

## Research Article

# Aflatoxin Contamination of Maize from Small-Scale Farms Practicing Different Artisanal Control Methods in Kitui, Kenya

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Aflatoxin contamination of maize is a threat to food security and public health for households that depend on farming in developing countries. The objective of this study was to determine levels of total aflatoxins in maize from farms adopting different artisanal aflatoxin control methods. A cross-sectional study was conducted with 315 maize farmers who provided maize samples for aflatoxin analysis and additional data on artisanal aflatoxin control methods applied at farm level. Maize grains were ground, and levels of aflatoxins were determined using competitive enzyme-linked immunosorbent assay. Data were analyzed by computing descriptive statistical measures, and binary logistic regression was used to determine the relationship between levels of aflatoxin in maize and artisanal control methods applied in different farms. Aflatoxin was detected in 98% of maize samples with a mean total aflatoxin level of 12.86  $\mu\text{g}/\text{kg}$  which was above the maximum tolerable limits. There was a significant difference in total aflatoxin levels in maize obtained from farms which practiced minimum tillage compared to those practicing deep tillage ( $p = 0.015$ ). Drying maize on bare ground had a higher likelihood of aflatoxin contamination than drying maize on tarpaulin ( $p = 0.005$ ). One-third of maize samples had aflatoxin levels exceeding the set maximum limit, with maize samples from lowland areas having high proportions of aflatoxin-positive cases as compared to uplands. Artisanal aflatoxin control technologies such as land tillage, types of platforms for drying maize, and sources of maize seed significantly influence the level of aflatoxins in maize samples. We recommend targeted active surveillance for aflatoxins, continuous public education, and adoption of farm-level mitigation measures to reduce the impact of aflatoxin contamination in farming communities.

## 1. Introduction

Agriculture is the mainstay of most African countries, and maize is an important cereal crop grown on over 47 million hectares cultivated by small-scale farmers with an annual output of 90 million tons [1]. In addition, maize farming supports the livelihoods of millions of subsistence farmers in Kenya. Currently, maize is cultivated on approximately 2.19 million hectares of land, creating employment for more than 3 million smallholder families with an annual output of 3.79 million tons [1]. Maize is therefore a staple food for an estimated 50% of the population, and it accounts for 65% of the staple food calorie intake in Kenya [2].

Aflatoxins constitute a major challenge to food and nutrition security in Africa and are the most commonly known noninfectious food-borne hazard that constitutes a major public health risk. Aflatoxins are a group of structurally related, toxic, secondary metabolites produced by *Aspergillus flavus* and *Aspergillus parasiticus* which are present in soils, air, seeds, and plant debris and can contaminate maize, peanuts, peanut meal, cotton seed, cotton seed meal, and beans [3]. Aflatoxin contamination is primarily associated with maize and maize products more than any other food crops. Kenya is one of the world's hotspots for aflatoxin contaminations, with a record of what is believed to have been the highest incidence of acute toxicity [4]. The country has suffered severe outbreaks of aflatoxin

poisoning since the first reported outbreak which occurred in 1981 with 20 hospitalized victims of which 12 of them died of liver failure [4]. In that study, victims were reported to have consumed maize with high levels of aflatoxins, and on necropsy, their liver tissues had up to 89 parts per billion of aflatoxin B<sub>1</sub>. In 2004, an acute outbreak of aflatoxin poisoning occurred in Kenya with a total of 317 reported cases and a case fatality rate of 39% [5]. It is argued that most outbreaks of aflatoxin poisoning occur in remote villages where access to medical facilities is hampered by the long distance people have to travel and the high incidence of rural poverty, and therefore, the actual number of people affected by aflatoxins poisoning could be higher than currently reported [6]. Indeed, aflatoxin contamination is known to be prevalent in Eastern region of Kenya, where home-grown maize is often contaminated during the postharvest stage of maize grain handling [5].

Human exposure to aflatoxin occurs mainly through ingestion of contaminated food [7]. The presence of toxins in food can cause acute and chronic effects referred to as aflatoxicoses. Approximately more than 5 billion people in developing countries are at risk of exposure to aflatoxins through consumption of contaminated foods [8]. Acute toxicity resulting from exposure to high levels of aflatoxins is a very rare event worldwide, although some cases have occurred in high-risk regions such as the documented outbreak in Eastern region of Kenya [9]. Acute exposure to high doses of aflatoxin results in patients showing symptoms of jaundice, vomiting, abdominal pain, and liver failure with case fatality rates of up to 40% [10]. Chronic exposure through cumulative ingestion of low quantities of aflatoxin in the diet over a period of time is widespread and is the leading cause of liver cancer in adult populations in developing countries [11]. Furthermore, chronic exposure to aflatoxins has been associated with malnutrition and stunted growth in children [12] and suppression of the immune system [13]. It is estimated that up to 28.2% of annual liver cancer cases in humans globally are linked to exposure to aflatoxin [14], while an estimated 26,000 people in sub-Saharan Africa die annually from aflatoxin-related liver cancers [15].

