Review of the Global Regulations and Assessment of the Exposure Risk of Aflatoxin Contamination in Spices from Tanzania

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ABSTRACT

Spices such as ginger, cinnamon, cardamom, black pepper, and chillies are important cash crops and culinary ingredients in Tanzania, valued for their flavour and health benefits. However, they also pose food safety risks due to potential aflatoxin contamination. This study reviewed existing aflatoxin regulations and assessed the contribution of spices to aflatoxin exposure by analysing contamination levels reported in both published and unpublished sources, comparing them against established Maximum Limits (MLs). A deterministic model was applied to estimate adult exposure based on average spice consumption and a standard body weight of 60 kg. Findings revealed that black pepper and chillies had the highest aflatoxin B1 concentrations, reaching up to 164 μg/kg, although most samples remained below the 5 μg/kg ML for aflatoxin B1. Estimated dietary exposure ranged from 0.01 to 13.74 ng/kg body weight/day, lower than exposure from maize-based foods, yet exceeding the European safety threshold of 0.04 ng/kg bw/day in certain cases, suggesting potential health risks such as hepatocellular carcinoma. While spices contribute less to overall aflatoxin exposure due to their lower consumption volumes compared to staples like maize and groundnuts, their frequent use in Tanzanian diets warrants targeted mitigation efforts. The study underscores the need for improved post-harvest handling practices, including proper drying, sorting, and storage, alongside stricter regulatory enforcement to enhance food safety. Continued surveillance and risk-based interventions are recommended to minimise aflatoxin exposure and support both public health and the growth of Tanzania's spice industry.

Keywords: Spices, Mycotoxins, Aflatoxins, Exposure, Contamination

INTRODUCTION

Tanzania was ranked third among the Least Developed Countries (LDCs) between 1995 and 1999, contributing 5% of LDCs' total spice exports (Maerere and Noort, 2014). The important spices in Tanzania include clove, turmeric, black pepper, ginger, cardamom, cinnamon, chillies, coriander, lemon grass, nutmeg and vanilla (Maerere and Noort, 2014). These spices are important not only as a cash crop but also for their uses in Tanzania's households. Spices are used as flavouring agents, aroma enhancers, and for their nutritional and health benefits, which include antioxidant, anti-inflammatory, antitumorigenic, anticarcinogenic, and glucose and cholesterol-lowering activities, as well as properties that affect cognition and mood (Jiang, 2019). The diverse range of health properties that spices possess via their bioactive constituents, including sulphur-containing compounds, tannins, alkaloids, phenolic diterpenes, and vitamins, especially flavonoids and polyphenols, has been reported by several researchers over the past decade (Jiang, 2019). However, studies have reported contamination of spices and herbs in Tanzania and other countries by various mycotoxins, including aflatoxin (Fundikira et al., 2020; Ahmed and Asghar, 2021; Gabriel, 2021).

Aflatoxins are the most potent toxin among other mycotoxins. They are mainly found in four types: aflatoxin B1, aflatoxin B2, aflatoxin G1 and aflatoxin G2. Aflatoxins are the metabolites of fungi, specifically, *Aspergillus flavus* and *Aspergillus parasiticus* (Bhat et al., 2010). Different types of foods are infested by aflatoxin-producing fungi and contaminated with aflatoxins. It is reported that approximately 25% of the world's food crops are infested each year with fungi (Atanda et al., 2011).

The health impact of aflatoxin exposure is primarily determined by two factors: the level of contamination in food (measured in micrograms per kilogram, µg/kg) and the amount of food consumed daily (kilograms per day), making exposure a direct function of both contamination and consumption levels. The adverse health effects of aflatoxins, resulting from the consumption of highly contaminated food over a short period, can lead to a condition known as acute aflatoxicosis, a life-threatening condition characterised by acute liver damage, jaundice, and potentially death. In contrast, chronic aflatoxicosis arises from the prolonged ingestion of food containing moderate levels of aflatoxins, and it has been extensively associated with liver cancer, stunted growth in children and immunological effects (IARC, 2002). Whereas acute aflatoxicosis results in direct liver damage and several deaths. The International Agency for Research on Cancer (IARC) classified aflatoxins in group 1: ''carcinogenic to humans''. There is also a strong synergy between aflatoxin exposure and the hepatitis B (HBV) virus and the hepatitis C virus (HCV) for liver cancer. Several cases of acute aflatoxicosis have occurred, resulting in several deaths in different countries like Malaysia (Lye et al., 1995), Kenya (Shephard, 2008) and Tanzania (Kamala et al., 2018).

In Tanzania, aflatoxin contamination in food has been widely studied and reported mainly for maize and groundnut, which are known to be prone to aflatoxin (Kimanya et al, 2014; Kamala et al., 2016; Magoha et al., 2016; Massomo, 2020). An aflatoxicosis outbreak was reported in

Tanzania in 2016 (Kamala et al., 2018) caused by the consumption of contaminated maize. In humans, aflatoxins were shown to retard both in-utero and postnatal growth (Gong et al., 2002; Turner et al., 2007; Magoha, 2014), and higher levels of AF-alb in maternal blood were significantly associated with lower weight and height gain (Gong et al., 2004). While extensive studies and documentation have been done on aflatoxin contamination in maize and groundnuts, there is limited information regarding aflatoxin contamination in spices in Tanzania. Estimating individual spice intake is challenging, as spices are typically used as integrated components of prepared foods and consumed in much smaller quantities than other dietary elements (Siruguri and Bhat, 2015). One study conducted in India assessed spice consumption by measuring: (i) the amount of spices added to routinely prepared dishes, and (ii) the portion of the prepared dish consumed by an individual. The results showed that chillies had the highest intake (mean: 3.0 g; range: 0.05– 20.2 g), while nutmeg had the lowest (mean: 0.14 g; range: 0.02–0.64 g). Overall, average spice intake was found to be higher through dishes consumed daily, with an average of 10.4 g per portion (Siruguri and Bhat, 2015).

Numerous studies have documented aflatoxin contamination in spices, with some samples exceeding the permissible limits set by regulatory authorities, thereby raising significant concerns about food safety (Zahra et al., 2018; Pickova et al., 2020). In Tanzania, Mkupasi and Peter (2025) analysed 120 spice samples, including black pepper, cinnamon, cloves, and turmeric and reported that 24.2% were contaminated with aflatoxins. Black pepper

exhibited the highest concentration at 164.86 µg/kg, far above the national safety threshold. Regulatory limits for aflatoxins in spices differ across countries, reflecting varying approaches to food safety and public health protection. In the United States, the Food and Drug Administration (FDA) sets the maximum allowable level of total aflatoxins in food commodities, including spices, at 20 µg/kg. The European Union, under Commission Regulation (EC) No 1881/2006, enforces stricter limits: 5 µg/kg for aflatoxin B1 and 10 µg/kg for the sum of aflatoxins B1, B2, G1, and G2 in spices. In India, the Food Safety and Standards Authority of India (FSSAI) has established a maximum limit of 30 µg/kg for total aflatoxins in spices, as per the Food Safety and Standards (Contaminants, Toxins and Residues) Regulations. Tanzania's limit for aflatoxins in spices is set at 5 µg/kg for aflatoxin B1 and 10 µg/kg for total aflatoxins. These differences highlight the need for harmonised international standards, especially given the global trade of spices and the health risks posed by chronic aflatoxin exposure. These findings underscore the need for enhanced monitoring and regulatory enforcement to ensure the safety of spice products in global markets. This paper aimed to review the existing regulations of aflatoxins in spices and assess the exposure risk associated with aflatoxin contamination in Tanzanian spices.

