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AFLATOXIN PREVALENCE AND ASSOCIATION WITH MAIZE GRAIN PHYSICAL AND NUTRITIONAL QUALITIES IN THE INFORMAL MARKETS IN MERU COUNTY, KENYA

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ABSTRACT

In Kenya, aflatoxin contamination in maize remains a persistent issue, with potential negative impacts on both public health and economic growth. Aflatoxins are toxic secondary metabolites produced by certain mold species, primarily *Aspergillus flavus*. The extent of *Aspergillus* fungal invasion in maize grains and the resulting increase in aflatoxin levels is heavily influenced by pre-and post-harvest practices. Before harvest, factors such as insect damage and exposure to warm, humid conditions increase the crop's susceptibility to *Aspergillus* infection and subsequent aflatoxin formation. Post-harvest, additional risks arise when kernels are damaged by pests like rats or when they are stored in unfavorable conditions for extended periods, leading to significant aflatoxin accumulation. This study examined the prevalence of aflatoxin contamination in maize and its association with the physical and nutritional characteristics of grains collected from 49 informal markets across eight sub-Counties in Meru County, Kenya. A total of 353 maize samples were collected from traders. A competitive enzyme-linked immunosorbent assay (ELISA) was used to determine aflatoxin levels, while proximate analyses of ground maize grain samples were conducted in duplicate, following the guidelines of the Association of Official Analytical Chemists (AOAC). The physical characteristics of maize grains including the proportions of undamaged, broken, and insect-damaged grains along with moisture content, were also assessed. The average aflatoxin level in maize samples was 8.66 ppb, with 35.2% containing less than one ppb (low or none), 47.8% falling between 1–10 ppb (moderate), and 17.0% exceeding 10 ppb (high). Physical factors found to be positively correlated with aflatoxin contamination included high proportion of broken grains, insect damage, and elevated moisture content. However, nutritional parameters, including fat, starch, and protein content, were consistent across sub-Counties and did not significantly associate with aflatoxin levels. To mitigate aflatoxin contamination, the study recommends implementing management practices such as ensuring adequate drying of maize to a moisture content below 13%, proper storage and transportation, and optimizing threshing and harvesting times to improve kernel quality. Relevant government agencies should support farmers, traders, and consumers by disseminating information and providing training programs on these practices.

Key words: *Aspergillus flavus*, Aflatoxin levels, Food handling practices, mitigate, Maize

INTRODUCTION

Wheat, rice, and maize constitute widely grown cereals worldwide [1], collectively contributing more than half of the calories consumed by humans [2]. In sub-Saharan Africa and Southeast Asia, these grains constitute the primary source of sustenance for about one-third of the world's poorest populations [3]. However, these essential crops face significant threats from fungal contamination, with certain fungi producing harmful mycotoxins, which are among the most dangerous and widespread food contaminants today [4, 5]. Cereals, mainly maize, provide an ideal substrate for mycotoxin-producing fungal species such as *Aspergillus flavus*, *Aspergillus parasiticus*, and the fumonisin-producing *Fusarium verticillioides*. *Aspergillus* species produce aflatoxin B1 (AFB1), while *F. verticillioides* produces fumonisin B1 (FB1) [6].

Aflatoxin, a particularly hazardous mycotoxin produced by *Aspergillus* species, affects staple foods such as cassava, rice, and maize in many African countries that rely heavily on agriculture, exacerbating food insecurity and health risks [7]. Aflatoxin exposure can lead to various harmful effects, including immunosuppression, birth defects, cancer, and damage to the gastrointestinal system and liver. Chronic low-level exposure to aflatoxins increases the risk of developing hepatocellular cancer [8]. Substantial doses of aflatoxins have been linked to severe, immediate liver damage with extensive morbidity and death [9]. Acute hepatitis and mortality can result from consuming 2-6 mg of aflatoxin every day for a month [10, 11]. Aflatoxin B1 (AFB1) exposure is particularly hazardous; while short-term exposure can be fatal, and long-term exposure has been linked to liver cancer, immune system suppression, nutritional malabsorption, and stunted growth in fetuses and young children [12]. Chronic AFB1 exposure is also associated with oesophageal cancer, impaired immunity, and growth retardation [13].

