Odongo *et al. Discover Food* (2026) 6:202
https://doi.org/10.1007/s44187-026-00923-y

Discover Food

RESEARCH

Open Access

Maize processors' food handling competency and associated aflatoxin contamination of maize bran in northern Uganda

Kizito Odongo[1,2], Lawrence Okidi[1], Godfrey Kilama[1] and Duncan Ongeng[1*]

*Correspondence:
Duncan Ongeng
duncanongeng@hotmail.com
[1]Department of Food Science and Postharvest Technology, Faculty of Agriculture and Environment, Gulu University, P. O. Box 166, Gulu, Uganda
[2]Department of Crop Production, Ministry of Agriculture, Animal Industry and Fisheries, P. O. Box 102, Entebbe, Uganda

Abstract

Aflatoxins pose a serious threat to food and nutrition security. In Uganda, efforts have focused on reducing aflatoxin contamination in maize flour, yet maize bran, a key ingredient in poultry and livestock feed, has received limited attention. This study, conducted in Lira and Gulu districts, examined: (i) the knowledge, attitudes, and practices (KAP) of maize bran producers regarding aflatoxin contamination; (ii) levels of aflatoxin B_1 in maize bran; and (iii) the status of regulatory monitoring. Using a closed-ended, interviewer-administered questionnaire and Enzyme Linked Immuno-Assay for aflatoxin B_1 quantification, a cross-sectional survey was conducted among 55 maize bran producers. Data were analysed using descriptive statistics and binary logistic regression at a 5% significance level. Findings revealed poor knowledge, negative attitudes, and inadequate practices among producers. A significant positive correlation existed between knowledge and practices ($p < 0.05$). The levels of aflatoxin B_1 detected exceeded regulatory limits: 10ppb (Uganda/EAC), 4ppb (EU), and 20ppb (US FDA). Aflatoxin contamination was significantly associated with weekly bran sales volume ($p = 0.001$), market size/stability ($p = 0.010$), water sprinkling during processing ($p = 0.003$), and drying of bran before storage ($p = 0.015$). There was limited regulatory monitoring, with only prioritisation of safety, profit, or both ($p = 0.048$) significantly associated with aflatoxin levels being below or above 20 µg/kg. The study has revealed that maize bran in northern Uganda is highly contaminated and unsuitable for animal feed. Enhancing producer KAP through food safety education and strengthening regulatory enforcement by responsible government agencies is urgently needed to address Aflatoxin contamination in maize bran.

Keywords Maize bran, Maize processors, Aflatoxin B_1, Contamination, Regulatory monitoring

1 Introduction

Food safety remains a major global public health and development challenge [1], particularly in low- and middle-income countries where food systems are highly vulnerable to contamination [2]. Food is considered safe only when it is free of contaminants and does not pose a risk to human or animal health when consumed as intended [3]. Among food contaminants, mycotoxins represent one of the most persistent and difficult challenges to control because they are produced naturally by fungi and can enter the food chain at multiple points [4, 5]. Several mycotoxins are of concern to food and feed safety, including aflatoxins, deoxynivalenol, fumonisins, ochratoxins, zearalenone, and T-2 and HT-2 toxins [6]. The importance of individual mycotoxins varies by commodity, climate, and intended use. In animal feeds, particularly cereal-based feeds, aflatoxins remain a priority due to their high toxicity, widespread occurrence, and ability to transfer from feed into animal-derived foods consumed by humans [7].

Aflatoxins are toxic secondary metabolites produced mainly by the fungi *Aspergillus flavus* and *Aspergillus parasiticus* that thrive in warm and humid environments common in sub-Saharan Africa [8–12]. Among the four major types, aflatoxin B_1 is of greatest public health concern because it is strongly hepatotoxic, immunosuppressive, and carcinogenic [13, 14]. The International Agency for Research on Cancer classifies aflatoxin B1 as a Group 1 human carcinogen [15]. After ingestion, aflatoxin B1 is metabolized in the liver, where it can bind to DNA and proteins, leading to liver damage and increased risk of hepatocellular carcinoma [14, 15]. In lactating animals, it can be converted to aflatoxin M1 and excreted in milk, creating an additional route of human exposure [16]. Aflatoxin contamination affects a wide range of staple crops used for food and feed, including maize, sorghum, rice, and groundnuts [17–19]. While global estimates often cite that about one quarter of food crops are contaminated by mycotoxins in general [20], aflatoxins account for a substantial share of the health burden associated with mycotoxin exposure, particularly in tropical regions [11, 13]. Chronic dietary exposure has been associated with impaired child growth, immune suppression, and increased cancer risk in humans [21]. In livestock, aflatoxin-contaminated feeds negatively affect productivity and health [8]. Poultry exposed to aflatoxins may experience reduced growth, poor feed efficiency, liver damage, and weakened immune responses [22, 23]. Similar effects have been reported in dairy cattle and pigs [24], with additional concern for carry-over of aflatoxin residues into milk, meat, and edible organs. These impacts translate into economic losses for farmers and increased food safety risks for consumers.

Maize bran is a particularly important but often overlooked component of this problem. It is a major by-product of maize milling and one of the most widely used feed ingredients for poultry and livestock in Uganda due to its affordability and availability [25]. Maize bran is nutritionally valuable, containing energy, fiber, protein, and B-complex vitamins [24]. Its economic importance in the feed sector is therefore substantial. However, milling does not destroy aflatoxins [26, 27]. Instead, evidence suggests that aflatoxins tend to concentrate in the outer layers of the grain, which are removed during milling [26, 28]. As a result, maize bran may contain higher aflatoxin levels than refined maize flour. Despite this risk, aflatoxin control efforts in Uganda and similar settings have largely focused on maize grain and flour intended for direct human consumption [29–31], with limited attention to maize bran destined for animal feeds. This creates a potential pathway for aflatoxins to re-enter the human food chain through animal-source foods. Available studies from Uganda indicate frequent aflatoxin contamination in maize and animal feeds [29, 32, 33], but data specifically on aflatoxin B1 levels in maize bran remain scarce. In addition to contamination levels, food safety outcomes are influenced by the knowledge, attitudes, and practices (competency) of actors along the value chain, as well as by the effectiveness of regulatory monitoring and enforcement [34]. For maize bran producers, inadequate awareness of aflatoxin risks, poor handling and storage practices, and weak regulatory oversight may contribute to unsafe contamination levels [35]. However, the extent to which these factors affect aflatoxin contamination of maize bran in Uganda is not well documented. Therefore, using northern Uganda as a case, this study investigated aflatoxin B1 contamination levels in maize bran, assessed the knowledge, attitudes, and practices of maize bran producers related to aflatoxin control, and examined the status of regulatory monitoring of maize bran for aflatoxin contamination.

2 Materials and methods

2.1 Study area and study population

2.1.1 Study area

The study was conducted in Gulu and Lira district in northern Uganda. These two districts were selected because they are among cities that host a high concentration of commercial maize grain mills that continuously produce maize bran for livestock feed as a by-product of flour milling [36]. Lira district is located on coordinates (02 20 N, 33 06E). It lies at an elevation of 1,080 m (3,540 ft) above sea level with a total area of 1,368.9 km^2 (Land; 1,328.9 km^2 & Water; 40 km^2) and a total population of 403,100 people (density of 303.3 persons per sq. kilometre). Similarly, Gulu district is located on coordinates (02 45 N, 32 00E) at an elevation of 1,100 m (3,600 ft) above sea level. The district has a total area of 3,452.1 km^2 with a population of 396,500 (density of 114.9 persons per sq. kilometre). The two urban centers are located in northern Uganda. The climate of northern Uganda is characterized by alternating wet and dry seasons [37], with average annual temperatures commonly reported between 18 and 35 °C [37] and relative humidity typically ranging from 60 to 75% [38], depending on season. Such conditions are widely recognized as favourable for the growth of aflatoxin-producing fungi when combined with poor post-harvest handling and storage.

The dominant livelihood activities in the region include crop production and livestock rearing [37]. Cassava is the primary staple crop, followed by cereals such as maize, sorghum, and millet [39]. Maize is of particular importance because it serves both as a staple food and as a major source of livestock feed ingredients [40], mainly in the form of maize bran. Poultry, pigs, goats, and cattle are the most common livestock species [41], and maize bran is widely used due to its availability and low cost [42].

2.1.2 Study population

The study population consisted of commercial grain millers who produced maize bran as part of their routine milling operations. Eligible participants were those who had been engaged in maize milling for at least one year and who consented to participate in the study.

2.2 Study design, sampling framework, and sample determination

2.2.1 Study design

A cross-sectional design was used. The choice of this design was based on the fact that it is quick, cheap and only conducted once at a given point in time [22].

