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Research Paper

Potential Impact of Current Agricultural Practices on Mycotoxin Occurrence and Mycotoxin Knowledge Along the Cassava Value Chain in Uganda

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ABSTRACT

Cassava is the second most important staple food crop for Uganda and is prone to contamination with mycotoxins. This study aimed at understanding the current agricultural practices, their potential influence on mycotoxin occurrence, as well as assessing mycotoxin knowledge among key cassava value chain actors, including farmers, wholesalers, and processors. Data were collected through individual interviews (210), key informant interviews (34), and 4 focus group discussions. The findings revealed that 51% of farmers peeled cassava directly on bare ground, resulting in direct contact with soil that potentially harbors mycotoxin-producing fungi, such as *Aspergillus* section *Flavi*. During postharvest handling, 51.6% of farmers dried cassava chips directly on bare ground. Nearly, all (95.2%) of wholesalers packed cassava chips in local gunny bags and placed them on ground instead of pallets. In the processing of cassava chips into flour, only one of the 14 processing machines was certified by the Uganda National Bureau of Standards. Additionally, there was only one processing machine available for every 180 (1:180) consumers bringing their cassava for processing. 50.8% of cassava consumers interviewed admitted to consuming cassava flour regardless of quality, while 73% blended cassava flour with flour from mycotoxin-susceptible crops mainly maize, millet, and sorghum. Most (96.2%) of the people along the cassava value chain did not understand what the term mycotoxins meant. However, 56% of interviewed respondents were familiar with the term aflatoxins. Of the cassava value chain actors aware of mycotoxins, 82.9% knew of methods for reducing aflatoxin contamination, but only 40.9% were putting such methods into practice. More farmers (47.9%) managed aflatoxins compared to wholesalers (33.3%) and processors (21.4%). Knowledge on aflatoxins was significantly associated with value chain actor ($P = 0.026$), head of household ($P = 0.004$), region ($P = 0.033$), age ($P = 0.001$), and experience ($P = 0.001$). This study highlights the critical areas of mycotoxin contamination within the cassava value chain in Uganda and underscores the need to improve the knowledge among value chain actors especially farmers.

Cassava (*Manihot esculenta* Crantz) is a major staple crop in Uganda that is consumed by more than 50% of the population (UBOS, 2019). Due to its cheap source of carbohydrates, resistance to drought, and capacity to produce significant yields even on marginal land where other crops fail, cassava production has spread and is now the second most important crop after bananas (Scott et al., 2021). Production and consumption of cassava is more concentrated in the eastern region (37%), followed by the northern region (34%), the western region (15%), and the central region (14%) (Buyinza & Kitinoja, 2018). Currently, 2.67 million MT of cassava are produced on 878,297 ha outpacing all other root crops in Uganda (FAOSTAT, 2022).

Historically, 88% of the cassava produced was consumed locally, and the crop was considered a food security crop for resource-poor farmers (Buyinza & Kitinoja, 2018). However, in 2016, the pharmaceutical, baking, and alcohol sectors transformed cassava into a wonder crop due to its novel attributes. For instance, it has been discovered that cassava is gluten-free and can replace wheat in bread (Garske et al., 2023; Oyeyinka et al., 2022; Rachman et al., 2023). Furthermore, the Nile Breweries Ltd, the largest brewer in Uganda, is utilizing cassava to produce beer that contains 60–68% cassava flour and the pharmaceutical industry is also drawn to the starch content in cassava (Graffham Andrew, 2017). For these reasons, the Ugandan

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government has identified cassava as one of the ten crops that will enable the country to change its status from a subsistence to a middle-income by 2040 (National Planning Authority, 2020).

Despite this, the production and marketing of cassava in Uganda face numerous challenges, including low productivity, postharvest losses, and contamination with mycotoxins (Atukwase et al., 2009). Mycotoxins are toxic secondary metabolites produced by fungi, which can grow on crops during preharvest, harvest, and postharvest stages (Bennett & Inamdar, 2015). The presence of mycotoxins in food and feed poses significant risks to human and animal health, including cancer, liver damage, immune suppression, and developmental problems (Zain, 2011; IARC, 2002). In Uganda, mycotoxin contamination in food crops is a significant public health concern (Oyesigye et al., 2024), with aflatoxins being the most prevalent and potent mycotoxins. In particular, aflatoxin B_1 (AFB_1) is the most potent naturally formed carcinogen (IARC, 2002).

The significance of mycotoxin contamination in cassava cannot be underestimated, especially considering that cassava is the second most widely consumed food crop in Uganda. Several studies have reported high levels of mycotoxin contamination in cassava-based products in Uganda. For example Kaaya and Warren (2005) reported that more than 60% of analyzed cassava flour samples had high levels of aflatoxins exceeding the World Health Organization (WHO) maximum permissible limit of 20 μg/kg. Kitya et al (2010) also found high levels of aflatoxins with an average of 16 μg/kg in Uganda's cassava flour, indicating the need for better postharvest handling practices to reduce contamination. Kaaya and Eboku (2010) reported aflatoxin levels in cassava flour ranging between 0.51 to 0.45 μg/kg. Another study conducted in Uganda by Serck-Hanssen (2013) reported acute poisoning and death of a 15-year-old child who consumed cassava that was contaminated with aflatoxin B_1 (AFB_1). The situation is worse given the increasing death cases reported at the national regional referral hospitals (*Mulago*) attributed to hepatocellular carcinoma- a cancer type highly linked to aflatoxins (Bukirwa et al., 2021). Addressing mycotoxin contamination in cassava is crucial for improving public health and enhancing economic growth. Recent studies have demonstrated that efforts to mitigate mycotoxin contamination are more effective when informed by a comprehensive understanding of the entire crop value chain (Cervini et al., 2022a; Massomo, 2020; Namubiru et al., 2022). By critically assessing activities along the value chain and examining the knowledge and practices of value chain actors, interventions can be better targeted towards addressing the specific factors contributing to mycotoxin contamination. However, there is a paucity of knowledge on cassava handling practices along the value chain (farmers, wholesalers, processors, and final consumers), and how these practices are likely to lead to mycotoxin contamination at each stage of the value chain. Furthermore, it is not clear the extent to which value chain actors know about mycotoxins. This study aimed to (1) understand the current methods used to handle cassava along the value chain and identify key practices that may potentially contribute to mycotoxin contamination, and (2) assess knowledge of mycotoxins within key cassava value chain actors.

