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Mycotoxins contamination in foods consumed in Uganda: A 12-year review (2006–18)

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ABSTRACT

Mycotoxins are secondary fungal metabolites with a potential to have adverse effects on humans and animals. The rationale of this review was to examine the current status of mycotoxins in Uganda and the problems associated with these toxins. The commonly studied mycotoxins in Uganda are aflatoxins and fumonisins with aflatoxin B1 being the most prevalent. The review has shown that aflatoxin contamination reduces economic growth by 0.26% in Uganda owing to decline in productivity. Uganda loses 577 US million dollars annually as a result of 3700 aflatoxin-induced liver cancer cases. Aflatoxins contamination of sorghum, maize and peanuts causes a decline in exports valued at 7.48 US million dollars which accounts for 45% reduction in total agricultural exports. There are no fully developed strategies for the control of mycotoxins contamination in food and food products in Uganda. Regulations for monitoring foods susceptible to aflatoxins contamination should be put in place and strict measures on the quality of food at both household and market levels be enforced by all policy makers.

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Introduction

Mycotoxins are secondary fungal metabolites with a potential to cause adverse effects in humans and animals [14]. Globally there are over 300 mycotoxins but the most important ones are; aflatoxins, fumonisins, ochratoxins, trichothecenes, zearalenone, and zearalenone [14,36,44].

The multiple dietary exposures to mycotoxins have been found to have serious health effects to humans and animals. Mycotoxins can be carcinogenic, neurotoxic, mutagenic, hepatotoxic, teratogenic, estrogenic, cytotoxic, and nephrotoxic

Abbreviations: AFs, Aflatoxins; IARC, International Agency for Research on Cancer; DON, deoxynivalenol; ZEA, zearalenone; PACA, Partnership for Aflatoxin Control in Africa; LSMS, Living Standards Measurement Study; EAC, East African Community; UNBS, Uganda National Bureau of Standards; AEZs, Agro-ecological zone; LOD, Limit of detection; MoH, Ministry of Health; HCC, hepatocellular carcinoma; MAAIF, Ministry of Agriculture Animal Industry and Fisheries; EU, European Union; WHO, World Health Organisation; FDA, US Food and Drug Administration; MTIC, Ministry of Trade Industry and Cooperatives; EU, European Union.

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and occasionally induce immunosuppression in humans [14,28,36]. In Africa, acute mycotoxicosis has been reported and persistent exposure to mycotoxins even in small amounts has been found to be a risk factor for human diseases such as cancer and childhood stunting [30,49].

Recently, there has been an in the prevalence of cancer among the Ugandan population and it is assumed that some of the foods consumed could be the source of the carcinogens associated with cancer and other diseases. In addition, the prevalence of malnutrition in Uganda among children has remained constantly high where 29% are stunted and 11% are underweight [45]. It is also expected that this might be associated with consumption of mycotoxins contaminated foods among this age category although there is no sufficient data to support this assumption.

According to Wild and Gong [48] and Wu et al. [53], the mycotoxins of concern in Sub-Saharan Africa are aflatoxins, fumonisins, ochratoxins, trichothecenes and zearalenone. In Uganda, the common mycotoxins are aflatoxins and fumonisins with aflatoxins being the most prevalent. The aflatoxins of importance in Uganda are Aflatoxin B1 (AFB1), Aflatoxin B2 (AFB2), Aflatoxin G1 (AFG1) and Aflatoxin G2 (AFG2). Another aflatoxin that has been studied in Uganda but to a very limited extent is Aflatoxin M1 (AFM1) [25].

Aflatoxin B1 is the most potent liver carcinogenic agent and is found in greater concentrations than any other occurring aflatoxins [53]. Aflatoxin B1 has been classified as a group one human carcinogen based on its high toxicity [7,14]. The aim of this review was to examine the current status of mycotoxins in Uganda, their health impacts, exposure levels, current mitigation strategies, and mycotoxins control gaps in the food industry.

Mycotoxins research in Uganda

Although mycotoxins contamination has recently gained much attention in Uganda, relatively few studies have been conducted compared to other members of the East African Community. This has been attributed to lack of well-equipped laboratories, inadequate capacity in terms of expertise, inadequate funding, and dearth surveillance.

In Uganda, mycotoxins have been mainly studied in maize, peanuts, cassava and millet [2,4,6,15,25,32,33]. There is also some scanty data on mycotoxins occurrence in milk products [25] and rice [41]. Despite the limited resources in Uganda, few studies about aflatoxin exposure have been done. Asiki et al. [2] reported human sera samples that are positive for aflatoxin–albumin adducts in south-western Uganda.

