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Knowledge of subsistence maize farmers on aflatoxin contamination and determinants for adoption of artisanal control technologies in Kitui, Kenya

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Widespread aflatoxin contamination of maize is a public health hazard in Sub-Saharan Africa and its management requires strategies which are implemented both at pre- and post-harvest stages of cereal production. This study aimed at assessing knowledge and practices for aflatoxin contamination of maize and factors associated with adoption of artisanal aflatoxin control technologies. A semi-structured questionnaire was administered to 315 household heads that were practicing subsistence maize farming in Kitui, Kenya. Data were analyzed to determine farm level factors which were associated with aflatoxin contamination. Farmers in uplands areas had partial knowledge on occurrence of aflatoxin at pre-harvest stages of maize growth and effects of aflatoxins on animal health and productivity. Adoption of aflatoxin control technologies was higher in farms located in lowland areas as compared to uplands. There was evidence of association between adoption of control technologies and farm level factors including farmer's knowledge on aflatoxin contamination, farmer's level of education and location of farm. The results demonstrate a knowledge gap on aflatoxin contamination and farm level barriers for adoption of aflatoxin control technologies. The findings call for enhanced capacity building activities through extension to influence change on farming practices for farms with high risk of aflatoxin contamination.

Key words: Pre-harvest and post-harvest aflatoxin control methods, barriers for adoption, knowledge, effects of aflatoxins.

INTRODUCTION

The global annual maize production is estimated at 1,151 million tons, with production distributed across all continents (OECD/FAO, 2021). Maize plays an important role as staple food in diets of millions of people in Africa, a constituent of animal feeds and an important source of income for farming households. Maize contains about 72% starch, 10% protein, and 4% fat, therefore supplying an energy density of 1527 kJ/100 g (Nuss and Tanumihardjo, 2010). It is the most important food crop grown on nearly 30 million hectares of land and supporting over 300 million people in Africa (Fisher et al., 2015; Johnson et al., 2018). In Kenya, maize is grown by

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90% of rural households with subsistence maize producers contributing 75% of the total production. In addition, it accounts for 40% of daily calories intake with a per capita consumption of 98 kg per annum (Muiru et al., 2015).

Aflatoxin contamination presents a challenge to global food security, human health and nutritional status for communities that rely on maize. An estimated 5 billion people in developing countries are at risk of exposure to aflatoxins through contaminated foods (Strosnider et al., 2006). Indeed, maize has been reported to be particularly susceptible to aflatoxin contamination (Bandyopadhyay et al., 2016). The warm and humid climatic conditions in tropical agro-ecologies of Sub-Saharan Africa favor growth of a fungus *Aspergillus flavus*, which is the primary source of aflatoxins (Wu and Khlangwiset, 2010). Kenya has experienced sporadic outbreaks of acute aflatoxicosis, with the most devastating outbreak reported in 2004 during which 317 human cases and 125 deaths were reported (Lewis et al., 2005). Majority of outbreaks occur among communities living in rural areas in lower Eastern parts of Kenya and are often associated with consumption of homegrown maize (Daniel et al., 2011).

Control of aflatoxin contamination in developed nations has been achieved through detection and strict adherence to set standards on good production practices for food crops. However, most agricultural activities in Sub-Saharan Africa occur in rural areas which are characterized by resource scarce communities with a lack of technical infrastructure which hampers routine quality control practices that minimizes risk of exposure to aflatoxins. Kenya, just as in many developing countries, has weak food safety regulations, besides the lack of enforcement of the existing regulations to help reduce aflatoxin contamination which predisposes communities to aflatoxicosis and its negative health effects (Wu and Khlangwiset, 2010).

Several technologies have been designed to manage and reduce the risk of aflatoxin in sub-Saharan Africa. The technologies include implementing good agricultural practices consisting of diverse pre- harvest and post-harvest measures applied at farm level where primary contamination occurs (Clarke and Fattori, 2013). These measures include adopting agronomic practices such as timely planting, applying manure and fertilizers, providing supplemental irrigation, crop rotation and application of atoxigenic strain of *A. flavus* (Njoroge, 2018; Bandyopadhyay et al., 2016). Post-harvest aflatoxin control can be achieved through proper drying of cereals, sorting of damaged grain and storage in well aerated facilities (Waliyar et al., 2015).

Implementation of aflatoxin control technologies is important for addressing food security challenges and human health outcomes in rural communities. However, there are limited data on level of knowledge on aflatoxins and farm level barriers that hampers adoption of recommended pre-harvest and post-harvest aflatoxin control technologies by subsistence farmers. The objective of this study was to determine farmers' knowledge and practices on aflatoxin control, to establish a baseline of available aflatoxin control technologies utilized by subsistence maize farmers and document barriers that hinder their adoption, which could support policy change on aflatoxin management.