METHODOLOGY
Review of Policy and Regulatory Limits on Aflatoxin in Spices
A systematic review of literature and policy documents was conducted to assess current regulatory limits for aflatoxins in spices worldwide. The search strategy for

this review was informed by a review of literature sources and relevant search terms. Time frame for available literature sources and language is as detailed below.

Academic databases such as PubMed, ScienceDirect, and Google Scholar were revisited. The time frame for reviewed literature ranged from 2010 and 2025, covering both published and unpublished articles related to aflatoxin contamination in spices. Keywords included "aflatoxin limits in spices," "aflatoxin regulations by country," "mycotoxin contamination in spices," and "food safety standards for aflatoxins." Studies were selected based on their relevance to aflatoxin contamination levels, regulatory frameworks, and cross-country comparisons, ensuring the inclusion of authoritative scientific and regulatory sources.

The review of regulatory frameworks focused on extracting information on the maximum limits (MLs) for different types of aflatoxins, including B1, B2, G1, G2, and total aflatoxins, in spices across various regions such as those covered by Codex, the European Union, the United States FDA, India's FSSAI, China's GB standards, and selected African regulations. Identification of the most recent aflatoxin limits involved reviewing the official websites of national and international food safety authorities

Specifically, these included the Tanzania Bureau of Standards (TBS), East African Community (EAC), European Union's Commission Regulation (EC) No. 1881/2006, the U.S. FDA guidelines under the Food, Drug, and Cosmetic Act, India's FSSAI regulations, and international standards from Codex Alimentarius. This multi-source approach provided a broad understanding of the global regulatory landscape for spice safety.

Prevalence Data for Aflatoxin Contamination in Spices

The prevalence data on aflatoxin contamination were obtained from surveillance studies that reported contamination levels in spices. Key information extracted from these studies included the sample size, country of origin, spice type, and both mean and maximum contamination levels were recorded to provide a comprehensive overview of aflatoxin occurrence in spices within Tanzania.

Selection of the Type of Spice Consumption Data

Within the East African Community (EAC), it is generally assumed that consumption levels are comparable across different types of spices. Based on this assumption, uniform maximum limits for aflatoxin contamination have been established, specifically, 5 μg/kg for aflatoxin B1 and 10 μg/kg for total aflatoxins applicable to all spice varieties. Consequently, this review includes all spices that have been reported and analysed for aflatoxin contamination, ensuring a comprehensive assessment aligned with the regional regulatory framework.

Assessment of the Risk of Aflatoxin Exposure in Tanzania

Aflatoxin exposure was calculated by using the deterministic approach, as described by Magoha et al. (2016). Briefly, aflatoxin contamination levels reported were used to estimate the exposure levels for an adult person; 60 kg bw; default average body weight- FAO/WHO (WHO, 2020), which

was based on the world average daily per capita spice consumption of 5g as estimated from the annual average consumption of 1.69 kg per person reported by Global Trade (2020).

RESULTS AND DISCUSSION
Regulatory Standards for Aflatoxin in Spices

Aflatoxins and other naturally occurring toxins present significant challenges to food safety and food security worldwide. To mitigate their harmful effects on human and animal health, regulatory authorities have established Maximum Limits (MLs) for aflatoxins in various food products, including spices. However, these limits vary across countries due to differences in agricultural practices, processing methods, climatic conditions, and risk assessment approaches.

In Tanzania, the MLs for aflatoxins in spices are set at 5 μg/kg for aflatoxin B1 and 10 μg/kg for total aflatoxins. These thresholds are stipulated in national and regional standards, including TZS 46:2021/EAS 917:2019 for turmeric; TZS 47:2021/EAS 916:2019 for ginger; and TZS 31:2021 for chillies and capsicum (whole and ground). Notably, there is currently no harmonised East African Community (EAC) aflatoxin limit specifically for chillies. The same aflatoxin limits are applied to other food commodities in Tanzania, such as maize grain (TZS 438:2017/EAS 2:2017), milled maize products (TZS 328-1:2020/EAS 44:2019), raw and roasted groundnuts (TZS 740:2018/EAS 888:2018), and peanut butter (TZS 844:2014, 2nd Edition/EAS 60:2013). However, maize is consumed in bulk, and even low levels of aflatoxin contamination can pose a significant health risk over time. In contrast, spices, though still vulnerable to contamination, are consumed in trace amounts, which may reduce the cumulative exposure risk.

As illustrated in Table 1, aflatoxin limits vary considerably across countries, with some limits reaching as high as 30 μg/kg. This variation highlights the importance of critically evaluating the current limits established in Tanzania. During the 15th session of the Codex Committee on Contaminants in Foods (CCCF), held from May 9 to 24, 2022, a proposed limit of 20 ppb for aflatoxins in dried chillies, paprika, nutmeg, turmeric, and ginger was discussed. This highlights the need for Tanzania to conduct a thorough assessment not only to align with international standards and enhance trade competitiveness, but also to ensure consistent and effective protection of consumer health across borders.

The variation in aflatoxin regulatory limits across countries presents both a challenge and an opportunity for Tanzania. Although the country has demonstrated a strong commitment to public health protection through the establishment of maximum aflatoxin limits, these thresholds may hinder cross-border trade and complicate compliance for exporters. Given the global nature of food markets, a critical evaluation of Tanzania's current aflatoxin limits is necessary to ensure they are scientifically justified, risk-based, and aligned with international benchmarks.

Table 1

Aflatoxin maximum limit for spices per country

Country	Commodities	Maximum acceptable limits (µg/kg)	
		AFB1	Total aflatoxin AFB1+AFB2+AFG1+AFG2
United States (FDA & FAO)	All foods	—	20
EU	Spices	5	10
Bulgaria	Spices	2	5
Croatia	Spices	15	30
Brazil	Spices	—	20
China	Spices	5	—
Czech Republic	Spices	20	—
Finland	All Spices	—	20
Indonesia	Spices powder	5	15
Brazil	Spices	20	30
India	All foods	30	—
Turkey	Spices	10	—
Iceland	All Spices	30	—
Iran	Spices	5	10
Republic of South Africa	All foods	5	10
Australia	All foods	—	5
Uruguay	All Spices	5	20
Hong Kong	All foods	—	15
Malaysia	All foods	—	35
Japan	All foods	10	—
New Zealand	All foods	—	5
Sri Lanka	All foods	—	30
Pakistan	Selected Spices	—	30

Source: Ahmed and Asghar (2021).

