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The roles of mycotoxins in cereal crops production: A comparative study of Hungary and Tanzania

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SUMMARY

Although Hungary and Tanzania's climatic, soil, and technological conditions differ significantly in crop production, cereals crop cultivation is of paramount importance; maize crop dominates the cultivated area (Hungary 1 million ha, Tanzania 3 million ha) both from a feed and food point of view. Unfortunately, in both countries, fungal species (Fusaria, Aspergilli, Penicillia, etc.) that produce various mycotoxins on cereals, including maize grains, are a growing concern. The situation is complicated because these fungal species and their toxins can appear not only on cereals but also on other crops. Despite the prevalence of mycotoxins in both countries, studies show higher exposure risks and contamination above tolerable levels for human consumption in Tanzania to Hungary, with Tanzania observing acute aflatoxicosis.

Keywords: *Mycotoxicosis, toxin-producing fungi, mycotoxin contamination, cereals*

INTRODUCTION

Mycotoxins are secondary metabolites produced by several fungal species and/or molds having adverse effects on humans, animals, and crops that result in illnesses and economic losses (Kumar et al., 2021; Zain, 2011). They may cause poisoning resulting in varied health problems from acute to chronic mycotoxicosis in animals and humans (Omotayo et al., 2019). They are worldwide natural contaminants of foods and agricultural products throughout their production chains (Rajarajan et al., 2013; Munkvold et al., 2019; Kumar et al., 2021). Mycotoxins contaminate several foods and/or feeds, including cereals (e.g., maize, wheat, barley, rice, oats, and sorghum); tubers notably (cassava, yam chips), and oilseeds (e.g., sunflower seed, groundnuts, cottonseed, and other nuts). Other commodities are coffee, some spices (ginger, turmeric, peppers); some vegetables, fruits and sugarcane juice, dried fruits as well as livestock by-products (Tóth et al., 2012; Frisvad et al., 2018; Munkvold et al., 2019; Abdallah et al., 2020; Benkerroum, 2020).

Mycotoxin contaminations occur because of fungal infestation and/or infection of crops. Streit et al. (2012) suggested that the contamination may be due to saprophytic fungi before harvest or endophytic fungi during storage after harvest. Thus, mycotoxin contamination is a complex process instigating in the field as fungal propagules from crop debris and soil infect the crop (Massomo, 2020). With the subjection to a conducive environment favouring fungal growth, the contamination extends during crop growth in the field, during harvest after crop maturation as well as during storage where, even new infections may occur, and the contamination levels may rise to when crop produces are ultimately consumed (Massomo, 2020).

Aspergilli, Fusaria, and *Penicillia* are major mycotoxigenic fungi genera amongst the mycotoxin-producing genera (Darwish et al., 2014; Pinton and Oswald, 2014; Eskola et al., 2020; Munkvold et al., 2019; Kumar et al., 2021). More than 300 different mycotoxins are currently identified (Berthiller et al., 2007) since the first mycotoxicosis in the UK in 1960, where over 100,000 turkeys were affected (Pitt, 2013). Moulds may produce one or more types of mycotoxins and/or some mycotoxins produced by more than one genera and/or species of fungi inter and intra genera, respectively (Kumar et al., 2021; Omotayo et al., 2019). They produce five mycotoxins or groups that commonly occur quite often contaminating cereals, namely, *aflatoxins, ochratoxin A, fumonisins, zearalenone,* and *trichothecenes,* mainly *deoxynivalenol* and T-2 (Desjardins and Proctor, 2007; Pinton and Oswald, 2014; Tola and Kebede, 2016; Omotayo et al., 2019). FAO estimates that 25% of the world's agricultural products are contaminated by mycotoxins (Park et al., 1999). However, a recent study by Eskola et al. (2020) revealed 60% and 80% contamination of deoxynivalenol and zearalenone mycotoxins to foods and feeds collected from various countries, raising uncertainty to the frequently cited FAO estimates. This opens a way for more investigation of current actual estimates of various mycotoxins contaminations in agricultural commodities. This review summarises the roles of mycotoxins in Hungary and Tanzania cereal crops production.