MATERIALS AND METHODS

Study area

The study was carried out in Kitui County, one of the 47 counties in Kenya located at about 160 km east of the capital City, Nairobi (Figure 1). It is the sixth largest county in the country based on land size, covering an area of 30,496.4 km^2. The county has a population of 1.136 million people based on 2019 census report (KNBS, 2019). It has a low-lying topography characterized as arid and semi-arid climate, with erratic rainfall distribution. Topography of the county is classified as hilly rugged uplands and lowlands with an altitude ranging between 400 and 1800 m above sea level. The field survey was conducted between the months of May and June 2021 in four administrative wards and 12 villages located in different climatic zones: Mutha and Athi wards are located in lowland areas of Kitui South sub-county while Miambani and Kyangwithya West wards are located in upland areas of Kitui Central sub-county. The rainfall pattern in the county is bimodal with two rainy seasons with a high variability in annual rainfall ranging between 500 and 1050 mm (Jaeztold et al., 2006).

Study design and sampling

A cross-sectional study design was employed for this study. Multi-stage sampling procedure was adopted to select study participants. First, Kitui County was intently selected because it is one of the counties within the aflatoxin hotspot zone with recurring outbreaks having been reported and consignments of maize condemned for being contaminated with aflatoxins (Migwi et al., 2020). Two sub-counties were randomly selected from eight sub-counties of Kitui County to represent the two main farming regions of the county (Uplands and Lowlands). Two wards were further purposively selected from each sub-county based on their potential for maize production. A list of villages growing maize in each of the selected wards was obtained from the ward agriculture office. Three villages from each selected ward were randomly selected forming a composite list of twelve villages which were selected as the study sites. Using Microsoft Excel random number table function, households were randomly allocated for the study. In total, 315 maize farming households were recruited for the study, with 80, 79, 79 and 77 households sampled from Athi, Mutha, Miambani and Kyangwithya West wards, respectively. The respondents were household heads of subsistence maize farmers aged 18 years and above. Exclusion criteria were farmers who did not plant maize in the previous planting season, and those who did not harvest maize from previous planting season.

Data collection

A semi-structured questionnaire was used to collect data on artisanal technologies used for control of aflatoxin by subsistence maize farmers and to determine level of knowledge, farmers' attitudes and practices on aflatoxin contamination. Trained enumerators were recruited to administer the questionnaires. The questionnaire was uploaded to Kobo Toolbox, deployed and administered through handheld electronic devices (Android phones/