Efforts to reduce aflatoxin contamination in food crops and products are hindered by various environmental and human-related factors. These include pest infestations, inappropriate agricultural and storage practices, limited access to detection techniques, chronic food insecurity, and the exacerbating effects of climate change [14]. One major difficulty is that aflatoxin contamination is invisible to the naked eye, making it hard for farmers, traders and consumers to recognize the extent of the problem. Additionally, the health effects of consuming aflatoxin-contaminated food, especially from chronic exposure, are not immediately obvious. As a result, consumers and farmers may underestimate the risks and fail to prioritize safety when consuming food. This challenge is particularly pronounced in informal markets, where food safety features like low aflatoxin levels are often undersupplied. Identifying observable factors associated with this invisible hazard, such as pest damage or easily measurable attributes like moisture content, can empower consumers and other stakeholders to make safer food choices. The objective of our study was to explore whether observable characteristics of maize, such as pest damage or moisture content, are associated with aflatoxin contamination. By identifying these relationships, we aim to provide insights that could support safer food handling and purchasing decisions in informal markets.

Aflatoxin research has been advocated worldwide due to its strong negative impacts on health and trade [15]. To safeguard public health and global trade, several countries have established maximum allowable levels of specific contaminants in food [16]. Aflatoxin standards are strictly enforced in developed countries like the USA and the EU, where premium markets do not accept commodities that exceed these aflatoxin limits [17]. Due to the absence of effective regulatory agencies to monitor mold contamination and the limited aflatoxin management practices and facilities for controlling aflatoxin buildup on farms and in stored food, most African countries and other developing nations continue to trade and consume products with high levels of aflatoxin [18, 19].

In Kenya, partly due to low dietary diversification and maize's status as a staple grain, human exposure to aflatoxins is high, especially in the informal markets [20]. In 2004, Kenya had its most significant outbreak of aflatoxicosis, with 317 cases documented and 125 deaths reported [21]. In 2005, 41% of samples collected from the eastern region of Kenya had high levels (GM = 12.92, maximum = 48,000 ppb), and this increased to 51% in 2006 (GM = 26.03, maximum = 24,400 ppb). In 2007, a non-outbreak year, only 16% (GM = 1.95, maximum = 2,500 ppb) of samples exceeded the limit [22]. A study by Sirma *et al.*, (2015) in Nandi County showed that aflatoxin contamination ranged from 0.17 to 5.3 parts per billion (ppb) in 69.7% (72/106), 73.3% (44/60), and 65.7% (67/102) of maize samples taken from Laboret, Kilibwoni, and Chepkongony, respectively [23]. Furthermore, more than half of the maize samples collected from informal markets in Wote (urban, 59.1%) and Kisau Kiteta (rural, 68%) sub-Counties in Kenya exceeded the acceptable limit of 10 ppb for aflatoxins set by the Kenyan government, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) [24]. A study carried out in Busia County, Kenya, showed that maize had the greatest contamination levels (1–1584 ppb), with 31% of samples above the 10 ppb [25].

Beyond aflatoxin, other important quality dimensions for grain include physical properties (such as moisture content, total damaged kernels, and broken kernels and intrinsic properties (such as oil, protein, and starch content) [26]. The quality properties of grain are affected by several factors such as its genetic traits, growing conditions, timing of harvest, grain harvesting and handling equipment, drying methods, storage practices and transportation procedures [26]. The physical and chemical properties of maize may change during drying and storage process due to

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abiotic factors such as storage temperature and relative humidity; and biotic factors such as pest infestations and mould infections [27, 28]. For example, research done in Ethiopia's Jimma zone found up to 37.5% less protein and 20.0% less oil [29]. The association of physical and nutrition properties of maize grain and aflatoxin levels is yet to be documented.

Several farmers and vendors employ various strategies such as using resistant cultivars, planting at the proper time, applying fertilizer, controlling weeds and insect pests, and preventing drought and nutritional stress to reduce the possibility of exposure to aflatoxin [29]. However, no research has compared the prevalence of aflatoxins and the impact on the quality attributes of maize traded in the informal markets. This study examines aflatoxin levels in maize from informal markets in Meru County, Kenya, and analyzes their relationship with the maize's physical traits and nutritional values, focusing on fat, protein, and starch content.

