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RESEARCH ARTICLE

Barriers to adoption of aflatoxin mitigating strategies: Insights from a case study of Uganda's West Nile region

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Abstract

Aflatoxin contamination in staple crops presents considerable health risks and economic losses for smallholder farmers in Uganda. This study assessed the knowledge and awareness of aflatoxin contamination and mitigation strategies among smallholder farmers in the West Nile region. A survey of 393 farmers, supplemented by four focus group discussions with 60 participants, was conducted. Quantitative results revealed that only 21.9% of farmers were aware of aflatoxins, while 24.6% were aware of mitigation strategies. Multivariate analysis indicates that age ($P < 0.001$), gender ($P = 0.015$), and education level ($P < 0.001$), are significant predictors of awareness. Qualitative findings from thematic analysis indicated that limited technical knowledge, financial constraints, and insufficient agricultural extension services are barriers to aflatoxin awareness and mitigation. The study underscores the need for improved agricultural extension services, hands-on training, and policy interventions to promote effective aflatoxin management practices, including the use of biological control products, such as Aflasafe, among smallholder farmers in Uganda.

Keywords

aflatoxins – mitigation – fungal contamination – smallholder farmers – Aflasafe

1 Introduction

Aflatoxin contamination presents a quiet, but devastating threat to Uganda's food security, public health, trade, and livelihoods. Staple crops such as maize, groundnut, and sorghum are most susceptible to aflatoxin contamination. For many smallholder farmers in Uganda, who depend on these crops for livelihoods, the impact of aflatoxin contamination can be especially severe (Akullo, *et al.*, 2023; Wokorach *et al.*, 2022).

Aflatoxins, produced primarily by *Aspergillus flavus* and *Aspergillus parasiticus*, are toxic secondary metabolites that contaminate crops including cereals, legumes, tree nuts, and spices, particularly in warm and humid regions such as sub-Saharan Africa (Wokorach, *et al.*, 2022). These toxins pose serious health risks to both humans and animals, with exposure being linked to hepatocellular carcinoma, immune suppression, stunted growth in children, interference in micronutrient metabolism, and decreased human and animal pro-

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ductivity (Sultan *et al.*, 2024). Aflatoxin levels exceeding permissible limits in grains has significant socioeconomic consequences, such as reducing marketability and limiting international trade opportunities for affected crops (Balan *et al.*, 2024).

In Uganda, smallholder farmers who predominantly grow maize, groundnuts, and sorghum primarily for subsistence and sale of surplus for income are vulnerable to aflatoxin contamination. Several studies have reported incidences of high levels of aflatoxins in these crops, particularly in maize and groundnuts (Akullo, *et al.*, 2023; Tibagonzeka *et al.*, 2018; Wokorach *et al.*, 2022). For instance, a recent study by Murokore *et al.* (2023) revealed that at least 90% of groundnuts that were being consumed 4-8 times a week in Southwestern Uganda had aflatoxin levels exceeding the COMESA acceptable limits of 10 parts per billion (ppb). In the same study, nearly 60% of the maize flour contained aflatoxin levels exceeding the COMESA regulatory limit. In Northern Uganda, assessment of sorghum samples collected from Kitgum and Lamwo districts showed that over 85% and 45% of the samples, respectively, contained unacceptable levels of aflatoxin as per the COMESA regulatory limit of 10 ppb (Echodu *et al.*, 2019). Similarly, according to Akullo *et al.* (2023), 42% of groundnuts and 63% of maize samples from Eastern and Northen Uganda contain aflatoxin levels above 10 ppb. The West Nile region of Uganda, including Arua district, is one of the areas where aflatoxin contamination in staple crops has been reported (Sserumaga *et al.*, 2021).

The high levels of aflatoxin in these commodities across Uganda has been attributed to several factors including cropping systems, storage conditions, climatic conditions, location, and traditional food processing techniques (Sserumaga *et al.*, 2021; Akullo *et al.*, 2023; Murokore *et al.*, 2023) For instance, millet and maize samples that were collected from the urban settings (maize = 60.9 ppb; millet = 25.5 ppb) of Southwestern Uganda had mean aflatoxin levels that were 3-5 times higher than those collected from the rural areas (maize = 12.0 ppb; millet = 8.0 ppb). In another study, Sserumaga *et al.*, (2021) reported that groundnut samples collected from the Lake Albert Crescent contained higher mean aflatoxin levels when compared with those sourced from the other agro-ecological zones. On the other hand, Akullo *et al.* (2023) found that groundnut samples obtained in Eastern Uganda were more contaminated than the groundnut samples from Northern Uganda. Despite the high prevalence of aflatoxin contamination, farmers in this region face several challenges, including limited access to agricultural extension services and aflatoxin management technologies (Jelliffe *et al.*, 2023; Omara *et al.*, 2020)

