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Maize and groundnut crop production among rural households in Zambia: Implications in the management of aflatoxins

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ABSTRACT

Maize and groundnut are important crops for both commercial and smallholder farming in Zambia, whose production is being threatened by their susceptibility to aflatoxin contamination. Despite this threat, there is limited knowledge of household growers' behaviour and applications related to suitable agricultural management practices, as well as growers' perception and knowledge of aflatoxins and their effects. This limited knowledge has major implications for acute human health effects such as liver cirrhosis and death, cancer, stunting in children, immune system suppression, impaired food conversion, and reduced livestock productivity and/or increased livestock mortality.

This cross-sectional survey of smallholder household growers in Zambia was conducted to identify the gaps in the knowledge and application of aflatoxin-associated agricultural management practices. A sample of 3865 maize- and groundnut-producing smallholder farm households were selected in 27 priority districts implementing the Scaling Up Nutrition (SUN)/First 1000 Most Critical Days Programme (MCDP) Phase II. Among the five pre-harvest management practices for maize and groundnuts – namely, controlling weeds, timely planting, controlling pests, and applying basal and top-dressing fertilisers – few households (8%) reported practising all of them. Among the recommended techniques for harvesting and handling maize and groundnuts, the most common harvest-management practices under maize production were drying (95.2% of households) and sorting at harvest (72%). In contrast, very few households (2%) practised at least three of four maize harvest management practices. Similarly, very few households (10%) practised at least 4 of the 6 groundnut harvest-management measures. Comparatively, post-harvest and storage management practices were more commonly practised, although most households did not practise all six post-harvest and storage management measures.

Overall, very few households (1% for maize and 4% for groundnuts) were observed to be practising at least 12 of the 14 recommended management practices, implying that there are considerable gaps in the implementation of aflatoxin-related management practices along all stages of maize and groundnut production, consequently posing a significant threat to health and contributing to malnutrition levels in Zambia.

As such, there is a need to develop tailored interventions and trainings for farming households, extension officers, and frontline health workers to prevent and manage aflatoxin contamination at different stages of crop production. Furthermore, the elimination of policy constraints, practical barriers of affordability and consumer awareness, and the value attached to the commercial product of Aflasafe, noted to reduce aflatoxin contamination by 80–100%, are of utmost urgency.

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1. Introduction

Maize and groundnuts are known to be key staples for millions of households throughout the sub-Saharan Africa (Bandyopadhyay et al., 2016; Cardwell & Cotty, 2002; Gong et al., 2003; Hell et al., 2000; Probst et al., 2014; Shephard, 2008).

Maize (*Zea mays* L.), a major food security crop in sub-Saharan Africa (SSA), is grown principally by smallholder farmers on more than 25 million hectares (Tembo et al., 2020). In Zambia, maize is the most important staple food, with an annual production of 3,387,470 tonnes cultivated over an area of 1,333,519 ha, and average yields of 2.8 t/ha (FAO, 2020). Globally, the country has one of the highest per capita maize consumption of around 130 kg/capita/year (Tembo et al., 2021) and ranks amongst the top 5 consumers (with Lesotho, Malawi, Zambia, South Africa, with averages exceeding 100 kg/capita/year), all after Mexico, which has triple the per capita consumption (Erenstein et al., 2022).

In addition, groundnut (*Arachis hypogaea* L), an important food legume native to South America, is cultivated on virtually all soils in tropical and subtropical countries in different agro-climatic zones, with an average global yield of 1600 kg ha^{-1} (Singh et al., 2014). The crop is among Zambia's main food and cash crops, empowering many smallholder farmers to earn a livelihood (Mukanga et al., 2019). The annual groundnut production in Zambia is 127,172 tonnes, cultivated over an area of 192,246 ha, with an average yield of 730 kg ha^{-1} (FAO, 2020).

The primary biotic constraints to maize and groundnut production are susceptibility to aflatoxin contamination (Boni et al., 2021). Aflatoxins, naturally occurring toxic compounds produced by fungi (*Aspergillus Flavi)*, are described as extremely hazardous (Cotty et al., 1994). The fungi are known to spread from soil, organic matter, and alternative hosts crops to host and susceptible crops, with crop infection and aflatoxin production at their peak when conditions are hot and dry and after crop maturation or harvest, when conditions are warm and humid (Cotty & Jaime-Garcia, 2007). Consuming food products and diets with high aflatoxin concentrations has been shown to cause acute health effects, such as liver cirrhosis, malnutrition, and death (Wild, 2002; Shirima et al., 2015; Githang'a et al., 2019; CDC, 2004; Probst et al., 2007). Chronic aflatoxin exposure is linked to cancer and connected to stunting in children, immune system suppression, and impaired food conversion (Bandyopadhyay et al., 2016; Bhat et al., 2010; Chan--Hon-Tong et al., 2013; Liu & Wu, 2010).

Aflatoxins also pose serious livestock health concerns (CAST, 2003, pp. 1–191); livestock and fish fed with aflatoxin-contaminated feed have been shown to have reduced productivity and/or increased mortality (Bryden, 2012; Monson et al., 2015; Oliveira & Vasconcelos, 2020). Most maize and groundnut crops and crop products used as feed for livestock are usually affected by fungal infections that produce aflatoxins (Ezekiel et al., 2012, 2014), which in turn affects the food value chain through reduced livestock growth rates and subsequent bio-transmission into livestock products (Bryden, 2012). Aflatoxins transferred through consumed feed reportedly resist decomposition or catabolism in animal digestive systems, hence permitting these aflatoxins to persistently occur in meat, eggs, milk, and dairy products (Gizachew et al., 2016; Iqbal et al., 2014, 2015; Prandini et al., 2009).

Besides its effects on humans and livestock, aflatoxin-contaminated foods and feeds also create negative impacts on trade, resulting in it being highly regulated through international trade standards and causing loss of markets for agricultural products and reduced income (van Egmond et al., 2007; Wu, 2014). In the 1960s, Zambia exported over 8000 metric tons of groundnut to the European market, which later suddenly collapsed, mainly as a result of the enforcement of aflatoxin regulations in Europe (Sitko et al., 2011), with the last export to the Netherlands of only 14,000 kg being in the year 2006 (Njoroge, 2018). The economic losses resulting from rejected groundnut export due to aflatoxin contamination were reported to be more than 450 million US dollars to Zambia (Wu, 2004).

Mycotoxins resulting from aflatoxins in the food value chains are a significant contributor to malnutrition in developing countries, especially in Sub-Saharan Africa (SSA) (Udomkun et al., 2017). Several factors, among them climate, crop production, handling, and storage, are normally conducive to increasing the vigour of fungal growth, especially when the crop has been infected during cultivation, subsequently leading to the formation of aflatoxins (Paterson & Lima, 2010). In addition, complementary factors such as genotype, water stress, soil conditions, insect activity, and socio-economic factors (such as unavailability of materials, tools, and equipment) have all been found to be influential and likely to further contribute to situations favouring aflatoxin contaminations (Wagacha & Muthomi, 2008). To effectively prevent fungal infections leading to aflatoxins and their proliferation, numerous pre-harvest, harvest, and post-harvest aflatoxin mitigation practices have been endorsed as good agricultural practices (Bandyopadhyay et al., 2016; Guchi, 2015; ICRISAT, 2016) (Table 1).

A number of studies have been undertaken in Zambia to quantify aflatoxins in maize and groundnut across the country's three agro-ecological zones, and to determine the vulnerability to aflatoxin after purchase (Kachapulula et al., 2017a). Other studies have resulted in improved understanding of fungal communities associated with aflatoxin contamination in cultivated and non-cultivated soils and in crops in Zambia (Kachapulula et al., 2017b).

Thus, the primary objective of the current study was to assess the extent of aflatoxin-associated management practices among maize- and groundnut-producing smallholder farm households in 27 districts of Zambia's Scaling Up Nutrition (SUN)/First 1000 Most Critical Days Programme (MCDP) Phase II.[1] The study's specific objective was to investigate aflatoxin knowledge and awareness levels among households in selected districts and to examine the aflatoxin management practices and methods applied from production to storage. The results of this work can serve as a guide to inform, enhance, and improve both household and programmatic aflatoxin management strategies, selection of areas to target intervention strategies for managing aflatoxin, and for targeting aflatoxin awareness-raising activities in Zambia and elsewhere.