MATERIALS AND METHODS

Study Area

The study was carried out in Meru County, Kenya, situated on the northeastern foothills of Mount Kenya. The average annual rainfall in lowland areas is 380 mm, but in highland zones it reaches 2,500 mm [30]. It covers an area of 7,006 km^2 and according to a census done in 2019, with population of 1,545,714 people [30]. The county is one of the 47 counties in Kenya, with causalities of aflatoxicosis reported in the past [24], and a known hotspot for aflatoxin contamination. It has nine administrative sub-Counties, as shown in figure 1.

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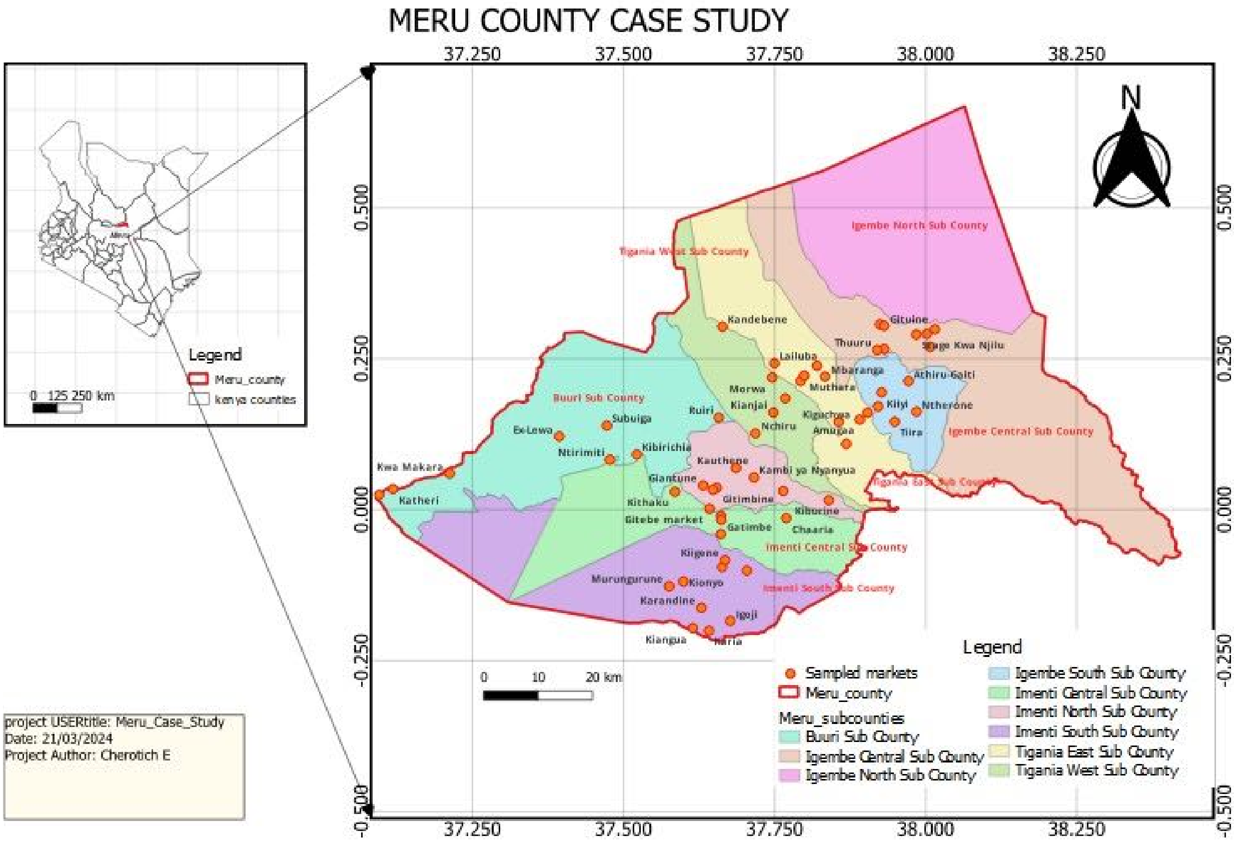