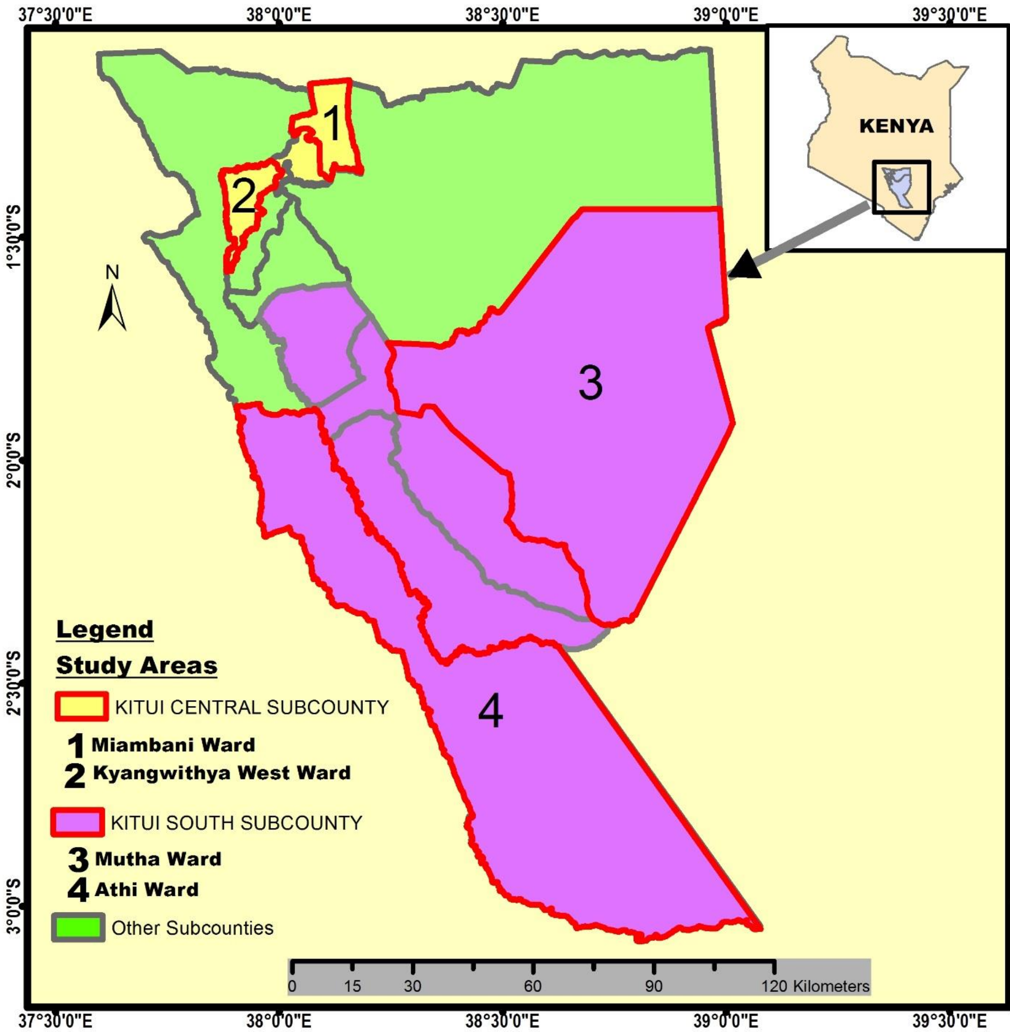

Figure 1. Map of Kenya showing the administrative wards in Kitui County where the study samples were obtained.
Source: Author, 2022

tablets). The questionnaire was divided into various sections containing specific questions in order to collect data on aflatoxin control technologies along the maize value chain as the following : (1) General information: Basic demographic data of respondents including age, gender of respondent and household head, marital status, educational level, monthly income, sources of income, size of household and land size. (2) Aflatoxin control strategies used from the point of planting all through to harvesting, storage and utilization. This included data on farm tillage practices, type of maize seed planted, use of organic manure and commercial fertilizer, method of grain harvesting, grain drying practices, grain sorting practices, method of shelling and maize storage practices. (3) Constraints that hinder adoption of aflatoxin control technologies and farmers' knowledge on causes, occurrence and effects of aflatoxin contamination of maize in livestock and human health.

Ethical considerations

The study was approved by the Biosafety, Animal use and Ethics committee in the Faculty of Veterinary Medicine of the University of Nairobi, Approval No. FVM BAUEC/2021/288 dated 8th March, 2021. In addition, a research permit was obtained from the National Commission of Science Technology and Innovation (NACOSTI) License No. NACOSTI/P/21/9773 to conduct research in Kitui County. Prior to data collection, each respondent was briefed on objective of the study and their oral consent obtained. The interviews were conducted on a voluntary and consensual basis. Upon receipt of oral consent, questionnaire was administered orally through an in-person interview with head of household or spouse using Kamba language.

Data analysis and presentation

An MS Excel® 2010 database was designed where data were entered and subsequently cleaned. The data were exported to IBM Statistical Package for Social Sciences (SPSS) software (version 23) for statistical analyses. Both descriptive and inferential statistical analyses were done. The frequencies of use for artisanal methods in control of aflatoxins in farms located in the upland and lowland areas were compared using unpaired t-tests and level of

Table 1. Pre-harvest artisanal aflatoxins control technologies practiced by maize farmers in Kitui.

Aflatoxin control method	Farmers practicing measures in lowlands (n=159)	Farmers practicing measures in uplands (n= 156)	Z*	0.95 CI	P-value
Dry planting	124 (78)	100 (64.1)	2.75	0.040 - 0.238	0.006
Organic manure	99 (62.3)	100 (64.1)	0.34	-0.088 - 0.125	0.735
Commercial fertilizer	4 (2.5)	25 (16)	4.24	0.073 - 0.198	0.001
Certified seed	49 (30.8)	86 (55.1)	4.49	0.137 - 0.349	0.001
Crop rotation	105 (66)	67 (42.9)	4.23	0.124 - 0.338	0.001
Land tillage					
Deep tillage (using tractors)	2 (1.3)	1 (0.64)	0.57	-0.015 - 0.028	0.572
Minimum tillage (hand hoe)	6 (3.8)	60 (37.8)	8.17	0.259 - 0.422	0.001
Oxen ploughing	151 (95)	95 (60.9)	7.97	0.257 - 0.424	0.001

Source: Author, 2022.

significance was set at 5%. Principal component analysis was used to create composite index for knowledge and technology adoption variables in order to obtain a continuous variable with which regression analysis was done to determine factors associated with adoption of artisanal control technologies for aflatoxin and factors associated with farmers' level of knowledge on aflatoxin contamination.

RESULTS

Respondents' social and demographic characteristics

Respondents varied in age between 20 and 85 years with a mean age of 51 years. About 71% of respondents were female while 76% of households headed by men with only 24% female-headed, and most female-headed households were widows. Most respondents had attained primary level of education (57.8%) and 16.5% had no formal education. Majority (81.3%) of respondents was married and 81% reported that their household income was below the minimum wage of KES 13,572. The mean household size was 6 persons. The average size of land owned by households was 2.6 acres, with the largest farm holding being 20 acres. Approximately 95.5% of respondents relied on crop farming and livestock keeping as their sources of income.

Pre-harvest artisanal aflatoxin control technologies applied in farms

Seventy-eight percent (78%) of farmers in the lowland areas were practicing dry planting when compared with 64.1% in uplands (Table 1). There were over 60% of farmers using organic manure in both lowlands and uplands areas. The number of maize farmers using commercial fertilizers was higher in uplands (16%) when compared with lowlands (2.5%). The number of farmers who planted certified maize seeds were higher in uplands (55.1%) compared to the lowlands (30.8%), while crop rotation was practiced more by farmers in the lowlands (66%) as compared to uplands (42.9%). With respect to method of land tillage, most maize farmers in both areas practiced oxen ploughing followed by minimum tillage using hand hoe and only a few practiced deep tillage using tractors.