2. Materials and methods

2.1. Study area

The study was conducted in 27 SUN/MCDP II districts, covering nine provinces (Central, Copperbelt, Eastern, Luapula, Muchinga, Northern, North-western, Southern, and Western). As part of the SUN/MCDP II, these districts also receive a wide range of multi-sectoral support from SUN/MCDP donors and implementing partners.

2.2. Sample selection

A total of 3865 maize- and groundnut-producing smallholder farm households in 27 SUN/MCDP II districts of Zambia were selected in a cross-sectional survey to assess the extent of their agricultural farming practices relating to aflatoxin management. Ethical approval for the survey was granted by the ERES CONVERGE Institution Review Board (IRB) (No. 00005948) on February 12, 2021 (Supplementary file S1). During data collection, the farm households' members present were

[1] Scaling Up Nutrition - Learning and Evaluation (SUN LE) is a USAID-funded project implemented by the Government of the Republic of Zambia (GRZ) in partnership with Khulisa Management Services, Inc., and in collaboration with its consortium partners Indaba Agricultural Policy Research (IAPRI), ICF International and the University of North Carolina at Chapel Hill (UNC). SUN LE provides survey, research, evaluation, and dissemination services to the GRZ's SUN 2.0 programme/First 1000 Most Critical Days Programme (MCDP) II in 30 priority districts across all 10 provinces of Zambia.

Table 1
Recommended pre-harvest, harvest, and post-harvest aflatoxin management practices.

Groundnuts	Pre-harvest measures	Harvest measures	Post-harvest measures
	Early planting to escape end-of-season drought that in general predisposes pods to cracking and entry by *A. flavus*.	Harvesting at the right stage to minimize exposure of the crop to extreme heat, sudden rain, or drought, which also influence infection.	Proper drying using Mandela Corks (ventilated stacking) to minimize the direct exposure of groundnuts to the sun.
	Maintaining field hygiene though timely weeding to retain soil moisture and termite control to prevent damage to developing pods.	Avoiding injuries to pods when using hand hoes.	Proper shelling using mechanical shellers and avoiding sprinkling water on pods when shelling.
	Harvesting of water in the field through use of tied ridges (box ridges) early in the cropping season and mulching.	Removal of soil attached to the pods during harvesting to avoid carrying the fungus into stores and processing facilities.	Grading and sorting kernels with cracked or damaged pods or seed coats, discoloured, small and shrivelled pods reduce the amount of infected produce in the lot.
	Soil amendments such as lime to the crop supports development of strong shells (pod resistance).		Proper storage to prevent entry of insects and moisture into the storage lots to avoid fungal entry and, eventually, aflatoxin contamination. Grains should be stored in a dry and secure place. Avoid using grade-outs as they usually contain higher toxin levels and should not be used for consumption and animal feed.
Maize	Pest management techniques using appropriate insect management techniques will reduce formation of holes and damage to the cobs, which, in turn, will reduce the entry points for the fungus.	Proper harvesting by drying cobs on polyethylene sheets spread on the ground, instead of directly drying them on the ground, and avoiding leaving cobs to dry in the field, on bare soil, where they can easily pick up soilborne fungus.	Sanitation by clearing the remains of previous harvests, destroying infected crop residue, and cleaning the stores before storing the new harvest also reduces aflatoxin contamination.
	Biocontrol through application of biocontrol agents to the crop, such as Aflasafe, two to three weeks before maize flowering, can prevent aflatoxin contamination throughout, even when grains are stored.	Grading cobs by avoiding mixing damaged cobs with healthy ones reduces spread of spores and subsequent infection. Sorting insect-damaged cobs and cobs with poor husk covering can reduce aflatoxin contamination. Winnowing, washing before cooking, and dehulling of maize grains are effective in achieving significant aflatoxin and other mycotoxins removal.	Proper storage by avoiding heaping the crop in stores, but instead packing in a clean, sealed container to avoid exposure to excessive moisture and humidity.

informed about the scope and purpose of the survey and asked for their permission and a signature confirming their consent to participate in the study before administering the questionnaire. The sample was a stratified sample selected in two stages from the Census of Population and Housing 2010 sampling frame designed to produce representative estimates at district-level, with ten standard enumeration areas (SEAs) randomly selected from each stratum (districts with probability proportional to size (PPS)) from the ordered list of SEAs. The size of each SEA was based on the number of households in the SEA, with 25 eligible households randomly selected in each sampled SEA as follows: The interviewer would move to the centre of the SEA, and then spiral outward, locating, and interviewing eligible households until the desired number of 25 households in the SEA was reached. Household distribution in each location was recorded using global positioning scale (GPS) coordinates (Fig. 1). A total of 3865 households were interviewed in the respective selected districts and summarized per province as follows: Central (484), Copperbelt (35), Eastern (680), Luapula (415), Muchinga (407), Northern (582), North-Western (355), Southern (272), and Western (635).

2.3. Data collection, questionnaires and analysis

The survey team comprised 40 enumerators, conversant in the local languages and experienced in data enumeration, who conducted data collection and entry. They were segmented into eight data collection teams, each with a supervisor that conducted daily logistics and quality control throughout the data collection period, and five enumerators. Local language proficiency was the basis of team and province assignments. Furthermore, four quality controllers provided quality checks on the questionnaires that supervisors reviewed. Structured interviews with a mix of closed- and open-ended questions were conducted with farm household members who voluntarily agreed to participate in the survey. Enumerators identified themselves and the organization they represented and provided contextual information of the study. Households were then asked to indicate their voluntary consent by accepting to participate in the interview or decline, should they not want to proceed. If households had any further questions about the survey, they were encouraged to contact the ERES Converge IRB or the Indaba Agricultural Policy Research Institute (IAPRI), the partner responsible for data collection. The questionnaire template is available online (Supplementary file S2). The questionnaire was pre-tested on a small group of selected farm households before the survey rollout and adjustments were made to ensure that the questions were phrased clearly enough to be understood correctly by farmers. Interviews were conducted in local languages or languages that respondents were most familiar with. Some questions were repeated and rephrased to enable households to understand and respond fully. The rephrasing was done without changing the original meaning of the questions.

The questionnaire was designed in 10 parts:

1. The first section was focused on explaining the study and the informed consent form.
2. The second section identified and recorded the household main respondent and their areas of residence.
3. The third section comprised the household roster and demographics, such as age, relation to head of household, marital status, education level, and primary occupation.

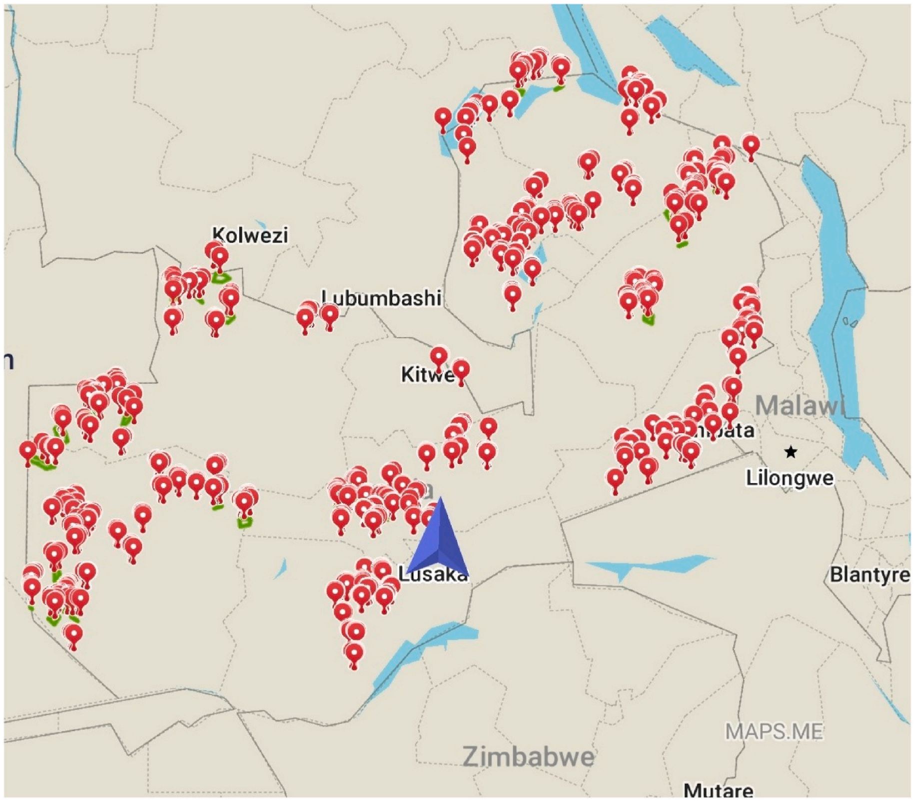

Fig. 1. Distribution map of the aflatoxin management practices household survey in Zambia, June–July 2021.