Aflatoxin contamination in food products is regulated in most countries, with maximum limits ranging from 5 to 20 µg/kg in human food [16]. The European Union has the most stringent standard for allowable limits of aflatoxin in maize with a maximum limit of 4 µg/kg for total aflatoxin [17]. Kenya has set a maximum limit of 10 µg/kg for total aflatoxins in maize and maize products which are similar to limits established by the Codex Alimentarius Commission and East African Community [18]. However, measures for prevention of contamination are sometimes not fully enforced within the context of developing countries, especially for food commodities sold within informal markets. Several technologies have been shown to reduce levels of aflatoxin contamination during the preharvest, harvest, and postharvest stages of maize production. At the preharvest stage, adoption of timely planting, application of manure, provision of supplemental irrigation, crop rotation, and application of atoxigenic strains of *Aspergillus flavus* have

been demonstrated to reduce levels of aflatoxins [3, 19]. Postharvest control of aflatoxin is achieved through proper drying of maize grains, sorting to remove damaged and shriveled kernels, and storage of maize grains in well-aerated facilities or in hermetic bags [20–22].

Despite the presence of these known technologies, aflatoxin contamination of maize and other cereals has persisted in rural farming communities, hence increasing risk of households' exposure to the negative consequences of aflatoxicoses. Several farms are implementing different measures to mitigate the risk of exposure, yet no study has compared levels of aflatoxins in maize from farms practicing different aflatoxin control measures. The objective of this study was to determine the level of total aflatoxins in maize grains and compare the levels of aflatoxin in farms practicing different control methods in two different production areas which were classified as hilly rugged upland areas and lowland dry areas. The findings will be useful in guiding policy formulation and farming practices in order to mitigate aflatoxin contamination in similar settings in sub-Saharan Africa.

## 2. Materials and Methods

**2.1. Study Area.** The study was carried out in Kitui County, located between latitudes 0°10' and 3°0' south and longitudes 37°50' and 39°0' east. The county is one of the 47 counties in Kenya. It is the sixth largest county with a land size covering 30,496.4 km<sup>2</sup> including 6,369 km<sup>2</sup> occupied by Tsavo East National Park (County Government of Kitui (CGoK), 2017). The county has a human population of 1.136 million based on the 2019 census. It has low-lying topography with arid and semiarid agroecological zones. Rainfall distribution is erratic and unreliable, and topography can be divided to hilly rugged uplands and lowlands areas with altitude ranging between 400 m and 1800 m above sea level. The county experiences high temperatures throughout the year ranging from 14°C to 34°C [23]. The rainfall pattern is bimodal with two rainy seasons (short rains come in the months of October–December while long rains come in April–May) with a high variability in annual rainfall amounts ranging between 500 and 1050 mm [24]. The county was purposively selected for the study because of its high risk for aflatoxin contamination of maize since it falls within an aflatoxin hotspot [25]. The field surveys were conducted between the months of May and June 2021 in four wards and 12 villages located in different agroclimatic zones. Mutha and Athi wards are located in lowland areas of Kitui south subcounty, while Miambani and Kyangwithya west wards are located in hilly upland areas of Kitui Central subcounty (Figure 1).

**2.2. Study Design and Sampling.** A cross-sectional study design was employed for the selection of study units which were defined as farming households which planted maize in previous season and got a harvest. However, households which did not plant maize in the previous season and those that did not harvest from their farms were excluded.