Post-harvest artisanal aflatoxins control technologies applied in farms

Eighty-six percent (86%) of farmers from uplands harvested maize by de-husking as compared to 57.9% farmers in lowlands (Supplementary Table 1). Similarly, there were more farmers in lowlands (23.9%) who harvested maize cob with husk as compared to uplands (5.8%). Grain drying practices included placing maize on a tarpaulin/mat, spreading it on bare ground and drying on a raised platform. There were slightly more farmers in lowlands (54.1%) who dried maize on a tarpaulin mat when compared to in uplands (49.4%). With regard to maize grain sorting practices, more farmers in lowlands (80%) sorted maize cobs when compared with farmers in uplands (70.5%). Regarding shelling of maize, slightly more farmers from the lowlands (89.3%) shelled maize by beating in a sack as compared to (79.5%) from uplands, while more farmers in the uplands (12.8%) used motorized shellers when compared with lowlands (2.5%).

With respect to maize storage practices, there were more farmers in lowlands (57.9%) using hermetic bags for storage of shelled grains compared to those in the uplands (30.8%) and the difference was statistically significant (p =0.0001). More farmers in the uplands used propylene bags (49.4%) as compared to the lowlands (28.9%). Regarding the storage structures, the study

Table 2. Knowledge of subsistence maize farmers on causes of aflatoxin contamination in maize.

Causes/sources of aflatoxins contaminations	Uplands (n =156)			Lowlands (n = 159)		
	Agree (%)	Disagree (%)	Not sure (%)	Agree (%)	Disagree (%)	Not sure (%)
Aflatoxins are caused by mouldy maize	80	3	17	99	1	0
Harvesting during rainy seasons increases maize spoilage	93	1	6	100	0	0
Delayed harvesting of maize causes aflatoxin contamination	65	20	15	85	11	4
Drying on bareground encourages aflatoxin contamination	60	30	10	86	9	5
Insect infestation increases grain spoilage	60	23	17	91	5	4
Broken and bruised grains increases chances of contamination	60	24	16	86	7	7
Grains which contain foreign materials promote aflatoxin	44	26	30	81	11	8
Poor storage conditions promotes aflatoxin contamination	96	1	3	98	1	1

Source: Author, 2022

revealed that most farmers in uplands (85.3%) stored maize in a room inside their house compared to 43.4% farmers in lowlands. The results show that over 90% of farmers in both lowlands (and uplands areas placed maize bags on wooden pallets. The common forms of maize treatment before storage were smoking, application of insecticides, use of wood ash, sun drying, and a combination of the aforementioned methods. Fifty-six percent (56%) of maize farmers in the uplands applied insecticides compared to 37.1% lowlands, with about 11% of farmers in uplands using a combination of ash and insecticides.

Farmers' knowledge on causes of aflatoxin contamination of maize grains

Farmers from the two regions were aware of causes of aflatoxin contamination in maize. For instance, 80 and 99% of farmers from uplands and lowlands respectively agreed that aflatoxin was caused by molds (Table 2) while 96 and 98% of respondents in uplands and lowlands, respectively agreed that poor storage conditions promoted aflatoxin contamination. However, there was a knowledge gap between maize farmers in the uplands (60%) and those in lowlands (91%) as to whether insect infestation of grains increases chances of contamination. Similarly, only 44% of respondents in the uplands agreed that grains with foreign materials promoted aflatoxin contamination compared to 81% of their counterparts in the lowlands.

Farmers' knowledge on occurrence of aflatoxins in foods and farm environments

With regard to occurrence of aflatoxin contamination, the level of knowledge varied between respondents from uplands and lowlands, with respondents from lowlands having higher level of knowledge than those from uplands (Table 3). For example, only 38% of the respondents in the uplands indicated that aflatoxins could be present in crops growing in the field as compared to 65% of the respondents from lowlands. Furthermore, 68% of respondents from uplands and 85% from lowlands indicated that aflatoxins could be transferred to animals through feeding of rotten maize grains; and only 59% of respondents from uplands were knowledgeable that aflatoxins could be transferred through cow milk and other dairy products as compared to 80% of the respondents from lowlands.

Farmers' knowledge on effects of aflatoxins in human and animal health and productivity

With respect to effects of aflatoxins on human and animal health, farmers in the lowlands were more knowledgeable compared to those in uplands. Only 56% of farmers from the uplands were aware that aflatoxin in maize grain could cause stunting in animals fed on this maize as feed compared to 86% of respondents from lowlands. Similarly, 66% of respondents from the uplands agreed that aflatoxins reduced productivity in livestock as compared to 86% of respondents from the lowlands. Likewise, 61% of maize farmers in the uplands were aware that aflatoxin causes cancer in humans compared to 89% of respondents in

Table 3. Knowledge of subsistence maize farmers on occurrence of aflatoxin contamination in maize grains.