2.2.2 Sampling framework

A multistage sampling process was used to locate the study participants. First, the municipal area was purposively selected from each of the two districts (Lira and Gulu). This is because the districts usually serve as business centres and have the highest concentration of maize grain millers in northern Uganda. Secondly, two divisions within each district were randomly selected to participate in the study. Thirdly, one ward/parish from each of the divisions identified was then selected and finally, random sampling was conducted to generate the study participants (see Fig. 1).

2.2.3 Sample determination

To obtain a reliable sample size, Slovin's formula was used [23].

$$n = \frac{N}{1 + Nd^2} \tag{1}$$

Where: n = sample size, N = population of bran producers, and ɗ = margin of error. Based on Eq. 1.

A total of 64 eligible maize bran producers were identified by the district commercial officer of the two districts. This constituted the accessible population. Considering, N of 64 bran producers and ɗ = 0.05, the sample size n was then determined to be 55 bran producers. Of these, 12 were from Gulu district and 43 from Lira district using probability proportional to size of 78.12% (N = 50) and 21.88% (N = 14), respectively.

2.3 Determination of maize bran producers' KAP regarding aflatoxin contamination

A closed-ended interviewer-administered questionnaire was used. The questionnaire had two parts adopted from Aba [43]. Part one was used to ascertain the socio-demographic characteristics of the study participants. The second part was designed to test respondents' knowledge, attitude, and practices related to safety aspects linked to aflatoxin based on constructs derived from previous studies [27–29]. The constructs were based on three key parameters: (i) environmental factors; (ii) thermal stability; and (iii) health effects associated with consumption of aflatoxin-contaminated products. Knowledge and attitude were each measured on a 3-point Likert scale. The scaling was: 1 = Agree, 2 = Do not Know, and 3 = Disagree for knowledge; and 1 = Disagree, 2 = Not sure and 3 = Agree for attitude. On the other hand, practices were measured on a 2-point scale (1 = Yes and 2 = No).

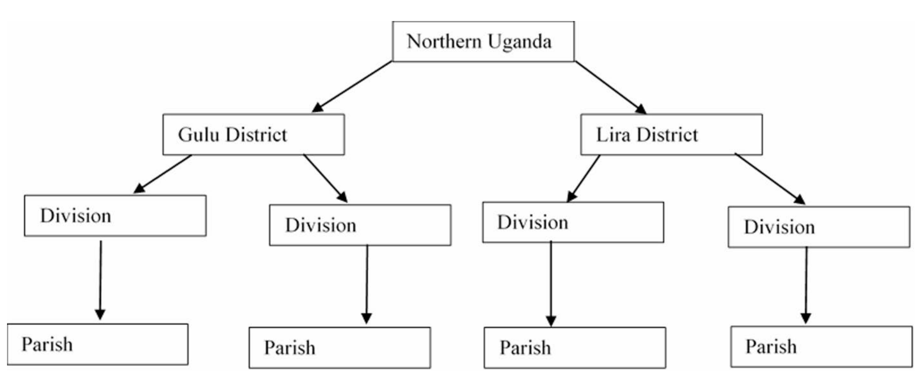

Fig. 1 Sampling flow chart

2.4 Determination of aflatoxin B_1 levels in maize bran

2.4.1 Sample collection

Maize bran samples were collected from each of the 55 producers. To address the heterogeneous distribution of aflatoxins, incremental samples were taken from multiple points within each batch, including the top, middle, and bottom of storage containers or sacks. These increments were combined into a composite sample weighing approximately 500 g per selected producer from Gulu ($n = 12$) and Lira ($n = 43$) district.

Samples were placed in clean, airtight aluminum foil bags, clearly labelled, and transported to the Uganda Industrial Research Institute (UIRI) laboratory within 24 h. Cold storage was not used during transport because samples were dry, sealed, and transported over short distances. This approach is consistent with standard aflatoxin sampling guidance for dry feed materials. UIRI is a nationally accredited public laboratory with established capacity for food and feed safety analysis and routinely supports regulatory testing and research in Uganda. Upon arrival, samples were stored at 4 °C and analyzed within 72 h to minimize any changes in aflatoxin concentration.

2.4.2 Sample preparation and extraction

The sample preparation and extraction was done in accordance to Association of Analytical Chemist as described by Maragos [44]. Briefly, each composite sample was thoroughly mixed, and a 50 g subsample was ground using a laboratory hammer mill until a uniform fine powder was obtained. The grinder (laboratory-grade stainless steel grinder, dedicated to mycotoxin analysis, and define powder suitability based on passage through a 0.5 mm mesh) was cleaned with 70% and allowed to dry between samples to prevent cross-contamination. All personnel used gloves and masks during grinding to minimize exposure to dust.

For extraction, 5 g of the ground sample was weighed into a 50 mL polypropylene centrifuge tube, and 25 mL of 70% methanol was added. The mixture was shaken on an orbital shaker at 200 rpm for 10 min, a duration selected to ensure efficient extraction from a complex feed matrix. The extract was filtered through Whatman No. 1 filter paper, and the filtrate was diluted according to kit instructions before analysis.

2.4.3 Enzyme-Linked Immuno-Assay (ELISA)

Aflatoxin B1 (AFB1) was quantified using a commercial competitive ELISA kit (RIDASCREEN Aflatoxin B1, R-Biopharm AG, Germany). ELISA was selected because it is cost-effective, validated, and widely used for aflatoxin monitoring in low- and middle-income countries. Exactly 50 µl of AFB_1 standard and prepared samples were pipetted into separate wells using separate pipette tips for each standard and sample. This was followed by the addition of 50 µl of enzyme conjugate and 50 µl of anti-aflatoxin antibody solution. The plate (holding the well) was shaken manually to cause mixing, followed by incubation for 30 min at room temperature (20–25 °C). Following incubation, the resultant solution was poured out of the wells, followed by tapping the microwell holder upside down (three times in a row) on a clean paper towel to remove remaining solution from the wells. The wells were then filled with 250 µl washing buffer and emptied again to remove the buffer. The washing step was repeated two more times. An aliquot of 100 µl of substrate/chromogen was added to each well, mixed gently by shaking the plate manually, and incubated for 15 min in the dark at room temperature (20–25 °C) to enable colour development. An aliquot of 100 µl of a stop solution was added to each well and mixed gently by shaking the plate manually, followed by reading the absorbance of the resultant solution at 450 nm using an ELISA Microplate Reader machine (DR–200 B Microplate Reader, Wuxi, China).

All standards, controls, and samples were analyzed in quadruplicate. Calibration curves were generated using manufacturer-provided standards. Absorbance was measured at 450 nm using a microplate reader. According to the kit validation data, the limit of detection (1 µg/kg) and limit of quantification (2 µg/kg) were within ranges suitable for regulatory assessment of feed materials. Quality control procedures included the use of blanks, standards, and recovery checks as specified by the manufacturer.

2.5 Assessment of regulatory monitoring of aflatoxin contamination of maize bran

A pretested researcher administered questionnaire was used to collect data on different aspects of regulatory monitoring practices. The questions were adapted from literature [24]. Aspects assessed included: frequency of regulatory monitoring by mandated agencies, testing for aflatoxin contamination and improving feedback mechanisms, among others.

2.6 Data analysis

SPSS (version 20) was used for data analysis. Data on socio-demographic factors were summarised using descriptive statistics (percentages, median). Responses to questions testing knowledge of bran producers regarding aflatoxin were each scored on a 3-point scale (2 = agree, 0 = don't know, 1 = disagree). The scores for each respondent were summed up and expressed as a percentage of the total possible score [16]. Attitude responses were scored on a 3-point scale (0 = disagree, 1 = not sure, and 2 = agree) upon reverse coding of negatively phrased questions, and the aggregated score for each respondent was expressed as a percentage of the total possible score [28]. Responses to questions testing practice were scored on a 2-point scale (1 = correct, 0 = wrong). The score for each respondent was aggregated and expressed as a percentage of the total possible score [14]. The status of knowledge or practices was considered good if the percentage score was above 80. In the case of attitude, a percentage of greater than 90 was considered as positive attitude [25]. Otherwise, the parameters were considered to be poor, negative and poor. Binary Logistic Regression (BLR) was used to determine predictors (independent variables) of good knowledge, attitude or practices [26]. Before BLR, one of any two highly correlated independent variables ($r \geq 0.7$) was discarded, and predictors were considered significant at 5% error limit. According to Dorman [27] and Fernandes [28], the following independent variables were coded as binary dummy variables to run the binary regression; sex of the bran producers (1 = Male, 0 = Female), education status of bran producers (1 = primary, 0 = secondary and tertiary), market size and stability (1 = stable and increasing and, 0 = declining), company size (1 = large, 0 = small and medium), employee type (1 = skilled, 0 = unskilled), employment type (1 = full time, 0 = part time). Additionally, data on the concentration of aflatoxin were subjected to Kolmogorov-Smirnov test for normality ($p > 0.05$). The results showed that the data were normally distributed. The mean concentration of AFB_1 from producers in each district and for the two districts was derived and compared to the national (UNBS)/regional (EAC), or international (EU, USFDA regulatory acceptable limits of 10 ppb, 4 ppb, 20 ppb), respectively. Chi-Square was used to establish an association between aflatoxin B_1 contamination level and bran producer characteristics. Furthermore, data on responses to questions testing regulatory monitoring were analysed using descriptive statistics (frequencies and percentages). Finally, the association between regulatory monitoring and aflatoxin B_1 contamination was established using Chi-square. For all analyses, the level of statistical significance was fixed at 5%.