Materials and methods

Study design

An explanatory mixed methods design approach was used. Individual interviews, on-site observations, focus group discussions (FDGs), and key informant interviews (KIIs) were used to collect data about cassava production and postharvest handling practices, and mycotoxin knowledge.

Sample

Data were collected from a purposive sample of cassava farmers, wholesalers, and processors. Sample size was determined using Raosoft online sample calculator (https://www.raosoft.com/samplesize.html). District Production and Marketing Officer (DPMO) data indicated that each district had an average of 35,000 cassava farmers and 506 wholesalers; thus, the sample was drawn from this. The inclusion criteria for farmers, wholesalers, and processors were as follows: Farmers were required to possess a cassava garden and store cassava chips and flour for a minimum of 30 days. Wholesalers needed to have been in business for at least 2 years and to have stocked cassava chips and flour for at least 30 days. Upon applying these criteria, the total number of farmers and wholesalers in the sample was reduced to 205 and 110, respectively. Utilizing the Raosoft sample calculator with this adjusted population, a minimum sample size of 124 farmers and 75 cassava wholesalers was determined for the study. Given the limited number of processors in the cassava value chain (Kleih et al., 2012), a sample size of 15–20 respondents was deemed adequate (Namey et al., 2016) and thus was targeted.

Data collection methods

According to Graves (2002), Namey et al. (2016), Vasudevan et al. (2020) 4–5 FGDs consisting of at least 15 people, and 15–34 KIIs are deemed enough to provide sufficiently reliable data, thus were targeted. For FGDs, the selection of participants, moderators, and preparing open-ended question was conducted as recommended by Nyumba et al. (2018). Of the four FGDs, two were from farmer groups and two from wholesalers (those owning stores). Despite targeting a FGD from processors, the attempt was unsuccessful since there were relatively few of them in the area, and they were also busy with clients. The FGD was conducted by a moderator and a note-taker, both native language speakers. Each FGD lasted an average of two hours, with the moderator probing participants when it was required to elicit more details. The questionnaire used was divided into 2 main sections firstly, to understand the processes that cassava goes through from the field to harvest, drying, storage, and consumption at the farmer level, and secondly to investigate procedures that wholesalers follow, after receiving cassava from farmers, including how it is stored, dried, processed, and sold.

For individual interviews and on-site observations, a total sample of 210 face-to-face in-depth interviews were conducted that included cassava farmers (121), cassava wholesalers (75), and processors (14) (Table S1). Enumerators were selected from the study communities based on their ability to communicate effectively and conduct semi-structured interviews in local languages. They underwent a four-day training session, which included the pretesting of the questionnaire. The final pretested and validated questionnaire was uploaded on an open-source KoboCollect app version 2024.1.3. The interview procedure began with a comprehensive explanation of the study's objectives and obtaining consent from the participants. Following preguided questions, the respondents were then interviewed for a duration of 20–30 min. On-site observations were made at each value chain stage following a mini-predetermined checklist (Table S2) about the state in which cassava is dried, stored, and processed. The team leader recorded these observations upon anonymous agreement with the data collection team.

For key informant interviews, a total of 32 Key Informant Interviews (KIIs) were carried out to systematically gather information on the handling, consumption, existing policies, and awareness of aflatoxin in cassava value chain. The key informants were dominated by

Agriculture Extension Officers (15), the Head of the cassava traders Organization (8), the District Production and Marketing Officer (4), and the District Agricultural Officer (5) (Table S1). The interview guide consisted of 2 major sections. The first section involved questions relating to cassava quality requirements, handling practices at farm, wholesaler, and processing level. The second section involved questions related to knowledge of aflatoxins, perception of communities towards aflatoxin, policies, and existing mitigation strategies being implemented. The same interview process as earlier explained was followed to conduct KIIs.

Moisture detection during storage

A precalibrated digital dry moisture meter (safeguard Europe Ltd) was used to measure the ambient moisture content (% MC) for respective storage sites. Three different readings were recorded from three different positions (at the two corners and center) of the store.

Data analysis

Quantitative data were exported to Microsoft Excel for data cleaning. The latter consisted of omitting questionnaires with responses less than 60%. After cleaning, quantitative data were analyzed with Stata version 17 (Stata 2017). Prior to analysis, the data were tested for normality using the Shapiro-Wilk and heteroskedasticity using the Breusch-Pagan tests. The analysis was parametric because the data passed these two tests without the requirement for transformation. Descriptive statistics mainly frequency tables and graphs were used to summarize data. To determine the factors that may contribute to knowledge about mycotoxins, simple binary dichotomy statements were used with one point (1) accorded to any right statement while no point (0) was awarded for a wrong response (1 = true, 0 = false). A Chi-square (X_2) test at a 95% confidence level was run to test associations between the categorical variables against the value chain actors (farmer, wholesaler, and processor). The relationship between knowledge on mycotoxins and demographic variables was determined with the bivariate logistic regression at a 95% confidence level. All other variables for instance gender, region, and head of household were converted into dummy variables with binary responses. To avoid perfect multicollinearity, dummy variables with more than one category, for instance, education level were converted to two categories to fit within the assumptions of the model (1).