To address the growing concern of aflatoxin contamination, the International Institute of Tropical Agriculture (IITA) developed Aflasafe, a biocontrol product that uses non-toxigenic strains of *Aspergillus* species to outcompete aflatoxin-producing fungi (IITA, 2014). The introduction of Aflasafe and other integrated management practices offers a promising solution for mitigating aflatoxin contamination (Bandyopadhyay *et al.*, 2022). Despite its efficacy, adoption of Aflasafe and other mitigation strategies remain limited among smallholder farmers. Therefore, it is necessary to understand the levels of awareness, knowledge, and adoption of aflatoxin mitigation practices among smallholder farmers in the region.

This study investigated the interplay between sociodemographic characteristics such as gender, education, and collective participation and their influence on farmers' awareness and implementation of aflatoxin control measures in West Nile region especially Arua district. This will support future decision making to promote effective management practices for aflatoxin in grains.

2 Materials and methods

Study area

The study was conducted in 2024 in Arua district, located in the West Nile region of Northern Uganda. This region has predominantly smallholder farmers relying on crops such as maize, groundnuts, and sorghum for subsistence and income. In terms of the proportion of production relative to total production in Uganda, the region produces 2.3%, 7.5%, and 6.6% of maize, groundnuts, and sorghum, respectively (UBOS, 2024). The climate in Arua is tropical, with two rainy seasons that promote favourable conditions for aflatoxin-producing *Aspergillus* species, which is the predominant mycotoxin reported in the crops of focus in the region (Wokorach *et al.*, 2021). The study was conducted in four sub-counties, namely Ajia, Arivu, Logiri, and Vurra, in 2024. Each sub-county represents a different level of agricultural intensity and crop diversity.

Study design, population, and sampling

A mixed-methods approach was used, combining quantitative cross-sectional surveys with qualitative focus group discussion (FGD) sessions. The quantitative component aimed to capture the extent of knowledge and

awareness about aflatoxin contamination and mitigation strategies among farmers, while the qualitative component sought to understand farmer perceptions, experiences, and barriers in adopting the mitigation strategies.

The study targeted smallholder farmers that grow maize, groundnuts, and sorghum. A multistage sampling technique was used to select 393 participants (i.e. farmers and produce dealers). The first stage involved purposive selection of the four sub-counties, based on production of the target crops and vulnerability to aflatoxin contamination. The second stage used simple random sampling to select farming households within each sub-county.

The sample size was determined using Cochran's formula for sample size estimation (Cochran, 1977), considering a 50% prevalence of aflatoxin awareness and a 5% margin of error, resulting in a sample size of 393. Farmers were eligible to participate if they cultivated any of the three target crops and were willing to provide informed consent for the study.

For the qualitative component, 60 participants were purposively selected to participate in FGD sessions from among key groups in the community, including smallholder farmers, produce dealers, and local agricultural leaders. Four FGD sessions were conducted, each involving 15 participants, to gain in-depth insights into aflatoxin management and their perspectives on Aflasafe.

Data collection

Data were collected using a structured questionnaire that was refined through a pre-test with a small group of farmers in a neighbouring sub-county not included in the final sample. The questionnaire covered key areas such as demographic information, awareness and knowledge on aflatoxins, identification of aflatoxin contamination in crops, and mitigation strategies used by farmers. Also, it included questions on the use of Aflasafe and other aflatoxin management strategies.

Face-to-face interviews were conducted by trained enumerators, fluent in the local language (Lugbara). Prior to data collection, the enumerators underwent a two-day training session to ensure uniformity in data collection procedures and ethical conduct. Farmers who could not read or write were assisted in filling out the questionnaire, ensuring that the data captured was accurate and reliable.

Data on aflatoxin awareness and mitigation strategies

The questionnaire included specific sections on farmers' awareness of aflatoxins and associated negative impacts, identification of aflatoxin contamination in crops, and mitigation practices. Awareness and knowledge on control measures were assessed by asking farmers whether they had ever heard of aflatoxins and whether they were familiar with any aflatoxin management strategies. For aflatoxin mitigation strategies, farmers were asked about their management practices, including proper drying, storage, use of chemicals, and adoption of bio-control agents such as Aflasafe. Additional questions explored farmers' perceptions of the effectiveness of strategies in reducing aflatoxin contamination.

The knowledge on aflatoxin contamination was explored through questions on traditional methods used to detect aflatoxins, such as discoloration of grains and fungal growth.