Major mycotoxins of cereals

The mentioned five mycotoxin groups (*aflatoxins, ochratoxin A, fumonisins, zearalenone,* and *trichothecenes,* mainly *deoxynivalenol* and T-2) have extensively been studied and documented by many researchers. Briefly, **aflatoxins** are produced mainly by *Aspergillus spp.* with over 18 distinct types discovered; however, there are four major types: aflatoxin **B1, B2, G1, and G2,** named based on the colour emitted in exposure to UV light (Green or Blue). aflatoxin B1 and B2 and aflatoxin G1 and G2 can be metabolised in the liver to form toxic metabolites of aflatoxin **M1 and M2** and aflatoxins **GM1 and GM2,** respectively. The

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metabolised aflatoxins are detected in animal products such as milk, eggs (Bennett et al., 2007; Marin et al., 2013; Pitt and Miller, 2017; Frisvad et al., 2019; Benkerroum, 2019; Munkvold et al., 2019; Benkerroum, 2020; Pfliegler et al., 2020). Ochratoxin A (OTA) is produced by both *Aspergillus* and *Penicillium* genera. There are about 20 other metabolites related to OTA being identified. However, the most significant are ochratoxin B (OTB), C (OTC), α (Otα), and β (OTβ) (Bui-Klimke and Wu., 2015; El Khoury and Atoui, 2010). fumonisins, trichothecenes, and zearalenone are major mycotoxins produced by Fusaria (D'Mello et al., 1999). They may cause numerous acute and chronic mycotoxicosis in humans (Antonissen et al., 2014). The genera are classified as field fungi since they contaminate food crops before harvest (Chilaka et al., 2017). *Fusarium species* produce trichothecenes that consist of a large family of compounds, of which deoxynivalenol (DON), T-2 toxin, nivalenol, and diacetoxyscirpenol are most important in cereal grains. DON and T-2 toxins have been most intensely related to humans and animals' acute and chronic toxicoses through inhibition of ribosomal protein synthesis mechanism (Desjardins and Proctor, 2007). fumonisin toxins recognised to be produced mainly by *Fusarium verticillioides* (Szécsi, et al., 2010*)*, are separated into four main groups as A, B, C, and P series; however, fumonisins B (FBs) comprised of FB1, FB2, and FB3 is the highly toxic group with FB1 predominating and contributing between 70–80% of the total fumonisins produced (Rheeder et al., 2002). Zearalenone is not acutely toxic and has not been associated with any fatal mycotoxicoses in humans or animals, although they have been associated with estrogenic syndromes in swine, experimental animals (Desjardins and Proctor, 2007; Massart and Saggese, 2010; Yiannikouris et al., 2003; Bennett and Klich, 2003), and in premature telarche patients (Szuets et al., 1997).

Global distribution of mycotoxins

The distribution of mycotoxins in the world agricultural commodities indicates significant geographical variation of disease severity, pathogen species composition, prevalent toxins, and options for management despite the commonalities in diseases and mycotoxins (Logrieco et al., 2021). They occur in temperate and tropical regions of the world; however, the effect of the problem is more significant in tropics and sub-tropics regions (Munkvold et al., 2019; Suleiman et al., 2013) between 40° North and 40° South of the equator (Suleiman and Kurt, 2015). The drives for the variations include geographical locations, climatic conditions, management practices, and resource availability (Adeyeye, 2016; Logrieco et al., 2021). *Fusarium* mycotoxins are considered important in cereals grown in the temperate climate regions (Mesterhazy et al., 2012; Tima et al., 2016; Munkvold et al., 2019). *Aspergillus* mycotoxins are dominant in the tropical and subtropical regions (Magnoli et al., 2007; Mesterhazy et al., 2012). They occur in warm environments and produce aflatoxins in drought-stressed maize and groundnuts in the field (Bhat and Miller, 1991), while *Penicillium* ochratoxin A dominates in cereals in the colder climatic conditions revealed by Lund and Frisvad (2003) in the northern parts of Europe. However, with climatic conditions, various factors interdependently affect the colonisation of fungi and, subsequently, the production of mycotoxins (Tola and Kebede, 2016; Zain, 2011).

Mycotoxin contamination in Tanzania

Agriculture is the main driver of Tanzania's economy, accounting for roughly 25 per cent of the country's GDP and employs more than 75 per cent of the labour force. The sector is also an essential source of export revenues on its major agricultural commodities such as coffee, cashew nut, cereals, and oilseed for foreign earning (FAOSTAT, 2022). Cereal crops are the major staple contributing over 50% of household calories, with maize occupying 41%, rice 11%, sorghum, and millet 3%, and wheat/other grains contributing 1%. (Cochrane and D'Souza, 2015). Cereals, mainly maize, are essential components of complementary foods for infants and young children (Kimanya et al., 2010). However, cereals are widely prone to mycotoxin contamination; Maize contamination is considered the highest public health hazard due to their harmful effects on human health in the country (Kimanya et al., 2014; Boni et al., 2021), as well as constraining maize trade and limiting the income of smallholder farmers due to trade restrictions on food safety concern (WHO, 2006). The crop is widely grown on more than 3 million hectares (*Figure 1*) in all 26 regions of mainland Tanzania mainly by smallholder farmers in the rural areas (Degraeve et al., 2016). The estimated daily maize consumption is 308 g per capita, equivalent to 112 kg annually per capita (Mboya et al., 2011).