A study undertaken in nothern Uganda by Natamba et al. [31] reported a causal effect relationship between aflatoxin exposure and impaired growth in infants. In Mukono district central Uganda, Lauer et al. [27] reported elevations in maternal Aflatoxin B1-Lysine levels which were significantly associated with impaired growth in infants at birth. In general, from 2006 to 2018, Uganda has made some progress on mycotoxins research although more work is needed to explore the impact of other mycotoxins in the different foods. The institutions that were reported by Kaaya and Warren [18] are still the same involved in aflatoxin research. Uganda does not have an independent single agency that monitors food safety but there exist different departments that work in a multi-sectoral system to control aflatoxins. The three ministries include, Ministry of Health; Ministry of Trade Industry and Cooperatives; and Ministry of Agriculture Animal Industry and Fisheries.

In addition, Uganda has managed to develop some aflatoxin standards for maize (US EAS 2:2013), groundnuts (US EAS 57-1), sorghum (US EAS 575:2013) and rice (US EAS 128). These aflatoxin standards have also been harmonised with the East African Community standards.

Health impacts and risk of mycotoxins in Uganda

Mycotoxins have serious chronic health risks and are ubiquitous in many sub-Saharan African countries due to the favourable tropical conditions which foster production of mycotoxins [38,49]. The cases of mycotoxins, most especially aflatoxins are on the rise in the developing countries and this account for 40% of the disease incidences [50]. Current evidence suggests that there is an association between chronic mycotoxins exposure and malnutrition, immunosuppression, impaired growth, risk of oesophageal cancer, risk of neural tube defects and diseases such as malaria and HIV/AIDS [13,22–24,47].

Mycotoxins such as aflatoxins and fumonisins are assumed to play a big role in development of oedema in malnourished people and they also aggravate the pathogenesis of kwashiorkor in children [23]. In addition, human deaths due to consumption of aflatoxins contaminated foods have been reported [28]. Death is mainly due to liver cancer, acute toxicosis and immune suppression [48].

According to Ferlay et al. [12], 14.1 million new cancer cases and 8.2 million deaths were reported globally in 2012 and liver cancer was the second most important cause of death after lung cancer, accounting for about 745,000 deaths annually. In Africa, 847,000 new cancer cases (6% of the world total) and 591,000 deaths (7.2% of the world total) were reported in 2012. Over 85% of the cases of hepatocellular carcinoma (HCC) occur in low-income countries due to risks of dietary aflatoxin exposure and chronic hepatitis B and C [35].

Furthermore, the World Health Organisation [51] statistics showed that hepatocellular carcinoma was the third prominent cause of cancer deaths in developing countries [51]. Palliyaguru and Wu [35] reported that of the 550,000–600,000 global new hepatocellular carcinoma cases that occur annually, about 25,200–155,000 have been attributed to the uncontrolled exposure to aflatoxins and most of these happen in Sub-Saharan Africa, East Asia, and China.

In Uganda, the prevalence of liver cancer was estimated to be 6.1% in males and 3.9% in females in the previous five years [12]. Kitya et al. [25] reported that in South Western Uganda over 40 cases of hepatocellular carcinoma were registered (HCC)

annually. Although Uganda does not have an efficient system for monitoring aflatoxin contamination and related effects, a few studies have linked certain illnesses like hepatocellular carcinoma to consumption of aflatoxins contaminated foods like sorghum, ghee sauce (*eshabwe*), millet, cassava, and peanuts [25].

Until recently there was no systematic study that examined levels of aflatoxin in people living in rural Uganda. According to the longitudinal study by Kang et al. [20] on evaluating aflatoxin exposure in South-western Uganda, 90% (642/713) of the sera samples from the General Population Cohort were positive for AFB-Lysine with the median level of 1.58 pg/mg and albumin range 0.40–168 pg/mg. Furthermore, AFB-Lysine adducts from the four year period (1999–2003) in the Rakai Community Cohort Study, showed a detection rate of 92.5% (346/374) with the median of 1.18 pg/mg and a range of 0.40–122.5 pg/mg. These results show that in this area the problem of aflatoxin exposure is still a major health concern which may be experienced in other parts of Uganda.

In South-western Uganda, aflatoxin–albumin adduct (AF–alb adduct) ranged from 0 to 237.7 pg/mg albumin among 100 adults (18–89 years) and 96 children (0–3 years) [2]. The results showed that aflatoxin–albumin adduct (AF–alb adduct) ranged from 0 to 237.7 pg/mg albumin. The results further revealed that 75% of the participants had levels above 7.1 pg/mg albumin, 50% had levels above 10.3 pg/mg albumin while 25% had levels above 15.1 pg/mg albumin. It was also observed that all the adults and the four children had detectable aflatoxin–albumin adducts. The results also showed that respondents who were living close to the trading centres had significantly ($p = 0.003$) higher levels of detectable AF–alb adduct compared to their counterparts living in the villages. It was also noted that respondents consuming *Matooke* (banana) had half detectable AF–alb adduct ($p = 0.002$) compared to those who did not consume it. This is because these respondents are more likely to consume other foods which may be prone to aflatoxins contamination hence people consuming *Matooke* are less likely to have detectable AF–alb adduct.