3 Results

3.1 Socio-demographic characteristics of the study participants

Generally, the proportion of maize bran producers was approximately 4 times more in Lira municipality compared to Gulu municipality, with a difference of 57.2% and was characterised by a median age of 35 years. Relatedly, in terms of ownership of bran production, males were more than females by a factor of 7. At least 60% of the respondents believed that the market of maize bran was expanding compared to those who believed that the market was stable and declining, respectively. This is, although more than 90% of the processors operated on a small scale, with more than 90% of the owners being employed in the bran production business on a full-time basis. In terms of education, more than 40% of maize bran producers attained at least a primary level of education, and none were illiterate. The highest proportion was in primary, followed by secondary and tertiary education in decreasing order of magnitude. In most (62.5%) of the processing facilities surveyed, bran production was largely managed by unskilled employees, while less than 15% of the processors employed skilled employees. It was apparent that about 20% of the processors employed both skilled and unskilled personnel in bran production activities. All the processors had access to the market for the bran, which was largely local. The processors had a median weekly bran production level of less than two tons and were concomitant with a median business experience of 5.5 years. In the context of marketing, the unit price of the bran was reported to be ten times higher during periods of scarcity than during periods of abundance. In terms of raw material holding, bran processors usually took a median of 2 days of grain storage before processing (see Table 1).

3.2 Status of knowledge, attitude, and practices regarding aflatoxins among maize bran producers

Generally, the level of knowledge, attitude, and practices was below the expected cut-offs of being good. In quantitative terms, the level of knowledge, attitude, and quality of practice was below the cut-off by 25, 45, and 22% points, respectively.

Generally, at least 50% of the bran producers were knowledgeable about 75% of the aspects used to test knowledge. However, based on the cut-off score (80%) for a good level of knowledge, bran producers had good knowledge only on the aspect of moist grains having a higher potential for aflatoxin development.

Above all, of all the aspects tested, bran producers exhibited the lowest level of knowledge on the key aspects regarding the potential of aflatoxin to bioaccumulate in livestock products used as food, acceptable regulatory limits for aflatoxin in animal feed and the fact that aflatoxins are not inactivated by the process of normal cooking practised at home (see Table 2).

Table 1 Socio-demographic characteristics of maize bran producers

Variable	%	Variable	%
District		**Education level**	
		No Formal Education ($n=0$)	0.0
Gulu ($n=12$)	21.4	Primary ($n=25$)	44.6
Lira ($n=43$)	78.6	Secondary ($n=18$)	32.1
Sex		Tertiary ($n=13$)	23.2
Female ($n=7$)	12.5	**Market availability**	
Male ($n=48$)	87.5	Yes	100.0
Market size and stability		**Location of the market**	
Declining ($n=7$)	12.5	Local	100.0
Expanding ($n=35$)	64.3	**Type of employees**	
Stable ($n=13$)	23.2	Skilled ($n=8$)	14.3
Company size		Unskilled ($n=34$)	62.5
Small scale ($n=54$)	98.2	Both ($n=13$)	23.2
Large Scale ($n=1$)	1.8	**Number of employees**	
Type of employment		1–6 ($n=46$)	83.9
Full time ($n=54$)	96.4	7–14 ($n=7$)	12.5
Part-time ($n=1$)	3.6	≥ 15 ($n=2$)	3.6
Number of skilled Employees			
0 ($n=34$)	60.7		
1–3 ($n=19$)	33.9		
≥ 4 ($n=3$)	5.4		
Other characteristics	**Median (LQ, UQ)**	**Other characteristics**	**Median (LQ, UQ)**
Age	35 (27.3, 48.0)	Duration grains take before processing (Days)	2.0 (1.0, 3.0)
Distance to the nearest town (Km)	1.3 (1.3, 5.0)	Price/Kilogram during abundance (USD)	0.08 (0.05, 0.10)
Duration spent in business in years	5.5 (2.0, 10.0)	Price/Kilogram during scarcity (USD)	0.18 (0.16, 0.22)
Maize bran produced weekly (Tonnes)	1.6 (0.5, 4.2)	Maize bran weekly sales (Tonnes)	0.85 (0.45, 1.64)

LQ means lower quartile, UQ means upper quartile, and USD refers to United States Dollar, small company ≤ 15 employees, and large scale ≥ 16 employees

Generally, most of the bran producers (at least 50%) had a negative attitude toward most of the actions that can control aflatoxin contamination of maize bran. On average, only 37% of bran producers reported a positive attitude, while majority disagreed (49%), and 14% were not sure. There was negative attitude among maize bran producers with majority (up to 75%) disagreed that regulating aflatoxin levels in maize bran by government is important, (86%) believing that discarding mouldy maize bran brings losses to the business, while others were confident that there is always market for maize bran despite being mouldy (71%), sun drying of maize bran was time-consuming and laborious (61%), testing for aflatoxins in maize bran was costly (63%), storing maize bran in air-tight containers was not cost-effective (66%).

In addition, 52% of maize bran producers believed that screening of maize for moisture content can lead to customer loss, with only 29% considering disinfection of storage facility essential to reduce aflatoxin contamination (Table 3).

Generally, maize bran producers employed a mix of practices, including proper and improper management practices, before, during and after bran processing. On average, about half (52%) of bran producers employed proper management practices for the

Table 2 Distribution of affirmative responses to questions testing knowledge on aflatoxins among maize bran producers

Question	Agree (%)	Don't Know (%)	Dis-agree (%)
Have you ever heard of aflatoxin?	57.1	33.9	8.9
Aflatoxins can occur in animal feed or feed ingredients?	71.4	26.8	1.8
Maize bran can be contaminated by aflatoxins?	73.2	19.6	7.1
Aflatoxins suppress immunity in livestock?	48.2	42.9	8.9
Aflatoxins does not accumulate in Animal products?[R]	23.2	42.9	33.9
Dry condition promotes Aflatoxins in maize bran?[R]	51.8	21.4	26.8
There are acceptable limits for Aflatoxins in feeds in Uganda and EAC	37.5	55.4	7.1
Maize bran should be dried regularly to prevent aflatoxins	78.6	17.9	3.6
Aflatoxins are not destroyed by normal cooking?	33.9	41.1	25.0
Export of maize bran can be rejected when aflatoxins are above-accepted levels	55.4	30.4	14.3
Government inspectors are mandated to regularly check maize bran for Aflatoxins	53.6	32.1	14.3
Rapid test kits can be used to test aflatoxin before export?	55.4	41.1	3.6
Proper ventilation of the milling room reduces occurrence of aflatoxins in maize bran	64.3	19.6	16.1
Storing maize bran on a dry raised platform does not reduce Aflatoxins[R]	55.4	19.6	25.0
Maize bran from moist maize will likely develop aflatoxins	82.1	14.3	3.6
Sprinkling water on maize during processing increases occurrence of aflatoxins	55.4	17.9	26.8
Cronbach's alpha	0.78		

[R]Means the item was reverse-coded, EAC means East African Community

Table 3 Distribution of responses to questions that tested producers' attitude towards aflatoxin contamination of maize bran

Question	Agree (%)	Not Sure (%)	Dis-agree (%)
I believe aflatoxin cannot contaminate maize bran?[R]	26.8	17.9	55.4
Poor hygiene can increase aflatoxin contamination?	25.0	16.1	58.9
Feeding livestock on maize bran containing aflatoxins cannot affect humans?[R]	37.5	26.8	35.7
I do not believe that proper ventilation can reduce aflatoxin contamination	30.4	21.4	48.2
Screening of maize for moisture content can lead to customer loss[R]	51.8	5.4	42.9
Storing maize/bran in airtight containers is not cost effective	66.1	16.1	17.9
I think regular disinfection of storage facility cannot reduce aflatoxin contamination	50.0	21.4	28.6
Sun drying of maize bran is time consuming and laborious	60.7	5.4	33.9
I believe regulating aflatoxin levels in maize bran by government is important?	14.3	10.7	75.0
aflatoxin contamination cannot be controlled by farmers, traders, transporters, and processors	42.9	7.1	50.0
Discarding of mouldy maize bran brings losses to the business	85.7	5.4	8.9
Testing aflatoxins in maize bran is costly	62.5	23.2	14.3
There is always market for maize bran despite being mouldy	71.4	1.8	26.8
I believe sprinkling of water on maize before milling cannot increase occurrence of aflatoxins	53.6	17.9	28.6
Cronbach's alpha	0.82		

[R]Means the item was reverse-coded

prevention of subsequent aflatoxin contamination. However, half (50%) of the producers reported marketing bran without quality consideration, even though the bran was mouldy, and 54% of the producers did not routinely check for mould growth in the bran. Above all, a majority (57%) of bran producers purchased maize grains from farmers when the grains still had high moisture content without any rejection.

