermetic storage (HS) is an ancient method to control insect infestation and preserve the quality of grain (Quezada et al., 2006). HS also termed as “hermetic silo storage”, “sealed storage”, “airtight storage”, “sacrificial sealed storage” has emerged as an alternative and cost-efficient methods for minimizing PHL and increases food security in developing countries.
The basic principle of HS based on the simultaneous depletion of oxygen and accumulation of carbon dioxide in the storage container (Sanon et al., 2011). This is achieved by the aerobic respiration of grain, insects, and molds (Quezada et al., 2006). The lack of O$_2$ inside the container cause insects to suffocate, become inactive and eventually die of asphyxiation or desiccation (Njoroge et al., 2014). The main advantages of hermetic storage are simple, feasible, eliminate the need of toxic chemical (insecticides) or fumigations, climate control and environmentally friendly (Navarro et al., 1994; Villers et al., 2008). HS is a technology that enables farmers to store their grains with negligible loss of quality and quantity.

Types of hermetic storage

Hermetic storage is categorized according to the amount of grain been stored, small quantity usually employs the use of bags and small containers, while huge or bulk storage employs larger storage facilities (Yakubu, 2009). For small quantity, two types of hermetic storage container (bags) have been developed, Purdue Improved Crop Storage (PICS) (Murdock and Baoua et al., 2014) and GrainPro Super Bags (Villers et al., 2010). Other HS includes metal silo technology and silo or grain bags.

Purdue Improved Crop Storage (PICS)

PICS bags (Figure 18), also known as the triple-layer bags consisting of three plastic liners. Two 80 micron high-density polyethylene plastic bags, one surrounded by the second; both are enclosed by a third bag made of woven polypropylene bag for reinforcement (Murdock and Baoua et al., 2014). This technology was created in late 1980’s under the USAID project for the preservation of cowpea grain in sub-Saharan Africa (Murdock et al., 2003). The technology was named “Purdue Improved Cowpea Storage” (PICS) bags and served as protection against *Callosobruchus maculatus* (F.) a destructive cowpea seed (bruchids)
beetles (Murdock et al., 2003). PICS are based on the principle of the bio-generated modified atmosphere, where oxygen environment low inhibits the growth and development of insect pests (Sanon et al., 2011). It takes advantage of an airtight seal where oxygen concentration dramatically decreases (Figure 19), While carbon dioxide levels proportionally increase within a few days after sealing through respiration of insect, fungal, and grains/seed (Quezada et al., 2006).

Further, the PICS technology has been considered low-cost non-chemical technology that enables smallholder farmers to store their seed and grains with minimal loss. Unlike other technologies, PICS has been easily accepted by farmers and many studies prove to be effective storage systems for a variety of crops, including cowpeas, maize, peanuts, sorghum, wheat, and common beans against insect infestation, fungal growth and aflatoxin accumulation (Zorya et al., 2011; Williams et al., 2014). However, the effectiveness of the hermetic technology depends on several factors such as airtightness of the seal, the commodity stored, agro-climatic conditions, type and prevalence of insect pests and mechanical strength of the barrier material (Njoroge et al., 2014).

The GrainPro Super bags

The SuperGrain™ bag is a portable hermetic sack suitable for the small-scale farmer to store maize and other commodities up to 1000 kg. It consists of a single reusable layer of 0.078 mm thick plastic film made from 2 plains polyethylene films between which is sandwiched a plastic layer that act as a gas and moisture barrier (Baoua et al., 2013). Then the sealed bag is placed in a protective woven outer bag (Bern et al., 2013). The technology is based on the principle of hermetic storage systems. There are a number of GrainPro Super bags (Figure 20) include GrainPro SuperGrainbag III™ used to store a range of dry agricultural commodities such as maize, wheat, sorghum, millet, paddy, coffee, and others (http://www.grainpro.com).
Other products of GrainPro Inc. include Cocoon Cargo and TranSafeLiner™ (Figure 21) that can accommodate up to 1000 tons of grain (http://www.grainpro.com). GrainPro bags have proven effective for storage of wheat in several Asia countries attacked by insect pests such as *Tribolium castaneum*, *Rhyzopertha dominica*, and *Sitophilus oryzae* (Baoua et al., 2013). Some advantages of GrainPro Super bags as mentioned on their website are; affordable and reusable, and environment-friendly. Also, prevent commodities against insect infestation, contamination, moisture, oxidation, fungi, and mold growth and damage of larger grain borers and cowpea weevils (http://www.grainpro.com).

Furthermore, these technologies are available in more than 100 countries include Mali, Burkina Faso, Ghana, Niger, Rwanda, Kenya, Malawi, Uganda, Ivory Coast, India, Costa Rica, Sri Lanka, Philippines, Pakistan, Guatemala, Zambia, Afghanistan to mention few (www.grainpro.com). “These technologies can provide a sustainable and affordable solution to the prevention and reduction of post-harvest loss, and thus increase global food and nutrition security” (Maier and Cook, 2014).

**Metals silo technology**

The metal silo technology is an effective method of reducing grains PHL for small and medium scale farmers in developing countries. This technology provides grains protection for both short and long time storage against insect pests, pathogen, birds, molds, rodent, theft, and other domestic animals (Yusuf and He, 2013; Tefera et al., 2011; Gitonga et al., 2015). A metal silo is a cylindrical (Figure 22), square or rectangular prism structure, constructed from a high quality galvanized iron sheet and hermetically sealed with a top inlet and a smaller bottom lateral outlet (Bokusheva et al., 2012). The main advantage of metal silo is hermetically sealed. Thus, eliminates or reduces oxygen and increases CO₂ concentration inside. Consequently, suffocate, and killing any insect pests inside (Quezada et al., 2006; Tefera et al., 2011).
The metal silo is a key and a promising technology for effective post-harvest management of grains for small-scale farmers in the developing countries (Tefera et al., 2011). In addition, metal silo improved food security, maintained grain quality, reduce women’s workload, improved family health, and reduce usage of storage pesticides. Also, improve hygiene, and welfare and creates jobs for artisans/metalworkers (Bokusheva et al., 2012; Bravo, 2009). As well as reducing macroeconomic fluctuations in grain price, and increases farmer’s flexibility to sell their grains in the lean season (Shiferaw et al., 2011).

Metal silo technology program or Postcosecha program considered most successfully PHL program in Central American countries (SDC, 2008). According to Raboud and others cited by Bokusheva et al. (2012) about 380,000 tons of maize are saved annually in Honduras, Guatemala, Nicaragua, and El Salvador, corresponds to 13% of the region annual production of maize. This is equivalent to food for over 50,000 families and worth more than US$12 million (Bravo, 2009). Metal silo’s technology are getting popular in many developing countries like Kenya, Malawi, Tanzania, Mozambique and others. For more information on metal silos, see an excellent review by Tefera et al. (2011) and a research paper by Gitonga et al. (2015).

**Silo bags**

The silo bag or “grain bag” was originally developed as a temporary storage system for chopped grain silage (Abalone et al., 2011). Nowadays has emerged as the best alternative for bulk grain storage in Argentina, Australia, Canada, and the US (Ward and Davis, 2012; Maier and Cook, 2014). Silo bags are hermetically sealed to prevent the growth and development of insect pests and molds, consequently, reduce postharvest losses, storage cost and maintain quality of grain (Barbosa, 2008; Maier and Cook, 2014). Typically, silo bags (Figure 23) consist of three-ply of 0.250 mm thick polyethylene films. The outer layer is painted white to reflect solar radiation while the inner layer is black to block sunlight. It is about 60 m by 3 m length to diameter and can store up to 200 tons of maize, soybean or wheat (Maier...
The silo bags can play an important role as temporary on-farm grain storage during bumper harvest in Mid-West and Mid-South US and eliminate the immediate need to transport grain to the elevator (Barbosa, 2008; Ward and Davis, 2012) as well as increase harvesting efficiency and reduce farming cost (Barbosa, 2008). Like other hermetic bags, when properly airtight the silo is water-resistant and achieved a high degree of oxygen and carbon dioxide level that attained hermetic storage environment (Maier and Cook, 2014).