Occurrence of aflatoxin in maize and environment	Upland (n =156)			Lowland (n =159)		
	Correct (%)	Not correct (%)	Not sure (%)	Correct (%)	Not correct (%)	Not sure (%)
Aflatoxin can be present in crops	38	25	37	65	13	22
Aflatoxin contamination can occur at any time of plant growth	38	27	35	62	11	27
Aflatoxin can be transferred to animals through feeding on rotten grains	68	8	24	85	1	14
Aflatoxin can be transferred to cow milk and other dairy products	59	11	30	80	3	17
Aflatoxin can be transferred to human breast milk	64	8	28	81	4	15
Aflatoxin can be found in cooked food	73	12	15	87	2	11

Source: Author, 2022

Table 4. Knowledge of subsistence maize farmers on effects of aflatoxin contamination in maize grain.

Effects of aflatoxin on health and productivity	Upland (n =156)			Lowland (n =159)		
	Agree (%)	Disagree (%)	Not sure (%)	Agree (%)	Disagree (%)	Not sure (%)
Aflatoxin contamination causes harmful effects on humans	89	0	11	100	0	0
Aflatoxin contamination causes stunting in animals	56	5	39	86	1	13
Aflatoxin contamination reduces animal productivity	66	2	32	86	1	13
Aflatoxin contamination can reduce the prices of maize	94	3	3	98	1	1
Aflatoxin contaminated maize cannot be sold as exports	84	7	9	95	2	3
Aflatoxin delays child growth	74	2	24	86	1	13
Aflatoxin causes cancer in humans	61	8	31	89	1	10
Some liver diseases have been linked to aflatoxin contamination	69	5	26	91	2	7
Aflatoxin contamination affects the health of animals	78	1	20	90	1	9
Aflatoxin increases susceptibility to diseases in animals	67	5	28	83	1	16
Aflatoxin contamination causes death in animals	81	2	17	91	1	8

Source: Author, 2022

the lowlands (Table 4).

Factors associated with farmers' knowledge on aflatoxin contamination

The gender of farmer influenced level of knowledge on aflatoxins and was statistically significant (p=0.044) with male respondents being more knowledgeable on aflatoxins compared to female respondents (Table 5). Marital status positively and significantly influenced knowledge about aflatoxin (p=0.026) with married farmers being more knowledgeable when compared with unmarried farmers. Land acreage also positively and significantly influenced knowledge with farmers with larger land sizes being more knowledgeable about aflatoxins (p=0.008). Farmers' main source of income influenced knowledge on aflatoxin with farmers whose main source of income was crop agriculture and livestock keeping being knowledgeable about aflatoxin compared to maize farmers in business and formal employment (p=0.026). Finally, the

Table 5. Factors associated with farmers' level of knowledge on aflatoxin contamination of maize.

Description of variable	Estimate	SE	t-Value	p-Value	[95% CI]
Agro-ecological zone					
Lowland	1.93	0.283	6.81	0.00	1.372 – 2.487
Marital status					
Married	1.483	0.662	2.24	0.026	0.180; 2.786
Divorced	1.748	1.045	1.67	0.095	-0.309; 3.805
Windowed	0.523	0.691	0.76	0.449	-0.837; 1.884
Size of land	0.173	0.065	2.66	0.008	0.045; 0.301
Main occupation					
Business	1.524	0.917	1.66	0.098	-0.28; 3.328
Employed	0.844	0.82	1.03	0.304	-0.77; 2.458
Gender of respondent					
Female	-0.641	0.318	-2.02	0.044	-1.266; -0.016
Source of income					
Salary	1.187	1.069	1.11	0.268	-0.917; 3.291
Self-employment	-2.309	1.045	-2.21	0.028	-4.366; -0.253
Monthly income	-0.713	0.345	-2.07	0.04	-1.392; -0.034
Mean dependent var		0.013	SD dependent var: 2.462		
R-squared: 0.342			Number of obs: 313		
F-test: 6.865			Prob > F: 0.000		
Akaike crit. (AIC): 1365.989			Bayesian crit. (BIC): 1452.152		

Source: Author, 2022

study established that location of farm influenced knowledge on aflatoxin (p=0.000) with maize farmers in the lowlands being more knowledgeable on aflatoxins when compared with their counterparts in the uplands.

Factors associated with farmers' adoption of aflatoxin control technologies

Farmers' level of education positively and significantly influenced adoption of aflatoxin control technologies (p=0.006) with maize farmers who are educated with secondary and tertiary level of education being more likely to adopt artisanal aflatoxin control technologies when compared with less educated farmers (Table 6). Farmers' knowledge about aflatoxin positively influenced adoption of aflatoxin control technologies (p=0.007) with farmers with more knowledge on aflatoxins being more likely to adopt aflatoxin control technologies when compared with maize farmers with less knowledge. The location of farm also positively and significantly influenced adoption of the technologies (p=0.00) with subsistence maize farmers in the lowlands more likely to adopt compared to those in the uplands.