Table 4 Distribution of the proportion of maize bran producers with proper/improper management practices towards aflatoxins

Question	Yes (%)
I always check moisture content in grain and bran before storage?	66.1
I often do not sprinkle water into the maize grains before or during processing?	25.0
I always dry the bran adequately before storage?	48.2
I often do not dry the maize bran on tarpaulins, mat, concrete slab?	19.6
I always package the grains or maize bran in airtight and moisture proof bags or containers?	23.2
I always ensure that the storage facility for maize bran does not leak?	71.4
I always maintain proper ventilation for storage facility for maize grain?	78.6
I always maintain proper ventilation for storage facility for maize bran?	60.7
I often do not disinfect or clean the stores regularly to reduce growth of aflatoxin causing organisms	42.9
I often sell maize bran even though it has grown mouldy	50.0
I always do not reject moist maize from farmers	57.1
I often check maize bran that has grown mouldy	46.4
I often separate maize bran obtained from maize of different moisture content	42.9
I always train new staff on how maize bran should be handled to reduce the growth of moulds (occurrence of aflatoxins)	62.5
Cronbach's alpha	0.76

Table 5 Association between knowledge, attitude, and practices towards aflatoxin contamination in maize bran

Knowledge	Knowledge	Attitude	Practices
	1		
Attitude	0.145	1	
Practices	0.477***	0.146	1

*** Shows significance at $p \leq 0.01$

Additionally, 57% of bran producers did not separate maize bran obtained from grains of different moisture contents, a situation which provides a favourable environment for mould growth and subsequent aflatoxin contamination. Furthermore, the majority (75%) of bran producers often sprinkled water on maize grains before or during processing, 52% of them did not dry the bran adequately, and 77% did not package the grains or bran in airtight and moisture-proof bags or containers before storage or transportation to the market. Despite improper management practices by a majority of bran producers, some had employed proper management practices. This is illustrated by the fact that 66% of the producers reported checking for moisture content in grains and bran before storage, while 71% reported ensuring that the storage facility had no leaks. In addition, 61% and 78% reported maintaining proper ventilation for both bran and grains, respectively (Table 4).

There was only a significant correlation between knowledge and practices towards aflatoxin management among maize bran producers. Directionally, the correlation was positive, indicating that a unit change in either knowledge or practices was associated with a 23% change in the other parameter ($r^2 = 0.228$) (Table 5).

There was no statistically significant association between producer characteristics investigated and knowledge, attitude, or practices towards aflatoxin contamination of maize bran (Table 6).

Table 6 Relationship between maize bran producer characteristics and knowledge, attitude, or practices

Producer characteristics	Knowledge		Attitude		Practices	
	Coefficient (β)	*p*-value	Coefficient (β)	*p*-value	Coefficient (β)	*p*-value
Duration in business	−0.114	0.273	−0.558	0.480	0.053	0.580
Maize bran produced per week (Tonnes)	−0.361	0.108	1.872	0.270	−0.545	0.272
Number of skilled employees	0.843	0.286	−49.346	0.999	4.216	0.293
Sex (1 = Male) [a]	0.428	0.788	−5.361	1.000	−20.523	0.999
Education of bran producers (1 = primary) [b]	1.172	0.237	41.794	1.000	21.064	0.997
Market stability (1 = stable and increasing) [c]	2.005	0.118	−18.905	0.999	4.940	0.260
Bran processor production scale (1 = Large) [d]	23.614	1.000	−232.346	0.999	14.883	1.000
Employee type (1 = Skilled) [e]	21.806	0.999	−37.627	0.999	21.411	0.998
Employment type (1 = Full time) [f]	−21.197	0.999	29.724	1.000	−2.775	1.000
Constant	−46.695		222.580		−62.371	

a: 1 = Male, 0 = Female; b: 1 = Primary, 0 = Secondary and Tertiary; c: 1 = Stable and Increasing, 0 = Declining;
d: 1 = Large, 0 = Small& Medium; e: 1 = Skilled, 0 = Unskilled; f: 1 = Full time, 0 = Part time

3.3 Aflatoxin B_1 contamination levels in maize bran

AF B_1 contamination based on pooled data for the two districts and individual districts was greater than EU, EAC/UNBS, and USFDA limits for tolerable aflatoxin concentration in animal feeds (Fig. 3). Quantitatively, the contamination level detected was greater than EU and EAC/UNBS limits by a factor of 7 and 2, respectively. When data was segregated by location (district), the contamination level detected was higher in Lira (37.3 µg/kg) than in Gulu (26.9 µg/kg) district by about 10 µg/kg (Fig. 3).

Generally, the quantity of the bran sold weekly ($p = 0.001$) and market size and stability ($p = 0.010$) were the only factors significantly associated with the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 µg/kg (Table 7).

Generally, only the practice of sprinkling water before or during processing ($p = 0.003$) and adequate drying of the bran before storage ($p = 0.015$) were significantly associated with the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 µg/kg (Table 8).

3.4 Association between regulatory monitoring practices and the likelihood of the concentration of aflatoxin being below or above the safety limit of 20 µg/kg

Generally, consideration of safety or profit or both among the bran producers was significantly ($p = 0.048$) associated with the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 µg/kg (Table 9).

4 Discussion

4.1 Knowledge, attitude, and practices (KAP) of maize bran producers

Generally, the level of knowledge, attitude, and practices towards aflatoxin contamination recorded in this study were poor, negative, and poor, respectively (Fig. 2). Although averagely 50% of bran producers proved knowledgeable of about 75% of key aspects testing knowledge, some were not knowledgeable that sprinkling water to maize grains during processing (Table 2) provides a conducive environment for fungal development and subsequent aflatoxin production in the bran. Additionally, bran producers displayed little knowledge on potential of toxins to bioaccumulate in animal tissues and products to

Table 7 Relationship between maize bran producer characteristics and the likelihood of the concentration of aflatoxin being below or above the safety limit of 20 μg/kg

Producers Characteristics		Producers with Aflatoxin B_1 level				χ2	p. value
		< 20 μg/kg		> 20 μg/kg			
		n	Percent	n	Percent		
Distance	< 5km	18	39.10%	28	60.90%	0.835	0.361
	≥ 5.1km	5	55.60%	4	44.40%		
Age of bran producer	18–35 years	12	42.90%	16	57.10%	0.025	0.874
	≥ 35 years	11	40.70%	16	59.30%		
Duration in business	0–5 days	12	42.90%	16	57.10%	0.025	0.874
	≥ 6 days	11	40.70%	16	59.30%		
Duration grains in storage	0-7days	23	43.40%	30	56.60%	1.492	0.222
	≥ 8 days	0	0.00%	2	6.20%		
Maize bran produced weekly	0-2tons	16	51.6%	15	48.4%	2.801	0.094
	≥ 2.1 tons	7	29.2%	17	70.8%		
Maize bran sold weekly	0–2 tons	20	60.60%	13	39.40%	11.969	0.001*
	≥ 2.1 tons	3	13.60%	19	86.40%		
The average duration of bran stock in storage before being sold	0–1 week	11	50.00%	11	50.00%	1.009	0.315
	≥ 2 weeks	12	36.40%	21	63.60%		
Number of employees	0–5 people	18	40.90%	26	59.10%	0.075	0.785
	≥ 6 people	5	45.50%	6	54.50%		
Number of skilled employees	0 person	11	32.40%	23	67.60%	3.279	0.070
	≥ 1 person	12	57.10%	9	42.90%		
Market size and stability for the bran?	Expanding	20	57.10%	15	42.90%	9.293	0.010*
	Stable	2	15.40%	11	84.60%		
	Declining	1	14.30%	6	85.70%		
Type of employees	Skilled	3	42.90%	4	57.10%	5.571	0.062
	Unskilled	11	31.40%	24	68.60%		
	Both	9	69.20%	4	30.80%		
Education level of bran producers	Primary	9	36.00%	16	64.00%	1.272	0.529
	Secondary	9	52.90%	8	47.10%		
	Others	5	38.50%	8	61.50%		
Type of employment	Part-time	1	50.00%	1	50.00%	0.057	0.811
	Full-time	22	41.50%	31	58.50%		
Company size	Small Scale	22	40.70%	32	59.30%	1.417	0.234
	Large Scale	1	100.00%	0	0.00%		
Sex of respondent	Female	18	37.50%	30	62.50%	2.890	0.089
	Male	5	71.40%	2	28.60%		

*Shows significance at α = 0.05

the extent of believing that aflatoxins are destroyed under normal cooking temperatures while affirming that there are no regulatory limits for aflatoxins in feeds in Uganda and East African Region.