Tanzania observes many mycotoxins from various fungi genera such as deoxynivalenol (DON), ochratoxin, zearalenone, HT-2, and T-2 (Kimanya et al., 2014; Kamala et al., 2015). However, frequently and often encountered mycotoxins are aflatoxins and fumonisins, and aflatoxins in contaminated maize were reported causing significant mycotoxicosis cases (Kimanya et al., 2010; Kamala et al., 2018; Massomo, 2020; Boni et al., 2021).

According to the economic assessment conducted by the Tanzania Food and Drugs Authority (TFDA) in Suleiman and Kurt (2015), AFB1 prevalence was reported above 5 ppb maximum acceptable limits for maize grain set by the Tanzania Bureau of Standards (TBS) in maize grain from multiple regions of the country as *Figure 2* indicates (TFDA, 2012). The results are supported by the recent survey by Boni et al. (2021) that detected the average lowest and highest AFB1 of 12.7 and 162.4, and 6.37 and 40.31 ppb AFB1 contaminated maize and groundnuts, respectively, collected from nine districts in the country. The study further indicates AFB1 prevalence of 10–80% and 92–100% for the maize and groundnuts samples, respectively, implying high mycotoxins exposure to the population, which may result in both acute and chronic mycotoxicosis incidences.

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Figure 1: **Area harvested cereals in Tanzania from 1999–2019 (FAOSTAT, 2022)**

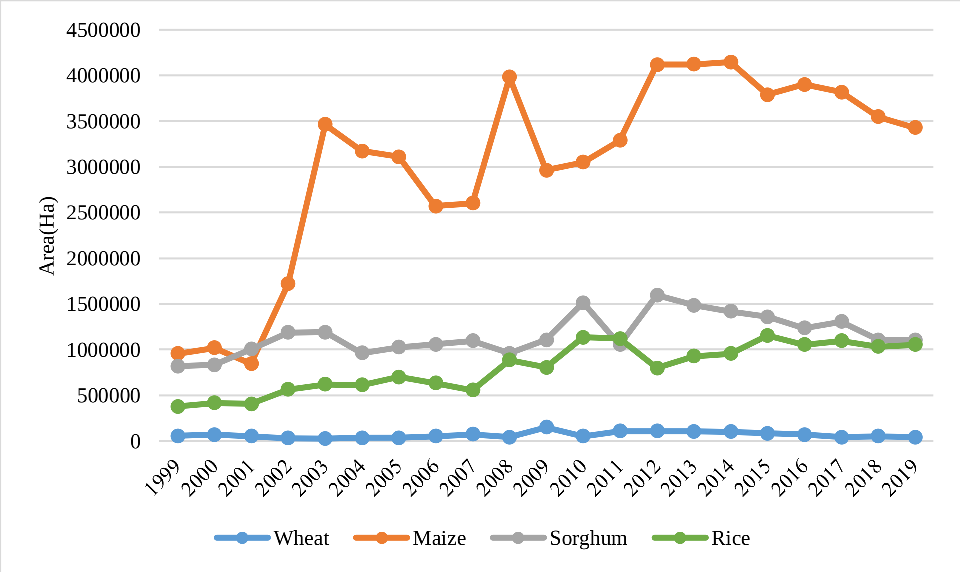
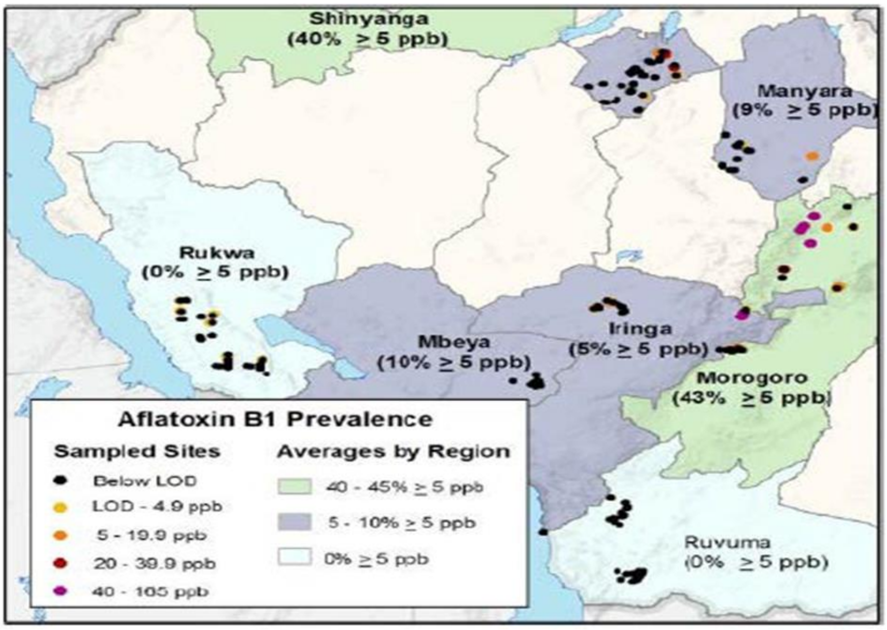