Figure 1: The map of the study area showing the locations of the markets where the samples were collected

Study Design and Sampling

A cross-sectional analytical study was conducted with small to medium-sized informal grain marketplaces being study units. Larger markets were excluded to ensure size uniformity of the study markets in terms of the number of maize grain vendors. Vendors who consented and are above 18 years of age in these markets were included in this study. Eight sub-Counties were purposively selected to represent all the informal markets in Meru County. A list of 90 informal maize trading markets was obtained from the Ministry of Trade Office during the pre-visit to the area. Out of the 90 markets, approximately 49 were selected for sampling, based on the availability and number of maize vendors in each market.

When the number of vendors exceeded 15, 15 traders were selected randomly. If the number of vendors was below 15, all vendors were included in the sample. In total, 353 maize grain vendors were selected.

Maize Sample Collection and Lab Analysis

Maize grain samples were collected in July 2022 (low maize trading season) from vendors who had given their consent. If the vendor had multiple bags of the same variety, small samples were taken from each bag and combined to form a composite

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sample. However, if the bags contained different varieties, separate samples were taken from each bag.

Each bag of maize grains offered by the trader was opened and the samples were randomly drawn from several points from the top to the bottom. This procedure was done using the respective sampling tools; spikes and scoops. If the maize sold was from different sources (maize purchased from a distributor or local farmers), then a 100g sample was taken from each source and thoroughly mixed to obtain a homogeneous representative sample. Samples were then packed in well labelled Khaki bags and transported to laboratories for physical and chemical assessment. Approximately 353 maize grain samples were collected from traders who volunteered to provide them.

Physical analysis was done at the Kenya Agricultural and Livestock Research Organization (KALRO) laboratory in Kiboko, Kenya while aflatoxin analysis was carried out at the Mycotoxin Research Centre at the University of Nairobi's Department of Public Health, Pharmacology and Toxicology and Nutritional analysis was done at the Department of Food Science, Nutrition and Technology, University of Nairobi. The samples were quickly assessed for physical quality before being checked for chemical quality (aflatoxin analysis and nutritional analysis).

Determination of Physical Parameters

Grain Moisture Content

The maize grain samples were analysed for moisture content using the standard oven method 930.15 [31]. The crucibles and lids were weighed and recorded (W_1). While partially opening the lid, 5g portion of the ground samples (W_S) were evenly spread in the crucibles and closed then oven-dried at 135°C for 2 hours. After drying, the crucibles plus the lids with the dried samples were carefully taken out from the oven using thongs and transferred to the desiccator for cooling. The final weight of the dried samples and crucibles plus the lids was recorded (W_2). The moisture content was then calculated as a percentage on wet weight basis using the following formula:

$$\text{Moisture content (\%)} = \frac{W_S - (W_2 - W_1)}{W_S} \times 100$$

Where; W_S is the weight of the sample before drying; W_1 is the weight of crucible plus the lid; W_2 is the weight of crucible plus the lid and sample after drying.

Undamaged, Broken and Insect Damaged Maize

Each (100g) maize sample was sorted into three distinct categories; undamaged grains, mechanically damaged (broken) grains and insect-damaged grains. The sorting was done independently by two experts to minimise bias. Each sample was sorted twice, and the results from both rounds were averaged to determine the final

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counts. The three categories of grain were expressed as percentages of the total grain in the sample. The means of grain categories were calculated and recorded for both market and sub-Counties representing the results at the trader level.

Aflatoxin Analysis

Sample Preparation

The subsamples of maize grains collected from the vendors were combined at the market level, resulting in 49 samples that represented the studied informal markets. The sample preparation followed the manufacturer's recommendations for the kit (Cat. No. 941AFL01M.96). A Retsch Grindomix GM 200 grinder (Retsch GmbH, Haan, Germany) was used to grind 20g of each maize grain sample into fine particles. To prevent cross-contamination between samples, the grinding part of the machine was periodically dismantled and soaked in sodium hypochlorite solution for 2 minutes. The parts were cleaned and allowed to dry. From the ground maize, 5g of pulverized sub sample was obtained for aflatoxin analysis in accordance with the recommended protocol (Cat. No. 941AFL01M.96). The remaining pulverized samples were stored in khaki bags at room temperature for nutritional analysis.