Although some studies have tried to associate aflatoxin consumption with incidences of stunting, the actual mechanism relating the two is not well known. However, it has been assumed that aflatoxins cause stunting by inducing intestinal enteropathy, a subclinical condition of the small intestine, characterized by reduced absorptive capacity and increased intestinal permeability [39] among children under five years. According to Turner et al. [42] and Keenan et al. [21], maternal aflatoxins exposure during pregnancy was found to be associated with growth faltering among Gambian infants while poor immunity to bacterial and parasitic infections was associated with aflatoxins exposure among Ghanaians.

Due to paucity of data, they are only two studies that have tried to examine the impact of aflatoxins on child growth in Uganda. In a study conducted in Northern Uganda, it was observed that aflatoxins have adverse effects on infant weight gain during pregnancy. The authors also reported that maternal aflatoxin exposure levels potentially affect infant height [31]. This study suggested that there was a cause-effect relationship between aflatoxin exposure and impaired child growth.

In another study that investigated the association between maternal aflatoxin exposure during pregnancy and adverse birth outcomes, Lauer et al. [27] reported that median maternal Aflatoxin B1- Lysine adducts (AFB-Lys) level was 5.83 pg/mg albumin (range: 0.71–95.60 pg/mg albumin) and elevations in maternal AFB-Lys levels were significantly associated with lower weight ($p = 0.040$), lower weight-for-age-score ($p = 0.037$), smaller head circumference ($p = 0.035$), and lower head circumference-for-age z-score ($p = 0.023$) in infants at birth in Uganda. These studies give very vital information that can help stakeholders in Uganda to design interventions that can help to reduce mycotoxins exposure in pregnant and lactating mothers in order to protect the lives of infants.

Economic impacts of aflatoxins

Mycotoxins contamination can cause high economic losses mainly due to damage or rejection of aflatoxin contaminated produce. According to Schatzmayr and Streit [37], recent global research findings show that detectable amounts of aflatoxins are still on the rise in food and feeds globally. Out of the 17,316 samples of feed and feed raw materials analysed, 72% of them tested for at least some aflatoxins while 38% were contaminated [37]. David and Gary [10] estimated that 25% of world's crops are contaminated with mycotoxins leading to a loss of around one billion metric tons of agricultural produce and food products.

In the United States of America (USA), aflatoxins were estimated to cause financial losses of up to 25.8 million dollars every year [54] while in Sub Saharan Africa aflatoxin contamination has led to the rejection of commodities at the international market [9]. The reported increase in aflatoxin contamination of feeds affects animal health by reducing weight gain, immune suppression, fertility problems, illnesses, and diseases, and sometimes lead to death [8].

Due to the lack of documented data on the economic impact of aflatoxins in both livestock and human health-related costs especially in sub-Saharan African countries, it is always very hard to estimate the losses. The available data from the recent Country led Situation Analysis for Mitigation of Aflatoxins in Uganda by Partnership for Aflatoxin Control in Africa report [34] shows that aflatoxin contamination reduces economic growth by 0.26% in Uganda due to reduced productivity as a result of aflatoxin related illnesses. It was also estimated that agricultural exports declined by 43.5% of the total exports of US$ 37.56 million and another reduction of 45% in the grain exports was realised out of the total agricultural exports. The household disposable incomes and the household consumption decreased by US$ 79.3 million and US$ 59.1 million respectively. It was also found that Uganda loses an estimated 38 million US dollars annually from export rejects due to aflatoxins.

Furthermore, Uganda loses US$ 577 million annually as a result of 3700 aflatoxin-induced liver cancer cases. In addition, the aflatoxin-related illnesses cost the government of Uganda an extra US dollars 910,000 on health services.

It is important to note that aflatoxins mainly cause losses by reducing the quality and quantity of food produced and also compromising animal health which sometimes results in the loss of animal lives [11]. There is generally a widespread negligence among stakeholders in Uganda with regard to establishing stringent measures for controlling aflatoxin contamination mainly because the impact of the aflatoxins in regard to health and market analysis is not felt directly.