4. The fourth section focused on the household's farmlands and usage, with questions related to land use, crop (s) grown, and the primary decision makers.
5. The fifth section related to maize and groundnut production, harvesting, and management. Households were asked about the seed varieties and quantities used, their sources of seed, fertilizer types used, and period applied, as well as crops planted in the previous season, and their harvesting, storage, and management post-harvest.
6. The sixth section comprised a set of open-ended questions to assess farm households' storage practices in terms of the form in which the maize and groundnut crops were stored, what methods of shelling were used, the treatment done before storage, materials used to store the maize, the kind of structures households store most of their maize and groundnuts in, how the households clean the storage structures before storage of the harvest, when the households treat the harvest after storage, and how often the households check on the maize and groundnut harvests after storage. Respondents were also asked whether they monitor for any signs of moulding of the stored grain, and if they do, what action they mainly take.
7. The seventh section was related to aflatoxin management practices during food processing for consumption. The questions probed whether the households mill the harvested maize and groundnuts into flour and how (wet milled or dry milled), whether they sort the harvest to remove any rotten/discoloured/shrivelled grains before milling or consumption and whether they dehull the harvest before milling or consumption.
8. The eighth section assessed household knowledge on aflatoxins - what aflatoxins are, what they understand about aflatoxins and their consequences, what they think the causes of aflatoxins are, what the health risks of aflatoxins are, how they can prevent aflatoxins, and if they ever had an experience with aflatoxins in their crops and, if yes, how they had addressed it.
9. The ninth section related to the sources and frequencies of obtaining information related to aflatoxins and the ranking of preferred pre-defined information sources or other sources specified by the respondent.
10. The tenth and final section was on the enumerators' physical field observations at the farm or the homestead. The observations were oriented towards the post-harvest and storage practices, i.e., what form the produce was in, if the produce was being dried and, if so, on what surface, if the storage structures and any grain handling equipment were free of leftover grain, whether the storage structures had roof sealing cracks and/or holes in the structures, whether the area around the structures were weed-free, whether the structures had cracks or light coming through, whether there were any debris and possible animal droppings, what kind of structure the household stored most of its produce in, if there were any presence of insects and mould on the produce, whether the produce felt wet to the touch, whether there were any sign of damaged or shrivelled produce, and in what conditions the household stores the produce, including the material the household uses to store the produce and whether the produce was treated.

The survey was undertaken between June 3 and July 11, 2021, the harvest/post-harvest season, therefore, no observations of pre-harvest practice were possible; only a few harvest/handling practices could be undertaken.

Data was electronically captured on tablets using CSPro (2021) software. Data cleaning was done in Stata v15 (2017) using frequencies to identify illogical responses. These were verified by calling interviewers and, where necessary, the households. Data analysis was done using Stata v15 (2017). Sets of descriptive statistics, including means and standard errors and cross tabulations were calculated. Results were expressed as percentages or absolute frequencies of responses obtained from households and were disaggregated by districts. The single factor ANOVA statistics were used to evaluate and compare the households' responses across the districts using GenStat (18th edition, VSN International 2013).

3. Results

3.1. Informed consent, identification, roster, and demographics of households

A total of 4100 households were targeted for the study. Of these, 3865 households were successfully interviewed, representing a 94% response rate (Table 2). One household was excluded from the analysis because of missing information, and 234 were not interviewed due to refusal, non-contact, dissolved households, or households that had moved out of the SEA since 2019 (the time the sample was drawn as part of a larger survey). Three enumeration areas (EAs) were completely inaccessible due to waterlogging, with no available alternative routes during the survey.

The households of interest were those that had produced either maize or groundnuts in the 2020/21 agricultural season. Most households were male-headed households (MHH) (82%); only 18% were female-headed households (FHH). The age distribution of household heads was dominated by people 35–44 years of age (Table 2). Farming was the primary occupation for most households (73%); self-employment/entrepreneurship ranked a distant second at 13%. Most household heads (53%) had attained primary level education, while only 3% had attained tertiary education.

3.2. Aflatoxin knowledge and awareness

More than 90% of households grew maize in the 2020/21 agricultural season, while 67% of households grew groundnuts (Table 3). Samfya District had the fewest households (54%) that grew maize, and Mongu District had the fewest households (10%) that grew groundnuts. 93% of households reported general awareness of aflatoxins, with significant differences ($p < 0.001$) across districts: awareness was lowest in Kalabo District (77%); while Isoka, Mpika, and Choma districts reported the highest awareness (100%) (Table 3). Very few households (17%) received aflatoxin-specific information (Table 3) regarding their crops, although again there were significant differences across districts ($p < 0.001$). Overall, Kasama District had the most households that received information (44%), while Solwezi, Kalabo, and Shang'ombo districts had the fewest (less than 2%). Most households who received information, applied it (89%) (Table 3). However, of the few households in Shang'ombo district who received information, none (0%) had applied the information they received, reporting that they did not understand the information. This was in contrast to Mumbwa, Katete, Mbala, Solwezi, Choma, and Kalabo districts, where all households that received information reported applying it.

Although most households were aware of aflatoxins, their understanding was highly skewed towards it being due to infections in crops (64%) rather than due to fungi (41%), poison (8%), rotting (3%) or wet produce (0%) (Table 4).

Given the paucity of data on households' awareness of aflatoxin causes, we provide additional detail on some individual rankings of the households' thoughts on factors attributed to aflatoxins. Humidity was ranked highest (60), followed by early harvest/high moisture content (46%) and poor post-harvest storage (32%), whereas poor pre-harvest handling, bad seed and soil, the use of too many chemicals, delayed planting, and the mixture of old and new stock ranked least (Table 4). Regarding the health effects caused by aflatoxins, most households reported disease symptoms such as stomach pain and diarrhoea (76%); only a few (7% or less) knew that aflatoxins could reduce disease resistance in humans, cause cancer, cause stunting, or cause congenital disabilities (Table 4). Common practices that households knew for reducing the prevalence of aflatoxins in their crops were mostly post-harvest practices, including proper storage (53%), proper drying of produce (45%), proper produce handling (16%), and the sorting of ungraded seed (10%) (Table 4). Few households (0%) mentioned pre-planting practices, such as practicing crop rotation, using good seeds, or planting on time. Similarly, post-harvest practices were the most commonly applied practices households used to reduce the prevalence of aflatoxins in their crops (Table 4).

Table 2
Informed consent and socio-demographic profile of households, June–July 2021.

Parameter	Variable	N	%
Informed consent	Refusal	1	0.
	Household moved out of SEA	82	2
	Household dissolved	5	0
	Non-contact	146	4
	Response	3865	94
Gender	Male headed households	3165	82
	Female headed households	700	18
Age	15–24	178	5
	25–34	1175	30
	35–44	1214	31
	45–54	684	18
	55–64	387	10
	>65	228	6
Education	Tertiary (>13 years)	120	3
	Secondary (8–12 years)	1411	37
	Primary (1–7 years)	2029	53
	No education	309	8
Primary occupation	Self-employed/entrepreneur	510	13
	Receive pension	4	0
	Casual work/piecework	259	7
	Private sector employee	93	2
	Parastatal employee	4	0
	Formal employee (government)	93	2
	Unemployed	70	2
	Student	4	0
	Farmer	2829	73

3.3. Source of aflatoxin information

The most frequently mentioned information source for aflatoxin practices and management was the Ministry of Agriculture (MoA) extension workers (mentioned by 28% of households), while 27% relied on information passed on from family members and fellow farmers (22%) (Table 5).