Aflatoxin Extraction

Approximately 25mL of a 70% methanol-water solution was added to 5g of pulverized maize grain samples at a weight/volume ratio of 1:5. The preparation was thoroughly mixed for 2 minutes, allowed to rest on the bench at room temperature for the particles to settle down then filtered through Whatman No.1 filter paper to obtain 10 millilitres of supernatant.

Aflatoxin Assay

The aspartame assay protocol was performed following the guidelines provided by Helica Biosystems, Inc., the producer of the kit, without any modification (Cat. No. 941 AFL01M-96). Dilution wells for each standard and sample to be tested were placed in a microwell holder. An equivalent quantity of microtiter wells coated with antibodies was put in a different microwell holder. A 200µL quantity of aflatoxin-HRP (Horseradish peroxidase) conjugate was added to each sample and mixed thoroughly in an Eppendorf precision pipette. For every sample and standard, a fresh pipette tip was used to avoid cross contamination of the samples.

Using a multi-channel pipettor, 100µL of the standards and samples respectively, were introduced to the suitable conjugate-containing mixing well with 200µL and the pipette was primed three times or more to ensure thorough mixing. The concentrations of the six standards were as follows: 0.0, 0.2, 0.5, 1.0, 2.0 and 4.0ng/ml. Each time, 100µL of the contents from the mixing well was transferred in duplicate using a fresh pipette tip to a matching microtiter well coated with antibody and incubated for 15 minutes at room temperature in the dark. The microwell

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contents were poured into a trash basin that contained 3.5% sodium hypochlorite sterilizer. One pouch of Tween 20 was combined with one litre of distilled water to create PBS-Tween wash buffer, which was then used to wash the microwells. Each microwell was filled with PBS-Tween wash buffer and then the buffer was discarded. This was done for a total of five washing cycles. To get rid of any remaining washing booster, the microwells were inverted and tapped on a layer of absorbent paper towels. Approximately 100µL of substrate-chromogen was added to each microwell, shaken and allowed to incubate for five minutes at room temperature. Following the incubation period, 100 microliters of the stop solution were introduced into every well.

Aflatoxin Limit Validation

Each microwell's optical density (OD) was measured at 450 nm using a Multiskan Plus reader (Labsystems Company, Helsinki, Finland). The average enzyme-linked immunosorbent assay (ELISA) reading value was calculated for every sample and standard. The total aflatoxin standard concentration values were plotted on the y-axis and the optical density values on the x-axis for each ELISA plate to create a standard curve. These regression curves were then used to calculate the aflatoxin value in each sample. A certified maize reference sample having a total aflatoxin level of 27ppb, batch number 02017-000079 (Texas State Chemist, Texas, USA), was utilized to validate the analytical procedure.

The total aflatoxin limit of detection (LOD) was 0.2µg/kg and the limit of quantification (LOQ) was 0.6µg/kg. Samples with toxin values below the detection limit were considered to have no detectable toxin present. Non-detectable levels were determined by analysing the toxin's detection limits (LOD) as per the test protocol. The East African Community (EAC)'s maximum tolerated limit (10ppb) was compared to the detectable aflatoxin levels.

Proximate Analysis

Proximate analysis of pulverised grain samples was done according to the Association of Official Agricultural Chemists (AOAC) methods [32]. Crude protein content was determined using the Kjeldahl method, where the nitrogen content of the sample was measured and then multiplied by a factor of 6.25 (method 978.04). Fat content was determined using Soxhlet extraction method (method 930.09), which involved extracting fat using a Soxhlet apparatus and a suitable organic solvent.

Data Analysis

The ranges of aflatoxin levels were determined and categorized into three groups; less than 1ppb (low or none); 1-10ppb (moderate); and greater than 10ppb (above permissible levels). Aflatoxin values were analyzed using a one-way ANOVA with sub-Counties as predictor variables to assess variations across regions. Separation of means was performed using Tukey's HSD test. The correlation of aflatoxin levels with physical parameters (undamaged grains, broken grains, insect damaged grains and moisture) and nutritional parameters (oil, proteins and starch) were established using Pearson's correlation analysis [31].