Figure 2: **Occurrence of mycotoxins in Tanzania (TFDA, 2012)**



Acute mycotoxicosis due to consumption of mycotoxins contaminated maize-associated food has been recorded in India, Kenya, and most recently in Tanzania. Krishnamachari et al. (1975) reported the occurrence of aflatoxicosis in western India in Rajasthan-Gujarat in 1974, where 397 cases caused 106 deaths. In Kenya, 137 deaths occurred from 337 patients where Ngindu et al. (1982) reported 12 deaths from 20 cases, and the most significant aflatoxicosis incidence happened in 2004, where 317 cases caused 125 deaths (Lewis et al., 2005; Gieseker and CDC, 2004) both incidences in East-Central Kenya.

Although there are limited studies on mycotoxins in Tanzania, the presentation of studies for mycotoxins in agricultural commodities in Tanzania, mainly maize related foods, cassava, and peanuts for the last 50 years mainly took place from the late 2000s and focuses on exposure and risks assessment and prevalence and contaminations levels. The studies list documenting mycotoxins' exposure and risk assessments in Tanzania for 50 years includes Kimanya et al., 2014, 2021; Mollay et al., 2021; Kamala et al., 2018; Chen et al., 2018; Geary et al., 2016; Magembe et al., 2016; Magoha et al., 2016; Gong et al., 2015; Shirima et al., 2013, 2015; Magoha et al., 2014; and Mboya et al., 2011. On the other hand, studies documenting mycotoxin contamination in maize related foods and other important food in Tanzania for 50 years includes

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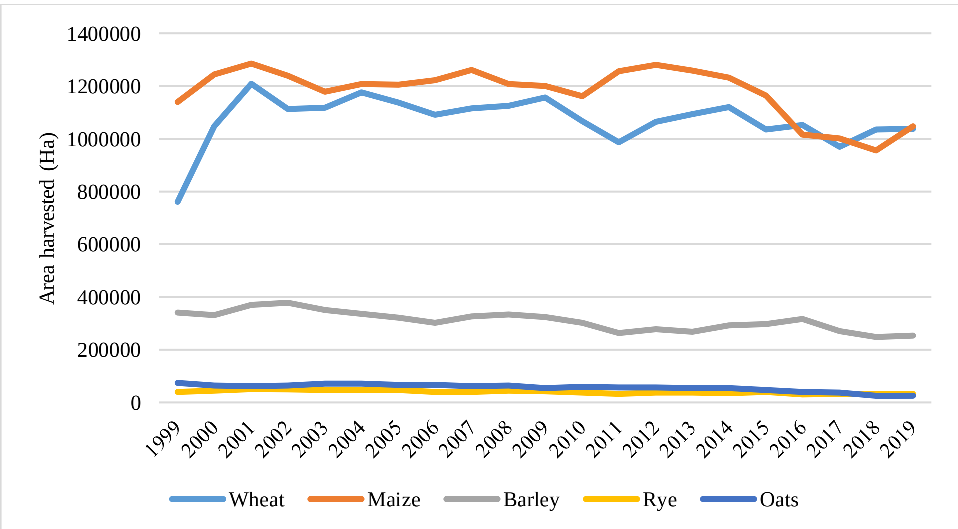
Boni et al., 2021; Massomo, 2020; Mtega et al., 2020; Sasamalo et al., 2018; Kuhumba et al., 2018; Seetha et al., 2017; Suleiman et al., 2017; Magembe et al., 2016; Nyangi et al., 2016; Kamala et al., 2016; Degraeve et al., 2016; Shabani et al., 2015; Kamala et al., 2015; Sulyok et al., 2015; Mboya and Bogale 2012; Manjula et al., 2009; and Kimanya et al., 2008. Mycotoxin exposure is proved by the incidence of current acute aflatoxicosis that caused the death of 20 people from 68 cases in central Tanzania in 2016, where above 50% of the cases affected individuals below the age of 15 years (Kamala et al., 2018).