Information was channelled to most households through informal conversations (46%) and meetings (36%). Of those who received their information through informal conversations, half (55%) received information from family members, while 42% received information from fellow farmers. On the other hand, of the 36% that received their information through meetings, more than half (55%) received the information from MoA extension officers, 23% from cooperative/farmer groups, and 12% from non-governmental organizations/civil societies. Among the aflatoxin-specific information received, drying methods was cited most (60% of households), proper produce handling (45%), moisture monitoring in storage (31%), aflatoxin prevention and control (26%), storage structure cleaning and maintenance (21%), types of structures to prevent moulding (11%), temperature monitoring in storage (11%), visual inspection of produce (8%). Information on stock rotation, diseases caused by aflatoxins, and where to test for aflatoxins (5%, 2% and 0%, respectively) were the least mentioned (Table 5). In terms of hurdles or challenges households faced in applying the information they received, households cited a lack of resources (29%) and inadequate technical guidance (10%).

Table 3
Summary data on households' aflatoxin survey responses, June–July 2021.

Districts	% Household Aflatoxin Variables						
	Households growing maize	Households growing groundnuts	Knowledge of aflatoxins	Received aflatoxin management information	Applied aflatoxin information received	Applied 12 out of 14 management practices (maize)	Applied 12 out of 14 management practices (groundnuts)
Chibombo	91	51	94	14	88	3	12
Kapiri mposhi	91	49	90	11	88	2	8
Mumbwa	100	90	96	10	100	3	2
Ndola	89	69	89	14	80	7	16
Chipata	100	86	93	15	96	0	3
Katete	100	88	96	17	100	1	7
Lundazi	99	88	94	26	91	0	0
Petauke	99	91	96	18	91	1	18
Mansa	70	46	89	26	94	1	1
Nchelenge	75	40	96	19	91	0	5
Samfya	54	49	86	18	87	0	1
Chinsali	92	90	99	27	90	0	1
Isoka	97	67	100	27	90	0	1
Mpika	100	88	100	33	97	0	0
Kaputa	72	45	95	22	90	1	6
Kasama	88	82	97	44	98	0	4
Luwingu	73	78	87	19	94	1	1
Mbala	99	72	91	34	100	0	0
Mwinilunga	99	73	96	11	67	0	0
Solwezi	100	84	98	2	100	0	0
Zambezi	93	81	91	8	91	0	0
Choma	100	87	100	9	100	1	4
Monze	99	95	99	20	97	1	5
Kalabo	85	16	77	1	100	0	1
Kaoma	100	79	86	10	83	1	1
Mongu	96	10	88	6	86	1	0
Shang'ombo	94	15	83	1	0	0	0
Mean %	90.93	67	92.8	17.11	88.48	0.76	3.54
SD	12.03	25.31	5.8	10.51	19.2	1.4	4.95
p-value	0.001	0.001	0.001	0.001	0.001	0.009	0.001

3.4. Crop production, harvesting and handling, and storage management practices

3.4.1. Pre-harvest management practices

Local maize was commonly grown among the households (51%), with recycling of hybrid maize the second most practiced phenomenon (11%) (Fig. 2). Maize varieties commonly grown among the households are the hybrid series, with non-specific hybrid maize (10%), Panner (8%), SeedCo (8%), Zamseed (5%), Pioneer (3%), Kamano (2%) with the least being open-pollinated varieties (OPVs) (0%) (Fig. 2).

Similar to maize varieties, local groundnuts were commonly grown among the households (76%), with Chalimbana being the most (5%) and SC Orion being the least (0%) grown varieties (Fig. 3).

Among the five pre-harvest maize and groundnut management practices – namely, controlling weeds, timely planting, controlling pests, and application of basal and top-dressing fertilisers – few households (8%) reported practising all of them. For maize, more households in Chinsali (33%) reported practising these, while none did in Kalabo and Shang'ombo districts. For groundnuts, almost no household practised all five pre-harvest management practices. While most households reported controlling for weeds and planting on time in maize or groundnut fields, they seldom reported applying adequate basal or top-dressing fertilisers (Table 6).

3.4.2. Harvest and handling management practices

Among the recommended techniques for harvesting and handling maize and groundnuts (Table 1), the most commonly reported practices under maize production were drying (95% of households) and sorting at harvest (72%), while the most common handling practices were milling maize dry (96%) and sorting before storage and processing (89%) (Table 6). Under groundnut production, most households (98%) dried their groundnuts unshelled after harvest and sun-dried or discarded mouldy groundnuts (86%). Sorting before making flour (96%) was the most common handling practice used by households (Table 6).

Applying the combined best practices is rare among households. There were very few households (2%) that practised at least three of four maize harvest management practising measures. The highest rates were obtained in Petauke District (15% of households), with none in 15 of 27 districts. Only 13% of households practised all three maize handling management measures, with Petauke again having the highest percentage of households (50%) and none in Mwinilunga and Solwezi. Similarly, very few households (10%) practised at least 4 of the 6 groundnut harvest management practices, with households in Chinsali (30%) being the highest while none in 6 of the 27 districts surveyed. Only 6% practised both groundnut handling management measures, with households in Katete (16%) being the highest and households in Shang'ombo (1%) being the least.

3.4.3. Post-harvest and storage practices

The post-harvest and storage management practices were the more commonly practised among households, especially the use of recommended material for storage (Jute/Polypropylene/hermetic bags) for groundnuts (86%) and maize (84%). Few households cleaned the storage structures before storing their groundnut harvest (22%) or maize harvest (30%) (Table 6). Again, applying the combination of practices was rare. Nearly no households practised all six post-harvest and storage management practices.

3.5. Observations on households' adherence to the application of general post-harvest management practices

Households' reported applications of post-harvest management practices were supplemented with observations based on the recommended harvest and post-harvest storage management practices. Maize

Table 4
Aflatoxin knowledge and awareness among households, June–July 2021.

Parameter	Variable	N	%
Understanding of the causes of aflatoxins	Infections in crops	2481	64
	Fungi	1600	41
	Poison	301	8
	Rotting	97	3
	Don't know	15	0
	Wet produce	12	0
Perceptions on the causes of aflatoxins	Humidity	2327	60
	Early harvest/high moisture content	1793	46
	Poor post-harvest storage	1217	32
	Poor post-harvest handling	595	15
	Delayed harvesting after crops attained physiological maturity	437	11
	Do not know	301	8
	Droughts and extreme temperature	228	6
	Pest/insects/disease infestation and infection	189	5
	Lack of chemical/fertilizer application	43	1
	Poor pre-harvest handling	19	1
	Bad seed	12	0
	Bad soil	8	0
	Use of too much chemicals	4	0
	Delayed planting	0	0
	Mixture of new and old stock	0	0
Knowledge on the health effects of aflatoxins	Diseases (Stomach pain, Diarrhoea, etc.)	2918	76
	Cancer	93	2
	Stunted growth in children	73	2
	Reduced disease resistance	66	2
	Do not know	50	1
	Birth defects	19	1
Common aflatoxin practices known by households	Proper storage	2048	53
	Proper drying of produce	1751	45
	Spray chemicals	1279	33
	Timely harvest	831	22
	Proper produce handling	634	16
	Sorting ungraded seed	383	10
	Do not know	259	7
	Add ash/animal dung	12	0
	Crop rotation	4	0
	Use of good seed	4	0
	Timely planting	4	0
Common aflatoxin practices that households use	Sorting ungraded seeds	1894	49
	Proper storage after harvest	1248	32
	Air drying without any contact with soil	800	21
	Did nothing	638	17
	Timely harvesting	622	16
	Shelling before drying	100	3
	Mandela cork (ventilated stalking)	39	1
	Applying chemicals	8	0

Table 5
Source of aflatoxin information among households, June–July 2021.