Qualitative data collection

Four FGD sessions were held across the sub-counties. These discussions, guided by a semi-structured question guide, explored participants' awareness, perceptions, and barriers related to aflatoxin contamination and its management. The sessions were moderated by local agricultural extension workers and notes were taken alongside audio recordings. The audio recordings were then transcribed.

Statistical analysis

Data were analysed using SPSS version 26 (IBM Corp. Armonk, NY, USA, 2019). Descriptive statistics were generated to summarise the socio-demographic characteristics of the participants, as well as their awareness and knowledge of aflatoxins. Categorical variables such as gender, age group, and education level, were presented as frequencies and percentages.

Bivariate analysis was performed using chi-square tests to examine associations among socio-demographic factors (such as age, gender, and education) and awareness of aflatoxins. Prevalence ratios (PRs), at 95% confidence intervals (CIs), were calculated to determine the strength of these associations.

Multivariate analysis was conducted using logistic regression to adjust for potential confounders and to identify independent predictors of aflatoxin awareness and mitigation practices. The independent variables included in the model were age, gender, education level, and belonging to a farmers' group. Significance was set at $P < 0.05$ for all the variables.

For qualitative data analysis, thematic analysis was applied to the qualitative data following the procedures of Braun and Clarke (2016). Transcripts from the

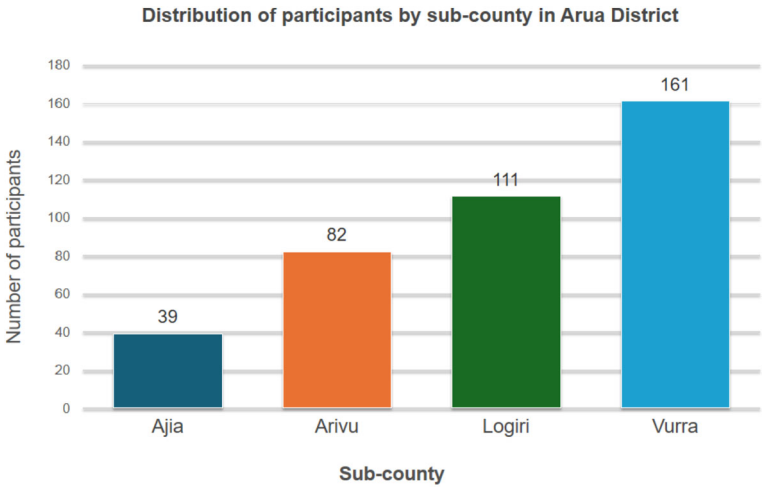


FIGURE 1 The distribution of participants/respondents by sub-county in Arua district.

FGD were read multiple times, and key themes such as knowledge, barriers to mitigation, and policy support were identified. Coding was done using NVivo 12 software, and emergent themes were refined through repeated discussion among the research team.

Ethical considerations

Ethical approval for the study was obtained from the Uganda Christian University Research Ethics Committee (UCUREC) [registration number UCUREC-2023-641]. Informed consent was obtained from all participants before their inclusion in the study, and participants were assured of the confidentiality and anonymity of their responses. Participation was voluntary, and respondents were at liberty to withdraw from the study at any point of the interviews or FGD sessions without any consequence. No personal identifiers were collected to ensure the anonymity of the data (WHO, 2011).

3 Results and discussions

Description of study participants

A total of 393 smallholder farmers participated in this study. The participants were distributed across four sub-counties in Arua district, with the highest proportion coming from Vurra (41.0%, n = 161), followed by Logiri (28.2%, n = 111), Arivu (20.9%, n = 82), and Ajia (9.9%, n = 39) (Figure 1). By age distribution, 68.5% (n = 269) were above 35 years of age, while 30.5% (n = 120) were between 18 and 34 years of age, and only 1.0% (n = 4) were under 18 years of age. The gender distribution was nearly balanced, with females accounting for 52.9% (n = 208) of the participants, and males representing 47.1% (n = 185). Considering the level of education, 64.9% (n = 255) of the farmers had attained primary school education, while 20.6% (n = 81) had attained secondary education. A smaller proportion of participants had a diploma (3.1%, n = 12) or a bachelor's degree (0.3%, n = 1). Notably, 11.2% (n = 44) of the participants had no formal education. Additionally, 76.6% (n = 301) of the farmers reported to belong to a farmers' group (Table 1). It is notable that the smallholder farmers in Arua district are majorly low educated who are active in crop production. This have confirmed typical characteristic of farmers in Northern Uganda and Uganda as a whole. For many decades in general farming have been left to the less educated persons. This has got influence in the level of knowledge in the crop production challenges, most importantly the post-harvest handling of grains hence leading to high risk of post-harvest losses in grains through aflatoxin contamination.