Moreover, the main shortcoming of silo bags are vulnerable to damage from birds, wild animals, insect pests, and rodents and silo bags can only be used once. In addition, it is difficult to monitor temperature and moisture movement within a grain mass, the grain conditions are influenced by the external climatic conditions, and moisture migration can occur within the bags (Barbosa, 2008; Abalone et al., 2011; Ward and Davis, 2011; Ileleji, no date). Likewise, an overload of silo bag can result in bag breaking, needs special loading and unloading equipment and the bag should be inspected regularly for leaks or damage by vermin (Maier and Cook, 2014).

**Mycotoxins**

**Fungi deterioration**

Insects, birds, mice, and rodents cause the more noticeable damage, but the role of storage fungi in the loss of stored grain cannot be ignored (Dunkel, 1988). Some storage insects are disseminators of storage fungi while others are the exterminators (Sinha, 1971). Fungi are well-known to cause a variety of deteriorating changes in grains and fresh produce, both before and after harvest (Sauer, 1988). It has been reported by many researchers fungi grow faster under warm conditions than under cool conditions. As a rule of thumb, deterioration is increasing about 10 times faster at 25 °C than at 3 °C (Sauer, 1988; Suleiman
et al., 2013). Contamination of maize to fungi can be categorized into two main classes: the field and storage fungi (Bankole and Mabekoje, 2004).

The field fungi are those that invade the developing or mature seed of cereal plant at moisture contents of about 20% (Christensen, 1957; Meronuck, 1987). Field fungi do not compete well under normal and dry storage conditions, but may grow extensively in improperly preserved maize at high moisture (Meronuck, 1987). *Fusarium, alternaria Cladosporium, Pullularia,* and *Helminthosporium* are a common genus of fungi that infect maize in the field (Bankole and Mabekoje, 2004). These fungi usually do not continue to grow after harvest (Christensen and Kaufmann, 1965) because most grains stored at moisture contents below 20%.

On the other hand, the storage fungi are those that develop on and within seeds at moisture contents often encountered in storage, principal species are *Aspergillus* and *Penicillium* (Christensen, 1957). The major effects of storage fungi on grain, including discoloration, losses in germination, caking, nutritional changes, heating, and mustiness, musty odors. Also cause, dry matter loss, mycotoxins production, nutrition and chemical changes and reduction in processing quality (Meronuck, 1987; Sauer, 1988). The storage fungi do not invade grains before harvest (Christensen and Kaufmann, 1965). However, it is unknown what factors determine why field fungi primarily develop on the standing crop while storage species became dominant in store. Nevertheless, fungi are well-known for their role to produce secondary metabolites or mycotoxins (Magan and Lacey, 1984).

Mycotoxins are a heterogeneous group of toxic secondary metabolites that are produced by several fungal genera and exert toxic effects (mycotoxicosis) on human and domesticated animals (Peraica, 1999). Contaminate a range of agricultural commodities such as grains and their derived processed products (Njumbe et al., 2014). Mycotoxins contamination are unavoidable and unpredictable can occur throughout the food chain from the field or pre-
harvest, during harvest, drying, during processing and storage (Lopez-Garcia et al., 1999). Which make it an enormous challenge to manage and control, particularly in developing countries (Anukul et al., 2013). The production of mycotoxins depends on various factors, such as the commodity, poor agricultural and harvesting practices, improper drying, handling, storage conditions, climatic conditions and seasonal variations (Marin et al., 2013; Leslie et al., 2008) often times most factors are beyond human control (Hussein and Brasel, 2001).

Mycotoxins contamination attracts worldwide attention due to the huge economic losses incurred and their impact on human, domestic animals and trade (Wu, 2006; Chilaka, et al., 2012). Maybe detrimental to the health of humans and animals. Dietary exposure to mycotoxins can result in serious health affect both acute and chronic. Ranging from sudden death to deleterious effects upon the central nervous, induction of hepatocellular carcinoma, effects on the cardiovascular, reproductive, pulmonary, and gastrointestinal systems to mention few (Burger et al., 2013; Suleiman et al., 2013).

In addition, it is well established in several clinical trials that mycotoxins in animals cause decreases in productivity, damage vital organs, reduce animal weight, cause growth retardation, immune suppression and interference with reproduction systems (CAST, 2003). Mycotoxins may also be carcinogenic, teratogenic, tremorogenic, haemorrhagic, and immunotoxic, oestrogenic, effects dermatitis and nephrogenic to a lot of organisms (Burger et al., 2013; Leslie et al., 2008). Likewise, a synergistic effect between mycotoxins exposure and some important common diseases in sub-Saharan Africa such as malaria, kwashiorkor, protein energy malnutrition, decrease resistance to infection such as diarrhea, and HIV/AIDS have been suggested (Wagatha and Muthomi, 2008; Rustom, 1997).

Further, an increasing awareness of the deleterious effects of mycotoxins on the health and productivity of human and animals have persuaded many countries around the world to implement regulations for maximum tolerable levels to control occurrence of these compounds
in human food and animal feed (Coker, 1991; Garrido et al., 2012). A recent report by the FAO on mycotoxins shows over 100 countries worldwide had set regulatory limits on allowable mycotoxins levels in human and animal feeds (Warth, et al., 2012; Wu and Guclu, 2012). Current regulations encompass about 13 different groups of mycotoxins (Van Egmond et al., 2007).

However, despite sporadic outbreaks of mycotoxins incident in sub-Sahara African and Asian countries. Regulatory limits are rarely in place or not properly implemented due to improper testing equipment, no monitoring and surveillance system in place, and poor management of grains and oilseeds (Wild and Gong, 2010; Wu and Guclu, 2012). Table 6 shows maximum acceptable limits of mycotoxins in maize for some selected countries.

Furthermore, mycotoxins can occur both in temperate and tropical regions of the world. However, the impact of the problem is higher in tropical and sub-tropical climatic regions of the world (Suleiman et al., 2013) between 40° North and 40° south of the equator. Currently, over 300 different mycotoxins have been identified; In general, mycotoxins are categorized by fungal species, structure, and mode of action (Darwish, et al., 2014). The most important and frequently encountered mycotoxins in maize include the aflatoxin (AFs), fumonisin (FUM), ochratoxins (OT), trichothecenes (TCT), deoxynivalenol (DON) and zearalenone (ZEA).

Aflatoxins (AFs)

Aflatoxins are a group of secondary metabolites produced by two main strains of fungi, Aspergillus flavus, and Aspergillus parasiticus (Marin et al., 2013; Feng et al., 2011). These fungi resist a wide range of conditions and contaminate several agricultural commodities. AFs are of great concern due to their detrimental effects on the health of humans and animals (Zinedine and Manes, 2009). AFs are the most common and probably the most significant mycotoxin in terms of human and animal health risk (Sauer, 1988; Bluma and Etcheverry, 2008).
In addition, due to potent of AFs, several studies have been conducted to look at the nature, identification, classification, biosynthesis, metabolism, and detoxification of these toxins. Toxicity of AFs can be categorized into two main groups: acute toxicity and chronic toxicity. Structurally, AFs are related to difuranocoumarins compounds and classified into four main chemotypes (Figure 24): AFB₁, AFB₂, AFG₁, AFG₂ and two more minor, M₁ and M₂, usually found in milk and milk product (Jolly et al., 2008).