Mycotoxins contamination of food products and their production statistics in Uganda

Production statistics of the main foods contaminated with mycotoxins

According to Uganda bureau of statistics [46], the production statistics of the major mycotoxins contaminated foods in Uganda are; Millet (236,000), Maize (2,868,000), Sorghum (299,000), Cassava (2,812,700) and Peanuts (295,600) tonnes per year.

Mycotoxins contamination of food products

Peanuts and peanut products

Peanuts (*Arachis hypogaea L.*) are an important source of proteins especially among the poor socio-economic groups in Uganda who cannot afford daily animal protein sources. Peanuts can be prepared/consumed in several forms [19]. The numerous uses of peanuts make it both a source of staple food and livelihood hence improving nutritional and economic status of the community [32]. PACA [34] reported that peanuts in Uganda are contaminated with mycotoxins. This poses a great challenge to the peanuts industry.

According to Baluka et al. [6], aflatoxins are still the predominant mycotoxins found in significant amounts in peanut products sold in Ugandan markets. The findings showed that out of the 55 samples, 34% had aflatoxin concentrations greater than 20 ppb FDA/WHO acceptable limits (Table 1). The high aflatoxins concentrations were attributed to poor practices during harvesting, drying, processing, and storage. The business people also buy peanuts in bulk during the bumper harvest and store them in poorly ventilated and highly humid premises.

In addition, Osuret et al. [33] found that total aflatoxins were detectable in 80% of the peanut and peanut paste samples sold for human consumption in Kampala and 40% of these samples exceeded FDA/WHO regulatory limit of 20 µg/kg (Table 1). The laboratory analyses indicated that peanuts and peanut paste had extremely high aflatoxin levels of up to 940 and 720 µg/kg respectively. Although the study provides information on the incidence of aflatoxins in the peanuts and peanuts paste, the relationship between aflatoxins levels and storage practices and conditions was not examined.

Kitya et al. [25] found that all the three samples of peanuts flour commonly consumed in southwestern Uganda were positive for total aflatoxins with a mean of 11.5 ± 0.43 ppb (Table 1). The lack of knowledge on how to prevent contamination was responsible for the high levels of mycotoxins in the foodstuff. In addition, traditional processing and poor production methods such as harvesting and storage were observed to be risk factors for the high levels of mycotoxins in the foodstuff.

Kaaya et al. [19] found that at the farm level in villages, at least 60% of the peanut samples had detectable levels of aflatoxins (Table 1). Low levels of awareness, poor storage practices, and poor processing practices (drying, sorting and milling) were responsible for the high levels of aflatoxins in the peanut samples.

This study also emphasised that aflatoxins contamination starts at farm levels which many farmers and business people always tend to overerlook as a significant factor. In addition, analysis of the samples from the markets also revealed that samples from retailers had significantly higher amounts of aflatoxins compared to those from wholesalers (Table 2).

In Uganda they **10** Agro-ecological zones (AEZs) that is; Southern Highlands, Southern Dry lands, Lake Victoria Crescent, Eastern, Mid Northern, Lake Albert Crescent, West Nile, Western Highlands, South East and Karamoja Drylands. According to PACA report [34] the Kioga plains (Iganga and Soroti districts) had 20% of the peanuts samples with aflatoxins levels above 10 ppb while Tororo had 10%. In addition, other AEZs (Table 3) had 10% peanut samples with aflatoxin contamination levels above 10 ppb with exception of Northern eastern which had none of the samples with detectable aflatoxins.

Aflatoxins in maize and maize products

Maize is one of the important crops cultivated in Uganda and it is ranked third in production after plantain and cassava [46]. Maize is among the foodstuffs that have been found to be contaminated with high levels of aflatoxins in Uganda. According to PACA [34], maize samples from Mubende (Western Savannah AEZ) had relatively higher aflatoxins levels (65ppb) compared to Tororo (20ppb) in the Kioga plains based on UNBS/EAC regulatory limit (Table 4). These results corroborate earlier reports that aflatoxin contamination is a major threat to maize [17,26,33,40]. These results show that aflatoxins are widely distributed in all the maize growing regions of Uganda which poses a great health threat to humans and animals [18].

Fumonisins in maize

According to IARC, [52] fumonisins are classified as group 2B toxins which are carcinogenic to humans. Although there is scanty information about fumonisins in maize, the available data shows that it is a health threat. According to Atukwase et al. [3], fumonisins in the three agro-ecological zones (Northern eastern, Grassland, and Western Savannah grassland) of Uganda, ranged from 0.85 to 10 mg/kg; 0.47 to 8.3 mg/kg; and 0.27 to 9.0 mg/kg respectively [3]. In addition, maize from high

Table 1
Mycotoxins contamination of Peanuts (*Arachis hypogea* L.) in Uganda.