Ethical Considerations

Ethical clearance and permission were sought from the Amref Ethics and Scientific Review Committee (ESRC) with Protocol Identification Number: ESRC PI 141/2022. Additionally, a research permit was issued by the National Commission for Science, Technology & Innovation (NACOSTI) License no: NACOSTI/P/22/17001. Before any data was collected, each respondent was made aware of the purpose of the study and given the chance to give their oral consent.

RESULTS AND DISCUSSION

Aflatoxin Prevalence

The aflatoxin levels observed in the sub-Counties ranged from 1.1ppb to 25ppb (Table 1). Aflatoxin levels varied significantly across the sub-Counties ($F = 17.51$ df $= 8$, $p < 0.0001$). The highest aflatoxin levels, exceeding the allowable level of 10ppb, were recorded in Tigania East (25ppb) followed by Imenti Central (17ppb), Tigania West (12ppb), and Igembe South (11ppb). Contrarily, sub-Counties such as Imenti North, Imenti South, Igembe Central, Buuri and Igembe North recorded lower levels ranging from 1-6ppb. The observed variations in aflatoxin levels can be partly associated to different agro-ecological conditions (temperature and humidity), pre and post-harvest practices in the regions. Notably, higher temperature and humidity favour the proliferation of aflatoxin-producing fungi such as *Aspergillus flavus*. These findings are consistent with those of Omara et al. [20], who reported that maize from Kenya contained highest levels of aflatoxins in East Africa with a mean of 131.7µg/kg. The results of the present study showed that Tigania East, Tigania West, Imenti Central and Igembe South sub-Counties had 80, 25.0, 16.7, and 14.3% of the samples considered unsuitable for human consumption due to aflatoxin levels exceeding 10ppb). Generally, the average aflatoxin was 8.66ppb with 35.2, 47.8 and 17.0% of maize samples from Meru County contains less than 1ppb (low or none); 1-10ppb (moderate); and greater than 10ppb (high) aflatoxin levels, respectively. Maize samples from sub-Counties such as Imenti North, Imenti South, Igembe Central, Buuri, and Igembe North showed safe aflatoxin levels (<10ppb), suggesting better agro-ecological conditions and possibly improved storage or handling practices in these areas.

Informal markets in Kenya including Meru County, have showed in previous studies to have higher aflatoxin prevalence due to factors such as poor storage conditions,

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inadequate storage facilities and practices can contribute to aflatoxin growth [32]. In lack of regulation, informal markets may not adhere to strict quality control measures, increasing the risk of aflatoxin contamination, under climate and environmental factors such as high temperatures and humidity, can foster aflatoxin growth [32].

Physical and Nutritional Properties of maize sold in informal markets

The physical properties (undamaged grains, broken grains, insect damaged grains) varied significantly across the sub-Counties ($p<0.05$) as shown in Table 2. However, grain moisture content did not exhibit significant variation among the sub-Counties. Similarly, Tadesse [33] reported that inadequate storage systems expose grains to risks from insect and rodent pests, resulting in significant losses. The current findings can be attributed to different pre- and post-harvest management practices that may influence physical maize quality [34]. Post-harvest losses are aggravated by late harvesting, poor processing practices and poor storage facilities [35, 36].

In contrast, the nutritional properties of the maize grains (such as crude fat, crude protein and starch) did not show any significant variation across the eight sub-Counties ($p>0.05$) (Table 2). This implies that the amounts of these nutrients in maize from each sub-County were comparable, and any variations that were seen were probably too small to be statistically significant. This can be explained by a number of factors, including the use of comparable maize varieties, uniform agricultural procedures, steady environmental conditions, and comparable crop management and fertilization methods, suggesting a high degree of uniformity in both cultivation and environmental conditions. The nutritional properties (crude fat, crude protein and starch) remained similar across the eight sub-Counties. The results align with the previous studies showing that consistent agricultural practices, stable environmental factors, and the use of similar maize varieties contribute to uniform nutritional properties in maize. Badu-Apraku *et al.* [37] found that consistent growing conditions, stable environmental factors and crop management leads to uniform nutrients.