Likewise, these AFs are pentaheterocyclic and highly conjugated compounds. Like many others heterocyclic fluoresce compounds, AFs also are distinguished by native fluorophore characteristics. AFB₁ and AFB₂ fluoresce blue color while AFG₁ and AFG₂ are endowed with yellow-green fluoresce under ultraviolet light (Hussein and Brasel, 2001; Vazquez et al., 1991). The abbreviations B and G show Blue and Green color, while 1 and 2 represents the relative migration distance, 1(higher) and 2 (lower) of the compounds as seen on a thin-layer chromatographic plate under ultraviolet light (Klich, 2007).

Moreover, AFB₁ are known to be highly toxic and several studies have shown to be carcinogenic, tetragenic, mutagenic, hepatotoxic, genotoxic, immune suppression, growth retardation, and inhibit several metabolic systems in humans and other animal species (Zinedine and Manes, 2009; Bluma and Etcheverry, 2008; Shephard, 2003). AFB₁ classified by the International Agency for Research on Cancer (IARC) as a class 1 carcinogen to humans (IARC, 1993). It is considered being the primary cause of hepatocellular carcinoma in mammals (Barkai-Golan and Paster, 2011). The risk of hepatocellular carcinoma is elevated in areas where hepatitis B virus infection is endemic (Lewis et al., 2005). Table 6 represents an association between food intake (cereals) and risk of AFB₁ that cause liver cancer for the human.

Further, the incidence of aflatoxins in maize are a perennial threat in warm and humid subtropical and tropical conditions (Kaaya and Kyamuhangire, 2006). The warm and humid
conditions provide a favorable environment for the growth of the molds and production of toxins both in field and storage (Rustom, 1997; Suleiman et al., 2013). In the field, the optimum thermal conditions for fungal growth is 36 °C to 38 °C. While aflatoxin production occurs at 25 °C to 27 °C and 0.99 water activity and about 85 % relative humidity (Pitt, 1993; Shephard, 2003). In storage, A. flavus requires at least 85 % R.H and grows fastest at fairly high temperatures (Sauer, 1988).

**Fumonisin (FUM)**

Fumonisins are a group of mycotoxins produced by some *Fusarium* species, primarily *F. verticillioides* (syn. *F. moniliforme*) and *F. proliferatum* (Marin et al., 2013). FUM was first isolated and identified in South Africa in the late 1980s (Gelderblom et al., 1988). Structurally, FUM is the disaster of proprane-1, 2, 3-tricarboxylic acid and can be classified into four main groups; A (A1 and A2), B (B1, B2, B3 and B4), C, and P. Moreover, FB1, FB2 and FB3 (Figure. 25) are highly toxic and occur naturally in maize and maize-based products (Shephard et al., 2005). The most potent form of Fumonisins is FB1 and classified by the IARC as a group 2B, possible human carcinogen (IARC, 2002).

Fumonisins are known to exhibit toxic effects on a number of animal species. Several ecological and clinical studies have shown Fumonisins to cause equine leukoencephalomalacia and neurotoxicity in horses (Marasas et al., 1988). Also, pulmonary edema in swine brain, hepatosis and nephrosis in sheep and promote tumor in rats, mice, and rabbits (Hussein and Brasel, 2001). In addition, Fumonisins have been found to produce a broad range of pathological effects in mammals (Shephard et al., 2000) such as interference with cellular foliate uptake (Stevens and Tang, 1997). Likewise, Fumonisins are detrimental effects to the central nervous system, liver, pancreas, kidney, heart and lung to several domesticated and other animal species (Bucci and Howard 1996). These effects are associated with decreases in food intake, inhibits ceramide synthesis and disruption of
sphingolipid metabolism (Merill et al. 1996; Smith et al., 2012).

**Ochratoxins (OT)**

Ochratoxins are mycotoxins produced by several fungal strains of *Aspergillus* and *Penicillium*. Three main types of ochratoxin are; A, B, and C (Figure 26). Ochratoxin A (OTA) is the most toxic of the three compounds. OTA is a frequent natural contaminant of many commodities such as coffee, dried fruit, grapes, raisins, red wine and beer (Erkekoğlu et al., 2008). In addition, OTA also occurs in wheat, barley, rye, corn, soy, peanuts, rice, oats, and cassava flour (Zain, 2010; CAST, 2003) and in several food of animal origins (Peraica et al., 1999). Chemically Ochratoxin are described as 3, 4-dihydromethylisocoumarin derivatives linked by an amide bond to the amino group of L-β-phenylalanine (Anli and Alkis, 2010).

OTA toxin is responsible for nephrotoxic, teratogenic, mutagenic, genotoxic, immunotoxic complications, as well as reproductive toxicity and other detrimental effects to several animal species (Erkekoğlu et al., 2008). OTA has been classified by the IARC as a Class 2B carcinogen, possible carcinogen to human (Murphy et al., 2006). Ochratoxin A toxin has been shown to be weakly mutagenic by its induction of oxidative DNA damage (Bennett and Klich, 2003). Several studies show OTA causes renal adenomas and carcinomas in male mice and rat (Schwartz, 2002). In addition, OTA has been suggested as an aetiological agent to interstitial nephritis, urothelial, and testicle tumors in human (Anli and Alkis, 2010). Also, OTA is associated with a chronic disease called Balkan Endemic Nephropathy (BEN) (Schwartz, 2002). BEN is a fatal chronic kidney disease affecting rural populations, in Romania, Bulgaria, and the former Yugoslavia (Schwartz, 2002).

**Trichothecenes (TCT)**

Trichothecenes are a group of mycotoxins which are produced by several fungal genera, most notably *Fusarium* species. TCT is a toxic tricyclic sesquiterpenoid compound with as a
12, 13-epoxy ring and a variable number of hydroxyl or acetyl groups (Eriksen et al., 2004; Sweeney and Dobson, 1998; WHO, 1990). At present over 150 TCT toxins are known, TCT is chemically classified based on the presence or absence of characteristic functional groups and their producer fungi (Sudakin, 2003). There are four subtypes of the TCT; Type A (Figure. 27) has a functional group other than a ketone at position C-8, include T-2 toxin (T-2) and HT-2 toxin (HT-2) produced by F. sporotrichioides and F. poae.

Moreover, type B (Figure 28) TCT has a ketone at position C-8, include nivalenol (NIV) and deoxynivalenol (DON) produced by F. culmorum and F. graminearum. Type C (Figure 29) has a second epoxy group at C-7, 8 or C-9, 10, include crotocin and baccharin produced by cephalosporium crotocingigenum. Type D TCT are potent compound has a macrocyclic ring linking C-4 and C-15 with two ester linkages, produced by S. alternans. Type D TCT is not produced by Fusarium species (Sweeney and Dobson, 1998; Foroud and Eudes, 2009; Moss, 2002; WHO, 1990). Trichothecenes are common mycotoxins occur worldwide in agricultural commodities such as maize, wheat, barley, rye, rice, oats and vegetables (Eriksen, 2004) as well as in animal feed (WHO, 1990). However, Type C and D are rarely found in human food.