Source of food commodity	Type of sample	Number of samples	Mycotoxins type	Positive samples (%, >20 ppb)	Range (μg/kg) = ppb	Mean ± SE (ppb)	Reference
Kampala markets (Nakawa, Bukoto, Kalerwe, and Owino/Balikudembe)	Peanut paste	33	AFB1,	34	0–540	Ns[d]	Baluka et al. [6]
			AFB2,	16	0–141		
			AFG1	32	0–213		
			AFG2,	66	0–36		
			Fumonisins	8	0.2–0.6		
Kampala markets (Balikudembe, Nakasero, Kalerwe, Nakawa, and Nateete)	Peanut grains	4	Aflatoxins	40	Ns[d]	Ns[d]	Osuret et al. [33]
	Peanut paste			100			
Southwestern Uganda	Peanut flour	3	Aflatoxins	3[e]	Ns[d]	11.5 ± 0.43 ppb	Kitya et al. [25]
Kiboyo[a]	Peanut grains	25	Aflatoxins	80[e]	Ns[d]	12.4 ± 5.31	Kaaya et al. [19]
Bugodi[b]	Peanut grains	20		75[e]		10.5 ± 6.15	
Gayaza[c]	Peanut grains	15		60[e]		7.3 ± 4.98	
Kabulamuliro[c]	Peanut grains	12		67[e]		9.8 ± 4.32	

Mean and ranges are aflatoxin contamination levels in the samples.
[a] Village in Iganga district.
[b] Village in Mayuge district.
[c] Villages in Mubende district.
[d] Ns value not specified.
[e] Percentages are based on samples being positive only.

Table 2
Aflatoxin levels (ppb) of different peanut forms sampled from wholesalers and retailers in common markets of Uganda.

Markets								
Peanut form	Market Segment	Iganga[a,c]	Magamaga[a,d]	Mityana[a,c]	St. Balikuddembe[b,e]	Kalerwe[a,c]	Nakawa[a,c]	LSD ($p \leq 0.05$)
Unsorted kernels	Wholesale	52.0 ± 7.73	44.5 ± 3.85	40.4 ± 6.74	42.0 ± 5.68	–	35.4 ± 4.94	4.874
	Retail	62.4 ± 4.72	65.4 ± 4.72	53.4 ± 6.65	–	60±5.60	38.9 ± 8.41	8.763
Sorted kernels	Wholesale	12.0 ± 8.65	11.8 ± 7.27	16.3 ± 3.76	10.0 ± 4.36	–	8.3 ± 4.66	1.661
	Retail	18.0 ± 7.60	20.5 ± 4.60	23.5 ± 3.90	22.5 ± 6.14	16.6 ± 2.26	21.2 ± 9.89	2.141
White flour	Wholesale	42.5 ± 5.76	–	35.5 ± 2.55	45.0 ± 7.25	–	–	8.426
	Retail	54.4 ± 8.29	59.4 ± 5.43	50.4 ± 5.82	55.8 ± 6.76	55.4 ± 3.95	43.5 ± 3.54	5.643
Pressed	Wholesale	39.2 ± 2.64	–	24.2 ± 5.52	24.7 ± 7.85	–	–	3.711
	Retail	46.3 ± 2.28	51.1 ± 2.22	32.5 ± 2.39	32.3 ± 6.19	28.4 ± 5.62	29.6 ± 5.29	2.621
Light brown paste	Wholesale	22.5 ± 5.55	=	22.3 ± 2.64	28.6 ± 4.45	–	–	2.934
	Retail	33.2 ± 2.09	28.3 ± 4.41	25.3 ± 4.78	28.5 ± 4.48	23.4 ± 3.57	24.3 ± 2.38	3.872
Brown paste	Wholesale	28.4 ± 3.36	–	20.8 ± 4.48	22.4 ± 4.32	–	–	3.141
	Retail	30.6 ± 4.67	29.5 ± 3.94	29.9 ± 6.66	27.8 ± 4.56	19.1 ± 3.41	17.4 ± 2.29	3.435
Dark brown paste	Wholesale	20.5 ± 4.46	–	11.2 ± 2.65	15.5 ± 3.65	–	–	2.984
	Retail	25.5 ± 3.31	22.6 ± 2.26	15.5 ± 7.76	25.5 ± 2.92	15.2 ± 2.88	12.7 ± 6.76	3.054
LSD ($p \leq 0.04$)		3.454	8.361	6.341	7.131	7.892	3.222	

Source: Kaaya et al. [19].
No samples were obtained from wholesalers or retailers.
[a] Means are for five samples for each form of peanut from wholesalers.
[b] Means are ten samples for each form of peanut from wholesalers.
[c] Means are ten samples for each form of peanut from retailers.
[d] Means are eight samples for each form of peanut from retailers.