DISCUSSION

The findings of the study reveal a knowledge gap on occurrence of aflatoxin in maize during plant growth and its effects on animal health and productivity amongst farmers. Indeed, a previous report argued that knowledge on mycotoxins and its adverse health effects were incomplete and that known risks were poorly communicated to governments in areas where contamination was prevalent (Wild and Gong, 2010). This calls for sustained capacity building of subsistence maize farmers on causes, occurrence and effects of aflatoxin and control technologies applicable in their geographical areas to curb the aflatoxin menace. Factors that were significantly associated with knowledge of aflatoxin contamination were gender of farmer and farm location. The male had higher knowledge on aflatoxins, which supports findings by Kang'ethe and Lang'at (2009), who had reported in their study that men had more knowledge on presence of aflatoxins in milk when compared to women. Women often are tasked with the role of preparing the family meals and are therefore in a better position to mitigate risks of aflatoxin exposure. Therefore, it is important to empower women with

Table 6. Factors associated with adoption of artisanal aflatoxin control technologies by farmers.

Variable	Estimate	SE	t-value	p-value	[95% CI]
Knowledge on aflatoxins	0.105	0.039	2.71	0.007	0.029; 0.181
Agro-ecological zone					
Lowland	0.808	0.202	4.01	<0.001	0.411; 1.205
Level of education					
Primary	0.635	0.25	2.54	0.011	0.144; 1.126
Secondary	0.834	0.298	2.79	0.006	0.247; 1.421
Certificate	1.6	0.527	3.04	0.003	0.563; 2.636
Diploma	0.911	0.545	1.67	0.096	-0.163; 1.984
University	0.814	0.738	1.10	0.271	-0.639; 2.267
Monthly income	0.407	0.229	1.77	0.077	-0.045; 0.859
Mean dependent var: - 0.001			SD dependent var: 1.502		
R-squared: 0.231			Number of obs: 313		
F-test: 3.781			Prob > F : 0.000		
Akaike crit. (AIC): 1107.388			Bayesian crit. (BIC): 1197.297		

Source: Author, 2022

knowledge about aflatoxins to help reduce the risk of exposure in rural areas. Majority (95%) of the respondents practiced mixed farming as their main source of income. This corroborates findings by Migwi et al. (2020), who reported that over 85% of their respondents practiced agriculture and that majority of rural population in Kenya obtained their livelihood from agricultural-related activities. Efforts geared towards enhancing farmers' knowledge about aflatoxin would increase knowledge base of rural communities hence impacting on behavior change on aflatoxin control. Majority of maize farmers in the lowlands were more knowledgeable about aflatoxin. This can be attributed to previous outbreaks that have occurred mostly in the lowlands compared to the uplands and more awareness campaigns and sensitizations that have targeted the villages where outbreaks have been reported.

Application of good agricultural practices is argued to be a good way to reduce mycotoxin levels in food. Both pre- and post-harvest practices applied largely dictate the extent of attack by *A. flavus* fungi and the intensity of aflatoxin production in maize grains (Agbetiameh et al., 2018). The results from the study showed that a significant number of subsistence maize farmers in Kitui have adopted dry planting and application of organic manure as pre-harvest aflatoxin control technologies.

However, there is low uptake of planting certified seeds, crop rotation, and use of commercial fertilizer and practice of deep tillage. According to a previous study, time of planting influenced contamination of grain by aflatoxin with lower levels of aflatoxin reported in maize planted early compared to maize planted late (Nyangi et al., 2016). Abbas et al. (2008) had also previously reported that corn planted in the mid-April season had lower levels of aflatoxin contamination compared to the early-May planting season. Early planting reduces levels of aflatoxin contamination by shifting the period between when the flower is fully open and functional and dough development in maize to a time frame in the growing season when the crop is less susceptible to drought and heat stress as compared to late planting.

The findings from the study revealed that organic manure was commonly used in farms compared to commercial fertilizers. Organic manure is relatively cheap and is a sustainable way of restoring soil health and increasing farm productivity. Farmyard manure has been associated with up to 90% reduction of total pre-harvest aflatoxin concentrations in harvested peanuts kernels. Furthermore, Chalwe et al. (2019) had previously observed that increasing levels of compost resulted in decreased pre-harvest total aflatoxin concentrations in peanut kernels. Manure application not only improves soil fertility, but also to help in combating aflatoxin threat. Majority of maize farmers in both climatic zones planted non-certified seeds relying on local variety from previous harvest season. As a result of many years of selection, local varieties have become adapted to local conditions. However, they are susceptible to fungal infection (Kang'ethe et al., 2017). Some farmers preferred the choice of local seed varieties rather than certified maize seeds "*local variety of maize seeds is adapted to the local climate and rainfall pattern of this area; they are early maturing; drought resistant and high yielding*". Other farmers argued that certified seeds were expensive and not promising in yield as compared to local varieties. Subsidizing certified seeds and training maize farmers on the importance of planting these varieties would help increase access by poor rural farming households and contribute to reduced aflatoxin exposure.