This implies that poor knowledge of bran producers could be contributing to the observed high levels of aflatoxin contamination of the bran. In another related study by Anitha [22], Malawian farmers reported a reduction in mean concentration of aflatoxin in grain samples after attaining training on the mitigation of aflatoxin despite the existence of favourable environmental conditions. However, it was largely unknown whether the knowledge acquired was able to influence their behavioural practices towards prevention of aflatoxin contamination. This finding is consistent with that of Nassanga [29], who reported good nutritional knowledge on complementary feeding among caregivers; however, they noted that this was not translated into practice to attain better child

Table 8 Relationship between maize bran producers' practices and the likelihood of the concentration of aflatoxin being below or above the safety limit of 20 μg/kg

Producers Practices		**Producers with Aflatoxin B_1 level**				**χ2**	**p. value**
		< 20 μg/kg		**> 20 μg/kg**			
		n	**Percent**	**n**	**Percent**		
I always check moisture content in grain and bran before storage?	No	7	36.8%	12	63.2%	0.295	0.587
	Yes	16	44.4%	20	55.6%		
I often do not sprinkle water into the maize grains before, or during processing?	No	13	31.0%	29	69.0%	8.623	0.003*
	Yes	10	76.9%	3	23.1%		
I always dry the bran adequately before storage?	No	9	28.1%	23	71.9%	5.897	0.015*
	Yes	14	60.9%	9	39.1%		
I often do not dry the maize bran on tarpaulins, mat, concrete slab?	No	17	37.8%	28	62.2%	1.661	0.198
	Yes	6	60.0%	4	40.0%		
I always package the grains or maize bran in airtight and moisture proof bags or containers?	No	17	40.5%	25	59.5%	0.132	0.717
	Yes	6	46.2%	7	53.8%		
I always ensure that the storage facility for maize bran does not leak?	No	8	50.0%	8	50.0%	0.621	0.431
	Yes	15	38.5%	24	61.5%		
I always maintain proper ventilation for storage facility for maize grain?	No	3	25.0%	9	75.0%	1.784	0.182
	Yes	20	46.5%	23	53.5%		
I always maintain proper ventilation for storage facility for maize bran?	No	9	42.9%	12	57.1%	0.015	0.902
	Yes	14	41.2%	20	58.8%		
I often do not disinfect or clean the stores regularly to reduce growth of aflatoxin causing organisms	No	12	38.7%	19	61.3%	0.282	0.595
	Yes	11	45.8%	13	54.2%		
I often sell maize bran even though it has grown mouldy	No	13	46.4%	15	53.6%	0.498	0.480
	Yes	10	37.0%	17	63.0%		
I always do not reject moist maize grains from farmers	No	10	41.7%	14	58.3%	0.000	0.984
	Yes	13	41.9%	18	58.1%		
I often do not sell maize bran that has grown mouldy	No	12	41.4%	17	58.6%	0.005	0.944
	Yes	11	42.3%	15	57.7%		
I often separate maize bran obtained from maize of different moisture content	No	13	40.6%	19	59.4%	0.045	0.832
	Yes	10	43.5%	13	56.5%		
I always train new staff on how maize bran should be handled to reduce the growth of moulds (occurrence of aflatoxins)	No	9	45.0%	11	55.0%	0.131	0.718
	Yes	14	40.0%	21	60.0%		

*Shows significance at α = 0.05

nutritional outcomes. Similarly, Ilesanmi [30] reported good knowledge on aflatoxin contamination in groundnuts among health workers in Nigeria. The disparity between the findings of the current study and those of Ilesanmi [30] could be explained by the profession of the participants in question. Health workers, typical of doctors and nurses could have received prior training on aflatoxins owing to its health significance as opposed to the bran processors considered in the current study who largely attained primary and secondary levels of education (Table 2).

Similarly, Azaman [45] reported positive attitude among stakeholders towards the reduction of aflatoxin contamination of food and feed products in peanut-based products. The disparity between, the findings of the current study (Fig. 2) and that of Azaman [45] could be explained by differences in the level of knowledge, a factor known to influence attitude between study participants in the two studies [29]. However, the key aspects that largely contributed to the negative attitude were; bran processors believing that discarding mouldy maize bran brings losses to the business, motivation that there is still an available market for maize bran despite being mouldy, considering that sun-drying of maize bran is time consuming, testing aflatoxins for maize bran is costly and

Table 9 Relationship between regulatory monitoring practices and the likelihood of the concentration of aflatoxin being below or above the safety limit of 20 μg/kg

Regulatory monitoring practices		Producers with Aflatoxin B_1 level				χ2	p. value
		< 20 μg/kg		> 20 μg/kg			
		n	percent	n	percent		
Does Government conduct regulatory monitoring to ensure aflatoxins free bran?	Yes	2	33.30%	4	66.70%	0.199	0.655
	No	21	42.90%	28	57.10%		
Frequency of monitoring aflatoxins in maize bran	Never	21	44.70%	26	55.30%	1.225	0.542
	Biannually	1	33.30%	2	66.70%		
	Annually	1	20.00%	4	80.00%		
Does the government agency bring feedback of samples tested for aflatoxins?	Yes	1	100.00%	0	0.00%	1.417	0.234
	No	22	40.70%	32	59.30%		
Does safety of the bran determine access to the market?	Yes	16	50.00%	16	50.00%	2.105	0.147
	No	7	30.40%	16	69.60%		
Type of market affected by safety of bran	Not aware	7	31.80%	15	68.20%	1.781	0.411
	Local	4	57.10%	3	42.90%		
	Regional	12	46.20%	14	53.80%		
Does regulatory monitoring measures by Government affect sales and price of bran?	Yes	3	42.90%	4	57.10%	0.004	0.952
	No	20	41.70%	28	58.30%		
Does safety of bran determine profit in the business?	Yes	12	41.40%	17	58.60%	0.005	0.944
	No	11	42.30%	15	57.70%		
What do you consider a priority and requires more attention?	Safety	2	22.20%	7	77.80%	6.073	0.048*
	Profit	1	12.50%	7	87.50%		
	Both	20	52.60%	18	47.40%		
What would you sacrifice?	Safety	18	46.20%	21	53.80%	1.036	0.309
	Profit	5	31.20%	11	68.80%		
Train employees on food safety	Yes	2	50.00%	2	50.00%	0.119	0.730
	No	21	41.20%	30	58.80%		
Can you do without selling bran?	Yes	3	30.00%	7	70.00%	0.702	0.402
	No	20	44.40%	25	55.60%		

*Shows significance at α = 0.05

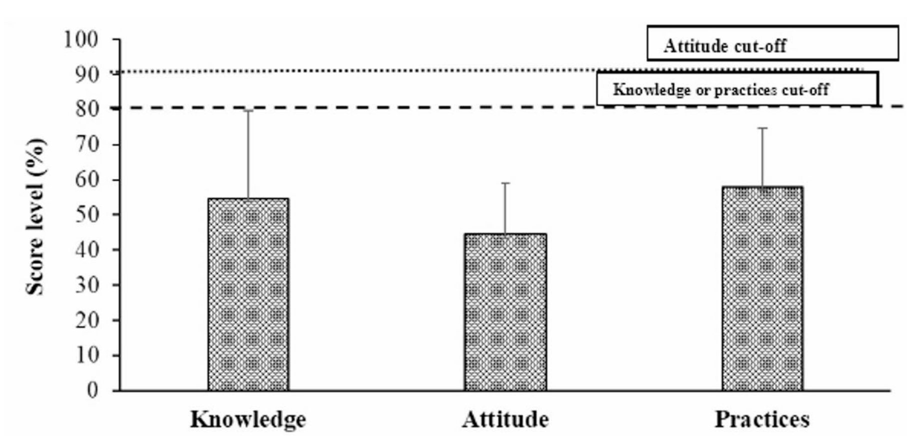

Fig. 2 Level of knowledge, attitude, and practices regarding aflatoxin among maize bran producers

leads to loss of maize grain suppliers, investing in storing bran in air-tight containers is not cost effective and disbelieve in disinfection of storage facility as an essential strategy to reduce aflatoxin contamination (Table 8).