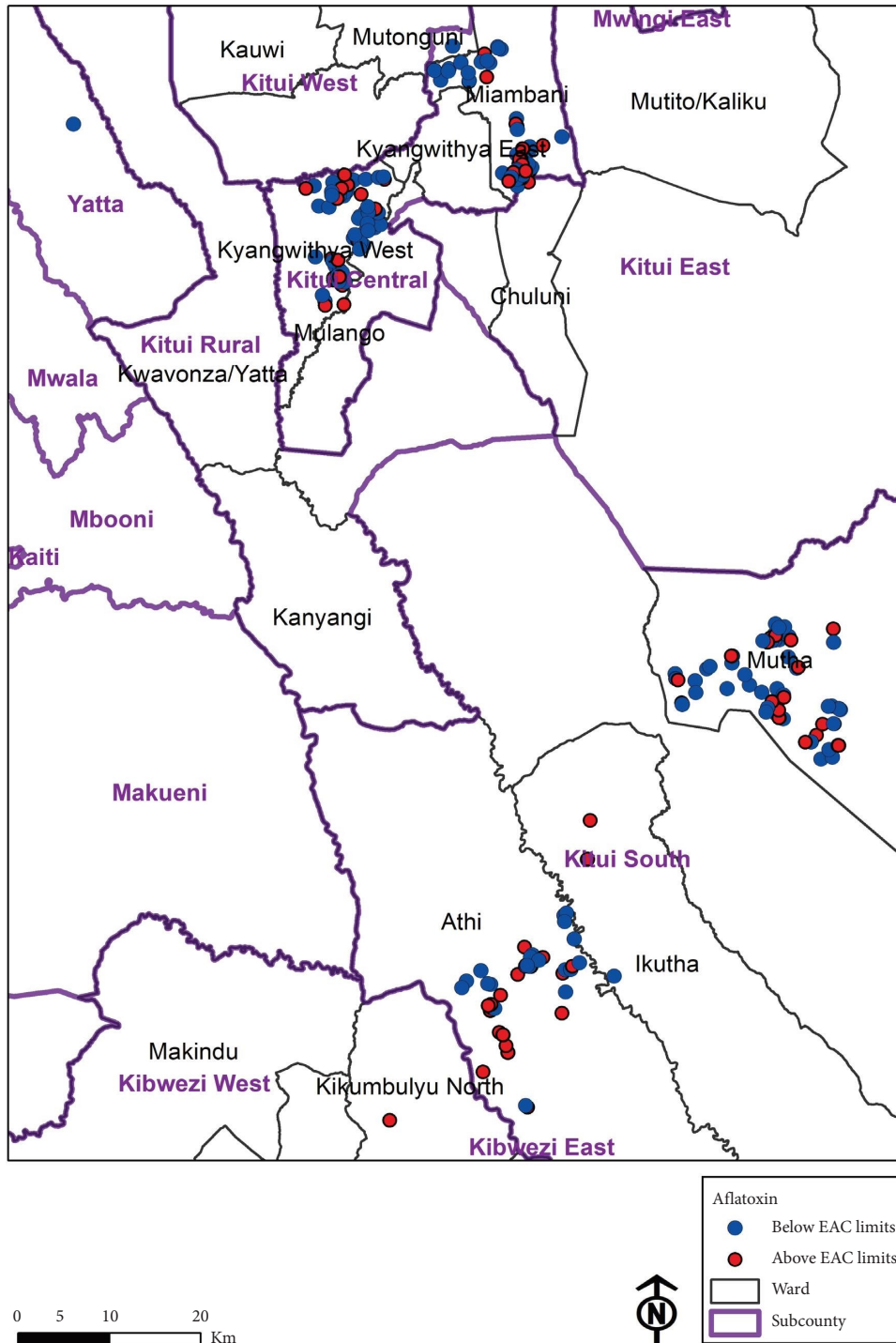


FIGURE 1: Map of study locations showing farms which had levels of total aflatoxins exceeding the acceptable limits and those with levels below acceptable limits in four administrative units in Kitui.

Multistage sampling procedure was used. Two subcounties were purposively selected from eight subcounties in Kitui to represent the two main farming areas (upland areas and lowland areas). From the two selected subcounties, two administrative wards were randomly selected from each subcounty to make four wards representing the two farming areas. A list of villages where maize is grown within the two wards was obtained from the ward agricultural officers.

Three villages from each of the four selected wards were randomly selected to form a list of twelve villages which were defined as the study sites.

The sample size was determined using the formula in [26]. The prevalence of aflatoxins in cereals was estimated at 25% [27], with a level of accuracy set at 5%. The estimated sample size was 288 maize farmers. This was adjusted upwards to cater for withdrawals from the study, and sample

size of a 315 maize farmers was used. The sampling proportionate to population size technique was used to select the number of maize farming households in each village. Using the Microsoft Excel random number table function, households were randomly allocated for the study. In total, 315 maize farming households were recruited, and the number of households selected from the wards was 80, 79, 79, and 77 for Athi, Mutha, Miambani, and Kyangwithya West wards, respectively. In each of the selected households, the study respondents were the head of household who was considered to be aged 18 years and above.

**2.3. Data Collection.** Prior to data collection, each respondent was briefed on the objectives of the study, and oral consent was sought for them to participate. Upon receipt of oral consent, a pretested semistructured questionnaire was administered to the household head using Kamba language, which the first author and research assistants understood and spoke fluently. The questionnaire sought to collect data on artisanal methods that small-scale farmers were using to control aflatoxin contamination in maize. These included data on practices on farm tillage, types of seed and where they obtained seeds from, use of organic manure and commercial fertilizer, crop rotation, method of maize harvesting, maize drying platforms, maize sorting practices, method of maize shelling, method of determining if maize grain was well dried before storage, and maize storage practices. Basic demographic data of the respondents including age, gender of the respondent and household head, marital status, education level, monthly incomes, size of household, size of land, and geo-referenced location of the farm were collected. After the interview, respondents provided 1 kg of maize grain sample from the previous harvest for further aflatoxin testing in a laboratory.

Maize grain samples were collected according to the recommended processes published by the Food and Agriculture Organization of the United Nations for aflatoxin analysis [18]. Briefly, from each farm, shelled maize grains were randomly sampled from different parts of the storage vessel. The incremental sample was thoroughly mixed to form a composite sample of which a maximum of 1 kg was drawn for aflatoxin testing. Samples were immediately placed in a brown khaki paper bag, properly labelled, and stored. The maize samples were transported to the Mycotoxin Research Centre at the Department of Public Health Pharmacology and Toxicology, University of Nairobi, for further laboratory testing.