Parameter	Variable	N	%
Source	Ministry of Agriculture Extension	1063	278
	Family (parents, relatives)	1036	27
	Fellow farmers	858	22
	Cooperative/farmer group	383	10
	Non-governmental organizations/civil societies	271	7
	Private input suppliers/stockists	73	2
	None	54	1
	Locally organized group	43	1
	Food Reserve Agency cooperative	31	1
	Ministry of Health/Health officer	31	1
	United Nations Agencies	12	0
	Church based groups	8	0
	TV/radio	4	0
	Private output traders	4	0
Medium of aflatoxin information dissemination	Informal conversations	1766	46
	Meetings	1391	36
	Visits	205	5
	Radio programmes	174	5
	Field days	135	4
	Training programmes	77	2
	Demonstration plots	77	2
	Workshops	27	1
	Internet/social media	4	0
	SMS	4	0
	Pamphlets/newspapers	4	0
Aflatoxin specific information received	Proper drying methods	2284	59
	Proper produce handling	1743	45
	Moisture monitoring in storage	1214	31
	Aflatoxin prevention and control	1001	26
	Storage structure cleaning and maintenance	823	21
	Types of structure to prevent moulding	429	11
	Temperature monitoring in storage	414	11
	Visual inspection of produce	317	8
	Leakage sealed storage structures	201	5
	Crop rotation	189	5
	Diseases caused by aflatoxins	58	2
	Where to test for aflatoxins	8	0
Challenges in applying aflatoxin information	None	1975	51
	Lack of resources for implementing	1129	29
	Inadequate technical guidance	390	10
	Labour intensive	205	5
	Did not understand the information	166	4

or groundnuts that felt dry (or not wet) to touch in storage or during the drying process was highest at 97% and 95%, respectively (Figs. 4 and 5). A few households were observed to be treating their maize and groundnuts (3% and 0%, respectively).

3.5.1. *Summary of household adherence to the recommended management practices*

There were significant differences in the reported application of 12 out of 14 management practices for maize ($p < 0.009$) and groundnuts ($p < 0.001$) among the households across the districts, with only 1% for maize and 4% for groundnuts practising at least twelve of the fourteen recommended management practices (Table 3).

Households' performance in management practices that could curb aflatoxin exposure and contamination across all stages of crop production value chains is summarized below (Table 7). We categorized the relative performance of households adhering to the practices by creating thresholds of performance whereby if 60% or more households adhered to a practice, the practice was placed under "performing well", and if less than 60%, under the category "performing poorly".

There were negative correlations ($r = -0.8560$, $p = 0.0210$) between farmers' knowledge of aflatoxins and the aflatoxin management information received, indicating that even though the farmers received the information on aflatoxin management, their knowledge pertaining to aflatoxins was inadequate. Possible reasons for this inconsistence could be the level of education of the farmers, lack of well packaged aflatoxin management information and methods that could ensure efficient assimilation by the households. Most farmers (61%) in this study were categorized as having only primary and no education at all. Studies have

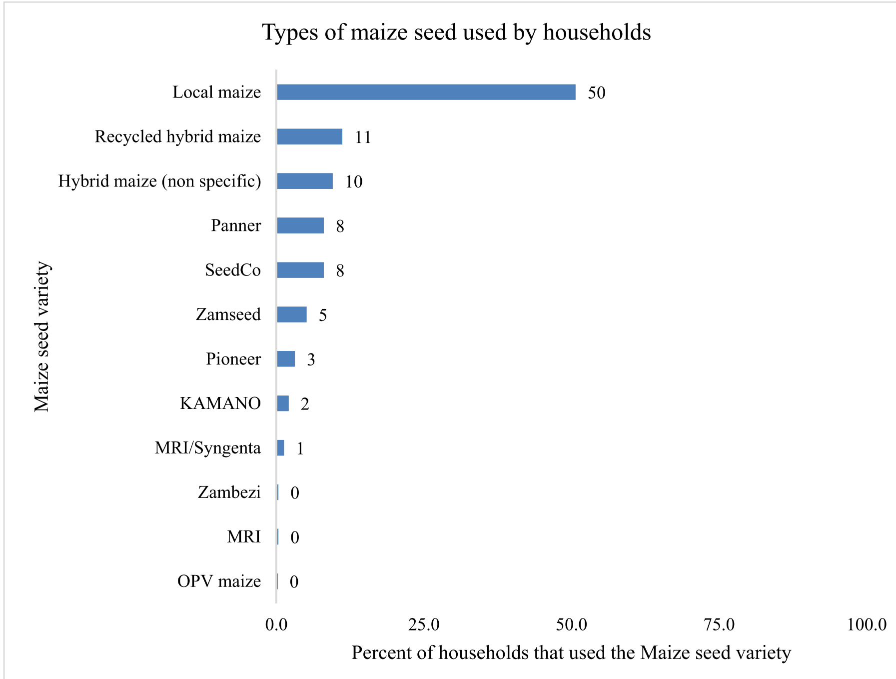

Fig. 2. Types of maize varieties grown by households in Zambia, June–July 2021.

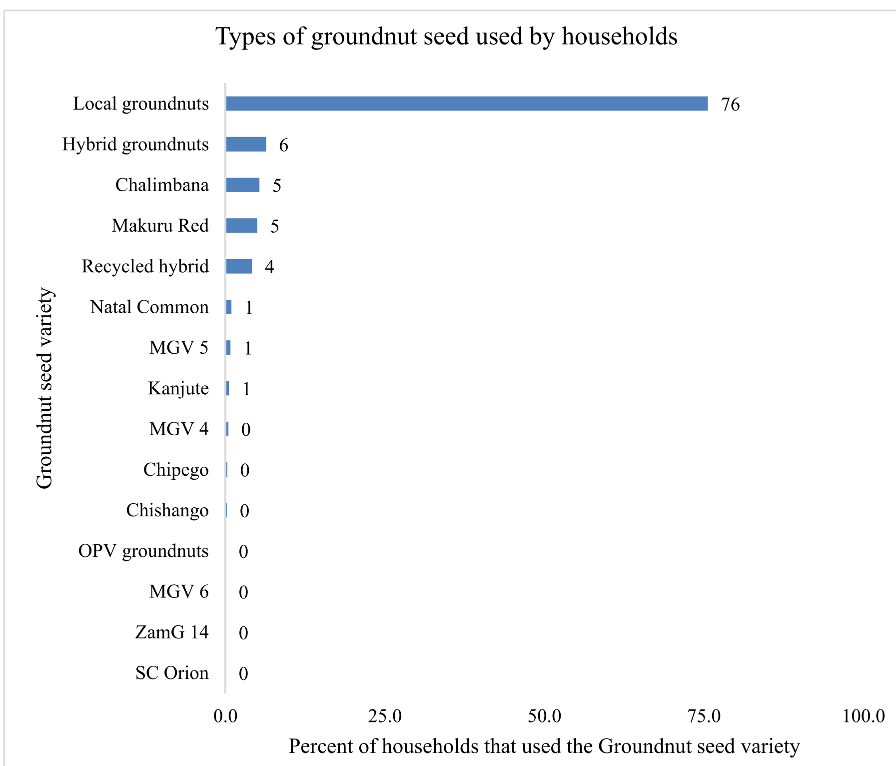

Fig. 3. Types of groundnut varieties grown by households in Zambia, June–July 2021.

shown that the more educated households were, the more knowledgeable about aflatoxins they were (Udomkun et al., 2018). The lack of association in the parameters further noted in the negative and significant correlation (r = −8380, $p = 0.0190$) in the knowledge of aflatoxins among households and those practicing at least 3 handling measures under maize production imply failure by the households to even utilise the aflatoxins knowledge on even just a few handling measures to minimize effects of aflatoxins contamination. Despite the farmers having indicated having received the aflatoxin management information, there was no association with them practicing all the pre-harvest management measures in maize production as shown from the highly significant and negative correlation (r = −0.7540, $p < 0.001$). Although not explained

Table 6
Pre-harvest, harvest and handling, and storage management practices among the households, June–July 2021.