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6 + e_i) \tag{1}$$

whereby Y = Knowledge about aflatoxins, X_1 = head of household, X_2 = education level, X_3 = gender, X_4 = age, X_5 = region, X_6 = experience and e_i = error terms.

Qualitative data from FGDs were analyzed following the thematic content analysis as recommended by Nyumba et al. (2018). Data were coded into themes, and individual responses to a question were first evaluated for the level of anonymous consensus among participants. The findings were then triangulated into the face-to-face in-depth interviews to provide a more detailed understanding of the subject studied. Data from KIIs that contained 28, predetermined statements were weighed against a Likert scale of 1–5. If a respondent selected 5 for each of the 28 statements, the maximum weight would be 140 (28 × 5), while selecting 1 for each of the 28 statements would result in the minimum weight of 28 (28 × 1). To check factor dimensionality, the Principal Component Analysis (PCA) was performed on the 5 constructs Likert scale. The scores were measured by Cronbach alpha (Cronbach, 1951) to check if the Likert statements were internally consistent (if Cronbach value, Ca > 0.7). A screen test with varimax rotation was used to obtain results that can easily be interpreted with statements of factor loading > 0.4 retained for further analysis.

Results

This study aimed to (1) understand the current methods used to handle cassava along the value chain and identify key practices that may potentially contribute to mycotoxin contamination, and (2) assess knowledge of mycotoxins within key cassava value chain actors. Results are presented as follows:

The current cassava handling practices and identify key practices that may potentially contribute to mycotoxin contamination

To understand the handling practices, the study first examined the duration cassava chips and flour remain at each stage of the value chain. A systematic review and analysis of results from FGDs and in-depth interviews resulted in the flow of dry cassava from the farmer to consumers (Fig. 1). The first step to produce cassava chips is to slice and dry fresh cassava. Three primary routes are used to move cassava chips from the farm. In the first route, farmers take cassava chips to the nearby wholesaler who stores the chips for 30–90 days. More than 72% of farmers use this route. The second route, which is used by 22% of farmers relies on village assemblers to collect the chips from farmers door to door and sell them to the wholesaler, and this is usually accomplished between 3 and 7 days. In the third route, 6% of the farmers directly sell to farmer groups contracted by industries to supply high − quality cassava chips as raw material for the industry sector. The producer organizations also sell the chips to wholesalers especially in the season when the supply supersedes their demand.

Between 5 and 90 days of acquiring the cassava chips, the wholesaler sells to retailers, and industries. Depending on the need, the wholesalers process the cassava chips into flour and sell the flour. The major value chain actors that significantly transform cassava chips into flour are the retailers that do this piecemeal; they store chips for a duration of 1–40 days and continue to transform them into flour, depending on the demand from the final consumer. The cassava flour obtained from the processor can be utilized for home consumption by making a cassava meal, animal feeds, small-scale brewing, and in the manufacturing of confectionery, starch, and ethanol. It should be noted that cassava stays the longest period during bulking and storage with the wholesaler and retailers holding it up to 90 days.

Pre and harvest handling practices of cassava

Majority of (75.6%) cassava farmers greatly rely on traditional indicators to decide whether cassava is ready for harvest. Only 24.6% of the farmers check their planting records to find out the maturity period; the majority (76.4%) perceive that once the soil around the cassava plant crack, the root will have reached the required size to be harvested (FGD-ST02). Since the months of November through February are sunny, most farmers (61.6%) take advantage of this time to maximize natural sunlight for drying their cassava. The harvesting process is carried out by both men and women (68.3%), primarily by digging out the cassava tubers using a hand hoe which cuts, injures, and bruises the cassava tubers allowing soil to intermingle with tubers which predisposes it to mycotoxigenic fungi. In the FGD ST02, farmer admitted that, unless it is to be used for roasting, in which case the customer needs a full root that is not damaged, 82.5% of the cassava harvested is sliced, injured, and encounters soil during harvest. "*We don't have time to worry about whether the tuber is cut or mixed with soil. What we typically care about is to remove as much as we can from the soil, whether they are cut or not. Cutting the tuber while it is still in the field even reduces labour costs for slicing it into manageable sizes during peeling, which ultimately speeds up and simplifies the peeling process, after all, we wash off any soil after peeling".* (FGD-KML1).