Relationship of Aflatoxin Levels with Physical and Chemical Properties of Maize Grains

Initially, the physical parameters were assessed for each individual sample. However, to reduce the cost of aflatoxin testing, I pooled 5-10 samples from the same market. Before performing the correlation analysis, I averaged the physical parameters of the samples within each pool. Aflatoxin levels were found to be significantly correlated with several physical properties of maize grains (Figure 2). There were positive and significant correlations of aflatoxin levels with broken grains ($r = 0.15$, $p = 0.0054$), moisture content ($r = 0.37$, $p < 0.0001$) and insect damaged grains ($r = 0.12$, $p = 0.\ 0.022$). These results imply that grains with high moisture content are prone to aflatoxin contamination and insect damage on the grains allows fungi to gain access and contaminate the grains. Our findings agree with what was found in Meru, that maize with the most broken kernels was most contaminated with aflatoxin [36]. Contrarily, the proportion of undamaged grains showed a negative but weak association with aflatoxin levels ($r = -0.064$, $p = 0.23$) suggesting that while undamaged grains are less likely to be contaminated, other factors like storage conditions, moisture, and fungi still play a role. Therefore, undamaged grains are at a lower risk of contamination, but not immune.

The pre- and post-harvest exposure of African populations to aflatoxin poisoning poses a serious health danger. Mould and mycotoxin contamination of grains are mostly caused by the moisture content and physical state of the grain. As noted in previous studies, insect damage affects the degree of mycotoxin contamination through their feeding habits, which can cause wound grains, introduce fungal spores onto surfaces and spread mycotoxigenic fungal spores from the plant to the inside of the stalk or kernels [33, 34].

We found that maize grains with the most damaged (broken) kernels, high insect infestation and high moisture content were the mostly contaminated with aflatoxin. In contrast, clean maize (undamaged kernels), had the lowest levels of aflatoxin contamination. Presumably, the broken maize kernels exposed the interior part of maize to opportunistic fungi promoting easy colonization by fungi. Previous studies have reported high incidences of maize being contaminated due to damage caused by insects [34-37]. Damage to maize kernels can occur during post-harvest processes, such as shelling. During the pre- and post-harvest stages, the damage can be caused by insect pests, rodents, and birds. Damaging the maize kernels increases the susceptibility to fungi infection and consequently to aflatoxin contamination [38].

Drying maize grains to 13% moisture or below before storage is one of the most critical aflatoxin management practices recommended [39, 29]. Similarly, Tonui [40] reported that high moisture levels of cereals (19% to 25%) increased the susceptibility of grains to aflatoxin-causing fungi by favouring their proliferation. High moisture also favours germination of grains, insect infestation and reproduction, further predisposing the maize to aflatoxin-causing fungi [38]. Although relatively low moisture levels ranging from 12.0% to 16.2% were recorded, significant correlation was observed between moisture levels and aflatoxin levels. Reportedly, moisture content of 12–13% and low temperatures (below 18°C) are not favourable for the growth of aflatoxin-causing fungi [41].

Although quality parameters such as moisture level, proportion of broken maize kernels, insect infestation, colour change and time of harvest/storage are key in

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assessing aflatoxin incidences, a survey conducted by Cherotich *et al.* [42] in Meru County indicated these quality parameters were least checked by vendors and consumers. Similarly, Hoffmann et al [43] reported that consumers may need to rely on easily observable physical parameters as indicators of the level of aflatoxin contamination in maize to make informed decisions during purchase of maize or before consuming maize produced from their own farms. Therefore, the present study confirms that there is correlation between physical parameters and aflatoxin level.