Parameter	Variable	N	%
Maize pre-harvest field management practices	Control for weeds	3803	98
	Timely planting	3602	93
	Control for pests	970	25
	Adequate application of top-dressing fertilizer	928	24
	Adequate application of basal fertilizer	928	24
Groundnuts pre-harvest field management practices	Control for weeds	3811	99
	Timely planting	3780	98
	Control for pests	2539	66
	Adequate application of top-dressing fertilizer	15	0
	Adequate application of basal fertilizer	4	0
Maize harvest and handling management practices	Maize harvested dry	3679	95
	Shrivelled and discoloured maize cobs sorted at harvest	2775	72
	Maize not damaged in the field	607	16
	Maize harvested with complete husk cover	128	3
	Maize dry milled	3695	96
	Shrivelled and discoloured maize grain sorted	3428	89
	Dehulls maize	665	17
Groundnut harvest and handling management practices	Dried groundnuts unshelled after harvest	2284	59
	Mouldy groundnuts dried in the sun or discarded when noticed	1743	45
	No broken, shrivelled or discoloured groundnuts	1214	31
	Groundnuts did not become wet or mouldy during drying	1001	26
	Harvest groundnuts when dry	823	21
	Dried groundnuts using recommended drying practices	429	11
	Sort groundnuts before making flour	414	11
	Soaks groundnuts before cooking them	317	8
Maize post-harvest and storage management practices	Used recommended storage structures for long term storage	3266	85
	Stored using recommended materials	3235	84
	Stored unshelled	2346	61
	Did not observe moulding/controlled moulding when observed	2304	60
	Cleaned storage structure before storage	1156	30
Groundnuts post-harvest and storage management practices	Used recommended storage structures for long term storage	3359	87
	Stored using recommended materials	3335	86
	Stored unshelled	3181	82
	Did not observe moulding/controlled moulding when observed	1272	33
	Cleaned storage structure before storage	839	22

as to what could have attributed to this scenario, elsewhere, it has been observed that even though there was an overall improvement in some of the management practices, this was however not up to the desired extent due to farmers attitudes, fear for thefts of produce that was left in the field and also insufficient space for drying at homestead (Anitha et al., 2019).

4. Discussion

A comprehensive Food Safety Act of 2019 exist in Zambia with the following regulations in place; the Food and Drugs Act and Public Health Act Cap 295, the Food regulations of 2001, the Environmental protection and pollution control Act Cap 204, the Plant Pests and Disease Act Cap 233 and the Stock Disease Control Act Cap 252. However, the regulations that govern the food component of these acts are not implemented efficiently and effectively to ensure the safety and quality of food. Laboratories are not accredited for aflatoxin analysis hence does not guarantee international recognition to certification made in respect to consignments destined for export and with most of them located in the main city and not in the major groundnut producing areas. Due to high costs associated with testing, farmer groups do not bother and rather leave it to the would-be exporter/processor. The aflatoxin testing, monitoring and surveillance is irregular and inconsistent unless as a trade requirement. There is very little public awareness on Aflatoxin contamination and its implications with no institutionalized campaign done. Any awareness activity done is because of being a requirement for a specific project mandate and individual scientists' research activities. In addition, there is inadequate coordination and communication among the various food regulatory agencies in the food safety system with inadequate capacity/or resources to enforce food regulation effectively.

Unsafe aflatoxin concentration levels, above the legal limit of 10 μg/kg, have been detected in maize (up to 108 μg/kg) and groundnut (up to 361 μg/kg) and widely distributed across all three agro-ecological zones of Zambia (Kachapulula et al., 2017a). Widespread aflatoxin contamination in maize and groundnuts seriously threatens public health, nutritional security, and food and feed commodity chains in Zambia. Yet there have been few studies examining farmers' agricultural practices that can mitigate or exacerbate aflatoxin contamination in crops at various production stages - before, during, and post-harvest. This study sought to investigate and examine the aflatoxin knowledge and awareness levels and the practices, methods, and beliefs associated with aflatoxin management (from production to storage) among smallholder farmer households involved in groundnut and maize production across 27 districts spanning Zambia's three distinct agro-ecological zones.

Most household respondents in this study were middle aged, implying greater experience or authority. A farmer's age has been shown to be a vital parameter to consider in farming, especially among those associated with eliminating persistent or perpetual problems such as aflatoxins (Adesina & Baidu-Forson, 1995; Adesina & Zinnah, 1993). Over 92% of farmers in our survey had completed at least primary education, indicating a measure of literacy. In studies done elsewhere (Udomkun et al., 2018), more educated farmers tended to be more conscious about the quality of the food they consume, as observed by lower aflatoxin concentration in their foods compared to the levels found in the food of less educated farmers. Furthermore, educated farmers practising effective crop husbandry had lower levels of aflatoxin contamination in their products than farmers with little education. Education is further regarded as a contributory element to technology acceptance and adoption because it typically tends to lessen the likelihood of risk aversion by farmers, thereby enabling them to try out innovations (Adesina & Baidu-Forson, 1995). Though their primary occupation was farming, educated farmers also engaged in off-farm activities that provided alternative sources of income and served as insurance against shocks.

Very few households in this study knew of the health risks of aflatoxins, such as their contributions to cancer, stunting, congenital disabilities and reducing disease resistance. Similar perceptions were recorded in other studies, where over 50% of smallholder households were unaware that aflatoxin contamination posed a serious problem (Gichohi-Wainaina et al., 2021; Udomkun et al., 2018). The lack of regulatory enforcement or even a definition of acceptable limits in Zambia could be contributing to the disregard of aflatoxin

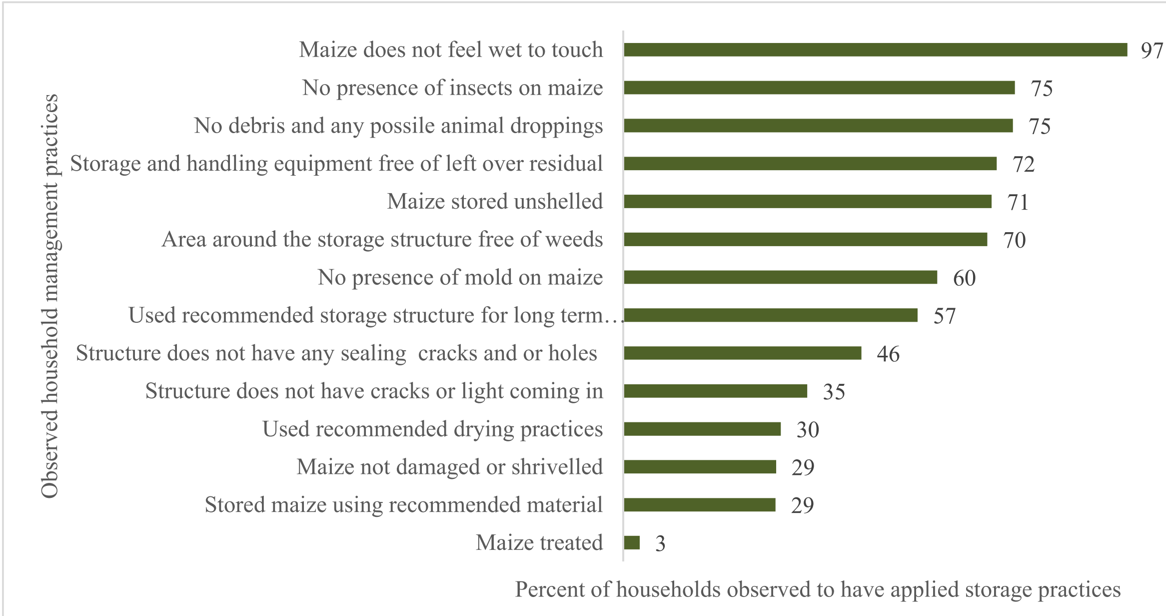

Fig. 4. Observed households applying post-harvest management practices under maize production.