Furthermore, the exactly metabolic toxicity of TCT to the vertebrate body are poorly understood but is related to the inhibition of protein and DNA synthesis on the ribosomal level (Fink-Gremmels, 1999). In addition, to their inhibition activity, they have a wide range of gastrointestinal, dermatological and neurologic effects such as vomiting, diarrhea, and bowel inflammation. Likewise, TCT has been previously associated with anemia, digestive disorders, leukopenia, and skin irritation. Also, feed refusal, decreased bone marrow, reduced ovarian function and cause growth retardation in several animal species (Erkekoğlu et al., 2008; Zain, 2010; Quiroga et al., 1995; Sudakin, 2003).

Moreover, TCL are recognized for their phytotoxic properties, and at very low-level cause wilting, chlorosis, necrosis and other symptoms in a variety of plant (Sudakin, 2003;
Muhitch et al., 2000). The phytotoxic effects of TCL on plants include inhibiting seed germination, growth retardation and green plant regeneration to both mono and dicotyledonous plant (Sudakin, 2003; Masuda et al., 2007).

**Deoxynivalenol (DON)**

DON is a trichothecene and non-fluorescent mycotoxin produced by *F graminearum* and *F culmorum* (Anukul et al., 2013). DON (Figure 30), also known as “vomitoxin” is the most well-studied group of mycotoxins contaminating many cereal grains, especially maize and wheat, in both tropical and template regions (Foroud and Eudes, 2009). Likewise, DON found in rye, rice, oat, barley as well as in safflower seeds and mixed feeds (Pestka et al., 2005). DON exposure has been linked to incidences of acute gastrointestinal diseases, kidney problems and immunosuppressive in animals (Pestka et al., 2005; Richard, 2007).

Moreover, a short-term exposure of DON causes a condition known as “anorexia”, decreased food intake or refusal to eat, thus the lower weight gain and decreased nutritional efficiency (Anukul et al., 2013; Pestka et al., 2005). Whereas a long-term exposure elicits “emesis” acute effects vomiting, abdominal distress, rectal bleeding, increased salivation, diarrhea, malaise and inhibiting reproductive performance in several monogastric animal species (Anukul et al., 2013; Pestka et al., 2005). Also found to reduce the milk in dairy cattle (Akande et al., 2006). The International Agency for Research on Cancer (IARC) placed DON in Group III, not classifiable as to its carcinogenicity to humans (CAST, 2003).

The worst effect of DON toxicity in human depends on the extent of contamination in the food ingested. Several studies show strong association between DON and outbreaks of acute diseases such as gastrointestinal upset, nausea, dizziness, vomiting, headache, abdominal pain and diarrhea after red mold intoxication in India and China, Korea, and rural Japan (WHO, 2011; Kpodo et al., 2008; Robert et al., 2010). The no-observed-effect level (NOEL) for adult is 0.5-mg/ kg body weight /day. Likewise, the NOAEL for fetal toxicity on based on impaired
fetal development is 2.5-mg/kg body weight/per days and considered to be a teratogen at 5-mg/kg body weight /days (Pestka, 2010).

Zearalenone (ZEA)

Zearalenone is classified as an estrogenic mycotoxin synthesized by several *Fusarium* species, including *F. graminearum, F. culmorum, F. cerealis, F. equiseti, and F. crookwellense* (Anukul et al., 2013). Contamination of ZEA occurring mainly in cereals such as maize, wheat, and barley fields, but also in sorghum, soybean, oats, hay, rice, rye, sesame seed and silages (Peraica et al., 1999; Zinedine et al., 2007). *Fusarium* species are common soil fungi and mostly grow in moist, warm, and temperate conditions (Richard, 2007). Chemically, ZEA (Figure 31) is described as a phytoestrogenic compound of a 6-(10-hydroxy-6-oxo-trans-1-undecenyl)-β-resorcylic acid μ-lactone (Hussein and Brasel, 2001).

ZEA is renowned for its detrimental effect to the urogenital system in animal species as well as neuroendocrine disruption by binding to estrogen receptors (Richard, 2007). The interaction of ZEA with estrogen receptors, resulting in apparent hyperestrogenism, reduced fertility, vulval edema, virginal prolapse, macromastia, and gigantomastia or mammary hypertrophy in females (Peraica et al., 1999; Zinedine et al., 2007). In addition, ZEA has been associated to induce feminization such as enlarged nipples, testicular atrophy and swollen prepuce in young male pigs (Peraica et al., 1999; Richard, 2007; Whitlow and Hagler, 2002).

Moreover, ZEA has been known to causes depress serum testosterone, weights of testes, spermatogenesis, fetal reabsorption, aborted pregnancies, reduced litter sizes and low birth weights, in swine. Likewise, in cows, ZEA has been linked to infertility, reduced milk production and hyperestrogenism (D'Mello et al., 1999; Zinedine et al., 2007).
Mycotoxins contamination in Tanzania

Maize and cassava are the two major staple foods in Tanzania and are essential components of complementary foods for infants and young children (Sulyok et al., 2014; Kimanya, et al., 2008). Nevertheless, these two crops are the most prone to mycotoxins contamination (Manjula et al., 2009; Sulyok et al., 2014). Mycotoxins contamination of maize is considered the greatest public health threat due to their detrimental effects to human health (TFDA, 2012). In addition, to health concerns, mycotoxins can restrict maize trade and limits income of smallholder farmers, because of food safety concern and trade restrictions (WHO, 2006). The most frequently encountered mycotoxins in Tanzania are aflatoxins and fumonisins (Kimanya, et al., 2008). However, other types of mycotoxins such as zearalenone, deoxynivalenol, ochratoxins, and T-2 toxins, HT-2 toxins have also been reported (Doko, et al., 1996; Mboya et al., 2011; Kimanya et al., 2014; Srey et al., 2015; Kamala et al., 2015).

The recent economic assessment conducted by Abt Associates in collaboration with Tanzania food and drug authority (TFDA) observed the significantly higher prevalence of AFB₁ in multiple regions around the country (TFDA, 2012). AFB₁ is the most potent types of mycotoxins responsible for liver toxicity. As shown in Figure 32, all regions assessed AFB₁ level was well above 5 μg/kg (5 ppb) maximum acceptable limits for maize grain set by the Tanzania Bureau of Standards (TBS). The report concluded that lack awareness about mycotoxins among the communities (farmers, traders, and consumers) and policy makers exacerbated the problem of mycotoxins in Tanzania (TFDA, 2012).

Further, the results obtained from this assessment concurred with several studies The research conducted by Kimanya et al. (2008; 2010) found 12 % of all samples of maize collected exceeded the maximum limit for total aflatoxins (10 ppb). In addition, the study conducted to assess occurrence of mycotoxins exposure for the stunting of infants and young children in rural Tanzania. The result revealed a high percentage of mycotoxins exposure,
particularly fumonisn and aflatoxins were significantly higher than provisional maximum tolerable daily intake (PMTDI) (Kimanya et al., 2010). On the other hand, a cross-sectional study conducted in Morogoro, Tanzania found 68% of all feed samples collected were contaminated by AFB1 (Kajuna et al., 2013). Likewise, the study conducted by Srey et al. (2014) shown young children in Tanzania is frequently exposed to DON due to consuming contaminated maize related food.