An Overview of Spice Production in Tanzania

Spices and herbs (which include turmeric, ginger, black pepper, chilli, paprika, cumin, cardamom, cloves, cinnamon and many others) are commonly consumed in small amounts as flavouring agents in food. The consumption of herbs and spices has increased in the world (Ivanišová et al., 2021), possibly due to their higher nutritional value and health benefits compared to other common food plants. Most spices act as sources of bioactive compounds which provide a pleasant taste, aroma and colours in several dishes. Some have medicinal and health-related effects that are associated with their nutritional composition, such as the presence of vitamins and bioactive compounds, such as

phenolic, anthocyanins, flavonoids, and tannins, among others. These compounds can have antihypertensive, anti-inflammatory, antioxidant (anticancer), and antimicrobial (antibiotic) properties (Jiang 2019; Ivanišová et al., 2021). Spence (2024) detailed the importance of black pepper (Piper nigrum Linn) in food. Despite their health benefits, some spices have been reported to contain aflatoxigenic fungi and aflatoxins, though the information behind their risks to human health is limited.

Tanzania's climate and soil conditions are very suitable for the production of various spices, including clove, turmeric, black pepper, ginger, cardamom, cinnamon, chillies, coriander, lemon grass, nutmeg,

and vanilla. A comprehensive list of spices produced in Tanzania is presented in Table 2 (Maerere and Noort, 2014). The main spices-producing regions include Tanga, Morogoro, Zanzibar, Pemba, Mbeya, Kilimanjaro, Kigoma, Ruvuma, Singida, Iringa and Coast regions (Maerere and Noort, 2014). The amount produced depended on the type of spice and the season of the year (Maerere and Noort, 2014).

The spice production data in Tanzania, presented in Table 3, provide annual figures from 2014 to 2019. Total spice production has also varied annually. These fluctuations can be attributed to a combination of agronomic, environmental, economic, policy-related, and external factors. Agronomic drivers include weather variability and climate shocks, pest and disease pressures, limited adoption of high-yielding varieties, and irregular access to agricultural inputs. Environmental factors such as declining soil fertility, constraints in water availability, and changes in land use also affect yields and the area under cultivation. According to FAOSTAT (2020), spice cultivation and trade increased between 2014 and 2020 (Table 3). The most widely produced spices during this period were chillies and peppers, with an annual average of 15,277 tons, followed by cloves (8,628 tons) and garlic (6,243 tons). While ginger has shown a general upward trend in production, other spices have exhibited fluctuations over the years.

Different regions in the country produce different types of spices due to agroecological characteristics such as altitude, temperature, humidity and rainfall. Clove, pepper, cardamom and cinnamon are mainly produced in Tanga and Morogoro regions, as well as in Zanzibar and Pemba islands. Zanzibar and Pemba are the main areas for the production of clove (Akyoo and Lazaro, 2007). Production of cloves for commercial purposes in mainland Tanzania, particularly in Tanga and Morogoro regions, is a recent development. Cardamom and cinnamon are also found in the Mbeya region. In the Kilimanjaro region, cardamom is also grown. Turmeric is mainly grown in Morogoro, and the main market is India. Ginger is grown in Kilimanjaro, Kigoma, Ruvuma and Morogoro regions, in that order of importance. Ginger is mainly marketed locally and in neighbouring countries. Some production is also done in Kagera and Mbeya regions. Vanilla is produced mainly in Kagera and Kilimanjaro regions, and to some extent in the Morogoro region. Chillies, including paprika, are important spices produced in Iringa, Mbeya, Arusha, Tanga, Coast, Morogoro regions and Zanzibar. Chillies' main market is India. Coriander is almost entirely produced in the Singida region in central Tanzania. Generally, due to lower land pressure on the mainland, farm sizes for spices are relatively bigger than in the islands, thus providing for the critical volumes needed for trading (Akyoo and Lazaro, 2007).

Spice production in the country is largely characterised by poor agronomic practices, primarily relying on traditional smallholder farming methods. Key challenges include improper plant spacing, lack of soil fertility management, inadequate soil conservation measures, and the absence of irrigation and drainage systems. Additionally, some agronomic practices are crop-specific but are often not effectively implemented.

Overall, pest problems have been minimal on most spices. Nevertheless, some incidences such as insect damage on cinnamon leaves, dieback in clove, wilting and premature shedding of spikes in pepper have been observed in some areas (Maerere and Noort, 2014). While conventional farmers typically sell their produce in a dried form, drying is often done improperly. The produce is just spread on the bare ground; thus, the risk of microbial contamination is very high (Akyoo and Lazaro, 2007). Addressing these issues is essential to improve quality, meet safety standards, and unlock the country's full trade potential.

Table 2
List of Spices Produced in Tanzania

SN	Common name	Scientific name	Family name	Main part(s) used)
Spice plants				
1	Black Pepper	*Piper nigrum*	Piperaceae	Berries (fruits)
2	Ginger	*Zingiber officinale*	Zingiberaceae	Rhizomes
3	Cardamom	*Elettaria cardamomum*	Zingiberaceae	Capsules (pods/fruits)
4	Chives	*Allium schoenoprasum*	Amaryllidaceae	Bulb
5	Garlic	*Allium sativum*	Amaryllidaceae	Cloves
6	Shallot	*Allium cepa var. aggregatum*	Amaryllidaceae	Bulb
7	Leeks	*Allium porrum*	Amaryllidaceae	Leaves
8	Other Alliums	*Allium* spp.	Amaryllidaceae	Leaves/bulb
9	Chillies and Paprika	*Capsicum* spp.	Solanaceae	Fruits
10	Nutmeg	*Myristica fragrans*	Myristicaceae	Nut and Mace
11	Vanilla	*Vanilla planifolia*	Orchidaceae	Pods
12	Turmeric	*Curcuma longa*	Zingiberaceae	Rhizomes
13	Celery	*Apium graveolens*	Apiaceae	Leaves
14	Fennel	*Foeniculum vulgare*	Apiaceae	Leaves
15	Mints	*Mentha* spp.	Lamiaceae	Leaves
16	Lemon Verbena	*Aloysia citrodora*	Verbenaceae	Leaves
17	Saffron	*Crocus sativus*	Iridaceae	Power stigma
18	Sage	*Salvia officinalis*	Lamiaceae	Leaves
Spices and essential oil sources				
19	Clove	*Syzygium aromaticum* L.	Myrtaceae	Flower buds and stems
20	Cinnamon	*Cinnamomum zeylanicum* Nees	Lauraceae	Barks and leaves
21	Coriander	*Coriandrum sativum*	Apiaceae	Seeds and leaves
22	Lemon Grass	*Cymbopogon spp.*	Poaceae	Leaves
23	Parsley	*Petroselinum crispum*	Apiaceae	Leaves
24	Dill	*Anethum graveolens*	Apiaceae	Seed and leaves
25	Rosemary	*Rosmarinus officinalis*	Lamiaceae	Leaves
26	Basil	*Ocimum basilicum*	Lamiaceae	Leaves
Plants for the extraction of essential oils				
27	Citrus	*Citrus spp.*	Rutaceae	Fruit
28	Ylang Ylang	*Cananga odorata*	Annonaceae	Flowers
29	Jasmine	*Jasminum spp.*	Oleaceae	Flowers
30	Eucalyptus	*Eucalyptus spp.*	Myrtaceae	Leaves and barks
31	Geranium	*Geranium spp.*	Geraniaceae	Leaves and flowers