Regarding land tillage practices, most farmers utilized moderate tillage by use of oxen ploughing as well as minimum tillage using hand hoe. Farmers provided reasons for use of oxen plough compared to tractors: "*We lack access to tractors because they are very expensive to hire and are not readily available while oxen ploughs are cheap and readily available".* Deep tillage conserves soil moisture and reduces *A. flavus* invasion and subsequent aflatoxin contamination. Studies have compared *A. flavus* density in land with no tillage and land with reduced tillage and found that land with no tillage and medium tillage had higher *A. flavus* density when compared with land with deep tillage (Zablotowicz et al., 2007; Nesci et al., 2006). They attributed this to high organic matter content in soils with no tillage. The low uptake of deep tillage in the study area was likely to contribute to high fungal densities and subsequent aflatoxin contamination.

Crop rotation is known to reduce occurrence of aflatoxin in crops by breaking the cycles and build-ups of toxigenic fungi (Achaglinkame et al., 2017). This farming practice also helps to breakdown the selection of toxigenic fungi that would infect the follower crop, thus reducing the risk of pre-harvest infection, toxin production, and contamination. Crop rotation was however, practiced by about half of the total number of maize farmers in the study area. Among the reasons for not practicing crop rotation were that "*the size of land was small to practice crop rotation" and "other farmers were not aware that it was an important practice"*. Crop rotation lowers the rate of survival of different soil-borne *Aspergilli*, especially when non-host crops are grown (Mutegi et al., 2012). Lack of crop rotation leads to depletion of soil nutrients, selecting fungal populations that specifically infect maize, thus increasing risk of attack by toxigenic fungi and ensuing aflatoxin contamination (Hell and Mutegi, 2011).

The conditions at harvest may also predispose maize to infection by fungi. Most farmers harvested their maize manually by de-husking in the field which could be bare or covered by farm weeds, and de-husked cobs come into contact with soil or brush against weeds on landing. Fungi is ubiquitous and the soil is very rich in fungi that can infect maize grains while the weeds may host fungi which contaminate the maize (Birgen et al., 2020). The reasons farmers gave for utilizing this practice was "*the cost of labor for harvesting was high while de-husking was fast and convenient"*. Fungal attack occurs during harvest mostly because of dropping and drying cobs on bare ground, allowing easy transfer of fungus from soil to storage facilities (Mutiga et al., 2019). Harvesting of maize with husk could reduce aflatoxin contamination (Demissie, 2018).

Given the ability of fungi to grow and spread after harvest, post-harvest aflatoxin control technologies are crucial in preventing aflatoxin contamination. At post-harvest, most farmers have adopted drying maize on a raised platform and use of tarpaulin (mat), sorting of maize cobs before shelling, storage of maize in hermetic bags and the practice of placing maize storage bags on wooden pallets. There was however, low uptake of good agricultural practices including motorized shellers or hand shellers for threshing maize. The farmers also utilized poor maize handling practices like drying maize on bare ground, shelling by beating maize in a sack, and storing maize in propylene bags. For many smallholder farmers, the most practicable option for drying their maize crops was using natural sunlight. Of the total farmers studied, 38% were drying maize on bare ground exposing it to toxigenic fungi and increasing the risk of contamination. Similar findings were reported by Kang'ethe et al. (2017) where 39.1 and 37.6% of farmers in Makueni and Nandi, respectively, were drying their maize on the bare ground.

Sorting of grains seeks to disregard maize of inferior quality, and through this practice, separation of damaged kernels can reduce the risk of contamination with aflatoxins (Kabak et al., 2006). Furthermore, exclusion of insect-damaged, broken and discolored kernels can reduce mycotoxin contamination of maize (Mutiga et al., 2014). It has been argued that sorting the physically damaged and infected grains from good ones can reduce aflatoxin levels by 40 to 80% (Kamala et al., 2016). Indeed, Matumba et al. (2015) in their study reported that hand sorting had greatest effect on mycotoxin removal from maize. Similarly, Kumar et al. (2017) reported that physical sorting alone reduced aflatoxin levels by 40 to 80%. In the present study, about a quarter of the maize farmers did not sort their maize cobs.

The most commonly used method of shelling maize was by placing maize cobs in a sack and beating using sticks. Farmers preferred this method because *"it was cheap and fast to thresh and those motorized shellers are few and expensive to hire".* This method of shelling maize resulted in many damaged grains which increases the ease by which fungal hyphae penetrate kernels hence increasing the risk of aflatoxin contamination. The use of motorized shellers and hand shellers was slowly being adopted by maize farmers in the study area.