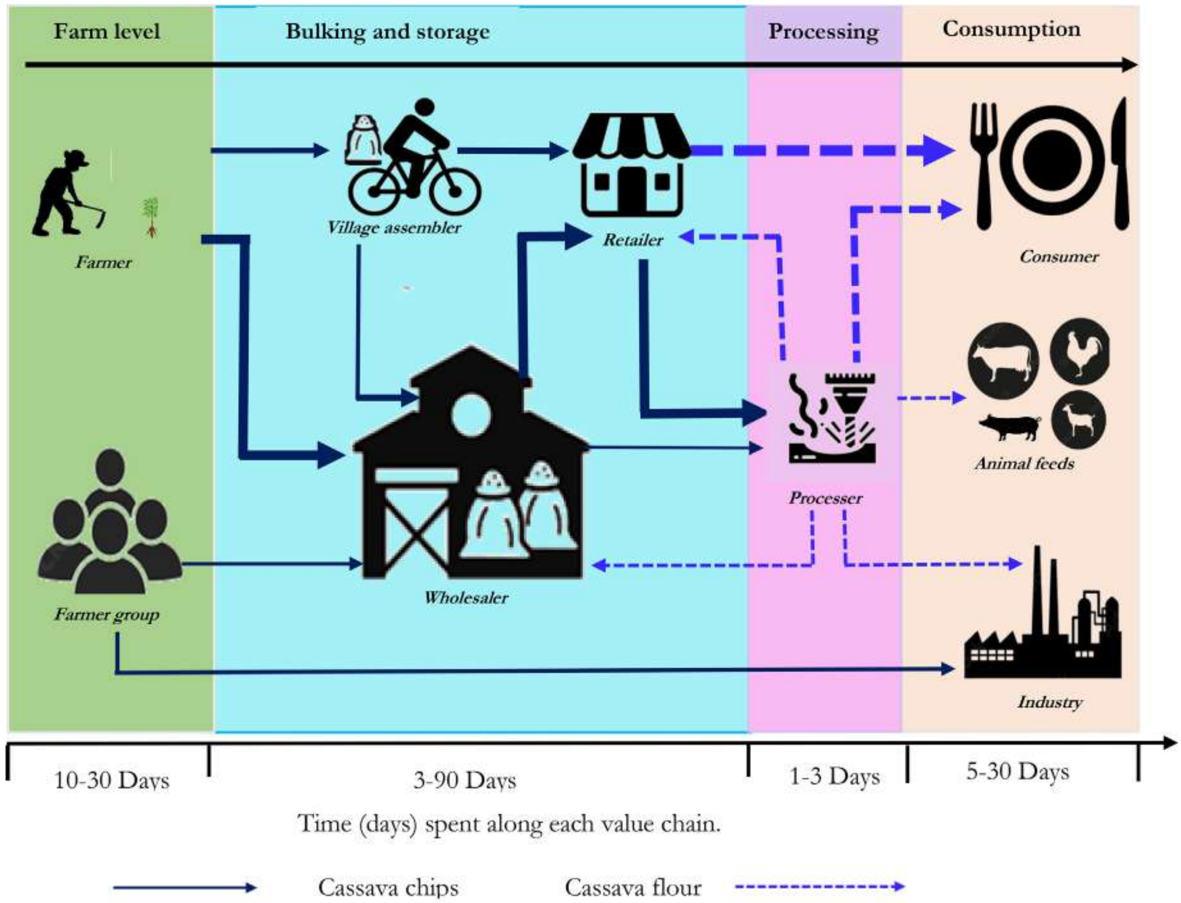

Figure 1. The main value chain actors involved in dry cassava business and time spent at each stage. The thickness of the arrows is proportionate to the commodity volume.

Postharvest handling of cassava

Peeling and drying cassava. Cassava is normally peeled on bare ground (51.6%). The peeling activity is dominated by women (85.1%) (Fig. 2; 01). Peeling is followed by drying which is majorly on tarpaulin and bareground (Fig. 2; 02). Although it is majorly dried in these two ways, the preferences differ by region. Whereas the Eastern region dries most of their cassava on bare ground (42.2%), the Northern region does so on tarpaulin (48.1%) (Fig. 3). To prevent direct contact of cassava with soil, 16% of farmers first smear the surface with cow dung and when the surface is dry enough, they dry their cassava on this surface '*cow dung smeared surface*'. The other drying surfaces were rocks and paved roads (3.9%), and gunny plastic bags (1.95%) (Fig. 3). The drying process takes an average of 6 days, after these days, farmers rely on traditional indicators to decide if the cassava chips are dry enough to be stored or processed. Most of the farmers (88.9%) break to check the brittleness of cassava. It is assumed that when the cassava chips can easily break without brittleness, then it is ready enough for processing or storage (Table S3).

Storing cassava

Moisture content in stores varied from 12.6% to 26% with an average of 15.6%. Cassava is stored either as chips or flour. The wholesaler prefers storing cassava in the form of chips so that retailers can buy it at any time and convert it into flour for selling to the final consumer. Farmers primarily store cassava for a long period (up to 1 year) as flour. The farmer stores cassava chips for 10–30 days. In this period, the farmer slowly sells the chips to get money for household use, while the rest of the chips are converted into flour for home consumption. When cassava chips/flour are ready for storage, both farmers (46.7%) and wholesaler (95.2%) dominantly use the plastic single-layered gunny bags for packaging and storage (Fig. 2; 06) (Table S4). The nature of storage is dependent on the value chain actor (Fig. 2; 04–05). Only 5.83% of the farmers owned stores which are built separate from the living room mainly intended for crop storage. The majority (86.7%) of farmers store cassava chips and flour in kitchen and bedrooms because they believe the smoke from kitchen preserves cassava, while storing in bedrooms protects the chips from thieves (Fig. 2; 07). Only 5% store cassava chips and flour in metallic barrels (Table S4).

Conversely, almost all the wholesalers (89.2%) store cassava chips in facilities which are normally rented in trading centers. These facilities are referred to as 'stores'. Within the storage facility, the chips are packed tightly in single – layered local gunny bags and placed on the ground (Fig. 2; 06). Only 22.4% of wholesalers place the cassava chips on pallets or raised surfaces. Before buying, wholesalers base on white color and brittleness as indicators for high-quality cassava chips. The responsibility of protecting the storage is sorely left to the farmers because when the chips are of poor quality, wholesalers will reject it. In this regard, whereas most farmers (72.9%) are more concerned with protecting their storage by continuously redrying, turning the chips, and regularly opening windows, only 30.1% of the wholesalers do so (Table S4).

Figure 2. Illustrates the predominant cassava handling practices identified based on their high frequency along the value chain. These practices include peeling cassava on bare ground (01), drying cassava on tarpaulin with animal trampling (02), drying cassava on bare ground (03), storage of cassava chips (04–06), storage of cassava flour in households (07, 08), cassava flour in wholesale and retail shops (08), and processing machines used to convert cassava chips to flour (06).