**2.3.1. Sample Preparation for Laboratory Testing.** The samples were prepared as per the kit manufacturer's instructions [28]. Briefly, twenty (20) grams of maize grain samples were weighed and ground at 8.5 revolutions for one and a half minutes and again at 10 revolutions for one minute to obtain a fine particle size with 95% passing through a 20-mesh screen using Retsch Grindomix GM 200. The milling machine was thoroughly cleaned using a sodium hypochlorite solution, wiped with paper towels soaked in methanol, and allowed to dry between samples to avoid cross

contamination. Subsequently, 5 grams of subsample were taken using a digital weighing scale and used to extract aflatoxins following the prescribed method [28]. The remainder of the sample was packed in quarter-kilogram paper bags and stored at room temperature as a reference sample. Afterwards, 5 grams of reference material were weighed, awaiting the aflatoxin extraction process.

**2.3.2. Aflatoxin Extraction Procedure.** Extraction solution was prepared by adding 770 ml of methanol to 330 ml of deionized water and properly mixing to make 70% methanol-water solution. To 5 grams ground grain sample, 25 ml of 70% methanol-water solution was added at the ratio of 1 : 5 weight/volume. The preparation was mixed well using an electric shaker for 3 minutes. After allowing the mixture to settle down on the bench at room temperature, 10 ml of supernatant was filtered through Whatman No. 1 filter paper, and the test filtrate was collected in 2 ml Eppendorf tubes.

**2.3.3. Aflatoxin Assay Procedure.** The aflatoxin assay procedure was carried out as per the kit manufacturer's (Helica Biosystems, Inc.) instructions without modifications [28]. Briefly, mixing wells containing ground maize samples and standards were placed on a microwell holder. An equal number of antibody-coated microtiter wells were placed in another microwell holder. Using an Eppendorf precision pipette, 200  $\mu$ L of aflatoxin-HRP conjugate was placed in each mixing well. Using a new pipette tip for each sample and standard, 100  $\mu$ L of both the standard and sample were added to the appropriate mixing well containing conjugate and mixed well by priming the pipette at least 3 times. The six standards had the following concentrations: 0.0, 0.2, 0.5, 1.0, 2.0, and 4.0 ng/mL in 70% methanol. Using a new pipette tip for each, 100  $\mu$ L of the content from each mixing well was transferred in duplicates to a corresponding antibody-coated microtiter well and incubated for 15 minutes. Thereafter, contents from the microwells were decanted in a discard basin containing 3.5% sodium hypochlorite. The microwells were washed by filling each with PBS-Tween wash buffer and decanting of the buffer in the discard basin. The washing was repeated 5 times. PBS-Tween wash buffer was prepared by mixing 1 pouch (Tween 20) with 1 litre of distilled water and refrigerated. The microwells were turned upside down and tapped on a layer of absorbent paper towels to remove residual washing buffer. To each microwell, 100  $\mu$ L of substrate-chromogen was added, shaken, and incubated at room temperature for 5 minutes. After incubation, 100  $\mu$ L of stop solution was added to each well. The optical density (OD) of each microwell was read with a Multiskan Plus reader (Labsystems Company, Helsinki, Finland) at a wavelength of 450 nm. Mean ELISA reading values for each standard and sample were determined. For every ELISA plate, a standard curve was generated by placing total aflatoxin standard concentration values on the  $y$ -axis and optical density values on the  $x$ -axis; these regression curves were used to determine the aflatoxin value in each of the samples.

The analytical method used was validated with certified corn reference material at 27 ppb total aflatoxin, batch no. 02017-000079 (the office of the Texas State Chemist, Texas, USA). Furthermore, the laboratory has been participating in an ongoing proficiency testing program for total aflatoxin in corn. The limit of detection (LOD) for this assay was 0.2  $\mu\text{g}/\text{kg}$  total aflatoxin and the limit of quantification (LOQ) was 0.6  $\mu\text{g}/\text{kg}$ . Samples with toxin values below the limit of detection were considered as containing no detectable level of toxin. For purposes of data analysis, nondetect levels were based on the detection limits (LOD) of the test method for the toxin. Detectable levels of aflatoxin were compared to the East African Community (EAC) that established maximum tolerable limits. Left-censored data involving samples with toxin values below the limit of detection were processed by applying the European Food Safety Authority's substitution method [29].

**2.4. Ethical Considerations.** The study was approved by the Faculty of Veterinary Medicine Biosafety, Animal Use, and Ethics Committee of the University of Nairobi, approval no. FVM BAUEC/2021/288 dated 8<sup>th</sup> March, 2021. In addition, a research permit was obtained from the National Commission for Science Technology and Innovation (NACOSTI) under License No. NACOSTI/P/21/9773 to conduct research in Kitui County. Oral consent was obtained from study respondents. Prior to the survey, each respondent was briefed on the objective of the study and the oral consent was sought. The interviews were conducted on a voluntary and consensual basis.

**2.5. Data Management and Analysis.** Data were entered in a database developed in MS Excel® 2010. The data were exported to IBM statistical package for social sciences software (version 21) for analyses. Descriptive statistical measures were computed to determine the mean levels of aflatoxins in maize samples. Based on East African Community standard, samples were categorized as either having high or low levels of aflatoxins. Maize samples with total aflatoxin levels above 10  $\mu\text{g}/\text{kg}$  were categorized as high, while samples with total aflatoxin levels below 10  $\mu\text{g}/\text{kg}$  were categorized as low. Inferential analysis using binary logistic regression was performed to compare levels of aflatoxin in maize from farms that implemented different artisanal aflatoxin control methods from the two different maize farming areas. For all inferential analysis, level of significance was set at 5%.