Source: Extracted from Maerere and Noort, 2014

Table 3
Spice production data for Tanzania*

Commodity	Annual Production Volume (Tons)							Total	Annual Average
	2014	2015	2016	2017	2018	2019	2020		
Anise, badian, coriander, cumin, caraway, fennel and juniper berries	1,309	1,371	1,293	1,324	1,330	1,316	1,323	9,266	*1,323.71*
Chillies and peppers, dry (*Capsicum spp., Pimenta spp.*), raw	7,242	7,369	7,191	7,204	7,255	7,217	7,225	50,703	*7,243.29*
Chillies and peppers, green (*Capsicum spp. and Pimenta spp.*)	14,809	16,024	14,944	15,259	15,409	15,204	15,291	106,940	*15,277.14*
Cloves (whole stems), raw	8,735	9,044	8,210	8,663	8,639	8,504	8,602	60,397	*8,628.14*
Ginger, raw	307	382	500	812	1,148	2,000	1,879	7,028	*1,004.00*
Green garlic	7,032	5,483	6,190	6,468	6,047	6,235	6,250	43,705	*6,243.57*
Nutmeg, mace, cardamom, raw	742	758	773	773	720	709	721	5,196	*742.29*
Black Pepper (*Piper spp.*), raw	398	502	433	445	460	446	450	3,134	*447.71*
								-	-
Total	**40,574**	**40,933**	**39,534**	**40,948**	**41,008**	**41,631**	**41,741**	**286,369**	*40,909.86*

https://www.fao.org/faostat/en/#data/QCL
*Only spices of interest were selected

An Overview of the Status of Aflatoxin Contamination in Tanzania Spices

In Tanzania, there is limited data regarding mycotoxin contamination of spices. Few studies reviewed in this assignment indicated the prevalence of aflatoxins in spices, though the contamination levels are not as high as those reported in maize and groundnuts. A study conducted by Ali (2018) on the levels of aflatoxins in spices produced and/or marketed in Zanzibar and Dar es Salaam indicated that 24 (33%) out of 72 samples (25 cinnamon, 16 ginger, 20 cloves and 11 mixed spices) analysed were found to be contaminated with aflatoxin B1. However, did not exceed 5 µg/kg. The study observed further that 53 samples (73.6%) were contaminated by aflatoxin, with only 2 samples exceeding the maximum limit of 10 µg/kg (national regulatory maximum limit for total aflatoxin). There was no significant difference between the total aflatoxin contamination levels of spice samples collected from Zanzibar and those collected from Dar es Salaam.

The results from various studies are presented in Table 4. Fundikira et al. (2020) indicated the prevalence of aflatoxin contamination in 57.5% of 120 samples analysed. For ginger specifically, the aflatoxin contamination ranged from 0.18-9.66 µg/kg for aflatoxin B1 and 0.55-9.66 µg/kg for total aflatoxin. Fundikira et al. (2020) report showed that the prevalence of aflatoxin B1 (the most potent toxin) was high in clove (63%) and ginger (40%) (Table 4). The study conducted by Gabriel (2021) observed the prevalence of aflatoxin in 24% of 120 samples collected, whereby 12% were contaminated with aflatoxin B1. Turmeric had the lowest contamination, aflatoxin B1 was not found in turmeric samples, and only 3% had total aflatoxin. The same year, the assessment of mycotoxin contamination conducted in ginger indicated that 70.6% of the samples analysed were positive for total aflatoxin, all were below 10 µg/kg, the Tanzania limit for total aflatoxin (Mkenda et al, 2021).

Aflatoxin situational analysis conducted in Zanzibar through the TANIPAC project under the Ministry of Agriculture involved

analysis of turmeric and black pepper in addition to maize, groundnuts and rice. Results in spices reported aflatoxin contamination in only one sample of turmeric out of 21 samples, with a concentration level of 3.5 μg/kg. In comparison, black pepper was highly contaminated. Forty-eight (48%) of the samples were positive for aflatoxin B1 with a range of 3.9 - 11.9 μg/kg, and 88% were contaminated with total aflatoxin with a range of 8.7 – 25.1 μg/kg. Twenty-five per cent and 63% of black pepper samples exceeded the regulatory limit for aflatoxin B1 and aflatoxin total, respectively (Kimanya, 2021), as shown in Table 4.

A recent study conducted by Magoha (2023) using spice samples collected from the big five markets in Dar es Salaam, which act as aggregation points of spice samples from various regions of Tanzania, including Morogoro, Mwanza, Kilimanjaro and Tanga, indicated aflatoxin contamination in ginger, turmeric and chilli at different levels. The prevalence of aflatoxins was high in chilli (66.7%) compared to ginger (23%) and turmeric (56.7%). Only one sample of ginger and turmeric exceeded 5 μg/kg for aflatoxin B1, while for chilli, 7 (23.3%) samples exceeded that limit. Only one (1) sample (3.3%) exceeded the limit for total aflatoxin in ginger, 4 samples (13.3%) for turmeric and 7 samples (23.3%) for chilli. The maximum limits used are those stipulated in the standards documents (TZS 46:2021/EAS 917:2019 for turmeric; TZS 47:2021/EAS 916:2019 for ginger, and TZS 31:2021 for chillies and capsicum whole and ground).