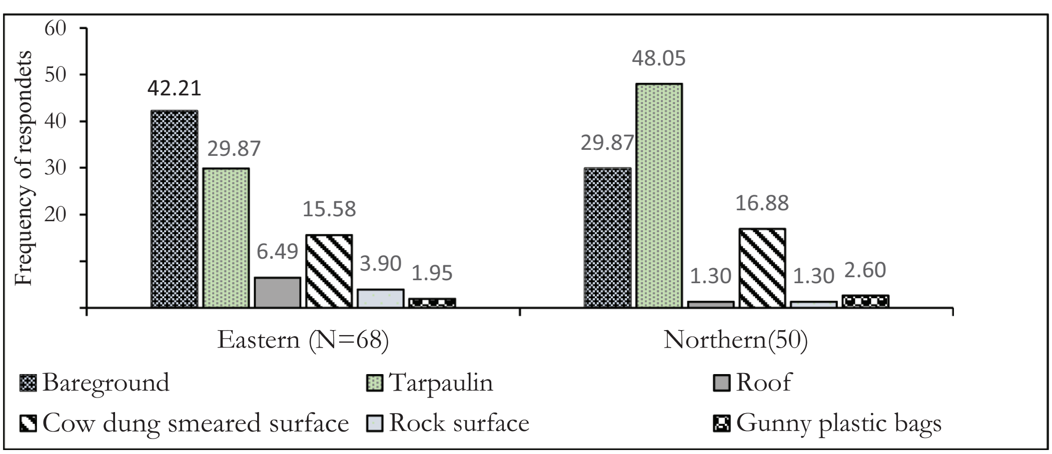

Figure 3. The predominant drying surfaces used by Northern and Eastern Ugandan farmers.

Processing of cassava chips into cassava products

Cassava chips are mainly converted into flour which is either used for preparing a cassava meal, manufacturing industries, local brew, and pancakes. In this study, the ratio of processing machines to consumers taking their chips for processing was found to be 1:180 and each machine processes an average amount of 26.43 kg of cassava chips daily (Table S5). Because electricity is not available in most parts of the study sites, the frequently (75%) used processing machines are diesel-powered milling machine (Fig. 2; 09). Despite the call by the Uganda National Bureau of Standards (UNBS) to register the milling machines so that they can be inspected and ensure they meet quality standards, only 1/14 machines (table S5) were certified and registered with UNBS. The same machines that process cassava are used to process other high mycotoxin contamination-prone crops particularly, maize, sorghum, and millet. When asked whether these machines are cleaned from one crop to another or from one lot to another, all machine operators admitted that they never do so.

Consumption of cassava

Cassava can be consumed either fresh or dried. The consumption characteristics are summarized in Table S5. A significant number of respondents (75%) expressed a preference for consuming cassava in its dry form, specifically as flour. The cassava meal, particularly when blended with flour derived from other crops, is considered a culinary delight by the majority (72.8%). The consumers who blend cassava do so because they believe that blending improves the taste and reduces the starch content thereby making the meal more viscous, and others do it because it is the traditional norm. In FGD K-04, one respondent stated, *'Mixing cassava flour with sorghum is the best for me. My husband loves it so much, if I don't mix it, he will not eat the meal and eventually becomes less productive. Because of this, my children have also started rejecting eating a meal prepared from cassava flour without any mixing. However, blending is sometimes expensive because if you don't have your own sorghum or maize, then you have to buy it and, in some periods, I don't have money'.* A few consumers (27.2%) who do not currently blend cassava with other crops expressed a desire to do so but the deterrent was the high cost of flour from other crops. This indicates that the preference for blending is nearly unanimous among consumers, with the limitation being primarily due to economic factors rather than personal choice. The highly preferred crops for blending included sorghum (54.9%), millet (36.6%), maize (7.19%), and sweet potatoes (Table S5).

Knowledge, determinants, and perception about mycotoxins along cassava value chain

Managing mycotoxins requires the value chain actors to have a basic understanding of mycotoxins, their causes, and mitigation strategies. The study assessed the knowledge of mycotoxins, particularly aflatoxins along the cassava value chain, demographic factors that may be linked to this knowledge, and what key informants perceive to be the knowledge capacity along the cassava value chain.

Knowledge about mycotoxins

The results in Table 1 indicate that the level of knowledge about mycotoxins varied significantly along the cassava value chain. The word mycotoxin seemed new to value chain actors. Only 3.82% had ever heard of the word mycotoxins. Of these, one was a farmer, seven were wholesalers and no processor had ever heard of mycotoxins. Conversely, aflatoxins were a more familiar terminology as a majority (55.7%) of value chain actors had ever heard of them. In terms of knowledge distribution, farmers had significantly low (48.8%) knowledge of aflatoxins compared to wholesalers (68%) and processors (50%) (Table 1). Additionally, the findings revealed that farmers (56.2) were more knowledgeable about the crops prone to aflatoxins contamination than either wholesaler (53.3%) or processor (21.4%). Similarly, a higher proportion of wholesaler (40%) than farmers (11.6%) or processors (14.3%) were aware of the consequences of consuming mycotoxin-contaminated food implying that wholesalers may be more aware of the dangers posed by aflatoxins.

The study also found that while more cassava value chain actors (82.9%) were aware of the methods for reducing mycotoxin build-up especially drying on tarpaulin and storing on pallets, only 40.9% were putting such methods into practice. Farmers were putting significantly more effort (47.9%) to manage aflatoxins than either wholesalers (33.3%) or processors (21.4%). This suggests that, even though people may be aware of the techniques to reduce mycotoxin contamination, there may be barriers to putting these practices into practice.