Table 3
Aflatoxins levels of peanuts in the different agro-ecological zones.

Agro-ecological zone	District	% samples >LOD	Total aflatoxin levels (ppb)		% samples		
			Range[a]	Mean[b]	>4 ppb[c]	>10 ppb[d]	>20 ppb[e]
Western	Mubende	25	3.0–13	7.0	20	10	0
Savannah	Kamwenge	30	5.5–12	8.82	30	10	0
Grasslands	Masindi	20	2.5–174.5	88.35	10	10	10
Kioga plains	Iganga	40	2.5–450	221.12	40	20	20
	Soroti	60	3–31.16	31.16	20	20	20
	Tororo	20	3.5–11	7.25	10	10	0
Northern Eastern	Gulu	20	4.0–5.5	4.75	10	0	0
Savannah	Amuria	60	2.1–17	5.3	20	10	0
Grasslands	Lira	40	2.5–21	7.5	10	10	10

Source: PACA [34]. Unpublished data
[a] The range is for samples with aflatoxin levels above Limit of detection.
[b] The mean is for samples with aflatoxin levels above Limit of detection.
[c] EU; European Union regulatory limit.
[d] UNBS/EAC; UNBS, Uganda National Bureau of Standards/ East African Community regulatory limit.
[e] FDA/ WHO; FDA, US Food and Drug Administration/ World Health Organisation regulatory limit.

Table 4
Aflatoxin levels in maize in Western Savannah Grasslands and Kioga plains agro-ecological zones.

Agro-ecological zone	District	% samples >limit of detection	Total aflatoxin levels (ppb)		%Samples		
			Range[a]	Mean[b]	>4 ppb[c]	>10 ppb[d]	>20 ppb[e]
Western	Mubende	95	3.5–247.5	75.2	95	65	55
Savannah	Kamwenge	100	3.25–104.5	26.56	85	45	35
Grasslands	Masindi	95	3.05–510	45.99	90	30	15
Kioga plains	Iganga	80	4.5–77.0	25.36	80	35	35
	Soroti	50	4.5–179.5	70.9	50	40	30
	Tororo	50	7.0–86.0	35.5	50	20	10

Source: PACA [34]. Unpublished data
[a] The range is samples with aflatoxin levels above limit of detection.
[b] The mean is for samples with aflatoxin levels above limit of detection.
[c] EU; European Union regulatory limit.
[d] UNBS/EAC; UNBS, Uganda National Bureau of Standards/ East African Community regulatory limit.
[e] FDA/WHO; FDA, US Food and Drug Administration/ World Health Organisation regulatory limit.

altitude zone had significantly higher ($p < 0.05$) mean total fumonisins content (4.93 mg kg^{-1}) than maize from the mid-altitude-moist (4.53 mg kg^{-1}) and mid-altitude-dry (4.50 mg kg^{-1}) zones. The major practices responsible for fumonisins contamination were intercropping, crop rotation, delayed harvesting, drying maize on bare ground and planting treated seeds.

Millet and sorghum

Millet and sorghum are becoming important food security crops due to the population increase as a result of urbanisation in the East and sub-Saharan African countries like Uganda, Zimbabwe, Rwanda, Tanzania, among others. Until recently, little was known about the aflatoxin contamination levels of sorghum in Uganda. According to PACA [34], the first detailed survey on aflatoxins contamination levels in sorghum showed that in all the regions, 70% of the samples had aflatoxin levels above 10ppb (UNBS/EAC regulatory limit (Table 5). These high levels are due to poor agronomic and postharvest handling practices because the production of sorghum is mainly at the subsistence level where there is no mechanism in place to regulate the quality of the produce.

Kitya et al. [25], also found that millet and sorghum samples from Uganda were contaminated with aflatoxins at levels 14.0 ± 1.22 mg/kg and 15.2 ± 0.2 mg/kg. These aflatoxin contamination levels were mainly due to poor storage and processing. This necessitates the need to invest in strategies that will improve the quality of the crops at both farm level and processing.

Milk and milk products

According to Balikowa [5], the dairy industry is one of the important sectors that supplies 1.08 billion litres of milk where over 65% is marketed in Uganda. The human exposure to aflatoxins is through consumption of aflatoxin M1 (AFM1) contaminated dairy products as a result of feeding dairy animals with AFB1 contaminated feeds.

The occurrence of AFM1 in milk has not received much attention but according to a study by Kitya et al. [25] in western Uganda, the ghee sauce (*Eshabwe*) milk product, was found to be contaminated with aflatoxins AFM1 at a level 18.6 ± 2.4 mg/kg. These results provide some information about the status of aflatoxins in Ugandan milk products, however,

Table 5
Aflatoxin levels in sorghum in agro-ecological zones in Uganda.