Table 4

Aflatoxin contamination in spices in Tanzania

Spices	Sample analysed	Aflatoxin B1			Total aflatoxin			Reference
		Positive sample n; (%)	Samples exceeding the limit n; (%)	Range (µg/kg)	Positive samples n; (%)	Samples exceeding the limit n; (%)	Range (µg/kg)	
Cinnamon	30	8; (26.7)	1; (12.5)	0.39 - 11.2	13; (43.3)	1; (7.7)	0.13-11.2	Fundikira S. S. et al., 2020
Cloves	30	19; (63.3)	1; (5.3)	0.15 – 11.2	21; (70.0)	1 (4.8)	0.16-11.2	
Ginger	30	12; (40.0)	2; (16.7)	0.18 - 9.66	17; (56.7)	0 (0.0)	0.55-9.66	
Cardamom	30	10; (33.3)	2; (20.0)	0.23 - 7.20	18; (60.0)	2 (11.1)	0.23-11.9	
Total spices	**120**	**49; (40.8)**	**6; (5.0)**	**0.15 - 11.2**	**69 (57.5)**	**4: (3.3)**	**0.13 – 11.9**	
Turmeric	30	0; (0.0)	0;(0.0)	NA	1; (3.3)	1; (3.3)	NA	Peter Gabriel Lilian, SUA, 2021
Cinnamon	30	5; (16.7)	5; (16.7)	10.33 - 26.94	7; (23.3)	6; (20.0)	3.85 - 109.85	
Cloves	30	6; (20.0)	4; (13.3)	0.58 – 147.49	15; (50.0)	7; (23.3)	0.201 – 147.49	
Black pepper	30	3; (10.0)	2; (6.7)	3.38 – 164.86	6; (20.0)	2; (6.7)	118.11 - 164.86	
Total spices	**120**	**14; (11.7)**	**11; (9.2)**	**0.58 – 164.86**	**29; (24.2)**	**16; (13.3)**	**0.2-164.86**	
Black pepper	25	12; (48.0)	NA; (25.0)	3.9 – 11.9	22; (88.0)	NA; (63.0)	8.7 – 25.1	Kimanya, 2021
Ginger	17	NA	NA	NA	12; (70.6)	0.(0.0)	1.60 – 4.48	Mkenda et al., 2021
Ginger	30		1; (3.3)	0.80 – 6.15	7; (23.0)	1; (3.3)	0.80 – 11.99	Magoha, 2023
Turmeric	30		1; (3.3)	0.45 – 5.28	17; (56.7)	4; (13.3)	0.37 - 97.37	
Chilli	30		7; (23.3)	0.50 – 90.60	20; (66.7)	7; (23.3)	0.50 – 150.70	
Total spices	**90**		**9; (10.0)**	**0.45 – 90.60**	**44; (49%)**	**12; (13.3)**	**0.37 – 150.70**	

NA – Not available

The occurrence of aflatoxins in spices is not only a challenge in Tanzania but also in other countries. A study by Ahmed et al. (2021) highlighted that chilli, red, and black peppers were more contaminated with aflatoxins compared to other spices in countries such as India, Pakistan, Turkey, Iran, Bangladesh, Indonesia, and Nigeria, similar to the findings from Tanzania. This might be caused by the high moisture content in chilli during harvesting (Ambrose et al., 2024), which makes the chilli have a conducive environment for fungal growth. However, Ahmed et al. (2021) also suggest that spices such as ginger, turmeric, clove, cinnamon, garlic, and cumin, which have antifungal and anti-toxigenic properties, tend to maintain lower levels of aflatoxin contamination. Further studies in other countries corroborate the presence of aflatoxins in spices. In Punjab, Pakistan, Iqbal et al. (2013) found varying levels of aflatoxin contamination in samples collected from open markets and restaurants, some of which exceeded the European Union limits of 5 μg/kg for aflatoxin B1 and 10 μg/kg for total aflatoxins. Similarly, a study in Sri Lanka by Yogendrarajah et al. (2014) suggested a public health risk due to the co-occurrence of mycotoxins in spices, signalling significant safety concerns. Jacxsens et al. (2016) reported that chilli samples in Sri Lanka were more frequently contaminated with mycotoxins (87%) than pepper samples (65%). Additionally, Santos et al. (2011) reported the co-occurrence of aflatoxin and other mycotoxins such as ochratoxin A, zearalenone, deoxynivalenol, and T2 in Capsicum powder samples, highlighting the complex nature of mycotoxin contamination in spices.

Among various spices, chilli pepper has been repeatedly reported as a major source of aflatoxin contamination. Khazaeli et al. (2017) found a 100% contamination rate for red pepper in Iran, further emphasising the widespread nature of this issue. In Tanzania, elevated levels of aflatoxin contamination in spices are largely attributed to poor handling practices across the entire value chain. Common post-harvest issues, such as drying spices directly on bare soil and storing them in poorly ventilated or humid environments, create ideal conditions for the proliferation of aflatoxigenic fungi, thereby increasing the risk of aflatoxin production (Maerere & Noort, 2014). Environmental factors, including high humidity and moderate temperatures, further exacerbate fungal growth (Bhat et al., 2010). As a tropical country, Tanzania experiences climatic conditions that align closely with these risk factors. Notably, chilli peppers, which are typically harvested with a moisture content of approximately 80% (wet basis), are especially susceptible to fungal colonisation and subsequent mycotoxin development if not properly dried and stored. Studies on chilli drying highlight the importance of reducing moisture content to 10–12% (wet basis) to prevent aflatoxin contamination and ensure the safety of the spice for both domestic consumption and export markets (Ambrose et al., 2024). Thus, further research into effective and efficient drying methods is crucial to safeguard spice quality.

While the contamination levels in spices such as black pepper, ginger, and cloves are concerning, they are generally lower than those observed in other commonly consumed food crops such as maize and groundnuts in Tanzania (AU-PACA, 2016).

For example, the highest aflatoxin contamination level observed in this review was 164 µg/kg for black pepper. In contrast, Gichohi-Wainaina et al. (2023) reported much higher levels in groundnuts (up to 1512 µg/kg) and maize flour (346 µg/kg). Despite this, the contamination rate in black pepper (63% of samples exceeding the total aflatoxin limit) remains alarmingly high and poses a significant risk to the export value of Tanzanian spices. This is particularly concerning since stringent limits on aflatoxins in international trade could lead to rejection of affected shipments. Black pepper, often referred to as the "king of spices," is widely valued for its antimicrobial and anti-carcinogenic properties, as well as its characteristic pungency, making it a popular ingredient in many cuisines globally (Spencer, 2024). Thus, maintaining its safety from contamination is essential to preserve both public health and its economic value in international markets.

Referring to the aflatoxin contamination maximum limits (MLs) presented in Table 1 for various countries, it is notable that both India and Iceland have set the MLs for aflatoxin B1 in spices at 30 µg/kg. If Tanzania adopted a similar threshold, the rejection rate of its spice exports would likely be significantly reduced. Fundikira et al. (2020) reported aflatoxin B1 contamination levels ranging from 0.13 to 11.2 µg/kg in Tanzanian spices, with all samples falling well below the 30 µg/kg limit. Similarly, studies by Kimanya (2021) and Mkenda et al. (2021) also documented contamination levels below this threshold. These findings suggest that the current ML may be unnecessarily restrictive and could hinder trade opportunities. Therefore, regulatory authorities such as the Tanzania Bureau of Standards (TBS), in collaboration with food scientists and trade experts, should consider reviewing and potentially revising the national ML for aflatoxin B1 in spices. Such a revision would not compromise food safety, given the low contamination levels observed, and could enhance Tanzania's competitiveness in regional and international spice markets.