Aflatoxins awareness and associated health risks

The prevalence of aflatoxin awareness among the smallholder farmers was 21.9% (n = 86, 95% CI: 15.6%-30.6%). Among the farmers who were aware of aflatoxins, several traditional and/or indigenous methods of identifying aflatoxin contamination were reported as seen in Figure 2. The results show that 64.0% of the participants identified aflatoxins by the discoloration of grains, 55.8% by the presence of fungal or mould growth, and 53.5% by a bitter taste in contaminated grains.

Most respondents (78.1%) were not aware of aflatoxins, although nearly all (91.1%) had observed fungal contamination on crops. Only 30.7% recognised that aflatoxins are poisonous, and 24.6% were aware of mitigation strategies. Awareness of the biocontrol product Aflasafe (5.9%) and training exposure on aflatoxin man-

TABLE 1 Socio-demographic characteristics of study participants/ respondents in the sub counties of Ajia, Logiri, Vurra and Arivu, Arua district

Characteristics	Categories	Frequency (n)	Percentage (%)
Age group	< 18 years	4	1.0
	18–34 years	120	30.5
	> 35 years	269	68.5
Gender	Female	208	52.9
	Male	185	47.1
Education	No formal education	44	11.2
	Primary	255	64.9
	Secondary	81	20.6
	Diploma	12	3.1
	Bachelor's degree	1	0.3
Belong to a farmers' group	Yes	301	76.6
	No	92	23.4

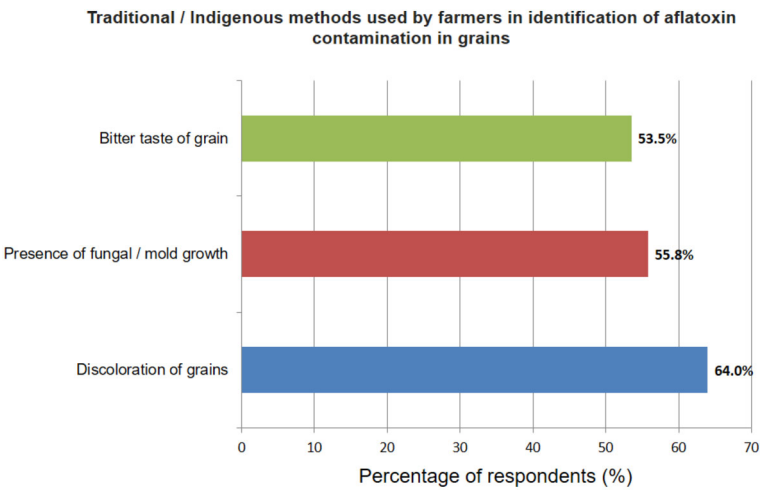


FIGURE 2 The traditional/indigenous methods used by farmers in identification of aflatoxin contamination in grains.

agement (6.9%) were particularly low, probably because it is still a relatively new biocontrol product and not widely distributed to farmers in Uganda. Farmers learnt about this product during aflatoxin and Aflasafe training organised by the International Institute of Tropical Agriculture (IITA) Uganda.

In terms of health risks associated with aflatoxin contamination, 45.3% (n = 39) of the participants were aware of the potential health effects associated with aflatoxin contamination. Liver cancer was the most commonly recognised risk (43.6%, n = 38), followed by vomiting (41.0%, n = 35), and headaches (20.5%, n = 18). Lesser-known risks included jaundice (15.4%, n = 14) and stunted growth (2.6%, n = 2). Coincidentally, among those aware of aflatoxins, 43.6% had experienced some form of health issues they believed were related to aflatoxin contamination from the food consumed (Figure 3). The primary sources of aflatoxin-related information were from the extension workers (38.1%, n = 42) and fellow farmers (33.3%, n = 36), while others received information from non-governmental organisations (14.3%, n = 15) or the radio (4.8%, n = 5) (Figure 3).