There are insufficient studies on the management practices for reducing mycotoxin contamination in the country pre-harvest and postharvest, raising a need for suitable testing practices. However, currently, the International Institute for Tropical Agriculture (IITA) conducted widespread field trials on the efficacy of non-toxigenic *Aspergilli* (Aflasafe TZ01), which revealed a reduction of aflatoxin on maize and groundnut by over 85% to levels that are fit for human consumption in Morogoro, Dodoma, Manyara and Mtwara regions (Massomo, 2020). Additionally, a field evaluation of aflatoxin resistance in maize inbred lines and commercial varieties grown under different fertiliser regimes was conducted (Manoza et al., 2017), which indicated no significant differences among the fertiliser regimes; however, hybrids impacted a significant reduction. The occurrence of acute mycotoxicosis and the prevalence of mycotoxins contaminations level above the tolerable levels in cereals which presents main staples for human consumption and/or animals throughout the country, calls for urgent actions in monitoring and establishing practices (integrated practices) for reducing contamination to tolerable levels).

Prevalence of mycotoxins producing fungi and mycotoxins contamination in Hungarian cereals

Mycotoxins in Hungarian agricultural commodities, their impacts and management practices, and the risk assessments have been extensively studied. Studies reveal incidences of mycotoxins from various fungi genera contaminating cereals, mainly *Fusaria*, *Aspergilli*, and *Penicillia* prevailing in Hungary; however, practices for management of mycotoxins to reduce the levels to tolerable levels are utilised such as breeding for resistance varieties (Mesterhazy et al., 2012) and the preharvest and postharvest management practices. Maize and wheat are the main cereal produced in Hungary after barley and oats (*Figure 3*). The Hungarian climate is temperate, with cold, humid winters and warm summers (Csima and Horányi, 2008). The climate characteristics are favourable for the prevalence of *Fusarium* toxins, essentially trichothecenes, zearalenone, and fumonisins, which are regarded as the most significant in cereals in temperates; however, mycotoxins produced by *Aspergilli* and *Penicillia* are also frequently identified in different cereal products (Lasztity et al., 1977; Borbély et al., 2010; Dobolyi et al., 2011; Tóth et al., 2012). The prevalence of *Aspergillus* fungi and the associated toxins believed to predominate in tropics and subtropics might have been influenced by climatic changes factors (Miraglia et al., 2008)

Figure 3: **Area harvested cereals in Hungary from 1999–2019 (KSH, 2022)**



As an EU member, Hungary uses the EU limits for mycotoxins in food and feeds. In cereals, 4 ppb total aflatoxin content, 5 ppb is the ochratoxin limit for unprocessed cereals and 3 ppb for cereal foodstuffs for direct human consumption. For fumonisins, 4000 ppb for unprocessed maize and 200 ppb for foods intended for infants and children are maximum limits, respectively (Tóth et al., 2012; Mazumder and Sasmal, 2001).

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Current studies determine the presence of mycotoxins in cereals in Hungary. However, the levels of toxins in cereal processed foods and feeds are often below the maximum tolerable levels. The study by Tima et al. (2016) indicates the presence of mycotoxins in maize, wheat, barley, and oats food and feeds from Győr-Moson-Sopron, Komárom-Esztergom, Somogy, Tolna, and Baranya Counties from 116 samples. Investigating the presence of ***Fusarium*** mycotoxins DON, T-2, and HT-2, the study results were below the recommended limits for *Fusarium* mycotoxins intended for use as food and feed (*Table 1*) except four samples of maize in which two samples indicated a higher concentration of T-2 as well as one sample of wheat which showed 1880 ppb, higher than maximum limits of 1750 ppb recommended. Investigating the presence of DON and ZEN in Hungary between 2003 and 2008, Búza and Marth-Schill (2010) also revealed 6.5% and 1.1% DON and ZEN contaminated 123 and 92 tested cereal samples, respectively, in a range of 0.500–1.000 ppb in 2005. However, the range was 8.5% for DON and 1.8% in 2008, with T-2 toxin indicating 94.6% and 75% of the tested grain samples (2003: 147, 2008: 12) below limits of quantification (LOQ) in 2003 and 2008.