When all these findings, taken together revealed that majority of Tanzanian population were at risk of exposure to different types of mycotoxins (Kimanya et al., 2008, 2009, 2011; 2014; Mboya and Bogale, 2012; TFDA, 2012; Magoha et al., 2014; Kamala et al., 2015). The contamination levels were alarming in respect to food safety and regarded most of these toxins were found on main staples food eating by the majority of the rural population. Thus, we wonder if these results relate to the recent WHO and WHR (World Health Ranking) report that shows an enormously increased in oesophagus and liver cancer in Tanzania. According to WHR website, oesophagus cancer is the second leading cause of death in terms of cancer in Tanzania and ranked 14 in the world (WHR, 2015).

Moreover, our speculation is because several studies have directly linked to those types of cancer with consumption of maize and mycotoxins contamination (Marasas et al., 1981; Sydenham et al., 1990; Mohanlall et al., 2013; Shephard et al., 2000; Van Der Westhuizen et al., 2003; Zhang et al., 1997; Barkai-Golan and Paster, 2011). In addition, majority of the Tanzanian population were frequently exposed to these toxins at an early age (Kimanya et al., 2008, 2009) and exposure levels increased as the children grew older (Avakian, 2014). Moreover, most reported cases of oesophagus cancer were related to young age and people from rural areas (Mchembe et al., 2013) were maize and cassavas are the main dietary staple food (Kimanya et al., 2008; Manjula et al., 2009; Kamala et al., 2015). However, extensive studies are needed to address these issues before jumping to any conclusions.
Mycotoxin economic aspects

Tanzania is an agricultural country, as explained in the previous section, agriculture played a vital role in Tanzanian economy, contributing around 33% of the total GDP and over 80% of export by value (CIA World Factbook, 2014). Tanzania’s economy mainly depends on the export of its major agricultural commodities such as coffee, cashew nut, cereals, oilseed and grains for foreign earning (FAOSTAT, 2015). Grain export like the maize has a significant driving force for overall economic growth, increase farmers’ income and poverty reduction (Diao et al., 2013). However, maize in most parts of the country are contaminated with mycotoxins well above acceptable levels (TFDA, 2012), thus, possess’s greater economic losses and risk to agricultural export and trade.

In general, the economic consequences of mycotoxin contamination are profound (Leslie et al., 2008). The economic losses associated with mycotoxin have been reported by many authors, although most of them agreed, difficult to assess in a consistent and uniform way. As well as a general formula to quantify the economic impact of mycotoxin contamination (Dohlman, 2003; Zain, 2011). “Thus, most reports on the economic impact of mycotoxins are on a single aspect of mycotoxin exposure or contamination” (Hussein and Brasel, 2001). The Food and Agriculture Organization of the United Nations estimates around 25% of the world crops and up to 50% in developing countries are affected by mycotoxins each year (Miller, 1995). In the USA, the estimated crop losses from mycotoxins are about $932 million per year (CAST, 2003). Similarly, the estimated cost due to management and testing of mycotoxins in US ranged between $500 million-1.5 billion per year (Robens and Cardwell, 2003). Similarly, According to Hell (2004) estimated economic losses due to mycotoxins in Africa are around $670 million in terms of export per year.

Mycotoxins have a significant impact on economic and trade. The main criteria used to assess economic impact due to mycotoxins are categorized into five main groups; crop value
losses due to contamination, yield losses due to diseases, losses in animal productivity, 
human health costs, and cost due management and prevention (Schmale and Munkvold, 
2015). Plus, regulatory, and research costs related to mycotoxins (Hussein and Brasel, 2001). 
Other researchers categorized economic losses into two main groups: direct and indirect 
economic losses. Direct economic losses are those related to reducing crop yields for growers 
and animal performance (morbidity and mortality) and rejection of crops by the international 
market (PACA, 2013). While indirect economic losses are those costs related to reduce the 
marketable value of the product, and costs associated with monitoring, research, loss of 
consumer confidence and increased processing costs (PACA, 2013).

Further, the economic losses of mycotoxins have both domestic and international trade 
effects. In domestic, economic losses occur at all stages of the product value chain from the 
producers (farmers) to the final consumer (WHO, 2006). On the other hand, in the international 
market, products that exceed the maximum tolerance level of aflatoxin B₁ (mycotoxins) are 
either quarantines and confiscated at the port-of-entry, assigned a lower price or diverted to 
animal feeds (PACA, 2013).

**Strategies for prevention of mycotoxins in maize**

The strategies to reduce mycotoxins in maize can be grouped into two main categories: 
pre-harvest and post-harvest strategies, it also termed ‘primary’ or agricultural interventions. It is described as strategies or technologies that can be applied either in the field, drying, storage, transportation or processing to reduce mycotoxins contamination in maize (Wu and 
Khlangwiset, 2010).

**Pre-harvest strategies**

It is well established that most of the mycotoxin contamination of maize start in the field 
and continue during storage (Kabak et al., 2006). Thus, prevention at this stage is crucial to
prevent the development of mycotoxins during drying and storage (Strosnider et al., 2006). As cited by Magan and Aldred (2007) pre-harvest factors are critical for effective post-harvest prevention of mycotoxins from contaminated maize entering the food supply chain. Several strategies have been investigated to manage, prevent, and reduce mycotoxins contamination in crops include biological, chemical and cultural control practices (Cleveland et al., 2003; Kabak et al., 2006; Strosnider et al., 2006; Wu and Khlangwiset, 2010; Yin et al., 2008; Dorner, 2004; Brown et al; 1991a; Wagacha and Muthomi, 2008; Magan and Aldred, 2007).

**Biological control (BC):** it is considered a promising strategy for reducing mycotoxins contamination in maize. BC referred as the use of organisms to reduce the incidence of pests, diseases, or toxins (Wu and Khlangwiset, 2010). Strategies include the application of atoxigenic fungal strains and antagonistic microorganisms (bacteria and yeasts) (Cleveland et al., 2003). Atoxigenic applications rely upon the ability of atoxigenic strains to competitively exclude toxigenic strains from infecting the crop (Cleveland et al., 2003; Wu and Khlangwiset, 2010; Strosnider et al., 2006). Atoxigenic fungal strains include application of competitive nontoxigenic strains of *A. flavus* and/or *A. parasiticus* (Dorner, 2004; Yin et al., 2008; Brown et al., 1991a), AF36 (cottonseed), Afla-Guard™ (groundnuts) and AflaSafe™ (maize) (Wu and Khlangwiset, 2010; http://www.aatf-africa.org). A detailed review of biocontrol of mycotoxins can be found on Cleveland et al. (2003).

**Chemical control:** Another important factor which is known to increase the susceptibility of mycotoxins to crops, is damage due to insect pests and fungal contamination (Kabak et al., 2006; Magan et al., 2010). Revealed by Magan et al. (2003) that pre-harvest insect damage can lead to increased post-harvest production of mycotoxins in crops (Magan et al., 2003). Thus, insect damage and fungal infection must be controlled in the vicinity of the crop by proper application of insecticides and fungicides (Kabak et al., 2006). For instance, application of itraconazole and amphotericin B fungicides to control *Aspergillus* species (Wagacha and
Muthomi, 2008). Also, application of tridemorph on T-2 toxin and diacetoxyscirpenol (DAS) to inhibit growth and development of *F. sporotrichioides* in vitro (Pirgozliev et al., 2003).