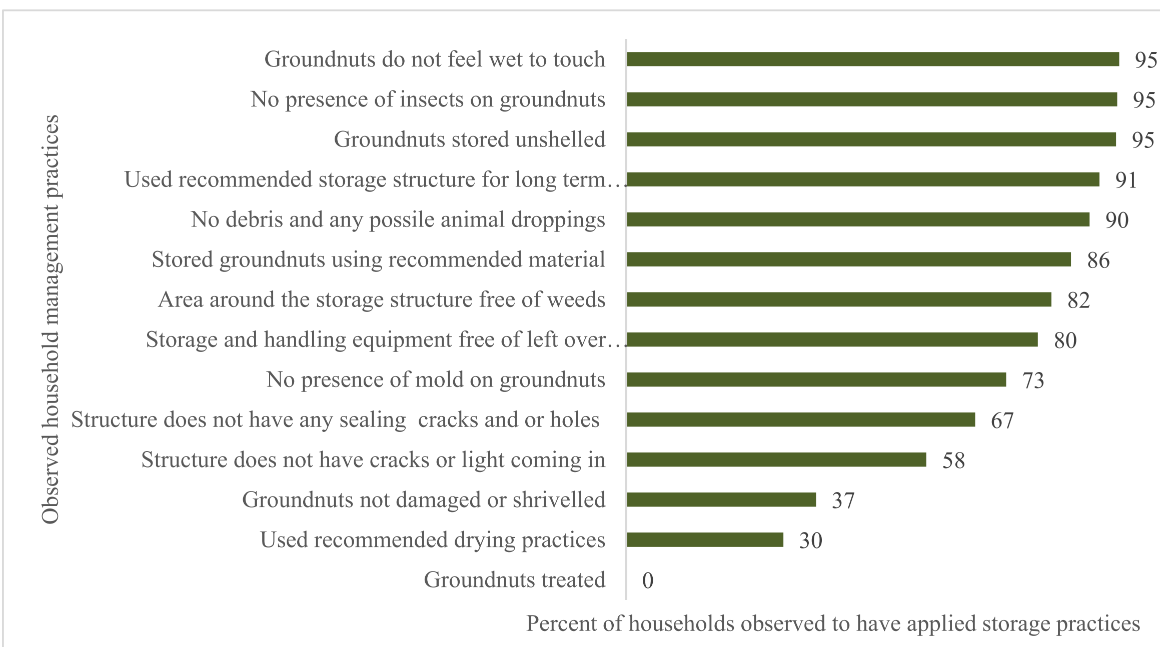

Fig. 5. Observed households applying post-harvest management practices under groundnut production.

contamination as a serious problem. Similar reports elsewhere of farmers not bothering about the serious problems that aflatoxin contamination cause have been attributed to lack of regulatory enforcements (Kumar & Popat, 2010; Udomkun et al., 2018).

Our findings show that households' knowledge and awareness of the causes of aflatoxins varied, with the majority attributing it to infections in crops and humidity. Few households attributed aflatoxin contamination to poison, rotting, poor pre-harvest handling, bad seed and soil, use of too many chemicals or delayed planting. They perceived mostly post-harvest practices, such as proper drying and storage, as ways to reduce the prevalence of aflatoxins. The development of accurate perceptions through the provision of trainings and promotion of resourcefulness among innovative households might increase awareness, knowledge, and understanding of aflatoxins and their harmful effects (Kumar & Popat, 2010). It has been shown that farmers' knowledge of aflatoxins is influenced by their socioeconomic and psychological characteristics, such as education, caste, farm size, social participation, extension participation, market orientation, economic motivation, innovativeness, and perceptions. Education clearly serves as an important mode of dispersing information and knowledge to the public, with positive and significant effects on farmers' knowledge and awareness - being crucial factors in alleviating the problems of aflatoxin in developing countries (Anitha et al., 2019; Midega et al., 2016; Strosnider et al., 2006). The results of this study underscore the important role of extension workers in providing information to household farmers, though family members and fellow household farmers were reported

Table 7
Performance of households' application of the aflatoxin management practices across all stages of crop production.

Stage of practice	Performing (Relatively) Well (>60% of households)	Performing Poorly (<60% of households)
Pre-Harvest Management	• Controlling for weeds • Timely planting • Controlling for pests (for groundnuts)	• Controlling for pests (for maize) • Fertilizer application (basal and top dressing)
Harvest Management Practices	• Harvest maize dry • Sort for shrivelled and discoloured maize cobs. • Dried groundnuts unshelled after harvest. • Discarded/dried mouldy groundnuts. • Sorting of shrivelled and discoloured groundnuts	• Maize not damaged in field. • Maize harvested with complete husk cover. • Harvesting groundnuts dry • Drying groundnuts using recommended practices • Groundnuts become wet and mouldy during drying
Handling Management Practices	• Dry milled the maize. • Sorting of shrivelled and discoloured maize • Sort groundnuts before making flour	• Dehulling maize • Do not soak groundnuts before cooking
Post-Harvest Practices	• Stored using recommended material. • Used recommended storage structures for long term storage. • Stored groundnuts unshelled	• Observing for moulding and doing something about it • Treating before storage • Cleaning storage structure before use • Stored maize unshelled
Observations	• Crops do not feel wet to touch. • No presence of insects • No debris and any possible animal droppings • Storage and handling equipment free of left-over crops • Store crops unshelled. • Area around storage structure free of weeds • No presence of mould • Use of recommended long-term storage structure for groundnuts • Storing groundnuts using recommended material • groundnuts storage structures with no sealing cracks or light coming in	• Use of recommended long-term storage structure for maize • Maize storage structures with sealing cracks or light coming in. • Use of recommended drying practices • Damaged and or shrivelled crops • Storing maize using recommended material • Crops not treated (in storage)

among the most common sources of agricultural information for households, whose reliability cannot be ascertained. This is similar to findings from previous studies in Malawi, where most households reported having received information from other individuals -agriculture extension workers, neighbours, and friends (Gichohi-Wainaina et al., 2021). Although, in our study, extension workers were the most trusted source of information, only a small proportion of household farmers were reached by this means. Our results demonstrate the need for household farmer education to improve knowledge and create awareness that is vital for effective reduction of aflatoxins contamination. Regular visits of trusted extension workers are required to provide household farmers with information on aflatoxins and its management at pre-harvest, harvest, and post-harvest stages. Although other sources of information, such as radio, television, or mobile phone text messages, can help reach household farmers and should not be ignored, to bridge the gap between scientific and indigenous knowledge, substantial effort should be invested in extension workers to train farmers on well-packaged information on aflatoxins and its management. The importance of deliberate efforts to include training on aflatoxin mitigation practices targeted to agriculture extension workers has been proven in previous studies showing that many agricultural extension services do not have a specific program which includes aflatoxins, mycotoxins, food safety, or good agricultural practices on mitigation in their messaging (Gichohi-Wainaina et al., 2021; Stepman, 2018). The observations elsewhere show this potential through significant reductions in aflatoxin quantities in food products assessed before and after the transfer of information through trainings and subsequent application (Anitha et al., 2019).

When probed further about some of the challenges the households faced in implementing the aflatoxin information they had received, farmers cited lack of resources and inadequate technical guidance as the main hurdles. Similar hurdles for aflatoxin prevention and control by most farmers, such as high costs, unavailability of technology, and low awareness of potential benefits, were equally mentioned as the main reasons for not applying or limited use of modern post-harvest aflatoxin management control technologies such as in Eastern Kenya and the Eastern Democratic Republic of Congo (Marechera & Ndwiga, 2014; Udomkun et al., 2018). The application of all five pre-harvest maize and groundnut management practices, namely, controlling weeds, timely planting, controlling pests, and application of basal and top-dressing fertilisers, was considerably low, with almost no households practising all five pre-harvest management practices in the case of groundnuts. Though most households controlled for weeds and planted on time in maize or groundnut fields, they seldom applied adequate basal or top-dressing fertilisers, thereby exacerbating the predisposition of the crops to aflatoxin contamination at the pre-harvest stage. The use of chemicals to control pests and the application of fertilisers requires their purchase, which might explain their limited use by households. The cost implications for farmers of buying consumables have been noted as discouraging households from applying some of the appropriate agricultural practices for controlling aflatoxin (Anitha et al., 2019; Udomkun et al., 2018). Pre-harvest contamination is a major concern, especially when crops experience end-of-season drought (Njoroge et al., 2017; Waliyar et al., 2015). However, farmers can mitigate aflatoxin contamination in crops before harvest and at harvest by adopting appropriate agronomic practices such as timely planting, providing supplemental irrigation, water harvesting, applying manure, and the application of atoxigenic strains of *Aspergillus flavus* (Bandyopadhyay et al., 2016; Njoroge, 2018).