### 3. Results

**3.1. Demographic Characteristics of Maize Farmers.** The age of maize farmers ranged between 20 and 85 years with a mean age of 51 years. About 71% of maize farmers were female, while 76% of farming households were headed by men. About 57.8% of respondents had attained primary level education, 17.5% had secondary education, and 16.5% had no formal education. The majority (81%) of maize farmers reported a household income that was below the minimum wage in Kenya of Ksh. 13,572 (exchange rates: 1 USD = Ksh.

120) per month. The average household size was 6 persons, and the average land size owned by households was 2.6 acres, with the largest farm size holding being 20 acres. The primary sources of income for households included crop agriculture and livestock farming (96%) with only a small proportion of respondents who were on salary employment [30].

**3.2. Artisanal Aflatoxin Control Technologies Adopted by Maize Farmers.** The majority of the maize farmers practiced dry planting. With regard to use of soil implements, 63% utilized organic manure, while a few applied chemical fertilizers (9%). Maize farmers relied on local maize seed from previous harvest seasons as opposed to use of certified seeds which are marketed by commercial seed producers, while oxen ploughing was the most frequently practiced method of land tillage. With regard to postharvest control technologies, 72% of maize farmers interviewed harvested maize by de-husking in fields with 30% drying maize on bare ground. Maize was mainly shelled by placing cobs in a sack and beating them with wooden sticks, and the majority (75.2%) of farmers sorted maize cobs before shelling. Shelled maize grain was stored either in hermetic bags (44%), propylene bags (39%), and gunny bags (13%), while the remainder was stored without shelling. Fifty percent of maize farmers applied insecticides before maize storage, while the majority of farmers placed maize bags on wooden pallets during storage [30].

**3.3. Occurrence and Prevalence of Aflatoxin Contamination in Maize.** The level of aflatoxin contamination in maize samples varied across the study sites. A majority of the maize samples conformed to the threshold set by the Kenyan Bureau of Standards (KEBS) of 10  $\mu\text{g}/\text{kg}$  (Table 1). Nevertheless, 35% of maize samples exceeded the regulatory limit with some samples exceeding by 5 times the acceptable limits for human consumption. Total aflatoxins were detected in 98% of 315 samples tested with only seven samples having nondetectable levels of aflatoxins. Aflatoxin contamination ranged from 0.26  $\mu\text{g}/\text{kg}$  to 53.91  $\mu\text{g}/\text{kg}$  with an average of 12.86  $\mu\text{g}/\text{kg}$  which was higher than the maximum acceptable limit. The level of aflatoxin contamination was higher in samples from lowland areas with average levels of 17.61  $\mu\text{g}/\text{kg}$  and 12.77  $\mu\text{g}/\text{kg}$  in Athi and Mutha wards, respectively, as compared to upland areas with average levels of 10.16  $\mu\text{g}/\text{kg}$  and 10.78  $\mu\text{g}/\text{kg}$  in Miambani and Kyangwithya west wards. The difference in mean aflatoxin contamination in the two farming areas was statistically significant ( $p=0.007$ ). The highest recorded aflatoxin contamination was in Mutha ward in the lowland areas. Athi ward had the highest overall proportion of aflatoxin-contaminated maize (46.3%) which exceeded the regulatory limit while Miambani had the least (27.8%).

**3.4. Farm-Level Practices and Their Association with Levels of Aflatoxin Contamination of Maize.** There was a significant difference in aflatoxin levels in maize obtained from farms

TABLE 1: Prevalence of aflatoxin contamination in farms and average level of total aflatoxins in maize samples in the two farming zones from Kitui.

Farming area	Ward	Mean aflatoxin ( $\mu\text{g}/\text{kg}$ )	Standard deviation	Maximum aflatoxin ( $\mu\text{g}/\text{kg}$ )	Frequency of aflatoxin contamination $>10 \mu\text{g}/\text{kg}$ (%)
Lowlands	Athi ( $n = 80$ )	17.61	17.76	52.42	37/80 (46.3)
	Mutha ( $n = 79$ )	12.77	15.98	53.91	27/79 (34.2)
Uplands	Kyangwithya west ( $n = 77$ )	10.78	13.85	41.18	24/77 (31.2)
	Miambani ( $n = 79$ )	10.16	14.19	44.5	22/79 (27.8)
Overall	Overall ( $n = 315$ )	12.86	15.74	53.91	110/315 (34.9)

EAC (East African Community) standard maximum limit for total aflatoxin in maize is  $10 \mu\text{g}/\text{kg}$ .

which practiced minimum tillage compared to farms which practiced deep tillage ( $p = 0.015$ ). Aflatoxin contamination increased with an increase in types of tillage with farms practicing minimum tillage exhibiting low levels of aflatoxin compared to farms practicing deep tillage by use of tractors and use of oxen plough. Farms which used oxen plough and tractors had an increased risk of having high levels of aflatoxin contamination above the acceptable limits. Drying maize on bare ground increased aflatoxin contamination of maize, while drying of maize on a raised platform and use of tarpaulin or mat for drying maize reduced the risk of aflatoxin contamination ( $p = 0.005$ ) (Table 2). The results also revealed a significant difference in aflatoxin levels from sources of maize seed, with certified maize seeds purchased from agrovets (shops selling agricultural inputs) exhibiting the lowest levels of aflatoxins ( $p = 0.009$ ). Similarly, storage of maize grains in hermetic and gunny bags reduced the risk of contamination with aflatoxins ( $p = 0.000$ ).