It should be stressed that regulatory limits alone are insufficient to eliminate exposure to aflatoxin and other mycotoxins, particularly in African countries like Tanzania, where regulations are not strictly enforced in local markets. The majority of people use spices directly from harvest, processing them traditionally without quality assessment measures. This poses a significant risk of microbial contamination, including aflatoxin-producing fungi. However, as Iha & Trucksess (2019) noted, there is no single best strategy for eliminating aflatoxin contamination and exposure in spices. It is crucial to prevent fungal growth and mycotoxin development at every stage in the value chain: pre-harvest, harvest, post-harvest, storage, transportation, and packaging. Pre-harvest strategies should include aflatoxin-smart agricultural practices such as selecting fungal-resistant cultivars and applying appropriate pesticides, fertilisers, and irrigation. In addition, good harvest and post-harvest control are essential to prevent increased mycotoxin levels in spices. It is important to avoid physical damage to the bark (e.g., cinnamon), seeds (e.g., cumin), pods (e.g., peppers), roots (e.g., ginger, turmeric), and leaves (e.g., bay leaf) of spice plants, whether caused by harvesting equipment or insect infestation. Drying should occur immediately after cleaning, as moisture is critical for fungal growth;

spices should be dried as quickly as possible to a moisture level close to 10% to avoid fungal proliferation. Ground drying should be avoided. Storage facilities and transport vehicles should be cool, dry, and insect-free. Spices are hygroscopic and can interact with moisture in the air; humid, warm air promotes fungal growth and mycotoxin production (Iha & Trucksess, 2019).

Furthermore, to effectively prevent aflatoxin contamination in spices in Tanzania, it is essential to promote and implement comprehensive codes of practice for aflatoxin control. These should include targeted awareness campaigns for traders and consumers to increase understanding of aflatoxin risks and safe handling practices. Improving post-harvest management, particularly drying, sorting, and storage, is critical to minimising moisture levels and inhibiting mould growth (Kamala et al., 2018b). Additionally, maintaining strict hygiene standards during processing and packaging can significantly reduce contamination risks. Finally, the development and

enforcement of regulatory limits, led by the Tanzania Bureau of Standards (TBS), will help ensure compliance and safeguard public health while supporting the integrity of Tanzania's spice industry.

Aflatoxin Exposure Through Spices

Exposure to aflatoxins through consumption of spices is estimated using the lowest and highest contamination levels as reported by each author (Table 4). A deterministic approach for an adult person (60kg bw), with consumption of approximately 5g/ day (Global Trade, 2020), this is the highest consumption level reported in India. No information regarding consumption levels has been reported in Tanzania. It is a fact that the intake of spices in India is high compared to Tanzania. In this regard, exposure for lower intakes of 1g per day was also computed. The trend of aflatoxin exposure through spices is presented in Table 5. The estimated exposure levels obtained from lower and higher intake, ranging from 0.01 to 13.74 ng/kg bw/day (Table 5), are considerably lower than the exposure levels reported in maize-based foods in Tanzania.

Table 5

The trend of aflatoxin B1 exposure through spices

Reference	Spice	Low aflatoxin B1 contamination level reported (ng/g)	Low aflatoxin exposure[1] (ng/kg bw/day)	Low aflatoxin exposure[2] (ng/kg bw/day)	High aflatoxin B1 contamination level reported (ng/g)	High aflatoxin exposure[1] (ng/kg bw/day)	High aflatoxin exposure[2] (ng/kg bw/day)
Fundikira S. S. et al., 2020	Cinnamon	0.39	0.03	0.01	11.2	0.93	0.19
	Cloves	0.15	0.01	0.00	11.2	0.93	0.19
	Ginger	0.18	0.02	0.00	9.66	0.81	0.16
	Cardamom	0.23	0.02	0.00	7.2	0.60	0.12
Peter Gabriel Lilian, SUA, 2021	Cinnamon	10.33	0.86	0.17	26.94	2.25	0.45
	Cloves	0.58	0.05	0.01	147.49	12.29	2.46
	Black pepper	3.38	0.28	0.06	164.86	13.74	2.75
Kimanya, 2021	Black pepper	3.9	0.33	0.07	11.9	0.99	0.20
Magoha, 2023	Ginger	0.8	0.07	0.01	6.15	0.51	0.10
	Turmeric	0.45	0.04	0.01	5.28	0.44	0.09
	Chilli	0.5	0.04	0.01	90.6	7.55	1.51

Exposure[1]: Exposure calculated by the intake level of spices of 5.0 g/day
Exposure[2]: Exposure estimated by the intake level of spices of 1.0 g/day

The average consumption level of maize reported in Tanzania is up to 450g per day, with exposure levels of up to 786 ng/kg bw/day from maize-based foods for children of two years (Kimanya et al., 2014). Magoha et al 2014 reported infants' exposure to aflatoxin from maize-based flour of up to 120 ng/ kg bw/day. This implies that aflatoxin exposure through spices does not constitute a significant public health problem in Tanzania as compared to the situation observed in the consumption of aflatoxin-contaminated maize. The results indicate further that consuming 1.0g/day may lead to low exposure to aflatoxin, except for black pepper and cinnamon, which had exposure above 0.04 ng/ kg bw/day. The exposure is regarded as a serious health problem only if it exceeds 0.04 ng/kg bw/day (EFSA 2020).

As previously noted, frequent exposure to low levels of aflatoxins can result in chronic health effects. Chronic aflatoxicosis has been strongly linked to liver cancer, as well as adverse nutritional and immunological outcomes (IARC, 2002). A study conducted in Cameroon found aflatoxin B1 in 35.5% of children with kwashiorkor and 45.5% of those with marasmus, compared to only 11% in the control group, suggesting a possible link between aflatoxin exposure and severe malnutrition (Tchana et al., 2010). Similarly, Gong et al. (2003) demonstrated a strong association between elevated aflatoxin–albumin adduct (AF-alb) levels and growth faltering in children in Benin

and Togo. However, in the context of Tanzania, it is important to note that children generally consume minimal amounts of spiced foods, which may reduce their direct exposure to aflatoxins through spices. Instead, their primary dietary exposure is more likely to come from staple foods such as maize and groundnuts, which are consumed in larger quantities and are also highly susceptible to aflatoxin contamination (Magoha et al., 2016; Kulwa et. al., 2015; Muhimbula and Issa-Zacharia, 2010). Therefore, while contaminated spices pose a public health risk, especially for adults and export markets, aflatoxin mitigation efforts targeting staple foods may have a more direct impact on child health outcomes.

It is important to note that if preventive measures against aflatoxin contamination are not implemented, contamination levels and prevalence may rise to unacceptable rates. Furthermore, the cumulative effects of exposure to aflatoxin and/or multiple mycotoxins may occur due to the consumption of food that is prone to mycotoxin contamination. Although the contribution of aflatoxin contamination from spices appears to be low, consuming spiced food contaminated with aflatoxin in combination with other contaminated foods in a meal may result in cumulative effects (Huang et al., 2021). To gain a comprehensive understanding of cumulative mycotoxin exposure and its associated health effects, it is essential to evaluate the dietary factors that contribute to this exposure, alongside the potential health risks. This approach will enable more accurate interpretation of epidemiological health outcomes linked to multi-mycotoxin exposure.

LIMITATION OF THIS STUDY

This review relies on secondary data, which may limit the analytical depth and contextual specificity of the findings. Nonetheless, the synthesis underscores the importance of integrating evidence-based risk assessment frameworks into the formulation of maximum limits. Such frameworks are essential for developing resilient systems that effectively capture the complexities of real-world scenarios.