Table 1: **Maximum limits and recommended levels (ppb of *Fusarium* mycotoxins in unprocessed cereals intended for use as food and feed components (at 12.5% moisture content)**

Mycotoxin	Cereals	Food	Feed
DON	Maize	1750	8000
	Barley	1250	
ZEN	Wheat	100	2000
	Maize	350	
T-2 and HT-2	Wheat	100	500
	Barley	200	

Adopted from Tima et al., 2016

A recent survey by Zentai et al., 2019, examining the presence of fumonisins in 326 samples from Hungarian maize-based foods indicates the toxin presence by 26.5% varying in maize flour, maize grits, corn flakes, and other maize-based snacks in the levels below limits of detections to all samples.

Aspergillus and *Penicillium* mycotoxins are also identified in Hungarian cereals. Tóth et al. (2012) examined *Aspergilli* and *Penicillia* genera and their mycotoxins in Hungarian maize for two consecutive years. fumonisins B1 and B2 were detected in amounts above the EU limit in some samples from various regions (4.66 ppb; 10.15 ppb; 5.13 ppb; 7.55 ppb) in 2010. Another survey by Kocsčubé et al. (2013) and Szigeti et al. (2012) in southern Hungary indicated the presence of *Aspergillus flavus* isolates in various cereal samples, including maize, wheat, and barley which were able to produce aflatoxins, though in levels below EU limits.

Nearly each of the cereals most frequently cultivated in Hungary used for animal and human feeding, collected from different parts of the country revealed a certain percentage is contaminated with the important mycotoxins produced by either toxigenic *Fusaria*, *Aspergilli*, and/or *Penicillia*, mostly in lower levels. This alarms for more precautions to be taken in monitoring the toxins levels in commodities.

Mycotoxins economic aspects

Mycotoxins have a significant impact on the economy and trade. Many researchers have reported the economic losses associated with mycotoxin. However, most of them stated a difficult to evaluate consistently and uniformly and/or a general formula to quantify the economic impact of mycotoxin contamination (Dohlman, 2003; Zain, 2011). Schmale and Munkvold (2009) categorised five main groups for assessing mycotoxins' economic impacts as (1) crop value losses due to contamination, (2) yield losses due to diseases, (3) losses in animal productivity, (4) human health costs, and (5) cost due management and prevention as well as regulatory, and research costs related to mycotoxins. Some studies group economic losses into direct and indirect economic losses. The strategy for prevention and control of mycotoxins in Africa (PACA, 2013) explains direct losses related to reducing crop yields for growers and animal performance considering morbidity and mortality and rejection of crops by the international market. It further explains indirect losses as those expenses associated with marketability and reduction of the market value of the product, costs associated with research, monitoring, loss of consumer confidence, and increased processing costs. Additionally, the losses result in domestic and international trade effects. Domestically, losses occur throughout the product value chain from farmers as producers to consumers (WHO, 2006), whereas the international market results in rejection, quarantines, and/or confiscation at the port of entry for products that exceed the maximum tolerable levels of mycotoxins or products intended for food be diverted to animal feeds and assigned lower prices.

CONCLUSIONS

Associating the risks of mycotoxins contamination in Hungarian and Tanzanian situations, research on various aspects of mycotoxins and the associated impacts is far explored in Hungary, which has resulted in mycotoxins contamination incidences under levels which are tolerable for human and animals' consumption with few cases above the limits. On the other hand, the risks of exposure are higher in Tanzania as the incidences of mycotoxins contamination in cereal samples from various parts of the country are reported above the maximum tolerable levels. From a research point of view, Tanzania lacks sufficient tested practices countrywide in establishing suitable integrated approaches for reducing contamination pre-harvest, during harvest and post-harvest. Therefore, Tanzania needs to focus on implementing and/or applying the various ways to reduce the contamination and regulate the mycotoxins levels to tolerable amounts

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taking some lessons from Hungary. On the other hand, the prevalence of the toxins below tolerable levels in Hungarian cereals signifies food safety and health risks, therefore monitoring of the levels remains of paramount importance as the production of the toxin may be enhanced by many factors such as the changing climate to levels above limits.

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