In addition, the poor practices towards aflatoxin contamination are not unique to this study but to the study commodity. Inappropriate practices that perpetuate contamination by aflatoxins has been previously reported by Anitha [22] in Malawi. Lastly, knowledge and practices positively influenced one another (Table 5). Similar findings were reported by Azaman [45] on aflatoxin contamination in peanut-based products, in which notable improvement in hygiene practices, storage and quality assurance, and certification among the stakeholders in Malaysia was associated with reduced aflatoxin contamination. Furthermore, Joseph [35] reported that aflatoxin contamination of maize grains was accelerated by adoption of practices that expose the grains to contamination by farmers and traders. The similarity between the current study and that reported by Azaman [45] and its disparity with that reported by Anitha [22] in Malawi could be explained by the fact that improvements in practices are influenced by farmers' behavioural change, which is motivated by the needs of farmers and incentives provided to support them. This implies that improving practices of bran producers does not only require the provision of adequate knowledge but a change in behaviours of all players along the chain for effective mitigation and control of aflatoxin contamination in bran. However, this may require supporting the bran producers to meet their critical needs and providing incentive opportunities to motivate them to improve on the practices along the bran value chain.

Generally, the key aspects that were considered as bad practices in this study include; sprinkling of water on maize grains before, or during processing, inadequate drying of maize bran, failures to package maize in airtight and moisture proof bags or containers, failure to disinfect or clean the stores regularly, selling mouldy maize, checking maize bran that has grown mouldy and separating maize bran obtained from maize of different moisture content. Therefore, efforts to address aflatoxin B_1 contamination in maize bran should improve the knowledge and practices aspects in which the bran producers scored low in.

4.2 Level of aflatoxin B_1 (AFB_1) contamination in maize bran and associated factors

Generally, on average as high as 37.3 μg/kg and 26.9 μg/kg of aflatoxin B_1 levels were registered in northern Uganda in the two districts of Lira and Gulu, respectively (Fig. 3). Indeed, improper practices such as inadequate drying of the bran and sprinkling of water to the grains before or during processing (Table 8), provide a suitable environment for proliferation and development of fungal moulds and subsequent aflatoxin production and hence increasing the likelihood of aflatoxin B_1 in the bran exceeding the acceptable limit. However, much as moisture and temperature significantly contribute to the development of moulds [30], the production of toxins can only occur when the fungal species responsible for aflatoxin production such as *A. flavus* and *A. parasiticus* are exposed to stressful conditions of nutritional imbalance, water surplus or drought [31]. The results of this study are in line with findings of previous studies on the fact that improper drying practices resulting into high moisture content of bran in storage beyond the recommended moisture levels of 13.0 g/100 g hence providing a favourable condition for aflatoxin production [32]. The abnormal high aflatoxin B_1 levels contamination of the

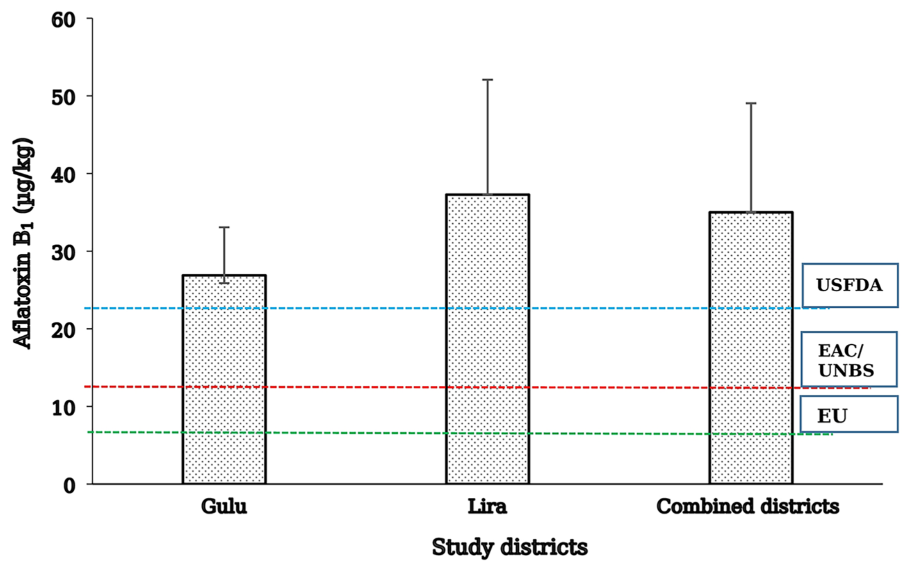

Fig. 3 Aflatoxin B_1 contamination levels in bran samples in comparison with regulatory acceptable limits. USFDA, EAC, UNBS, and EU refer to the United States Department of Food and Drug Administration, East African Community, Uganda National Bureau of Standards, and European Union, respectively. (*n* = 55, with 43 from Lira and 12 from Gulu)

bran beyond the acceptable regulatory limits of 4ppb established by European Union, 10ppb by Uganda National Bureau of Standards and East Africa Community and, 20ppb by United States Food and Drug Administration (Fig. 3) could be attributed to poor knowledge, negative attitude, and poor practices by bran producers (Tables 2, 3 and 4) coupled with weak regulatory monitoring and surveillance system (Table 9).

In addition, the market size and, stability was significantly associated with the likelihood of the concentration of aflatoxin being below or above the safety limits (Table 7). This implies that bran producers were more responsive to market size, whether expanding, stable or declining rather than the safety of the product. Furthermore, the quantity of bran sold weekly was significantly associated with the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 µg/kg (Table 7). This implies that weekly sales in large quantities (> 2.1 tons) compared to smaller quantities (< 2 tons) were more likely to be associated with a high concentration of aflatoxin B_1 levels thereby exceeding the acceptable safety limit of 20 µg/kg. This could be due to the fact that handling of large volumes of bran sales by the bran producers compromise adherence to recommended practices along the bran production chain. Non adherence to good manufacturing practices have been implicated in *Aflatoxin* contamination of maize products in several studies [22, 38] and could have contributed to increased contamination with sales volume observed in this study. Therefore, suggesting that the safety of the bran can only be improved if there is a change in bran producers' knowledge, attitude, and practices along the entire food chain.

Considering that feed and feed ingredients provide the starting point of the food chain, therefore, the quality of maize bran as a major feed ingredient is paramount in reducing the risk of contamination of entire food chain [33]. Furthermore, the high aflatoxin B_1 contamination levels of maize bran could have been enhanced by socio-economic and environmental factors, agronomic and post-harvest handling practices along the bran production chain [40]. Many studies have reported that the environmental conditions such as high temperatures, high humidity, and moisture coupled with poor post-harvest handling and manufacturing practices favour fungal development leading to increased aflatoxin B_1 contamination [34].

Previous studies [24, 42] have demonstrated that dry, hot, and moist weather conditions typical of that in the two districts where the current study was conducted plays a moderating role in the production of aflatoxin B_1 production. As such, the environmental conditions could have contributed to the high aflatoxin B_1 contamination levels recorded in the study from the two districts. Furthermore, many studies have reported that such environments provide a favourable or condition for the development and proliferation of fungal spores characterized by Aspergillus species responsible for aflatoxin B_1 [35]. Additionally, there is need for bran producers to follow the Good Manufacturing Practices (GMP) that is critical during processing or production of the bran for livestock feeds and much attention is also directed to observing the Hazzard Analysis Control Critical Point (HACCP) as a long-term measure for reduction of aflatoxin contamination and particularly aflatoxin B_1 levels in the bran and hence improving the safety of the bran in the livestock feed chain.

Among aflatoxins, aflatoxin B_1 (AFB_1) is the most potent and carcinogenic secondary metabolite with the ability to cause cancer [36] and the risk of contamination in Africa is greatly influenced by socio-economic and environmental factors, agronomic and post-harvest handling factors [21]. This, therefore, calls for urgent and concerted efforts to reduce the levels of aflatoxin B_1 in grains as well as bran and entire livestock feed chain. Generally, more than half of the bran producers didn't dry the maize bran adequately before storage, implying that most of the bran was processed and stored in moist conditions which favoured development of moulds responsible for aflatoxin B_1 in the bran. This implies that inappropriate practices of drying, storage and processing (Table 8) could have contributed to aflatoxin B_1 producing fungi in the bran. Interventions to address aflatoxin B_1 should improve the pre-disposing practices recorded. Aba et al. [43] also reported that aflatoxin levels increase as the supply chain progresses, this therefore increases the risk of contamination in the bran which is a key feed ingredient in livestock industry. This presents a potential risk to livestock productivity [37] and consumers of animal-sourced foods such as poultry and milk products regionally [38]. Therefore, strategies to reduce aflatoxin B_1 contamination in maize bran should take into consideration the storage duration and sales within a given timeframe to reduce the likelihood of aflatoxin B_1 levels exceeding acceptable regulatory limits. Whereas high aflatoxin B_1 levels beyond acceptable limits have been recorded in this study, its bioaccumulation in animal products that pose public health risks has not been investigated. Future studies should consider this aspect.