CONCLUSION AND RECOMMENDATION

In conclusion, it has been noted that different countries have set varying Maximum Limits (MLs) for aflatoxin contamination in spices, with Tanzania adopting stricter limits of 5 μg/kg for aflatoxin B1 and 10 μg/kg for total aflatoxins. In contrast, other countries have higher limits that facilitate spice trade and reduce rejection rates due to contamination. This review has shown that spices in Tanzania are contaminated with aflatoxins at varying levels, but these levels are generally lower than those observed in contaminated maize and groundnuts. Among the spices analysed, black pepper and chilli exhibited higher contamination rates compared to others. Although spice consumption is typically much lower than that of maize, the growing use of spices and the recorded contamination levels suggest a potential health risk if effective intervention is not prioritised. In some instances, aflatoxin exposure levels have been estimated to exceed 0.04 ng/kg bw/day, which warrants attention. Given Tanzania's active participation in the global spice market, it is crucial to educate all stakeholders along the spice value chain on methods to prevent and control aflatoxin contamination. Furthermore, it is important to review the maximum limits for aflatoxins in spices while ensuring that food safety is not compromised.

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REFERENCES

Ahmed, F., & Asghar, MA. (2021). Aflatoxins occurrence in spices. *IntechOpen*. https://doi.org/10.5772/intechopen.96793

Akyoo, A., & Lazaro, E. (2007). *The spice of Tanzania: General profile, supply chain structure, and food standards compliance issues.* Danish Institute for International Studies. https://www.diis.dk

Ali, KS. (2018). *Levels of aflatoxins in spices produced and/or marketed in Zanzibar and Dar es Salaam* (Master's thesis). University of Dar es Salaam.

Ambrose, DC., Naik, R., & Patil, H. (2024). Studies on the drying behaviour of red chilli and its effect on quality. *Journal of Applied Horticulture, 26*(2), 182-185.

Asghar, MA., Zahir, E., Rantilal, S., Ahmed, A., & Iqbal, J. (2016). Aflatoxins in composite spices collected from local markets of Karachi, Pakistan. *Food Additives and Contaminants: Part B, 9(2), 113-119.*

Atanda, SA., Pessu, PO., Agoda, S., Isong, IU., Adekalu, OA., Echendu, MA. and Falade, TC. (2011) Fungi and Mycotoxins in Stored Foods. *African Journal of Microbiology Research, 5, 4373-4382.*https://doi.org/10.5897/AJMR11.487

AU-PACA. (2016). *Country and economic assessment for aflatoxin contamination and control in Tanzania: A supplement to the 2012 report.* African Union Commission.

Bhat, R., Rai, RV., & Karim, AA. (2010). Mycotoxins in food and feed: Present status and future concerns. *Comprehensive Reviews in Food Science and Food Safety, 9(1), 57-81.*

CAST. (2003). *Mycotoxins: Risks in plant, animal, and human systems* (Task Force Report No. 139). Council for Agricultural Science and Technology.

EFSA - European Food Safety Authority. (2020). Risk assessment of aflatoxins in food. *EFSA Journal, 18(3), 6040.*

European-Commission. (2006). Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Union L 364 (5).

FAO/WHO Codex Alimentarius Commission. (2022). Report of the 15th session of the Codex Committee on Contaminants in Foods (virtual), 9–13 and 24 May 2022. Joint FAO/WHO Food Standards Programme. https://www.fao.org/fao-who-codexalimentarius

Food and Agriculture Organization/World Health Organization (FAO/WHO). (2003*). Assuring food safety and quality: Guidelines for strengthening national food control systems.*

Food Safety and Standards Authority of India (FSSAI). (2011). Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011. Ministry of Health and Family Welfare, Government of India. https://www.fssai.gov.in/upload/uploadfiles/files/Contaminants_Regulations.pdf

Fundikira, S., De Saeger, S., Kimanya, M., & Mugula, J. (2020). Awareness, handling, and storage factors associated with aflatoxin contamination in spices marketed in Dar es Salaam, Tanzania. *World Mycotoxin Journal, 14 (2), 191-200.*

Gabriel, L. (2021). *Aflatoxins contamination in spices and associated predisposing factors in Morogoro Region, Tanzania* (Master's dissertation). Sokoine University of Agriculture.

Gichohi-Wainaina, WN., Kimanya, M., Muzanila, YC., Kumwenda, NC., Msere, H., Rashidi, M., Mponda, O., & Okori, P. (2023). Aflatoxin contamination, exposure among rural smallholder farming Tanzanian mothers, and associations with growth among their children. *Toxins, 15(4), 257.* https://doi.org/10.3390/toxins15040257

Global Trade. (2020). The global spice market lacks to regain its former momentum: Consumption by country. *IndexBox AI Platform.* https://www.globaltradema

g.com/the-global-spice-market-lacks-to-regain-its-former-momentum

Gong, Y., Hounsa, A., Egal, S., Turner, P. C., Sutcliffe, A. E., Hall, A. J., Cardwell, K., & Wild, C. P. (2004). Postweaning exposure to aflatoxin results in impaired child growth: A longitudinal study in Benin, West Africa. *Environmental Health Perspectives, 112(13), 1334-1338.*

Gong, YY., Cardwell, K., Hounsa, A., Egal, S., Turner, PC., Hall, AJ., & Wild, C. P. (2002). Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo: Cross-sectional study. *British Medical Journal, 325(7354), 20-21.*

Gong, YY., Egal S., Hounsa, A., Turner, PC., Hall, AJ., Cardwell, KF. and Wild, CP. (2003). Determinants of aflatoxin exposure in young children from Benin and Togo, West Africa: the critical role of weaning. *International Journal of Epidemiology 32:556-562.*

Huang, Q., Jiang, K., Tang, Z., Fan, K., Meng, J., Nie, D., Zhao, Z., Wu, Y. & Han, Z. (2021). Exposure assessment of multiple mycotoxins and cumulative health risk assessment: A biomonitoring-based study in the Yangtze River Delta, China. *Toxins, 13(2), 103.*

Iha, MH., & Trucksess, MW. (2019). Management of mycotoxins in spices. *Journal of AOAC International, 102*(6*), 1732-1739*. https://doi.org/10.1093/jaoac/102.6.1732

International Agency for Research on Cancer (IARC). (2002). *Monographs on the evaluation of carcinogenic risks to humans: Some traditional herbal medicines, some mycotoxins, naphthalene, and styrene* (Vol. 82).

Iqbal, SZ., Asi, MR., Zuber, M., Akhtar, J., & Saif, MJ. (2013). Natural occurrence of aflatoxins and ochratoxin A in commercial chilli and chilli sauce samples. *Food Control, 30*(2), *621-625.*

Ivanišová, E., Kačániová, M., Savitskaya, TA., & Grinshpan, DD. (2021). Medicinal herbs: Important source of bioactive compounds for food industry. *In Herbs and spices-new processing technologies*. IntechOpen.