**Cultural control:** CC are the practices designed to reduce mycotoxin contamination of crops have their roots in plant disease epidemiology (Munkvold, 2003). Cultural control strategies include crop rotation, tillage practices, appropriate application of fertilizers, weed control. As well as tillage practices, plant density, irrigation, insect control, planting, and harvesting dates, genotypes of seed planted, competitive exclusion and good agricultural practices (Wagacha and Muthomi, 2008; Munkvold, 2003; Pirgozliev et al., 2003; Strosnider et al., 2006). The main principles of cultural control is to alter the conditions under which the crop is grown so that infection by the offending fungus is avoided and discourage disease development (Munkvold, 2003; Battilani et al., 2008). However, many cultural practices require decisions to be taken before planting (Munkvold, 2003; Battilani et al., 2008).

In addition, other pre-harvest strategies include plant resistance to insects, integrated management programs, prevention of invasion of mycotoxigenic fungi through the incorporation of antifungal resistance into crops that comprised. Development of aflatoxin resistance screening assays, identification of resistance-associated proteins and natural products in corn, which inhibit *A. flavus* growth and aflatoxin contamination. Also, plant breeding strategies for enhancing resistance to mycotoxigenic fungi, genetic engineering strategies to enhance resistance in crops to mycotoxin contamination (Cleveland et al., 2003).

**Post-harvest strategies**

Post-harvest strategies for mycotoxins must be implemented to maintain proper storage conditions, including insect and mold control (Munkvold, 2003). Poor post-harvest management can lead to a growth of spoilage fungi, especially mycotoxigenic fungi as well as the rapid loss of maize quality (Aldred and Magan et al., 2004). Post-harvest strategies to reduce mycotoxins contamination include proper storage (hermetic storage), and drying
conditions, thermal treatment, grain milling, chemical treatment such as inactivation with ammoniation and ozonation, and adsorbents/binders. Other include minimize the time between harvesting and drying, sanitation, efficient dry to below 14 % moisture content, physical separation of damaged grains and processing such as dehulling (Jouany, 2007; Magan and Aldred, 2007; Lopez-Garcia et al., 1999; Suleiman et al., 2013). Table 9 summarized pre and post-harvest strategies to reduce mycotoxins in maize and other cereal grains.

Conclusion

Agriculture is the backbone of the Tanzanian national economy. It accounts for about one-third of the gross domestic product, provides 85 percent of all exports and saves as a livelihood to over 80 percent of the total population. Maize is a primary staple crop; it’s grown in nearly all agro-ecological zones in the country. Tanzania is a major maize producer in Sub-Saharan Africa. However, despite been the highest producer of maize in the EA region, post-harvest losses of maize remained significantly higher. Such loss often aggravated by inappropriate handling, poor storage facilities, insects, and other pests, and contamination by spoilage fungi. The major effects of fungi on maize are discoloration, reduce quality and contaminate maize with mycotoxins. Mycotoxins are toxic secondary metabolites of fungi that frequently contaminate the maize in the field and/or during storage. Mycotoxins contamination of maize poses a health risk to humans and domesticated animals if not properly managed because of their acute and chronic effects. The most important mycotoxins in maize are the Aflatoxins, Fumonisins, Deoxynivalenol, and Ochratoxin.

Furthermore, postharvest losses are a major factor negatively affecting smallholder farmers in Tanzania. The major constraints to maize production include pests (maize weevils and LGB), diseases, weeds, pathogens, and viruses. In addition, reducing PHL has positive consequences for society like poverty alleviation, increase food security, improving nutrition
status, and increases household income of smallholder farmer. Also, impacts on the environment, and reduces the utilization of production resources. The main strategies to reduce include things like improving varieties, harvest at the right time, and improve storage structures like metal silos, PICS bags. As well as improve drying efficiency, uses of moisture and temperature meters, proper hygiene and sanitation and access to market information.

Moreover, mycotoxins contamination of maize is considered the greatest public health threat due to their detrimental effects to human health. In addition, to health concerns, mycotoxins can restrict maize trade and limits the income of smallholder farmers, because of food safety concern and trade restrictions. The strategies to reduce mycotoxins in maize include pre-harvest and post-harvest strategies. Likewise, pre-harvest strategies include the application of atoxigenic fungal strains and antagonistic micro-organisms, crop rotation, tillage practices, appropriate application of fertilizers, weed control, irrigation, insect control, genotypes of seed planted. On the other hand, post-harvest strategies to reduce mycotoxins contamination include proper storage (hermetic storage), improve drying conditions and grain milling. Minimizes times between harvesting and drying, sanitation, efficient dry to below 14% moisture content and physical separation of damaged grains.
References


Bravo, J. (2009). Metal silos and food security. Lessons learned from a successful Central


FAO/GIEWS. (2014). Global information and early warning system on food and agriculture. GIEWS Country Brief- United Republic of Tanzania. Online; available at:


(CIMMYT). The United Republic of Tanzania, and the Southern African Center for Cooperation in Agricultural Research (SACCAR).


Peter, R., Pablo, P. R., & Maria, N. G. C. (2013). Global maize production, utilization, and consumption. PenaRosas, J. P; GarciaCasal, M. N; Pachon, H. (Eds.). In Technical


Tadious, T., & Bogale, T. (1994). Effect of different weed management methods on grain yield of maize in western Ethiopia (pp. 223-228). Mexico. CIMMYT.


grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers’ food security in developing countries. *Crop Protection* 30(3): 240-245.