#### 4. Discussion

The average level of total aflatoxins in maize samples estimated at  $12.86 \mu\text{g}/\text{kg}$  was higher than the acceptable limit of  $10 \mu\text{g}/\text{kg}$  based on the East African Community standards [18]. The estimates are comparable to findings by Kimani [31], who reported a mean aflatoxin level of 13.17 ppb in maize grain. However, other studies had previously reported higher estimates of total aflatoxins in maize samples in Kenya [6, 32]. The study has further revealed that 35% of maize samples contained aflatoxins at levels above the acceptable limits and therefore were generally unfit for human consumption, a finding which had also been reported in a previous study [32]. Similar results were reported by Mwihi et al. [33] at 35.5% for home-grown maize in Makueni. Mutiga et al. [34] also reported that 37% of maize samples collected from local commercial maize mills during an active outbreak in Kitui were contaminated with aflatoxins above the acceptable limits of  $10 \mu\text{g}/\text{kg}$  limit. Given the dietary importance of maize as a staple food, it is likely that most rural households in Kitui are frequently exposed to aflatoxins. Indeed, previous outbreaks of aflatoxicoses in Kitui have been traced back to consumption of contaminated maize [6, 32]. Similarly, results from a 3-year cross-sectional survey in Makueni and Kitui between 2005 and 2007 reported that the overall geometric mean of aflatoxins in household maize samples was  $17.8 \mu\text{g}/\text{kg}$  [32]. In

a different survey within the same area, Mahuku et al. [35] reported that aflatoxin contamination levels in maize samples ranged between 0.98 and  $722 \mu\text{g}/\text{kg}$ . Furthermore, a report had documented that 90% of cooked food for consumption by lactating mothers in Makueni had aflatoxins levels above acceptable limits [36]. The occurrence of aflatoxins has also been associated with seasonality; for example, Obonyo and Salano [27] reported that maize grain harvested in the month of May had lower aflatoxin levels as compared to those harvested during the October–December months with high levels of precipitation. From the two seasons, these authors reported 16% and 44% of maize samples, respectively, to have total aflatoxins above the maximum acceptable limits. Awuor et al. [37] also reported that one-third of maize samples from farms in Busia, western Kenya, have levels of aflatoxin above acceptable limits. Likewise, a report had previously estimated an average aflatoxin level of  $12.47 \mu\text{g}/\text{kg}$  in Tanzania [38] and  $18.8 \mu\text{g}/\text{kg}$  in freshly harvested maize [39]. Even though the study by Seetha et al. [39] reported a high level of aflatoxins estimated at  $57.2 \mu\text{g}/\text{kg}$  during storage. In Ghana, Kortei et al. [40] reported that 52.2% of maize samples of white and colored grains had aflatoxin levels above the acceptable limits sets by the Ghanaian standard authority. From that study, the majority (56.9%) of samples analyzed for total aflatoxins in white maize samples exceeded the country's set limits for total aflatoxins with only 16.7% of colored maize samples found to exceed the limit. These reports corroborate our results of 35% level of prevalence of contamination above acceptable limits in maize farms and an average level of total aflatoxins of  $12.86 \mu\text{g}/\text{kg}$  in maize samples.

The results of this study revealed that aflatoxin levels in maize kernels differed significantly between the farming areas with the lowland regions exhibiting high aflatoxin levels in maize compared to uplands. The results of this study are similar to those of Malusha et al. [41], who reported that low altitude areas had more aflatoxin-contaminated maize than high altitude areas with the aflatoxin positivity rate of maize contamination being 33.3% in low altitude area as compared to 12.5% in high altitude area. Nyangi et al. [42] also found that maize from drier areas had significantly higher levels of aflatoxin as compared to those from wetter areas. The low attitude areas are usually characterized by warmer and hotter weather with high temperature and humidity, which are conditions that favor fungal growth and consequent release of aflatoxin. This is in contrast to high

TABLE 2: Artisanal control technologies associated with risk of aflatoxin contamination in maize.