Jacxsens, L., Yogendrarajah, P., & De Meulenaer, B. (2016). Risk assessment of mycotoxins and predictive mycology in Sri Lankan spices: Chilli and pepper. *Procedia Food Science, 6*, 326-330.

Jiang, TA. (2019). Health benefits of culinary herbs and spices. *Journal of AOAC International, 102*(2), 395-411. https://doi.org/10.5740/jaoacint.18-0418

Kamala, A., Kimanya, M., De Meulenaer, B., Kolsteren, P., Jacxsens, L., Haesaert, G.,Kilango, K, Magoha, H, Tiisekwa, B. & Lachat, C. (2018b). Post-harvest interventions decrease aflatoxin and fumonisin contamination in maize and subsequent dietary exposure in Tanzanian infants: a cluster randomised-controlled trial. *World Mycotoxin Journal, 11(3), 447-458.*

Kamala, A., Kimanya, M., Haesaert, G., Tiisekwa, B., Madege, R., Degraeve S., Cyprian, C. & De Meulenaer, B. (2016): Local post-harvest practices associated with aflatoxins and fumonisins contamination of maize in three agro-ecological zones of

Tanzania, *Food Additives & Contaminants*: Part A, doi: 10.1080/19440049.2016.1138546.

Kamala, A., Shirima, C., Jani, B., Bakari, M., Sillo, H., Rusibamayila, N., De Saeger, S., Kimanya, M., Gong, Y. & Simba, A. (2018). Outbreak of an acute aflatoxicosis in Tanzania during 2016. *World Mycotoxin Journal, 11(3), 311-320.*

Khazaeli, P., Mehrabani, M., Heidari, M., Asadikaram, G., & Lari Najafi, M. (2017). Prevalence of aflatoxin contamination in herbs and spices in different regions of Iran. *Iranian Journal of Public Health, 46(11), 1540-1545.*

Kimanya, M. (2021). *Aflatoxin situation analysis in Zanzibar. Tanzania Initiative for Preventing Aflatoxin Contamination Project. Ministry of Agriculture. Tanzania*

Kimanya, ME., Shirima, C. P., Magoha, H., Shewiyo, D. H., De Meulenaer, B., Kolsteren, P., & Gong, Y. Y. (2014). Co-exposures of aflatoxins with deoxynivalenol and fumonisins from maize-based complementary foods in Rombo, Northern Tanzania. *Food Control, 41, 76-81.*

Kulwa, KB., Mamiro, PS., Kimanya, ME., Mziray, R., & Kolsteren, PW. (2015). Feeding practices and nutrient content of complementary meals in rural central Tanzania: implications for dietary adequacy and nutritional status. *BMC pediatrics, 15(1), 171.*

Lye, MS., Ghazali, AA., Mohan, J., Alwin, N., & Nair, RC. (1995). An outbreak of acute hepatic encephalopathy due to severe aflatoxicosis in Malaysia. *The American journal of tropical medicine and hygiene, 53(1), 68-72.*

Maerere, A., & Noort, W. (2014). *Tanzania spices sub-sector strategy.* International Trade Center (ITC).

Magoha, H. (2023). The status of aflatoxin contamination in Chilli, Ginger and Turmeric in Tanzania. Tanzania Initiative for Preventing Aflatoxin Contamination Project. Ministry of Agriculture. Tanzania

Magoha, H., Kimanya, M., De Meulenaer, B., Roberfroid, D., Lachat, C., and Kolsteren, P. (2016). Risk of dietary exposure to aflatoxins and fumonisins in under six months of age infants in Rombo, Northern Tanzania. *Maternal and child nutrition 12 (3) 516 – 27.*

Magoha, H., Kimanya, M., De Meulenaer, B., Roberfroid, D., Lachat, C., & Kolsteren, P. (2014). Association between aflatoxin M1 exposure through breast milk and growth impairment in infants from Northern Tanzania. *World Mycotoxin Journal, 7(3), 277-284.*

Mkenda, B., Asiimwe, W., Magoha, H., Chesang, L., Ndayitwayeko, W. and Tabaro, D. (2021). Consultants' report to the GIZ/EAC on: Assessing the levels, challenges, measures, costs and impacts of compliance with the EA and EU food safety and quality standards of coffee, tea, avocado, ginger, cocoa beans and French beans.

Mkupasi and Peter 2025. Status of aflatoxin contamination in spices produced in Morogoro, *Tanzania. East African Journal of Science, Technology and Innovation*

Muhimbula, HS. & Issa-Zacharia, A. (2010). Persistent child malnutrition in Tanzania: Risks associated with traditional complementary foods (A

review). *African Journal of Food Science 4:679-692.*

Pickova, D., Ostry, V., Malir, J., Toman, J., & Malir, F. (2020). A Review on Mycotoxins and Microfungi in Spices in the Light of the Last Five Years. Toxins, 12(12), 789. https://doi.org/10.3390/toxins1212078 9

Santos, L., Marín, S., Mateo, E. M., Gil-Serna, J., Valle-Algarra, F. M., Patiño, B., & Ramos, A. J. (2011). Mycobiota and co-occurrence of mycotoxins in *Capsicum* powder. *International Journal of Food Microbiology, 151(3), 270-276.*

Shephard, GS. (2008). Impact of mycotoxins on human health in developing countries. *Food Additives and Contaminants, 25(2), 146-151.*

Spence, C. (2024). The king of spices: On pepper's pungent pleasure. *International Journal of Gastronomy and Food Science.*

Tchana, AN., Moundipa, PF. and Tchouanguep, FM. (2010). Aflatoxin Contamination in Food and Body Fluids in Relation to Malnutrition and Cancer Status in Cameroon. *International Journal of Environmental Research and Public Health 7:178-188*

Thanushree, MP., Sailendri, D., Yoha, KS., Moses, JA., &

Anandharamakrishnan, C. (2019). Mycotoxin contamination in food: An exposition on spices. *Trends in Food Science & Technology, 93, 69-80.*

Turner, PC, Collinson AC, Cheung YB, Gong YY, Hall AJ, Prentice AM. and Wild, CP. (2007). Aflatoxin exposure in utero causes growth faltering in Gambian infants. *International Journal of Epidemiology 36:1119-1125.*

WHO/FAO (2015). Codex Alimentarius Commission Procedural Manual. 24th edition. Joint FAO/WHO Food Standards Programme, Rome.

Yogendrarajah, P., Jacxsens, L., Lachat, C., Walpita, C. N., Kolsteren, P., De Saeger, S., & De Meulenaer, B. (2014). Public health risk associated with the co-occurrence of mycotoxins in spices consumed in Sri Lanka. *Food and chemical toxicology, 74, 240-248.*

Zahra, N., Khan, M., Mehmood, Z., Saeed, M. K., Kalim, I., Ahmad, I., & Malik, K. A. (2018). Determination of Aflatoxins in Spices and Dried Fruits. *Journal of Scientific Research, 10(3), 315–321.* https://doi.org/10.3329/jsr.v10i3.37075