Social-demographic factors influencing knowledge on mycotoxins

The analysis of results in Table 2 reveals that cassava farmers have significantly less negative knowledge of mycotoxins ($P = 0.026$), compared to wholesalers and processors. Equally, female-headed households were not aware of mycotoxins ($P = 0.004$), with female-headed households having relatively less knowledge about aflatoxins than male-headed households. Similarly, there were significant differences ($P = 0.033$) in aflatoxin knowledge between regions, with farmers from the northern region more aware of aflatoxins than the eastern region. Age emerged as a crucial factor influencing aflatoxin knowledge. The analysis indicates a significant negative association between age and knowledge ($P = 0.001$) suggesting that older actors along the cassava value chain have lower knowledge about aflatoxins. Experience was significantly associated with knowledge ($P = 0.001$), the more experienced value chain actors had higher levels of knowledge of aflatoxins ($P = 0.001$). It is important to note that education level and gender did not show significant associations with aflatoxin knowledge.

Perception of key informants on knowledge spread of mycotoxins along value chain

The results presented in Table 3 provide information on the perception of key informant interviews on the knowledge spread and practices of farmers, wholesalers, and processors regarding mycotoxins in a community. The factor loadings reveal the strength and direction of each item's association with the three respondent categories (farmers, store clerks, and processors).

The findings show a strong correlation between key informants' perceptions and the community's awareness of aflatoxins. As indicated in the loading factors of 0.63–0.67 for "The community is aware of mycotoxins" and 0.648 for "There are currently in place guidelines on mycotoxins", key informants acknowledge community's awareness of aflatoxins and the availability of recommendations to manage afla-

Table 1
Knowledge about mycotoxins along cassava value chain

Variable	Total (N = 210)		Farmer (N = 121)		Processor (N = 14)		Wholesaler (N = 75)		X^2	P value
	n	%	n	%	n	%	n	%		
1. Ever heard of mycotoxins, yes	8	3.82	1	0.83	0	0	7	9.33	9.74	0.008
2. Ever heard aflatoxins, yes	117	55.7	59	48.7	7	50	51	68	12.6	0.002
3. % consuming mycotoxins, low	46	21.9	25	20.7	3	21.4	18	24	0.30	0.859
4.Know crops spoilt by mycotoxins	111	52.8	68	56.2	3	21.4	40	53.3	6.09	0.047
5. Knows causes of mycotoxins, yes	98	46.7	35	28.9	2	14.2	61	81.3	57.4	0.001
6. Can identify mouldy cassava, yes	194	92.4	111	91.7	11	78.6	72	96.0	5.26	0.072
7. Know consequence of eating mycotoxin contaminated food, yes	46	21.9	14	11.6	2	14.3	30	40.0	1.57	0.001
8. Knows the practices to reduce mycotoxin build-up, yes	174	82.9	94	77.7	11	78.6	69	92.0	6.87	0.032
9. Practices methods to reduce mycotoxins, yes	86	40.9	58	47.9	3	21.4	25	33.33	6.45	0.040

Table 2
Factors that influence knowledge on aflatoxins along the cassava value chain

Demographic variable	Coef.	St.Err.	*t*-value	*p* value	[95% Conf	Interval]	Sig
Respondent, farmer	−1.62	0.73	−2.23	0.026	−3.04	−0.19	**
Head of household, male	−2.22	0.77	−2.86	0.004	−3.73	−0.70	***
Education level	−0.29	0.73	−0.40	0.692	−1.72	1.14	
Gender	−0.35	0.47	−0.75	0.451	−1.27	0.57	
Region	−0.87	0.41	−2.14	0.033	−1.67	−0.07	**
Age	−0.12	0.02	−5.54	0.000	−0.165	−0.08	***
Experience	0.08	0.02	3.38	0.001	0.035	0.13	***
Constant	7.49	1.25	5.99	0.000	5.04	9.94	***
Mean dependent var	0.57		SD dependent var		0.49		
Pseudo r-squared	0.41		Number of obs		177		
Chi-square	44.7		Prob > chi2		0.0000		
Akaike crit. (AIC)	157		Bayesian crit. (BIC)		182.8		

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 3
Varimax loading factor of 11 items measured on Likert scale statements from key informant

Variable	Farmer	Wholesaler	Processor
Farmers in this community follow recommended drying	−0.38	–	–
This community do not store cassava as recommended	0.75	0.80	–
The community knows about mycotoxins	0.66	0.67	0.63
The community don’t know the consequences of mycotoxins	0.77	0.34	0.86
Recommended practices are not often implemented	0.46	0.70	0.87
Value chain actors were trained on the mitigating mycotoxins	0.60	0.79	0.83
The community consumes mycotoxin-free foods	−0.74	–	–
Cassava meal is prepared by mixing with maize and sorghum	0.63	–	–
Wholesalers/wholesalers buy low-quality cassava	–	0.75	
Processors are not certified; machines don’t meet standards	–	–	0.76
There are existing guidelines on aflatoxins along value chain	0.65	–	–
Cronbach’s alpha	0.78	0.84	0.04
Kaiser-Meyer-Olkin measure of sampling adequacy	0.712	0.71	0.71
Chi2(28) = 76.04 Prob > chi2 = 0.0001			

toxins. However, it was worrying that some value chain actors, especially farmers did not understand the negative effects of mycotoxins. This is seen by the loading factors of 0.77 for “The community does not know the consequences of mycotoxins” and 0.86 for “The community does not know the consequences of mycotoxins.” These results show that the key informants believe there is a knowledge gap in the community regarding the potential risks associated with mycotoxins. It was also revealed by key informants that the community is frequently consuming aflatoxin-contaminated foods as shown by a high loading factor of 0.74. Consequently, key informants strongly agreed (factor loading 0.63) that cassava meal is normally prepared with other aflatoxin-prone foods mainly millet and maize.