Both the quantitative and qualitative data show a significant gap in awareness and understanding of aflatoxin among smallholder farmers. The low level of awareness aligns with previous studies conducted in sub-Saharan Africa, where smallholder farmers are often unaware of the risks associated with aflatoxins due to limited access to information and education (Ayo *et al.*, 2018; Ebrima *et al.*, 2022; Gidabedi, 2023; Matemu *et al.*, 2018). The qualitative data complemented these findings, highlighting that many farmers were unaware

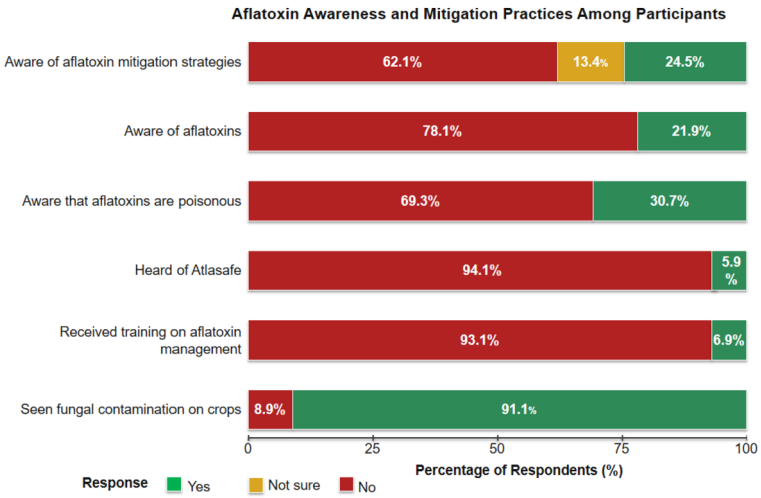


FIGURE 3 Aflatoxin awareness and mitigation practices among participants. The stacked bars represent the proportion of 'Yes,' 'No,' and 'Not sure' responses for each characteristic.

of the dangers associated with fungal contamination in crops. This lack of awareness may be attributed to inadequate agricultural extension services and the absence of structured training programs on aflatoxin management, which ultimately limits farmers' ability to take proactive measures against aflatoxin contamination.

A significant disparity in awareness in relation to gender was also observed, with males being more likely to be aware of aflatoxins than females (PR: 2.210, 95% CI: 1.641–2.977). This difference may reflect disparities in access to agricultural information, with men often having greater access to agricultural extension services, farmer groups, and training opportunities (Ebrima *et al.*, 2022). Addressing this disparity in awareness will require targeted interventions that specifically address the needs of female farmers, who make up a large portion of Uganda's agricultural workforce.

Among the farmers who were aware of aflatoxin, most were able to identify contamination through visual cues such as grain discoloration, fungal growth, and bitter taste. Awareness on other associated health risks such as vomiting, stunted growth, immune suppression, and jaundice was limited, suggesting that farmers may not fully comprehend the broader spectrum of health consequences related to aflatoxin exposure.

The lack of awareness coupled with limited information dissemination limits the capacity of farmers to take proactive measures to reduce aflatoxin contamination and protect their health. Previous studies have shown that education on the health impacts of aflatoxins can drive behaviour change, leading to improved adoption of mitigation strategies (Ayeni, 2015). Therefore, future actions should focus not only on raising awareness of aflatoxins, but also on enhancing farmers' understanding of the health consequences of aflatoxin exposure.

Farmer perception aflatoxin prevalence on staple crops and mitigation strategies

The majority of participants (91.1%, n = 358) reported to have seen fungal/mold contamination on their crops, a sign associated with aflatoxin contamination. Maize was reported as the crop most frequently affected (83.7%, n = 300), followed by groundnuts (67.0%, n = 240), beans (47.8%, n = 171), and cassava (19.2%, n = 69) (Figure 4a).

Of the farmers who had reported to have seen fungal contamination, only 30.7% (n = 110) were aware that the contamination might be related to aflatoxin and was poisonous. Furthermore, only 24.6% (n = 88) of the farmers were aware of specific aflatoxin mitigation strategies, while a significant proportion of them (62.1%, n = 223) were not aware of any control strategies. Of the 358 farmers who reported seeing fungal contamination, extremely few (6.9%, n = 27) had undergone prior training on aflatoxin management with only 5.9% (n = 23) reporting to have heard of Aflasafe, a biocontrol product for aflatoxin.

Farmers used various strategies to mitigate aflatoxin contamination. Good agronomic practices (18.2%, n = 65), proper drying and storage (22.4%, n = 80), and the use of chemicals to control storage insects (38.6%, n = 138) were the most commonly cited strategies (Figure 4b). Notably, 94.3% of aflatoxin-aware and/or trained farmers perceived that these strategies were useful in reducing aflatoxin contamination, with 40.9% rating them as very effective, and 46.6% as somewhat effective. A small proportion of farmers (4.5%) reported