Artisanal aflatoxin control technology	Coef	SE	<i>t</i> value	<i>p</i> value	95% confidence interval		Sig
Practice of dry planting	0.029	0.348	0.08	0.933	-0.652	0.711	
Use of manure	-0.044	0.320	-0.14	0.890	-0.671	0.583	
Use of commercial fertilizer	0.841	0.557	1.51	0.131	-0.25	1.932	
Source of seed (base-own store)							
From neighbor	-0.019	1.595	-0.01	0.990	-3.146	3.107	
From the market	0.688	0.504	1.36	0.173	-0.301	1.676	
Provided by government	-0.345	1.114	-0.31	0.756	-2.528	1.837	
Shops selling agricultural inputs (agrovet)	-1.178	0.451	-2.61	0.009	-2.063	-0.294	***
Planting certified seed	0.904	0.376	2.40	0.160	0.167	1.641	
Practice of crop rotation	0.035	0.299	0.12	0.906	-0.551	0.622	
Method of land tillage (base-minimum tillage)							
Oxen ploughing	1.854	0.515	3.60	0.000	0.845	2.863	***
Deep tillage (use of tractors)	3.509	1.438	2.44	0.015	0.690	6.328	**
Method of maize harvesting							
Cut stoves with cobs	0.07	0.462	0.15	0.879	-0.836	0.976	
Harvest cobs with husk	0.29	0.456	0.64	0.525	-0.605	1.185	
Maize drying practices (base-on bare ground)							
On tarpaulin sheet/mat	-0.888	0.316	-2.81	0.005	-1.508	-0.268	***
On a raised platform	-0.344	0.527	-0.65	0.513	-1.377	0.688	
Methods of maize shelling (base-beating in a sack)							
Use motorized sheller	0.757	0.515	1.47	0.141	-0.252	1.766	
Using hand sheller	-0.483	0.842	-0.57	0.566	-2.132	1.167	
Maize storage practices (base-propylene bags)							
Hermetic bags	-1.406	0.378	-3.72	0.000	-2.146	-0.666	***
Gunny (sisal/jute) bags	-1.176	0.479	-2.45	0.014	-2.116	-0.237	**
Granary	-1.027	0.782	-1.31	0.189	-2.559	0.505	
Placement of maize storage bags (base-on the floor)							
On wooden pallet	-0.922	0.693	-1.33	0.183	-2.28	0.436	
Maize sorting	-0.029	0.352	-0.08	0.934	-0.72	0.661	
Form of treatment before storage (base-drying only)							
Smoking	-0.032	0.858	-0.04	0.970	-1.715	1.650	
Use of ash	0.193	0.539	0.36	0.721	-0.864	1.249	
Insecticide application	-0.304	0.359	-0.85	0.396	-1.007	0.399	
Constant	-0.901	0.864	-1.04	0.297	-2.595	0.793	
Mean-dependent variable			0.349		SD dependent var	0.477	
Pseudo <i>r</i> -squared			0.182		Number of obs	315	
Chi-square			74.004		Prob > chi2	0	
Akaike crit. (AIC)			393.577		Bayesian crit. (BIC)	506.154	

\*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ .

altitude areas which are cooler and are characterized by low temperatures and humidity which do not favor fungal growth. This argument is corroborated by a previous report that documented that maize grain from temperate regions had a relatively low mean aflatoxins contamination as compared to those from semiarid and subhumid zones in Kenya [43]. The authors of this previous report had attributed this to unfavorable climatic conditions in cooler high altitude areas that did not favor fungal growth and aflatoxin development. In addition, the eastern region of Kenya has been reported to harbor deadly strains of *Aspergillus flavus* [44]. Research has shown that increasing temperatures, particularly when combined with lower precipitation levels during early growing season, lead to higher levels of aflatoxin contamination [45]. The risk of chronic aflatoxin exposure is therefore a significant health risk in the lowland farming region, given that maize is a staple in the region. Likewise, a study conducted in Ghana

showed that the occurrence of aflatoxins was influenced by rainfall patterns and levels of humidity in the different agroecological zones [46].

Preharvest and postharvest farm-level practices play a key role in reducing levels of aflatoxin contamination in maize. Our study explored the association between artisanal aflatoxin control methods and the level of aflatoxin contamination of home-grown maize. There was a significant difference in aflatoxin levels in maize samples obtained from farms that practiced minimum tillage and farms which practiced deep tillage with maize farms practicing deep tillage exhibiting high levels of aflatoxins in maize samples. Similar findings have been reported by Nyangi et al. [42], who found that farms that used hand hoe and oxen plough for tillage had low levels of aflatoxin when compared to farms that used tractors. These results are contrary to conventional knowledge since minimum tillage has been associated with higher levels of aflatoxins contamination as

opposed to deep tillage. This occurrence is explained by the fact that soil quality highly depends on factors such as soil fertility, soil structure, human influence, and tillage method which are key management practices affecting soil physical parameters [47]. *Aspergillus flavus* is argued to sit on soil surface and often jumps to maize ears during rain splash or wind. However, if the fungal population is submerged due to deep tillage, it will not be able to contaminate crops since it cannot reach the soil surface [48]. Furthermore, Helgason et al. [49] have argued that no tillage practices can result in increased bacterial and fungal biomass at the soil surface which may imply that there would be a higher likelihood of fungal growth and mycotoxins production in a farm practicing shallow tillage or under no tillage than in cases of a farm implementing deep tillage. However, our results could have been influenced by other postharvest handling practices since the maize samples obtained from households had been subjected to other postharvest management practices including methods of maize drying, storage, and shelling, and therefore, the effects of land tillage methods would be masked by aflatoxin contamination from these postharvest practices.