Figures

**Figure 1.** Map of Tanzania (modified from Wikipedia).
Figure 2. Average monthly temperature and rainfall for Tanzania from 1900-2009 (www.worldbank.org/climateportal/index.cfm).
**Figure 3.** Tanzania maize crop calendar (WFP, 2010; FAO/GIEWS, 2014).
Figure 4. Maize production area in Tanzania (Cochrane and D'Souza, 2015).
Figure 5. Tanzania maize production, consumption and area harvested for 25 years (FAOSTAT, 2014; http://www.indexmundi.com).
**Figure 6.** Utilization of maize in Tanzania- average for 2012-2013 (FAOSTAT, 2014).
Figure 7. Postharvest losses pipeline for maize (Modified from Bourne, 1977 and Abass et al., 2014).
Figure 8. Pile of maize stored outside house (Source: https://busiweek.com/index)
Figure 9. Estimated percentage (%) weight losses of maize in Tanzania (2003-2012). (APHLIS, 2014).
Figure 10. African armyworms (www.lancaster.ac.uk).
Figure 11. Maize plants infected by MSD (Karavina, 2014).
Figure 12. The adult, larger grain borer, *Prostephanus truncatus* (Hon) http://www.infonet-biovision.org).
Figure 13. Distribution map of *P. truncatus* in Africa (www.cabi.org).
Figure 14. Adult maize weevil, *Sitophilus zeamais* (http://keys.lucidcentral.org).
Figure 15. Life cycle of maize weevil, *Sitophilus zeamais*.
Figure 16. Litters of multimammate shamba rat, *Mastomys natalensis* (http://www.biolib.cz).
Figure 17. Repaired postharvest losses leaky pipeline for maize (Authors).
Figure 18. PICS-schematic presentation of three plastic liners (Murdock and Baoua et al., 2014).
Figure 19. Oxygen and CO$_2$ concentration within PICS bags for 21 days (Murdock and Baoua et al., 2014).
**Figure 20.** Different GrainPro Super bags (www.grainpro.com).
Figure 21. GrainPro Cocoon™ and TransSafeliner™ (www.grainpro.com).
Figure 22. Different parts of metal silo.
Figure 23. The picture silo-bag hermetic storage system (INTA, 2014).
Figure 24. Chemical structures of aflatoxins B (B1 and B2), G (G1 and G2) and M1.
**Figure 25.** Chemical structures of Fumonisin B (B₁ and B₂).
Figure 26. Chemical structure of Ochratoxin A, B, and C.
Figure 27. Chemical structures of Type A, T-2 Toxin, and HT-2 Toxin.
Figure 28. Chemical structures of Type B, Nivalenol, and Deoxynivalenol.
Figure 29. Chemical structure of Type C and D.
Figure 30. Chemical structure of Deoxynivalenol.
Figure 31. Chemical structure of zearalenone.
Figure 32. Aflatoxin B₁ Contamination in Maize in Tanzania (TFDA, 2012).
Table 1. Top 25 world maize producing countries.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Production (million tons)</th>
<th>Yield (tons/acre)</th>
<th>Area harvested (million Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United States</td>
<td>367.68</td>
<td>12</td>
<td>33.63</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>271.00</td>
<td>6</td>
<td>36.80</td>
</tr>
<tr>
<td>3</td>
<td>Brazil</td>
<td>75.00</td>
<td>5</td>
<td>15.00</td>
</tr>
<tr>
<td>4</td>
<td>EU-27</td>
<td>71.02</td>
<td>7</td>
<td>9.57</td>
</tr>
<tr>
<td>5</td>
<td>Ukraine</td>
<td>25.00</td>
<td>5</td>
<td>4.60</td>
</tr>
<tr>
<td>6</td>
<td>Argentina</td>
<td>23.00</td>
<td>7</td>
<td>3.25</td>
</tr>
<tr>
<td>7</td>
<td>Mexico</td>
<td>22.50</td>
<td>3</td>
<td>6.90</td>
</tr>
<tr>
<td>8</td>
<td>India</td>
<td>21.00</td>
<td>2</td>
<td>8.60</td>
</tr>
<tr>
<td>9</td>
<td>South Africa</td>
<td>13.50</td>
<td>4</td>
<td>3.20</td>
</tr>
<tr>
<td>10</td>
<td>Russian Federation</td>
<td>12.00</td>
<td>5</td>
<td>2.60</td>
</tr>
<tr>
<td>11</td>
<td>Canada</td>
<td>11.50</td>
<td>9</td>
<td>1.25</td>
</tr>
<tr>
<td>12</td>
<td>Indonesia</td>
<td>0.92</td>
<td>3</td>
<td>3.12</td>
</tr>
<tr>
<td>13</td>
<td>Philippines</td>
<td>0.79</td>
<td>3</td>
<td>2.63</td>
</tr>
<tr>
<td>14</td>
<td>Nigeria</td>
<td>0.75</td>
<td>2</td>
<td>4.25</td>
</tr>
<tr>
<td>15</td>
<td>Serbia</td>
<td>0.69</td>
<td>0.9</td>
<td>1.28</td>
</tr>
<tr>
<td>16</td>
<td>Ethiopia</td>
<td>0.65</td>
<td>3</td>
<td>2.15</td>
</tr>
<tr>
<td>17</td>
<td>Egypt</td>
<td>0.58</td>
<td>8</td>
<td>0.71</td>
</tr>
<tr>
<td>18</td>
<td>Vietnam</td>
<td>0.54</td>
<td>5</td>
<td>1.20</td>
</tr>
<tr>
<td>19</td>
<td>Tanzania</td>
<td>0.50</td>
<td>1.5</td>
<td>4.00</td>
</tr>
<tr>
<td>20</td>
<td>Pakistan</td>
<td>0.50</td>
<td>4</td>
<td>1.14</td>
</tr>
<tr>
<td>21</td>
<td>Thailand</td>
<td>0.50</td>
<td>4</td>
<td>1.10</td>
</tr>
<tr>
<td>22</td>
<td>Turkey</td>
<td>0.46</td>
<td>8</td>
<td>0.55</td>
</tr>
<tr>
<td>23</td>
<td>Malawi</td>
<td>0.39</td>
<td>2</td>
<td>1.75</td>
</tr>
<tr>
<td>24</td>
<td>Zambia</td>
<td>0.34</td>
<td>3</td>
<td>1.21</td>
</tr>
<tr>
<td>25</td>
<td>Paraguay</td>
<td>0.31</td>
<td>4</td>
<td>0.70</td>
</tr>
</tbody>
</table>

FAOSTAT (2014) and indexmundi (2014).
Table 2. Common Field Pests of Maize in Tanzania.

<table>
<thead>
<tr>
<th>Insects</th>
<th>Scientific name</th>
<th>Agricultural zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize Stalk Borer</td>
<td><em>Busseola fusca</em></td>
<td>South Highlands, Lake, Northern,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Western, Eastern, Central</td>
</tr>
<tr>
<td>Africa armyworm</td>
<td><em>Spodoptera exempta</em></td>
<td>Northern, Western, Eastern, Central</td>
</tr>
<tr>
<td>Leaf hoppers</td>
<td><em>Cicadulina mbila</em></td>
<td></td>
</tr>
<tr>
<td>Mole crickets</td>
<td><em>Gryllotalpidae</em></td>
<td></td>
</tr>
<tr>
<td>Africa bollworm</td>
<td><em>Helicoverpa armigera</em></td>
<td>South Highlands</td>
</tr>
<tr>
<td>Cutworms</td>
<td><em>Agrotis ipsilon</em></td>
<td></td>
</tr>
<tr>
<td>Maize Stem Borer</td>
<td><em>Chilo Partellus</em></td>
<td>Northern</td>
</tr>
</tbody>
</table>

ASSP (2004)
# Table 3. Common weeds of maize in Tanzania.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Agricultural zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wild lettuce</td>
<td><em>Lactuca virosa</em></td>
<td>South Highlands, Lake, Northern, Western, Eastern, Central</td>
</tr>
<tr>
<td>Wandering Jew</td>
<td><em>Tradescantia pallid</em></td>
<td>Eastern, Central</td>
</tr>
<tr>
<td>Witch weed</td>
<td><em>Striga</em> spp.</td>
<td>Lake</td>
</tr>
<tr>
<td>Simama (Mbigili/Nyamwezi)</td>
<td><em>Oxygonum sinuatum</em></td>
<td>Lake</td>
</tr>
<tr>
<td>Bristly Starbur weeds</td>
<td><em>Acanthospermum hispidum</em></td>
<td>Lake,</td>
</tr>
<tr>
<td>Star grass</td>
<td><em>Heteranthera zosterifolia</em></td>
<td>Eastern,</td>
</tr>
<tr>
<td>Crabgrass</td>
<td><em>Digitaria</em> spp.</td>
<td>South Highlands</td>
</tr>
<tr>
<td>Mexican poppy</td>
<td><em>Argemone mexicana</em></td>
<td></td>
</tr>
</tbody>
</table>

ASSP (2004)
<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Agricultural zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize Streak Virus (MSV)</td>
<td></td>
<td>South Highlands, Lake,</td>
</tr>
<tr>
<td>Leaf rust</td>
<td><em>Puccinia sorghi</em> and <em>P. polysora</em></td>
<td>Northern, Lake,</td>
</tr>
<tr>
<td>Leaf blights</td>
<td><em>Helminthosporium turcicum</em> and <em>maydis</em></td>
<td>Lake, Northern,</td>
</tr>
<tr>
<td>Common smut</td>
<td><em>Ustilago maydis</em></td>
<td>Lake</td>
</tr>
<tr>
<td>Grey leaf spot</td>
<td><em>Cercospora zeae-maydis</em></td>
<td></td>
</tr>
<tr>
<td>Northern leaf blight</td>
<td><em>Exserohilum turcicum</em></td>
<td>South Highlands</td>
</tr>
</tbody>
</table>

ASSP (2004)
Table 5. Common Storage Pests of Maize in Tanzania.