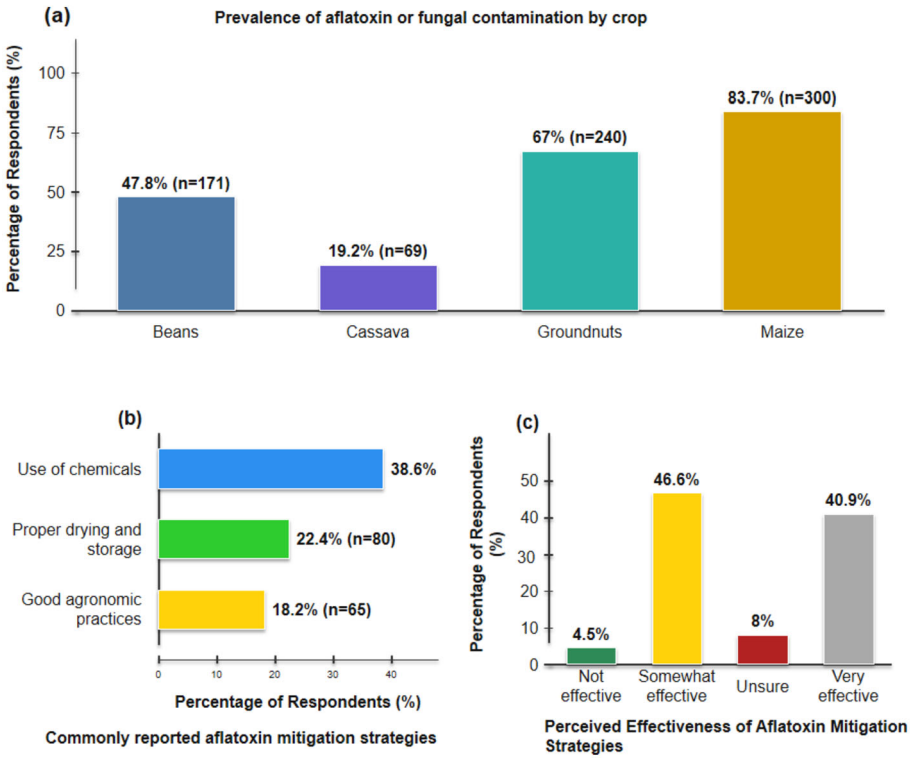


FIGURE 4 Prevalence of aflatoxin contamination and mitigation strategies among farmers.

that the strategies were not effective, while 8.0% were unsure of their effectiveness (Figure 4c).

Despite the low levels of awareness on aflatoxins among farmers, 91.1% had seen signs associated with aflatoxin contamination such as fungal/mould growth on their crops. However, only 24.6% of farmers reported being aware about aflatoxin mitigation strategies, indicating a significant gap in knowledge and practice. The most reported mitigation strategies were proper drying and storage (22.4%) and the use of chemicals (38.6%). While these practices can reduce aflatoxin contamination, reliance on chemical methods may result in potential misuse and associated health and environmental risks.

A promising aspect of this study is that 94.3% of farmers who implemented mitigation strategies perceived them as effective in reducing aflatoxin contamination. This suggests that farmers are receptive to adopting new practices when provided with adequate information and training. Nevertheless, awareness on Aflasafe, a bio-control agent, was exceptionally low at only 5.9%. This finding is consistent with reports from other regions in Africa, where the adoption of Aflasafe remains limited despite its proven efficacy in reducing aflatoxin levels in maize and groundnuts (Marechera and Ndwiga, 2015; Mahuku *et al.*, 2023). The qualitative data showed that even farmers who were aware of the risks associated with aflatoxins, lacked the resources to implement proper mitigation practices. This highlights the importance of targeted interventions to provide both knowledge and resources to farmers.

Socio-demographic factors associated with aflatoxin awareness

The bivariate analysis showed that age, gender, and education level were significantly associated with aflatoxin awareness (Table 2). Farmers below 18 years of age were markedly less likely to be aware of aflatoxins (crude Prevalence Ratio [cPR]: 2.07e-6, 95% CI: 7.57e-7–5.67e-6, $P < 0.001$) compared to those aged 18 years and above. Male farmers demonstrated significantly higher awareness (cPR: 2.210, 95% CI: 1.479–3.301, $P < 0.001$) than their female counterparts. Likewise, education showed a strong positive association with awareness; farmers with no formal education were considerably less likely to be aware of aflatoxins (cPR: 0.091, 95% CI: 0.036–0.232, $P < 0.001$) than those with formal education (Table 2).