In terms of recommended practices, the key informants perceive that value chain actors have received training on the management of aflatoxins (0.6–0.83), but there is a general lack of implementation especially in drying and storage. This is evident from the loading factors of 0.46 for “Recommended practices are not often implemented. Similarly, processors were pinpointed as strong contributors to aflatoxin contamination as depicted in the factor loading of 0.759 for ”Processors are not certified; machines don't meet standards.“ These findings suggest that the key informants believe that the recommended practices for handling aflatoxins are not consistently followed, and there may be issues related to certification and adherence to standards among processors. Overall, the results indicate a mixed perception among the key informants regarding aflatoxins in the community. While there is a general awareness of aflatoxins and existing guidelines, there is also a need to improve understanding of the consequences and ensure better implementation of recommended practices.

Discussion

The current cassava handling practices and identify key practices that may potentially contribute to mycotoxin contamination

This study compared practices along the cassava value chain with existing literature to determine the critical areas potentially contributing to mycotoxin contamination. This discussion is based on key findings from the following stages: preharvest activities (harvesting and peeling), postharvest (drying, storage, and processing), and consumption. At preharvest stage, the study identified two critical areas that are likely to increase the risk of mycotoxin contamination: intercropping and contact of freshly harvested tubers with soil. Results revealed that freshly harvested tubers can get in contact with soil through damage of tubers during harvesting and placing peeled cassava directly on bare ground. In both scenarios, farmers wash off the soil to make the peeled tuber clean. However, rinsing the tubers with water may not effectively detach mycotoxigenic species and will provide a humid environment for fungal growth (Donner et al., 2009; Nyangweso Salano et al., 2016), thus increasing the risk of mycotoxin contamination. The cell wall of *Aspergillus* section *Flavi* species are composed primarily of glucan and chitin, which provides them with a strong attachment ability to various materials, including cassava tubers (Ruiz-Herrera, 1967). Therefore, contact between freshly harvested cassava and soil represents a significant predisposing factor for mycotoxigenic-producing fungi that lives in soil to get in contact with fresh cassava, hence encouraging contamination. Moreover, it is crucial to characterize the specific species of *Aspergillus* section *Flavi* present in the soils within cassava fields. This characterization will enable a comprehensive assessment of their toxigenic potential in different geographical contexts, thereby identifying areas with a higher risk of mycotoxin contamination. Understanding the geographical distribution of these species and their toxigenicity levels is essential for implementing informed management practices to effectively mitigate the risk.

The cassava postharvest stage encompasses drying, storage, and processing. Three critical areas that potentially expose cassava to mycotoxin contamination were identified. First, farmers dried cassava chips directly on the ground that was prevalent in the eastern region. This practice is sometimes intentionally done because cassava dried on the ground appears to weigh more, leading to higher monetary value (Kaaya & Warren, 2005). However, drying cassava chips on bare ground has been found to significantly contribute to mycotoxin contamination, primarily aflatoxins and fumonisins (Atukwase et al., 2009; Kitya et al., 2010) and should be avoided. The widespread practice of drying cassava on bare ground and rocky surfaces in the eastern region is a prominent factor that is likely to increase mycotoxin contamination and requires urgent intervention. Secondly, farmers admitted that animals, particularly chickens, goats, and pigs, trample over the drying cassava, resulting in fecal contamination of the chips. Fecal matter from such animals is highly contaminated with mycotoxins (Dersjant-Li et al., 2003; Nishimwe et al., 2019; Schrenk et al., 2022). This represents another pathway that can lead to the accumulation of mycotoxins in cassava. Majority of respondents reported drying cassava during the peak months of sunshine, from November to February, and relied on subjective methods like brittleness to determine if the cassava chips were sufficiently dry. There is a need for innovative and economically feasible alternative drying methods, such as solar dryers (Cervini et al., 2022a), that can be used year-round especially in rainy seasons when the prices for cassava chips are high. These dryers would not only prevent animals from trampling over the drying cassava but also reduce the labor involved in removing the chips from drying surfaces when it rains.

Thirdly, wholesalers pack cassava chips in high moisture-absorbing gunny bags and place them on the ground for storage. Poor storage conditions, particularly in unhygienic, and poorly ventilated environments have been reported to increase mycotoxin levels (Swai et al., 2019; Uwishema et al., 2022). Although double-layered polythene bags, such as hermetically sealed bags are highly recommended for storage, only 1% of wholesalers are utilizing these bags, hermetic bags may protect the products but may not necessarily reduce mycotoxin contamination of the cassava chips. It is crucial to explore affordable packaging solutions that can effectively reduce the levels of mycotoxin, like recent advancements in sodium metabisulphite sheets for reducing aflatoxin B_1 in chili powder (Al-Jaza et al., 2022) and in peanuts (Cervini et al., 2022b). Additionally, the responsibility of protecting the storage has been mainly left to the farmers, with only a few wholesalers (30.1%) concerned about checking storage quality. Wholesalers play a crucial role in mycotoxin contamination as they dictate prices and buy cassava chips based on their preferences (Essuman et al., 2022). This situation allows them to pay less attention to the quality of stored cassava. Therefore, the implementation of innovative packaging materials, such as sodium metabisulphite sheets and other alternatives, which can reduce mycotoxin levels in chips already contaminated, becomes crucial in addressing the negligence displayed by these actors.

Furthermore, it was found that only one processing machine was certified and registered with the national standards regulatory body (UNBS), and these machines were never cleaned between consecutive lots. The same machines are used to process other crops including maize, millet, and sorghum, which are highly prone to mycotoxin contamination. This factor can contribute to the problem, as the levels of mycotoxin in the crops brought for processing may vary among different owners. Consequently, even if one strives to produce uncontaminated cassava chips, there is a likelihood of contamination during the processing stage when utilizing these machines. The impact of processing machines on mycotoxin levels has been investigated on peanut butter in Kenya (Ndung'u et al., 2013), and adherence to registration requirements set by the national standard bureau was identified as a crucial intervention to mitigate contamination levels, the same is recommended in Uganda.