4.3 Regulatory monitoring of aflatoxin B_1 contamination of maize bran in northern Uganda

Aflatoxin contamination in feeds and food products is of public health concern and yet feeds and feed ingredients provide the starting point of the animal-sourced food chain. Generally, the current study indicates that only prioritisation of safety or profit or both was significantly associated with the likelihood of aflatoxin B_1 contamination level being below or above the acceptable regulatory limit of 20 μg/kg (Table 9). Implying that, bran producers considered either safety or profit, or both safety and profit, as a priority in determining access to the market for the bran. The results from the current study further indicate that there was the poor status of regulatory monitoring of bran producers which was facilitated by failure of government and mandated agencies to conduct regular monitoring to bran producers to ensure quality (Table 9). This is made worse by a lack of regular feedback to bran producers on the quality of bran produced and sold in the market. Hence, compliance by bran producers to recommended regulatory monitoring practices along bran production chain was weak and hence increases the likelihood of aflatoxin B_1 concentration being below or above acceptable limits recorded in this study (Fig. 3).

In addition, bran producers reported that prices of the bran did not affect them in any way, and the majority were motivated to continue with the bran business and yet most of them were also willing to sacrifice safety over profit. This implies that bran business is one of the lucrative investments offering better incentives to bran producers. However, the fact that bran producers were willing to sacrifice safety over profit presents a high risk of aflatoxin contamination of the bran. This is further exacerbated by the fact that majority of employees deployed were unskilled and had not received any training on food safety. Therefore, suggesting the need to strengthen regulatory monitoring and feedback mechanisms along the bran production chain to ensure quality of bran in the national, regional, or international markets. Furthermore, it is important to note that appropriate strategies to mitigate the risk of aflatoxin contamination in feeds and feed ingredients are critical and should be put in place [30]. However, previous studies across the world also reported that aflatoxin B_1 is the most common mycotoxin with levels higher than the acceptable limits in feeds and food, hence exposing animals and humans to serious health risks [14]. The results of this study are in line with findings from other studies suggesting the need to strengthen regulatory monitoring and surveillance systems to mitigate the harmful effects of aflatoxin B_1 in the bran [39]. This study's findings suggest that a regulatory monitoring and surveillance system should be put in place to ensure strict adherence to specific aflatoxin free market specifications so as to ensure safety of the bran in local, regional and international markets. This could be done by mandated government institutions notably; the Ministry of Agriculture, Animal Industry and Fisheries, Ministry of Health, Ministry of Trade, Industry and Cooperatives, and Uganda National Bureau of Standards to strengthen aspects of regulatory monitoring along the bran production chain.

5 Conclusions

Generally, there was poor level of knowledge, a negative attitude, and bad practices towards mitigating aflatoxin B_1 in maize bran. The key aspects that should constitute food safety education to improve knowledge, attitude, and practices should take into consideration the specific aspects in which the producers scored low. Additionally, aflatoxin B_1 (AFB_1) contamination level in maize bran in northern Uganda exceeds the regulatory limits for safety according to EAC/UNBS, EU, and USFDA regulatory standards. Generally, the quantity of bran sold weekly, market size and stability, the practices of sprinkling water to the grains before or during processing, as well as drying of bran before storage were the contributing factors to the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 μg/kg. Thereby, implying that aflatoxin accumulates in maize bran under poor management practices, hence predisposing poultry birds and other livestock to a high risk of aflatoxin B_1 through contaminated feeds. Also, there was a low level of regulatory monitoring conducted among bran producers in the study area. However, prioritisation of safety or profit during bran sales was the only significant factor contributing to the likelihood of the concentration of aflatoxin B_1 being below or above the safety limit of 20 μg/kg. Therefore, the District Production, Commercial Service and Health departments, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda National Bureau of Standards (UNBS), Ministry of Trade, Industry, and Cooperatives (MTIC) and Ministry of Health should jointly strengthen stakeholders' knowledge and attitude for the adherence to appropriate practices for aflatoxin reduction in maize bran among maize processors. Food safety education should consider the following aspects in which the producers scored low in; adequate drying of bran before storage, use of recommended facilities for drying such as concrete slab, tarpaulins or mats, packaging bran in recommended materials such as airtight and moisture-proof bags, routine disinfection and cleaning of storage facilities, ensuring proper ventilation in storage, discarding mouldy bran and training of bran producers on safety. Food safety education should also consider market dynamics of bran and the practices of sprinkling water during processing and adequate drying of bran before storage. Furthermore, there is a need to strengthen regulatory monitoring, inspection, sampling, testing, monitoring of grains from farmers and suppliers, and enforcement of accepted standards among maize bran producers by district Production, Health and Commercial Service Departments, MAAIF, UNBS, and MTIC or other mandated government Departments and Agencies. Strengthening regulatory monitoring should focus mainly on attaining a balance between ensuring safety and profit among the bran producers. Additionally, efforts should be put towards improving the frequency of monitoring, providing feedback to processors, supporting routine testing for aflatoxins, and training of bran producers on safety.

Acknowledgements
The authors sincerely appreciate the bran producers in Gulu and Lira cities for their invaluable participation and support throughout the study.

Author contributions
Odongo Kizito, MSc: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Resources, Writing - original draft, and Writing - review and editing. Lawrence Okidi, Ph.D: Conceptualization, Formal analysis, Methodology, Supervision, Validation, and Writing - review and editing. Godfrey Kilama, MSc: Formal analysis, Writing - original draft, and Writing - review and editing. Duncan Ongeng, Ph.D: Conceptualization, Formal analysis, Methodology, Supervision, Validation, and Writing - review and editing.

Funding
This work received no financial support.

Data availability
The datasets supporting the conclusions of this article are included within the article and its additional file.

Declarations

Ethics approval and consent to participate
All the experimental protocols involving human data were carried out in accordance with the guidelines of national/international/institutional or Declaration of Helsinki and the ethical approval was sought from Gulu University Research Ethics Committee (Approval No: GUREC/113/19). Additional authority was obtained from the respective Municipal Council Offices, including Division, Ward, and Cell within the respective Municipal Councils in the target districts.
The study's purpose was thoroughly explained to the target respondents for better understanding and participation. Informed consent was sought from the voluntary willing bran producers who were eligible to participate in the study. The participants were assured of the confidentiality of the information provided. The names of the study respondents were captured using codes to ensure confidentiality of the information provided.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 19 September 2025 / Accepted: 3 March 2026
Published online: 11 April 2026