<table>
<thead>
<tr>
<th>Insect species</th>
<th>Scientific name</th>
<th>Agricultural zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger grain borer (LGB)</td>
<td><em>Prostephums truncates</em></td>
<td>South Highlands, Lake, Northern, Western, Eastern, Central</td>
</tr>
<tr>
<td>Maize weevil</td>
<td><em>Sitophilus zeamais</em></td>
<td>South Highlands, Lake, Northern, Western, Eastern, Central</td>
</tr>
<tr>
<td>Red flour beetle</td>
<td><em>Tribolium castaneum</em></td>
<td>Lake</td>
</tr>
<tr>
<td>Dried bean beetle</td>
<td><em>Callosobruchus maculatus</em></td>
<td>Lake</td>
</tr>
<tr>
<td>Indian moths</td>
<td><em>Plodia interpunctella</em></td>
<td>Eastern, South Highlands</td>
</tr>
</tbody>
</table>

ASSP (2004)
### Table 6. Maximum acceptable limits of mycotoxins in maize for some selected countries.

<table>
<thead>
<tr>
<th>Countries</th>
<th>Maximum regulatory limits (μg/kg)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AFB1</td>
<td>AFB2</td>
</tr>
<tr>
<td>FAO/WHO (JECFA)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Australia/ New Zealand</td>
<td>15</td>
<td>0.5-5.0</td>
</tr>
<tr>
<td>Argentina</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Canada</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>EU</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Egypt</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Mozambique</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Nigeria</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td>700</td>
</tr>
</tbody>
</table>

Kimanya et al., 2010; Darwish et al., 2014; WHO, 1991
Suleiman et al., 2013; Vicam, 2010
Suleiman et al., 2013; Souza et al., 2013
Suleiman et al., 2013; Wu, 2007; Kubo, 2012
Suleiman et al., 2013; Kubo, 2012; Li et al., 2014
Garrido et al., 2012; Marin et al., 2013; Souza et al., 2013
Darwish et al., 2014
Suleiman et al., 2013; Kubo, 2012
Suleiman et al., 2013; Wu, 2007; Kubo, 2012
Suleiman et al., 2013
Warth et al., 2012
Suleiman et al., 2013; van Egmond, 1991
Ezekiel et al., 2012
Rai & Bai, 2014; Kubo, 2012; Zinedine et al., 2007
<table>
<thead>
<tr>
<th>Countries</th>
<th>AFB1</th>
<th>AFB2</th>
<th>AFG1</th>
<th>AFG2</th>
<th>FB1</th>
<th>FB2</th>
<th>FB3</th>
<th>DON</th>
<th>ZON</th>
<th>OTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>20</td>
<td>20</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1000</td>
<td>2-80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>5</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources:
- Suleiman et al., 2013;
- Roben & Cardwell, 2003;
- Marasa et al., 2008;
- Wu, 2007;
- Kubo, 2012;
- Rai & Bai, 2014
- Lewis et al., 2005
- TFDA, 2012;
- Kimanya et al., 2010
Table 7. Food intake at different AFB1 levels of contamination and risk of liver cancer (cancers per 100,000 population).

<table>
<thead>
<tr>
<th>AFB1 (ng/g)</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.014</td>
<td>0.069</td>
<td>0.14</td>
<td>0.21</td>
<td>0.28</td>
<td>0.55</td>
</tr>
<tr>
<td>2</td>
<td>0.028</td>
<td>0.14</td>
<td>0.28</td>
<td>0.41</td>
<td>0.55</td>
<td>1.1</td>
</tr>
<tr>
<td>5</td>
<td>0.069</td>
<td>0.34</td>
<td>0.69</td>
<td>1</td>
<td>1.4</td>
<td>2.8</td>
</tr>
<tr>
<td>10</td>
<td>0.14</td>
<td>0.69</td>
<td>1.4</td>
<td>2.1</td>
<td>2.8</td>
<td>5.5</td>
</tr>
<tr>
<td>20</td>
<td>0.28</td>
<td>1.4</td>
<td>2.8</td>
<td>4.1</td>
<td>5.5</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>0.69</td>
<td>3.4</td>
<td>6.9</td>
<td>10</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>100</td>
<td>1.4</td>
<td>6.9</td>
<td>14</td>
<td>21</td>
<td>28</td>
<td>55</td>
</tr>
</tbody>
</table>

Note: The shaded area represents region of risk in excess of 1 per 100,000 (Adapted from Shephard, 2008b).
Table 8. Relationships between food intake (maize) and fumonisin contamination.

<table>
<thead>
<tr>
<th>FB (µg/g)</th>
<th>Maize intake (g/60 kg person/day)</th>
<th>10</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>1.4</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>0.4</td>
<td>0.8</td>
<td>1.3</td>
<td>1.7</td>
<td>3.4</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.2</td>
<td>0.8</td>
<td>1.7</td>
<td>2.5</td>
<td>3.3</td>
<td>6.6</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>1.7</td>
<td>1.3</td>
<td>5.0</td>
<td>6.7</td>
<td>13</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>2.5</td>
<td>5.0</td>
<td>7.5</td>
<td>10</td>
<td>20</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.7</td>
<td>3.3</td>
<td>6.7</td>
<td>10</td>
<td>13</td>
<td>27</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>4.2</td>
<td>8.3</td>
<td>13</td>
<td>17</td>
<td>33</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.7</td>
<td>8.3</td>
<td>17</td>
<td>25</td>
<td>33</td>
<td>67</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Note: white area = Provisional Maximum Tolerable Daily Intake (PMTDI) - tolerable daily intake levels; lightly shaded area = risk of hepatocarcinogenicity; Medium shaded region = risk of nephrotoxicity; Dark shaded region = above maximum PMTDI tolerable daily intake levels (Adapted from Marasas et al., 2008).
Table 9. Summary of pre and post-harvest control strategies to reduce mycotoxins in maize.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-harvest</td>
<td>Choice of suitable cultivars</td>
</tr>
<tr>
<td></td>
<td>Timing of planting and crop planted</td>
</tr>
<tr>
<td></td>
<td>Field management: Soil cultivation, Irrigation, crop rotation, fertilization.</td>
</tr>
<tr>
<td></td>
<td>Transgenic or conventional breeding for resistance</td>
</tr>
<tr>
<td></td>
<td>Competitive exclusion</td>
</tr>
<tr>
<td></td>
<td>Biocontrol</td>
</tr>
<tr>
<td></td>
<td>Time of harvest</td>
</tr>
<tr>
<td></td>
<td>Chemical control (insecticides, fungicides)</td>
</tr>
<tr>
<td></td>
<td>Good agricultural practices (GAPs)</td>
</tr>
<tr>
<td></td>
<td>Antioxidants (caffeic acid, gallic acid)</td>
</tr>
<tr>
<td>Post-harvest</td>
<td>Cleaning</td>
</tr>
<tr>
<td></td>
<td>Sorting and segregation</td>
</tr>
<tr>
<td></td>
<td>Improved storage (hermetic storage)</td>
</tr>
<tr>
<td></td>
<td>Improved drying (solar drying) and transportation</td>
</tr>
<tr>
<td></td>
<td>Chemical control (insecticides, fungicides)</td>
</tr>
<tr>
<td></td>
<td>Processing; Crushing, Dehulling, Nixtamalization, Acidification, Chemoprotectant, Ammoniation</td>
</tr>
</tbody>
</table>