Agro-ecological zone	District	% samples >limit of detection	Total aflatoxin levels (ppb)		% samples		
			Range[a]	Mean[b]	>4 ppb[c]	>10 ppb[d]	>20 ppb[e]
Kioga plains	Soroti	100	98.25–265.5	170.1	100	100	100
	Tororo	90	4.0–215	61.14	85	70	65
Northern eastern	Gulu	90	5.5–119.5	70.5	90	90	85
Savannah	Amuria	100	28.5–472	11.5	100	100	100
Grasslands	Lira	100	27.5–227	102.27	100	100	100

Source: PACA [34]. Unpublished data
[a] The range was calculated for samples with aflatoxin levels above Limit of detection.
[b] The mean was calculated for samples with aflatoxin levels above Limit of detection.
[c] EU; European Union regulatory limit.
[d] UNBS/EAC; UNBS, Uganda National Bureau of Standards / East African Community regulatory limit.
[e] FDA/WHO; FDA, US Food and Drug Administration / World Health Organisation regulatory limit.

there is a need for more research to ascertain the magnitude of the problem. In addition, there are no stringent regulations that monitor feed manufacturers and dairy farmers in Uganda and this may pose a great challenge to the health of animals and humans.

Cassava

Cassava is a food security crop in developing countries like Uganda [1] and greatly contributes to the nutrient pool and livelihoods of many people. In Uganda, the per capita food consumption of cassava stands at 214 g/person/day (EAC report (EAC/TF/405/2013). Despite the nutritional role of cassava, it has been found to be contaminated with aflatoxins on an average of 0.5 ng/g (EAC report (EAC/TF/405/2013). Osuret et al. [33] found that one out of five samples (20%) was contaminated with aflatoxins above the regulatory limit of 20 µg/kg based on FDA/WHO.

In addition, Kitya et al. [25] indicated that cassava chips are contaminated with aflatoxins at levels of 16.0 ± 1.66 ppb in southwestern Uganda. The cause of the contamination in these products stems from the poor methods of processing which include sun drying on bare ground and fermentation. The lack of awareness among the people involved in production and processing of cassava and cassava products is paramount and should be given priority.

Kaaya and Eboku [15], reported that dry cassava chips from eastern Uganda were contaminated with *Rhizopus* (66.7%), *Mucor* (37%), *Penicillium* (22.2%), *Aspergillus* (20.4%) and *Fusarium* species (5.6%). Overall, 30% cassava samples were positive for aflatoxin contamination with a mean of 0.51 μg/kg and a range of 0–4.5 μg/kg. It was also revealed that *Aspergillus flavus* occurred in 18.5% of the samples. The factors associated with high levels of aflatoxins included drying cassava on bare ground and storage by heaping on the bare floor and old containers. It is unfortunate that due to inter-trading in the country, these cassava products cross from one region to another hence increasing the risk of exposure to other consumers.

Consumption of aflatoxin prone foods in Uganda

Maize, millet, and peanuts constitute a significant part of the diet among Ugandans. The other foods consumed include locally processed cereal based foods, dried/cured fish, and cassava. According to the PACA report [34], the mean consumption of aflatoxins contaminated staple crops was highest for maize (177 g/person/day) followed by sorghum (147 g/person/day) and peanuts (83 g/person/day). The consumption of maize was relatively high because it is consumed by many households in form of posho and it is also used in the manufacture of complementary foods for children. In addition, the median consumption levels were maize (134 g/per person/day), sorghum (83 g/per person/day), and sorghum (61 g/per person/day). In addition, the consumption of maize is relatively high because it is consumed by many households in form of posho and also used in the manufacture of complementary foods for children. In addition, maize is used as a raw material for brewing both at industry and local beverages [29].

In regard to peanuts, the per capita consumption was 93.2, 91, 90.4 and 88.1 g/day for Eastern, Central, Northern and Western regions respectively. On the other hand, the per capita consumption of sorghum was 160.4, 158.4, 141.8 and 133.3 g/day in Central, Northern, Eastern, and Western region respectively [29]. The trends recorded in the per capita food consumption in the regions were alike due to the similar agronomic and postharvest handling practices and the inter-regional marketing of produce in Uganda [34].

Reduction and prevention of aflatoxins contamination

According to Kaaya and Warren [18], preventing and reducing aflatoxins requires an understanding of the different environmental conditions that promote the growth and development of molds. Some of the common environmental conditions

include insect/rodent damage, moisture content, relative humidity, temperature, storage, and drying but this varies from one region or one country to another.