References

1. Unnevehr LJ. Addressing food safety challenges in rapidly developing food systems. Agric Econ. 2022;53(4):529–39. https://doi.org/10.1111/agec.12724.
2. Grace D. Burden of foodborne disease in low-income and middle-income countries and opportunities for scaling food safety interventions. Food Secur. 2023;15(6):1475–88. https://doi.org/10.1007/s12571-023-01391-3.
3. Garcia SN, Osburn BI, Cullor JS. A one health perspective on dairy production and dairy food safety. One Health. 2019;7: 100086.
4. Hamad GM, Mehany T, Simal-Gandara J, Abou-Alella S, Esua OJ, Abdel-Wahhab MA, et al. A review of recent innovative strategies for controlling mycotoxins in foods. Food Control. 2023;144: 109350.
5. Silva AS, Dubey NK, Moore MD. Fungal mycotoxins in food commodities: present status and future concerns. 2023. pp. 1–21.
6. Mackay N, Marley E, Donnelly C, Leeman D, Poplawski C. Analysis of Aflatoxins, Fumonisins, Deoxynivalenol, Ochratoxin A, Zearalenone, HT-2, and T-2 Toxins in Animal Feed by LC – MS / MS Using Cleanup with a Multi-Antibody Immunoaffinity Column. J AOAC Int. 2022;105:1330–40.
7. Adeniji OO, Akinmoladun OF, Njobeh PB. Microbial interventions for aflatoxin control in food systems: a 25-year global bibliometric analysis (2000–2024) with implications for food security and smart agriculture. Food Saf Risk. 2025;12(1): 11. https://doi.org/10.1186/s40550-025-00120-2.
8. Ting WTE, Chang CH, Szonyi B, Gizachew D. Growth and Aflatoxin B1, B2, G1, and G2 Production by *Aspergillus flavus* and *Aspergillus parasiticus* on ground flax seeds (*Linum usitatissimum*). J Food Prot. 2020;83(6):975–83.
9. Fouad AM, Ruan D, El-senousey HK, Chen W, Jiang S, Zheng C. Harmful effects and control strategies of aflatoxin B 1 produced by *Aspergillus flavus* and *Aspergillus parasiticus* strains on poultry. Toxins. 2019;1:1–21.
10. Benkerroum N, Aflatoxins. Producing-molds, structure, health issues and incidence in southeast Asian and Sub-Saharan African countries. 2020.
11. Dai C, Tian E, Hao Z, Tang S, Wang Z, Sharma G. Aflatoxin B1 toxicity and protective effects of curcumin: molecular mechanisms and clinical implications. 2022.
12. Claeys L, Romano C, De Ruyck K, Wilson H, Fervers B, Korenjak M, et al. Mycotoxin exposure and human cancer risk: a systematic review of epidemiological studies. Compr Rev Food Sci Food Saf. 2020;19(4):1449–64.
13. Syraji Y, Jeyaramraja P, Mada T, Karuppasamy G. Comprehensive review of aflatoxin contamination, its occurrence, effects, management, and future perspectives. Discov Food. 2025. https://doi.org/10.1007/s44187-025-00680-4.
14. Shabeer S, Asad S, Jamal A, Ali A. Aflatoxin contamination, its impact and management strategies: an updated review. Toxins (Basel). 2022. https://doi.org/10.3390/toxins14050307.
15. Gbemenou B, Gnonlonfin J, Traore AS, Samake S. Effective control of aflatoxin contamination in staple maize food crop in Sub-Saharan Africa: a review of current pre- and postharvest low-cost technologies and perspectives. J Agric Sci Technol. 2019;9:135–51.
16. Ortega-Beltran A, Bandyopadhyay R. Contributions of integrated aflatoxin management strategies to achieve the sustainable development goals in various African countries. Glob Food Sec. 2021;30: 100559.
17. Eskola M, Kos G, Elliott CT, Hajšlová J, Mayar S, Krska R. Worldwide contamination of food-crops with mycotoxins: validity of the widely cited 'FAO estimate' of 25\%. Crit Rev Food Sci Nutr. 2020;60(16):2773–89. https://doi.org/10.1080/10408398.2019.1658570.
18. Qin M, Cheng L, Li Y, Tang X, Gan Y, Zhao J, et al. Disease burden contributed by dietary exposure to aflatoxins in a mountainous city in Southwest China. Front Microbiol. 2023;14(July):1–11.
19. Yu J, Pedroso IR. Health of humans, livestock animals and pets. 2023.
20. International L. Piggery and poultry market roadmap for sustainable value chain development Identifying opportunities in the Ugandan poultry and piggery sectors prepared for prepared by date: draft version. Bulletin. 2020.
21. Gemede HF, Toxicity M. and Chemical analysis of aflatoxins and other toxic metabolites produced by Aspergillus : a comprehensive review. 2025;(Fig 1):1–27.
22. Jagoda K. Alimentary risk of mycotoxins for humans and animals. 2021.
23. Nampanzira DK, Kizza D, Okello S, Kayemba V, Awino W, Nabulime M et al. Feeds and feeding dynamics among chicken farmers and feed millers: insights into practices, quality, and challenges in selected districts of Uganda. 2025.
24. Hussain M, Raza MA, Saeed F, Afzaal M, Tufail T, Ahmad A, et al. Maize bran as an agro-industrial by-product: its bioactive compounds and their potential health benefits. Cogent Food Agric. 2024;10(1): 2390157. https://doi.org/10.1080/23311932.2024.2390157.
25. Massarolo KC, Rodrigues P, Ferreira CFJ, Kupski L, Badiale-Furlong E. Simultaneous distribution of aflatoxins B1 and B2, and fumonisin B1 in corn fractions during dry and wet-milling. J Food Sci Technol. 2022;59(8):3192–200.
26. Trucksess M, Abbas H, Weaver C, Shier WT. Distribution of aflatoxins in shelling and milling fractions of naturally contaminated rice. Food Addit Contam Part Chem Anal Control Expo Risk Assess. 2011;28:1076–82.
27. Karlovsky P, Suman M, Berthiller F, Meester JD, Eisenbrand G, Perrin I, et al. Impact of food processing and detoxification treatments on mycotoxin contamination. Mycotoxin Res. 2016. https://doi.org/10.1007/s12550-016-0257-7.
28. Akullo JO, Amayo R, Okello DK, Mohammed A, Muyinda R, Magumba D, et al. Aflatoxin contamination in groundnut and maize food products in Eastern and Northern Uganda. Cogent Food Agric. 2023;9(1):2221015. https://doi.org/10.1080/23311932.2023.2221015.
29. Udomkun P, Mutegi C, Wossen T, Atehnkeng J, Nabahungu NL, Njukwe E, et al. Occurrence of aflatoxin in agricultural produce from local markets in Burundi and Eastern Democratic Republic of Congo. Food Sci Nutr. 2018;6(8):2227–38.
30. Ilesanmi FF, Ilesanmi OS. Knowledge of aflatoxin contamination in groundnut and the risk of its ingestion among health workers in Ibadan, Nigeria. Asian Pac J Trop Biomed. 2011;1(6):493–5.

31. Omara T, Nassazi W, Omute T, Awath A, Laker F, Kalukusu R, et al. Aflatoxins in Uganda: an encyclopedic review of the etiology, epidemiology, detection, quantification, exposure assessment, reduction, and control. Int J Microbiol. 2020;2020:4723612.
32. Nakavuma JL, Kirabo A, Bogere P, Nabulime MM, Kaaya AN, Gnonlonfin B. Awareness of mycotoxins and occurrence of aflatoxins in poultry feeds and feed ingredients in selected regions of Uganda. 2020;2:1–10.
33. Begum IA, Alam MJ, Shankar B, Mastura T, Cooper G, Rich K, et al. Food safety knowledge, attitudes, and practices among vegetable handlers in Bangladesh. J Food Prot. 2025;88(1): 100428.
34. Falade TDO, Kadjo D, Ortega-Beltran A, Atser G, Sanni L. Knowledge, perceptions and practices regarding aflatoxins and aflatoxin management solutions among women: a perspective from two communities in Nigeria. Cogent Food Agric. 2025;11(1): 2460464. https://doi.org/10.1080/23311932.2025.2460464.
35. Barungi BM. State of Uganda ' s maize industry. 2020; pp. 1–8.
36. Oriangi G, Mukwaya P, Luwa J, Menya E, Maxwell M, Bamutaze Y. Variability and changes in climate in Northern Uganda. Afr J Clim Chang Resour Sustain. 2024;3:81–97.
37. NARO. Northern Uganda Agro-ecological Zone and its climate. 2025. https://www.slm.go.ug/index.php/zones/northern-uganda
38. Upton N, Yasin I. Review of the past, current, and the future trend of the climate change and its impact in Uganda East African journal of environment and review of the past, current, and the future trend of the climate change and its impact in Uganda. 2022.
39. Depetris Chauvin N, Porto G, Mulangu F. The Case of Uganda. In: Agricultural supply chains, growth and poverty in sub-Saharan Africa. 2017. p. 111–35.
40. Wokorach G, Landschoot S, Anena J, Audenaert K, Echodu R, Haesaert G. Mycotoxin profile of staple grains in northern Uganda: Understanding the level of human exposure and potential risks. Food Control. 2021;122: 107813.
41. UBoS. National livestock census 2021. 2024.
42. Okello DM, Odongo W, Aliro T, Ndyomugyenyi E, González-Redondo P. An assessment of pig feed diversity amongst smallholder pig farmers in Northern Uganda. Cogent Food Agric. 2021;7(1):1937867. https://doi.org/10.1080/23311932.2021.1937867.
43. Aba RPM, Garcia PYQ, Juan JKB, Linsangan AT. Influence of food safety knowledge, attitudes, and practices (KAP) of vendors in the City of Manila on microbiological quality of ready-to-drink coconut water. Food Humanit. 2023;1:119–27.
44. Maragos CM. Extraction of aflatoxins B1 and G1 from maize by using aqueous sodium dodecyl sulfate. J AOAC Inter. 2008;91(4):762-7.
45. Azaman NN, Kamarulzaman NH, Shamsudin MN, Selamat J. Stakeholders' knowledge, attitude, and practices (KAP) towards aflatoxins contamination in peanut-based products. Food Control. 2016;70:249–56.

Publisher's Note