This finding highlights the need to target younger farmers and those with lower educational attainment in aflatoxin mitigation programs. Agricultural extension education interventions should be designed to be accessible to all farmers, including those with limited literacy skills. Farmer groups can serve as important platforms for the dissemination of agricultural knowledge, and strengthening these networks may enhance the spread of information about aflatoxin management. Previous

TABLE 2 Bivariate and multivariate analysis of socio-demographic factors associated with farmers' awareness and knowledge of aflatoxin contamination in grains among 393 smallholder farmers in Arua District[1]

Characteristics	Categories	Crude PR (95% CI)	cPR (*P*-value)	Adjusted PR (95% CI)	aPR (*P*-value)
Age group	Below 18 years	2.07e-6 (7.57e-7–5.67e-6)	<0.001*	2.58e-6 (8.94e-7–7.44e-6)	<0.001**
	18–34 years	0.971 (0.646–1.460)	0.956	1.011 (0.675–1.515)	0.956
	≥35 years	Reference	–	Reference	–
Gender	Male	2.210 (1.479–3.301)	<0.001*	1.709 (1.110–2.630)	0.015**
	Female	Reference	–	Reference	–
Education level	No formal education	0.091 (0.036–0.232)	<0.001*	0.148 (0.054–0.403)	<0.001**
	Primary	0.180 (0.139–0.234)	<0.001*	0.237 (0.166–0.340)	<0.001**
	Secondary	0.346 (0.256–0.467)	<0.001*	0.386 (0.281–0.531)	<0.001**
	Diploma	0.583 (0.361–0.942)	0.029*	0.649 (0.391–1.080)	0.096
	Degree	Reference	–	Reference	–
Farmer group membership	Yes	1.716 (0.998–2.953)	0.399	–	–
	No	Reference	–	–	–

1 PR = Prevalence Ratio; CI = Confidence Interval; *Statistically significant at bivariate level ($P < 0.05$); **Statistically significant at multivariate level ($P < 0.05$).

studies have shown that peer-to-peer learning within such groups can significantly improve the adoption of new technologies (Lasdun *et al.*, 2021).

Farmers' awareness and knowledge of aflatoxin mitigation strategies

Bivariate and multivariate analyses were performed to identify sociodemographic factors associated with farmers' awareness and knowledge of aflatoxin mitigation strategies (Table 3). In the bivariate analysis, age, gender, and education were significantly associated with awareness. Farmers below 18 years of age were markedly less likely to be aware of mitigation strategies (crude Prevalence Ratio [cPR]: 2.04e-6, 95% CI: 6.45e-7–6.47e-6, $P < 0.001$) compared to older farmers. Male farmers were more likely to be aware than females (cPR: 1.737, 95% CI: 1.192–2.530, $P = 0.01$). Similarly, education level was positively associated with awareness; farmers with no formal education were substantially less likely to be aware of mitigation strategies (cPR: 0.135, 95% CI: 0.060–0.306, $P < 0.001$) compared to those with formal education (Table 3).

In the multivariate analysis, age and education remained significant predictors after adjusting for other socio-demographic factors. Farmers below 18 years continued to have significantly lower awareness (adjusted Prevalence Ratio [aPR]: 2.65e-6, 95% CI: 8.21e-7–8.58e-6, $P < 0.001$). Similarly, farmers with no formal education were less likely to be aware of mitigation strategies (aPR: 0.136, 95% CI: 0.060–0.307, $P < 0.001$) relative to those with higher education. Gender and farmers' group membership did not retain statistical significance in the multivariate model (Table 3). The results of the bivariate and multivariate analysis buttress under the results as in the farmer perception aflatoxin prevalence on staple crops and mitigation strategies.

The high level of perceived effectiveness (94.3%) of the mitigation strategies reported by farmers indicates that once farmers adopt aflatoxin control methods, they recognise their value. However, the low levels of awareness and implementation of strategies such as Aflasafe highlight the need for greater dissemination of information and training, mainly because the product is still relatively new and not yet widely distributed in the Ugandan market. Scaling up the availability of bio-control agents like Aflasafe and educating farmers on how to use them can help reduce aflatoxin contamination in staple crops (Bandyopadhyay *et al.*, 2022).

Qualitative results: perceptions and barriers in aflatoxin management

Knowledge and awareness of aflatoxin contamination

Farmers showed a range of awareness levels regarding aflatoxin contamination. Participants associated afla-

TABLE 3 Bivariate and multivariate analysis of socio-demographic factors associated with farmers' awareness and knowledge of aflatoxin mitigation strategies among 358 smallholder farmers in Arua District[1]