At the consumer level, it was evident that individuals are reluctant to discard flour that appears to be contaminated with some opting to mix the new batch of flour with the visibly contaminated portion to reduce the overall level of contamination. To make matters worse, the majority prepare cassava meal by blending it with flour from highly mycotoxin susceptible crops (maize, millet, and sorghum). Mixing cassava flour with other known mycotoxin – prone crops like millet and sorghum (Kitya et al., 2010; Lukwago et al., 2019; Murokore et al., 2023) may increase the risk of mycotoxin contamination among consumers.

Knowledge about mycotoxins within key cassava value chain actors

The study also examined mycotoxin (particularly aflatoxins) knowledge among various actors along the cassava value chain. Aflatoxins were the most recognized mycotoxins, with the majority being aware of them. However, the term "mycotoxins" itself was not familiar to many respondents, indicating a lack of awareness about the broader category. The limited knowledge of aflatoxins within farmers has been documented along the value chain (Massomo, 2020; Nakavuma et al., 2020; Namubiru et al., 2022), yet they are at the beginning part of the entire value chain. More efforts should be directed to educate farmers about mycotoxins. The study also found that while some cassava value chain actors (especially wholesalers) were aware of the methods for reducing aflatoxin contamination, the actual implementation of these methods was relatively low. This suggests that although people may be aware of the techniques to reduce aflatoxin contamination, there may be barriers to putting these practices into action.

The analysis of social-demographic factors influencing knowledge on mycotoxins along the value chain in Table 2 revealed several interesting findings. The role of being the head of the household exhibited a significant negative correlation with aflatoxin knowledge, with female-headed households having relatively less knowledge about aflatoxins than male-headed households. Region and age were also identified as crucial factors influencing mycotoxin knowledge, with the northern region and younger actors demonstrating higher levels of knowledge. Women are responsible for family nutrition and are better placed to manage mycotoxins than men (Kang'ethe & Lang, 2009), thus should be targeted for trainings on aflatoxins. Additionally, the experience was significantly associated with knowledge, indicating that more experienced value chain actors had higher levels of knowledge on aflatoxins. Contrary to other researchers (Magembe et al., 2016; Namubiru et al., 2022), our study showed that level of education and gender did not influence knowledge of mycotoxins. Findings in this study highlight the need to pay keen attention to household heads, age, and region while designing or revising existing aflatoxin management strategies.

Perceptions of KIIs regarding knowledge spread and practices of farmers, wholesalers, and processors regarding aflatoxins were also assessed (Table 3). The results showed a strong correlation between KIIs' perceptions and the community's awareness of mycotoxins. However, there was a concerning knowledge gap among farmers regarding the negative effects of aflatoxins. The KIIs also highlighted the high consumption of mycotoxin-contaminated foods in the community. In terms of recommended practices, they perceived a lack of consistent implementation, particularly in drying and storage, and identified processors as contributors to aflatoxin contamination. KIIs provide an overview on the level of implementation and are at the forefront for most trainings and enforcing policies in relation to mycotoxin contamination highlighting the need for their involvement during designing or revising existing aflatoxin management strategies.

Limitations of the study: This study faced several limitations. Firstly, the number of processors in the cassava value chain was relatively small, which constrained the sample size for this group to 14 participants. This small sample size may limit the depth of insights gained from processors. Additionally, wholesalers were often unable to allocate sufficient time for more in-depth questioning due to their busy schedules, which might have restricted the comprehensiveness of their responses. While the study aimed to conduct multiple focus group discussions (FGDs), logistical challenges prevented the inclusion of additional FGDs. This limitation potentially affected the breadth of qualitative data collected. Despite these challenges, the study made considerable efforts to capture a broad range of perspectives through the available individual interviews, FGDs, and key informant interviews.

Conclusion

This study delved into two main objectives: the current cassava handling practices along the value chain, and their potential to increase mycotoxin contamination as well as the level of knowledge regarding mycotoxins among key actors within the cassava value chain in Uganda. Critical areas were identified as potential contributors to mycotoxin contamination, including contact between freshly harvested tubers and soil, poor postharvest practices such as direct ground drying and inadequate storage conditions, as well as improper processing. Interventions such as innovative drying methods, improved storage facilities, monitoring and regulating milling machines used in the processing of cassava chips into flour, and alternative packaging materials were recommended to mitigate these risks. While awareness of aflatoxins was relatively high among value chain actors, there was limited understanding of mycotoxins as a broader category. This highlights the need for targeted educational efforts to improve awareness and implementation of practices to reduce mycotoxin contamination. Furthermore, the findings indicate that while most value chain actors are aware of recommended practices for managing aflatoxins, they are not implementing them. This suggests a need for either a revision of existing practices or stronger enforcement measures. Factors such as household headship, age, region, and experience were found to influence mycotoxin knowledge, suggesting the need for tailored educational interventions. Addressing these identified gaps in cassava handling practices and mycotoxin knowledge among value chain actors is crucial for improving food safety and public health in Uganda. Collaborative efforts involving policymakers, researchers, extension officers, and community members are essential to implement effective interventions and ensure the adoption of best practices along the cassava value chain.

CRediT authorship contribution statement

Elias Oyesigye: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Carla Cervini:** Writing – review & editing, Supervision, Investigation, Conceptualization. **George Mahuku:** Writing – review & editing, Supervision, Conceptualization. **Angel Medina:** Writing – review & editing, Supervision, Conceptualization.

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.

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Author declaration

The author's contribution for this research is summarized as follows: Developing and pretesting the data collection tools: EO, AM previsit for arranging study sites with local leaders: EO, data collection: EO, GM, data analysis and writing the first draft, EO, CC, AM, GM, reviewing the first draft: CC, AM, GM, supervision: AM, GM, CC. All mentioned authors have read and agreed to this submitted manuscript.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT in order to paraphrase and correct grammatical errors. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jfp.2024.100340.

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