Aflatoxin contamination was also associated with the sources of maize seed used for planting. Mean aflatoxin levels in maize were lower in maize samples from farmers who purchased certified seeds as compared to other sources including farmers who used maize seeds from their previous harvest. Similar findings have been documented by Daniel et al. [32], who reported that aflatoxin was lower in maize purchased from markets and higher in home-grown maize seeds. While similarities exist in these findings, the methodology employed in both studies was different. Our study sampled home-grown maize obtained from the previous cropping season, while Daniel et al. [32] sampled maize from farm stores that was purchased from the market for consumption. The agrovets (shops selling agricultural inputs) are a source of certified seed varieties that are drought-resistant and suitable for that geographical region. Although certified maize seeds are not necessarily fungal resistant, they are ecologically adapted since they are tested for pest and disease resistance, drought, and low nitrogen tolerance. Other studies have also revealed that purchased maize grains from markets contained higher aflatoxin levels compared to home-grown maize. A study by Mutiga et al. [50] reported that Kenyan farmers valued the maize they cultivated and harvested themselves more than what they purchased from millers and markets. Similar findings were reported by Hoffmann and Gatobu [51], who argued that people valued home-grown maize more because they are sure of its safety and quality. These could be the drivers for most farmers using maize seeds from the previous planting season as seeds. These findings agree with our study results that about two-thirds (58%) were planting seeds obtained from their own farm-sourced maize grains of local varieties as compared to those purchased from markets, certified seeds from agrovets, or received donation from the government. This practice could also result in the accumulation of aflatoxins in the farms since already infected seeds are continuously recycled in the farms, hence maintaining higher levels of

aflatoxins. Factors associated with the choice of seed variety by the farmers were drought resistant, high yielding, and adaptability to local climatic conditions. Although local varieties are adapted to local conditions as a result of many years of selection, they could still be susceptible to fungal infections [52].

Maize drying methods influenced aflatoxin contamination with maize dried on tarpaulin/mat exhibiting lower levels of aflatoxin than maize dried on bare ground. Maize dried on bare ground had a higher predisposition for contamination. The findings are consistent with previous reports that had documented that aflatoxin contamination of maize grains dried on the ground was significantly higher than those dried on tarpaulins and raised racks [53]. Pretari et al. [54] reported in their study that maize dried on plastic sheets was 61% less contaminated with aflatoxin than that dried on other surfaces. Similarly, Hoffmann et al. [55] tested the impact of distributing drying sheets to groundnut farmers and reported a 52% reduction in aflatoxin levels compared to farmers who were not given drying sheets. An increase in the level of aflatoxin in maize dried on bare ground can be explained by the possible uptake of moisture by maize from the soil. This leads to increased water activity that provides favorable condition for fungal growth. Toxicogenic fungi are ubiquitous in nature; however, most of them are found in the soil. Allowing maize to come into contact with the soil predisposes it to a higher fungal load, thus increasing the chances for contamination.

The maize storage bags used by farmers significantly influenced the level of aflatoxin in maize. There was a significant statistical difference in aflatoxin in maize stored in hermetic and propylene bags. In a randomized controlled trial performed in Senegal, Bauchet et al. [56] reported that the use of hermetic storage bags causes a significant marginal decrease in total aflatoxin levels. Ng'ang'a et al. [57] reported that maize stored hermetically had five to eight times lower total aflatoxin levels after 35 weeks compared to maize stored in polypropylene/jute bags. Conversely, Sasamalo et al. [58] reported that maize stored in propylene bags showed an increase in aflatoxin levels with time. Nyanga and Ambali [59] reported that hermetic technology was more effective against the increase of aflatoxin B<sub>1</sub> in stored maize than in conventional storage facilities. Hermetic storage is impermeable to oxygen, creating anaerobic conditions that inhibit the growth of fungal spores and weevils, while propylene bags lead to build up of moisture, encouraging fungal growth and aflatoxin contamination [52]. Our study showed that farmers have adopted the use of hermetic bags for maize storage, but some lacked knowledge and skills of their proper use; therefore, effectiveness of the technology was not fail-safe. There is therefore a need to train farmers on the proper utilization of this technology.

## 5. Conclusion and Recommendations

We conclude that 35% of small-scale maize farms had levels of aflatoxin contamination exceeding acceptable limits of EAC standards, with a mean total aflatoxin of 12.86 µg/kg in maize samples. Artisanal aflatoxin control technologies that



have an impact on levels of aflatoxin contaminations in the area include the use of certified maize seeds and drying of maize on tarpaulin mat or raised platforms, with farms drying maize on bare grounds having a high risk of aflatoxins contamination. Furthermore, farms which stored maize in hermetic bags and gunny bags had reduced risk of aflatoxin contaminations. We therefore recommend targeted active surveillance activities to enhance monitoring and changes in levels of aflatoxin contamination of maize and the provision of mitigation measures to minimize negative consequences in health and sources of livelihoods for communities. Furthermore, public health education should be implemented to create awareness amongst the community at risk.

### Data Availability

The data used to support the findings of this study are available at the University of Nairobi repository <https://eRepository.uonbi.ac.ke/>.

### Conflicts of Interest

The authors declare that there are no conflicts of interest.

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