Characteristics	Categories	Crude PR (95% CI)	cPR (*P*-value)	Adjusted PR (95% CI)	aPR (*P*-value)
Age group	Below 18 years	2.04e-6 (6.45e-7–6.47e-6)	<0.001*	2.65e-6 (8.21e-7–8.58e-6)	<0.001**
	18–34 years	0.920 (0.614–1.378)	0.852	0.963 (0.647–1.434)	0.852
	≥35 years	Reference	–	Reference	–
Gender	Male	1.737 (1.192–2.530)	0.01*	–	–
	Female	Reference	–	Reference	–
Education level	No formal education	0.135 (0.060–0.306)	<0.001*	0.136 (0.060–0.307)	<0.001**
	Primary	0.190 (0.146–0.249)	<0.001*	0.196 (0.144–0.265)	<0.001**
	Secondary	0.403 (0.307–0.529)	<0.001*	0.407 (0.305–0.543)	<0.001**
	Diploma	0.583 (0.361–0.942)	0.029*	0.587 (0.364–0.946)	0.029*
	Degree	Reference	–	Reference	–
Farmer group membership	Yes	1.358 (0.837–2.203)	0.399	–	–
	No	Reference	–	–	–

1 PR = Prevalence Ratio; CI = Confidence Interval; *Statistically significant at bivariate level ($P < 0.05$); **Statistically significant at multivariate level ($P < 0.05$).

toxins with crop spoilage and reduced market value, but were often unaware of the potential health risks. One farmer from Ringili Parish in Arivu sub-county expressed uncertainty: '*I always observe green mould on grains, but I do not know if it is toxic*.' This uncertainty was prevalent across the FGD sessions.

Aflatoxin management strategies

Farmers reported using basic strategies, such as drying and sorting grains, although there was limited knowledge about more advanced methods like Aflasafe. A farmer from Ozoo Parish admitted that '*I've heard of something called Aflasafe, but I don't know how to use it*.' This points to a lack of technical knowledge and awareness about innovative solutions.

Barriers to adoption

The major barriers identified in the FGD sessions were financial constraints and limited technical support. Farmers reported that while they understood the importance of drying and proper storage, they lacked the resources to implement these practices effectively. '*We know drying is important, but we don't have the equipment to do it right*,' shared one farmer from Anyavu Parish.

Training and technical assistance

Farmers consistently expressed the need for more training and technical assistance. Most participants indicated they had never received formal training on aflatoxin management. One participant from Ringili Parish said, '*We need more experts to come and teach us how to protect our crops*.' On-farm demonstrations and radio broadcasts were suggested as effective ways to reach more farmers.

Policy and institutional support

Participants expressed a desire for stronger government intervention in regulating grain quality and promoting aflatoxin mitigation. One participant from Yiepi Village emphasised, '*The government should enforce laws to ensure safe food for everyone*.' Farmers recommended subsidies for aflatoxin management tools such as Aflasafe and greater support from local agricultural offices.

The findings of this study have vital implications for policy and practice in Uganda and other regions facing similar challenges with aflatoxin contamination. First, there is a clear need for improved agricultural extension services that focus specifically on aflatoxin awareness and management. Second, aflatoxin education should be integrated into existing agricultural training programs, with an emphasis on reaching marginalised

groups such as women, young farmers, and those with lower educational levels. Third, scaling up the use of bio-control products such as Aflasafe could significantly reduce aflatoxin contamination in staple crops, but this will require a concerted effort from both governmental and non-governmental organisations to ensure that the product is accessible and affordable to smallholder farmers.

This study has the following limitations. First, the reliance on self-reported data may introduce bias, as farmers may not accurately recall their experiences with aflatoxin contamination and management practices. Second, it was conducted in a specific region of Uganda, and the findings may not be generalisable to other areas with different environmental or socio-economic conditions. Future research should explore the effectiveness of aflatoxin mitigation strategies in a wider range of settings and over a longer period of time.

4 Conclusions

This study revealed a significant gap in the awareness and knowledge of aflatoxins among smallholder farmers in the West Nile region of Uganda, despite the widespread reports of fungal contamination in crops. The low uptake of mitigation strategies, including Aflasafe, highlighted the need for enhanced agricultural extension services and targeted interventions, particularly for women, younger farmers, and those with limited education. To effectively combat aflatoxin contamination, efforts must be focused on promoting good agricultural practices and increasing access to bio-control products. The findings also underscored the importance of scaling up awareness campaigns and training to reduce aflatoxin-related health risks and improve food safety.

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Authors' contribution

Authors SO, WO, AA, GM, FE, JA, and FO contributed to conception and design of the study. SO and WO collected and analysed all the data. SO prepared the first draft manuscript. WA, AA, GM, FE, JA, and FO reviewed the manuscript. All authors approved the submitted version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships, therefore there is no conflict of interest.

Data availability

All data generated or analysed during this study are included in this published article. And raw data is available when requested.

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