Maize can also be contaminated with aflatoxin during storage. Since fungi are aerobic organisms, technologies have been developed to reduce the growth of *A. flavus* during storage by reducing the oxygen content and increasing carbon dioxide content. Based on triple bagging method, hermetic bags have been developed where the bag has a second lining which is impervious to oxygen therefore creating anaerobic conditions that prevent growth of fungal spores and weevils (Ben et al., 2009). Although the number of maize farmers who used hermetic bags and metal silos for maize storage was relatively high, about 40% of maize farmers studied used propylene bags for maize storage. Propylene bags have been reported to increase moisture content, which encourages fungal growth resulting in aflatoxin production (Mutegi et al., 2013). Maize farmers' reasons for not using hermetic bags were that "*hermetic bags were expensive and not readily available".*

CONCLUSION AND RECOMMENDATIONS

The artisanal aflatoxin control technologies implemented by subsistence maize farmers comprised dry planting, use of organic manure, drying of maize on a tarpaulin mat and sorting of maize cobs. Furthermore, factors that were associated with adoption of artisanal aflatoxin control technologies by subsistence maize farmers included level of education of respondent, farms located in lowland areas and farmer's level of knowledge on aflatoxins. This study recommends increased awareness campaigns to increase maize farmer's knowledge on risks of exposure to aflatoxins and support for adoption of the aflatoxin control technologies, and further research on the economic feasibility of adopting these artisanal aflatoxin control technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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SUPPLEMENTARY MATERIALS

Table S1. Post-harvest artisanal aflatoxin control technologies practiced by subsistence maize farmers in Kitui, Kenya.

Artisanal methods applied post-harvest to control aflatoxins	Farmers reporting practicing measures in lowlands (n=159)	Farmers reporting practicing measures in uplands (n= 156)	Z*	0.95 CI	P-value
Method of maize harvesting					
a) Cutting maize stovers with cob	29 (18.2)	12 (7.7)	2.83	0.032 – 0.179	0.0047
b) De-husking in the field	92 (57.9)	134 (85.9)	5.83	0.186 – 0.375	0.001
c) Harvesting cob with husk	38 (23.9)	9 (5.8)	4.69	0.106 – 0.257	0.001
d) Others (specify)	0	1 (0.6)	1	-0.025	0.3158
Maize drying platform					
a) In a ventilated raised granary	1 (0.6)	1 (0.6)	0.01	-0.017 – 0.018	0.9892
b) On a raised platform	8 (5.0)	20 (12.8)	2.44	0.015 – 0.140	0.0146
c) On tarpaulin sheet/mat	86 (54.1)	77 (49.4)	0.84	-0.063 – 0.158	0.4005
d) On the ground	61 (38.4)	53 (34.0)	0.81	-0.062 – 0.150	0.4169
e) Other (specify)	3 (1.9)	5 (3.2)	0.74	-0.022 – 0.048	0.4578
Sorting of maize grains	127 (80)	110 (70.5)	1.93	-0.001 – 0.189	0.0532
Method of shelling					
a) Beating in a sack	142 (89.3)	124 (79.5)	2.42	0.019 – 0.178	0.0155
b) Use motorized shellers	4 (2.5)	20 (12.8)	3.49	0.045 – 0.161	0.0005
c) Using hand shellers	9 (5.7)	2 (1.3)	2.14	0.004 – 0.084	0.032
d) Other (specify)	4 (2.5)	10 (6.4)	1.68	-0.007 – 0.084	0.0934
Maize storage					
a) Gunny (sisal/jute) bags	13 (8.2)	28 (17.9)	2.6	0.024 – 0.171	0.0094
b) Hermetic bags	92 (57.9)	48 (30.8)	5.03	0.165 – 0.376	0.0001
c) Propylene bags	46 (28.9)	77 (49.4)	3.8	0.099 – 0.310	0.0001
d) Other (specify)	8 (5.0)	3 (1.9)	1.51	-0.009 – 0.071	0.1300
Storage structure					
a) A room inside the house	69 (43.4)	133 (85.3)	8.63	0.324 – 0.514	0.0001
b) A storage structure outside the house	89 (56.0)	21 (13.5)	8.87	0.331 – 0.519	0.0001
c) Other (specify)	1 (0.6)	2 (1.3)	0.6	-0.015 – 0.028	0.5518
Placement of storage bags					
a) On the floor	5 (3.1)	12 (7.7)	1.79	-0.004 – 0.095	0.0737
b) On wooden pallets	151 (95.0)	142 (91.0)	1.37	-0.017 – 0.096	0.1696
c) Other (specify)	3 (1.9)	2 (1.3)	0.43	-0.022 – 0.034	0.6670
Treatment before storage					
Smoking	4 (2.5)	6 (3.8)	0.67	-0.025 – 0.052	0.5012
Use of insecticides	59 (37.1)	88 (56.4)	3.50	0.085 – 0.301	0.0005
Use of ash	17 (10.7)	13 (8.3)	0.71	-0.041 – 0.088	0.4750
No treatment except drying	77 (48.4)	27 (17.3)	6.24	0.213 – 0.409	0.0001
Smoking and use of ash	2 (1.3)	2 (1.3)	0.02	-0.024 – 0.025	0.9847
Smoking, use ash and apply insecticides	0	2 (1.3)	1.42	-0.005 – 0.030	0.1546
Use ash and use insecticides	0	18 (11.5)	4.51	0.065 – 0.166	0.0001