The application of the combined best practices during the harvesting stage is rare among households, with few households practising at least three of four maize harvest management practising measures. However, there was a higher application of the management practices during harvesting and handling of maize and groundnuts, with the most common harvest management practices under maize production being drying and sorting at harvest, while the most common handling practices were milling maize dry and sorting before storage and processing. Under groundnut production, most households dried their groundnuts unshelled after harvest and sun-dried or discarded mouldy groundnuts while sorting them before making flour. Sorting has been reported to reduce the aflatoxin amount in crops significantly. It has been noted as a critically important grading step in mitigating aflatoxin contamination reducing it by 40–80% (Anitha et al., 2019; Kumar et al., 2017; Njoroge, 2018; Park, 2002).

The post-harvest and storage management practices were some of the more commonly practised among households, with the common practices being the use of recommended material for storage (jute/polyethylene/hermetic bags) in both groundnuts and maize. Our findings contradict that of Kumar and Popat (2010), where in India, they observed that due to low levels of awareness, the farmers neglected the post-harvest management of pods, which was evidenced by the low adoption of polyethylene-lined gunny bags for storage (29%), storage in proper places (32%) and under optimum conditions (35%), and fumigation of the storage room (14%). The lack of post-harvest management, or its poor implementation, has been shown to significantly promote *A. flavus* infection (Kumar & Popat, 2010). However, in our study, nearly no households practised all six possible post-harvest and storage management practices. Post-harvest strategies are critical in preventing aflatoxin contamination given *A. flavus* ability to grow and spread during this period; the use of appropriate sorting, drying, and storage techniques at this stage has been found to significantly reduce aflatoxin contamination by between 63 and 88% (Turner et al., 2005; Unnevehr et al., 2013). We consolidated the households' responses regarding the application of post-harvest management practices with observations made based on the recommended harvest and storage management practices. Among the many observations on the households' adherence to the application of post-harvest management practices, the most frequent was of households that did not have maize or groundnuts that felt wet to touch in storage or during the drying process, an indication of appropriately dried crop and storage conditions. In general, few households were observed to be treating their maize and groundnuts and practising at least twelve of the fourteen recommended harvest and storage management measures. This has been similarly observed in studies elsewhere where even if about 65% of the farmers knew that they needed to dry plants and pods for proper storage, many of the farmers did not implement other harvest and post-harvest operations and did not appreciate their implications for aflatoxin management (Kumar & Popat, 2010). It is worth noting that not all aflatoxin management practices adhered to could be attributed to households receiving aflatoxin-specific information, as observed in this study, where only 17% of households received aflatoxin-specific information, or as a result of households being aware that these measures limit aflatoxin exposure or contamination, but rather because some of these are generally good agricultural practices.

4.1. Conclusion

This study's limitation was failure to explore the broader social and cultural factors affecting farmers' attitudes and practices towards aflatoxin management. However, for the first time and to the authors' best knowledge, this work presents a comprehensive synopsis of the country-wide household farmers' agricultural farming practices across all the agricultural ecological zones and how they relate to threats posed by the eminent exposures to life-threatening aflatoxins and aflatoxins contaminated maize and groundnut produce and products. There are considerable gaps in the implementation of aflatoxin-related management practices along the stages of maize and groundnut production in Zambia. At the pre-harvest stage, controlling for pests and adequate fertilizer application are not adhered to sufficiently. At the harvest stage, recommended measures such as crops not being damaged in the field, harvesting with a complete husk cover, preventing the crops from becoming wet and mouldy during drying, and drying crops with recommended practices were not being adhered to. At post-harvest, observing for moulding and doing something about it, treating crops before storage, cleaning storage structures before use, and storing unshelled crops were not followed. Observations to validate reported practices show further poor implementation, particularly in the use of recommended long-term storage structures, for example, long-term storage structures with sealing cracks or light coming in; the use of recommended drying practices; damaged and or shrivelled crops; not storing crops using recommended material; and no treatment of crops in storage.

A considerable number of households were aware of what aflatoxins were and knew them to be fungi and/or infections in crops. But households were not aware that the rotting of crops could indicate the presence of aflatoxin and/or aflatoxin contamination. In addition, households were not aware of the chronic health risks of aflatoxins, besides acute health risks such as stomach pains and diarrhoea. Most households have had experience with aflatoxin contamination and attributed humidity and moisture as the most common causes. Despite knowing that humidity can cause aflatoxin contamination, households had limited knowledge of other causes of aflatoxin contamination. Very few households received aflatoxin-specific information (good farming and storage practices) that could protect their crops from aflatoxin exposure. Meetings and informal conversations were the common channels through which households received information about aflatoxins. While households have the ability to apply the information they receive, they cited a lack of technical guidance and resources as challenges to implementation.

There is mixed adherence to aflatoxin management measures across districts and households. Few to no households apply <u>all</u> the recommended management practices, which was confirmed through observations. Thus, most households' crops are susceptible to aflatoxin contamination. Some households practised almost all pre-harvest and handling aflatoxin management measures on maize, but fewer households did so on groundnuts. Virtually no households practised all post-harvest management measures for both maize and groundnuts. Pre-harvest mitigation of aflatoxins is not sufficient to prevent aflatoxin contamination. Therefore, aflatoxin management must continue during harvest and post-harvest periods. In addition, households had compromised storage structures, and their produce had the presence of mould and insects.

There is a need for more intensive sensitisation on aflatoxins, their causes, and their health effects, especially the chronic health-associated risks. This study's findings demonstrate that in Zambia, with a reported high aflatoxin occurrence, rural farming households, who may be aware of aflatoxin contamination of food crops in general, may still have substantial knowledge gaps regarding exposure to and prevention and control of aflatoxins contamination. Therefore, providing rural farming households with better information about aflatoxin control and prevention in food crops could improve their knowledge and limit exposure to aflatoxins in the communities. Even though this knowledge may not necessarily lead to a change in behaviour, the identified gaps in the population's knowledge of aflatoxin contamination conditions, and the consequences of the aflatoxin contamination of crops, should form the basis for developing tailored interventions to prevent and manage aflatoxin contamination at different stages of crop production. These tailored interventions could be in the form of training on the various aflatoxin management practices provided to households' farmers, given the low adherence to ideal aflatoxin-related management practices, and to extension officers, given that most farmers receive agricultural information from them. In addition, frontline health workers need to be empowered to impart knowledge on aflatoxin exposure and its health impact, especially on women of reproductive age and children under 2 years, for whom exposure to aflatoxin has detrimental effects. Thus, the existing education efforts need to be scaled up, with an emphasis on aflatoxin-specific information, using various communication mediums readily/easily available to rural households. Furthermore, there is a need to expedite the elimination of policy constraints and practical barriers to affordability and increase consumer awareness and appreciation of biocontrol products that have proven to reduce aflatoxin contamination among farming households. There is also a need for more regular annual aflatoxin surveillance and mycotoxin monitoring to track possible changes in contamination levels due to interventions provided to households. We conclude that the problem of aflatoxin contamination will need concerted efforts and partnerships involving research institutions, the department of agriculture, marketing agencies, non-governmental organizations (NGOs), farmers' groups, consumer groups, academia, and other key stakeholders to arrive at feasible strategies and interventions for addressing the problem.

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CRediT authorship contribution statement

Mathias Tembo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, preparation, Writing – review & editing. **Mary Lubungu:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, preparation, Writing – review & editing. **Fwasa K. Singogo:** Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, preparation, Writing – review & editing. **Mike Mwanza:** Conceptualization, Methodology, Validation, Investigation. **Mathews Onyango:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – review & editing, Funding acquisition. **Patricia Sakala:** Conceptualization, Methodology, Validation, Investigation, Resources, Funding acquisition. **Mary Pat Selvaggio:** Conceptualization, Methodology, Validation, Writing – review & editing, Funding acquisition. **Edna Berhane:** Conceptualization, Methodology, Validation, Writing – review & editing, Funding acquisition, All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2023.109964.

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