Atukwase et al. [3] observed that many Ugandan farmers dry their produce, such as maize, on the bare ground while others inadequately dry their maize to retain more weight so that it attracts more money at the time of selling. In addition, some farmers leave their maize to dry in the gardens naturally. These practices favour the growth of *Aspergillus flavus*. Proper storage and drying of foods are very important in preventing mycotoxins contamination.

This was found to be very effective in Guinea where adequate drying of produce reduced aflatoxin contamination from 40% to 60% [43].

In Uganda, some sections of the food industry, for example, coffee sector is quite strict on drying to recommended moisture content levels and those who fail to meet the requirements have their products rejected, are paid a lower price or they are required to re-dry. Such practices may help in pushing farmers to adequately dry their produce. This subsequently also contributes towards preventing the production of aflatoxins in dried foodstuffs.

Aflatoxin contamination of crops can also start in the field before harvest although it commonly occurs during harvest and storage as a result of damp warm conditions that enable the fungi to multiply rapidly. Kaaya and Kyamuhangire [16] observed that lack of human labour, unpredictable weather conditions, insufficient harvesting equipment, and machinery are some of the factors that lead to elevated aflatoxins levels in the field crops. Therefore, timely harvesting is one of the strategies that should be advocated for to reduce aflatoxin contamination of crops.

In Uganda, there are no established strategies for reducing mycotoxin contamination. However, there is ongoing research on groundnut varieties with resistance to *Aspergillus flavus* invasion [32]. Kaaya and Kyamuhangire [17] observed that, drying maize using biomass-heated natural convection dryer delays insect infestation by three months and significantly reduces molds and aflatoxins contamination for six months during storage.

According to PACA [34], the following strategies were recommended to be of paramount interest in the control of aflatoxins in Uganda.

- Training on pre-and postharvest handling practices, increasing access to storage facilities and promoting the use of biocontrol products.
- Processing and marketing, where all processors and dealers should be acquainted with the knowledge of aflatoxin quality control and assurance in order to adhere to the set standards.
- Public health management systems should be strengthened with the capacity to carry out research on aflatoxins risk and exposure and promote dietary diversification to reduce consumption of aflatoxin-contaminated foods.
- Advocacy and awareness creation should be done to sensitise all stakeholders on the health and economic impacts of aflatoxins and these should be advocated for through the ministries of health, trade and agriculture and district local government.
- There should a multi-sectoral approach in the control and management of aflatoxins. These approaches should be incorporated in National Development Plan (NDP) and related plans like the Agricultural Sector Strategic Plan (ASSP) and the Health Sector Strategic Plan (HSSP).

Challenges of aflatoxin regulations in Uganda

The Uganda National Bureau of Standards (UNBS) which is under Ministry of Trade Industry and Cooperatives (MTIC) is the only prime body for regulating standards in Uganda. Other public institutions that are mandated to control aflatoxins are Ministry of Agriculture Animal Industry and Fisheries (MAAIF), and Ministry of Health (MoH) but they have inadequate infrastructure. In Uganda, the enforcement of aflatoxin regulations is hindered by many factors such as inadequate capacity within the underlying institutions, lack of political will, insufficient legislation; inadequate enabling policy and law on enforcement of aflatoxin standards, lack of direct budget support for aflatoxin control, poor laboratory facilities, inadequate public knowledge and awareness, insufficient human resource capacity, limited access to appropriate postharvest technologies, and lack of sufficient epidemiological evidence to support government food safety directives.

In addition, the new Food Safety Bill is awaiting approval in the parliament of Uganda but its approval may not help solve the coordination challenges due to the existing conflicts among some ministries and institutions. Lastly, Uganda is one of the East African countries that is experiencing the impact of climate change (hotter and humid climate changes). These weather conditions are suitable for the proliferation of mycotoxins yet they are no measures in place to mitigate the potential effects.

Conclusion and recommendations

Uganda is at a risk of mycotoxicosis and immediate assessments to determine the impact of the aflatoxins in agriculture, trade and health-related costs in humans and livestock should be done. It is recommended that: there should be continuous testing and effective monitoring (surveillance systems) of mycotoxins along the food chain at all times. The government of Uganda should provide capacity building to all relevant sectors in the food industry including the major food handlers at the household levels, farm level, and industries. People should be sensitized about mycoatoxins including school children. In addition, all consumables and equipment used in testing and monitoring mycotoxins should be subsidized by the

government to make them accessible and affordable. There is a need to conduct further studies on mycotoxins in the region. It is also imperative that regulatory programmes for monitoring mycotoxins levels in foodstuffs are developed and implemented.

Authors' contributions

Fred Brany Lukwago developed the idea of writing and drafting this review paper.

Conflict of interest

None.

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Supplementary materials

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