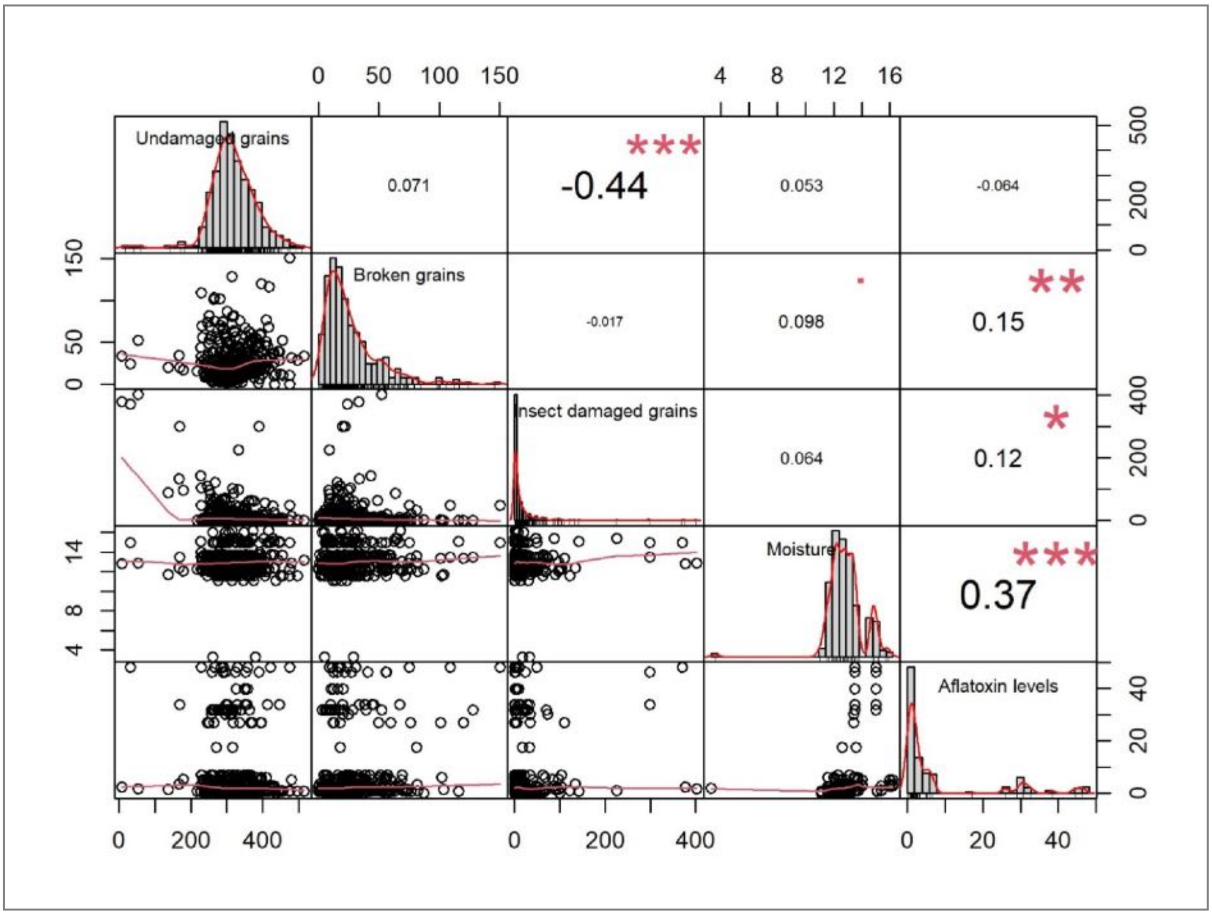

Figure 2: Illustration of relationship of observable physical attributes and aflatoxin levels of maize grains

Relationship between Nutritional Properties and Aflatoxin Levels of Maize Grains

The aflatoxin levels were negatively and not significantly associated with both fat content (R = -0.05, p = 0.71 and starch (r = -0.03, p = 0.31). Aflatoxin levels showed a positive but not significant association with protein (r = 0.10, p = 0.39), (Figure 3). One possible explanation for the lack of a significant association between aflatoxin levels and fat or starch content is the utilization of these nutrients by insect pests and fungi as essential sources of energy and building blocks during proliferation. As

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the insects and fungi feed on the grains, they may reduce the fat and starch content, which may lead to a slight decrease in the nutritional quality of the maize. Most of the substrates that support the growth of fungi are rich in nitrogen (proteins) and carbon (carbohydrates and fats) [44]. Additionally, insect infestation has also been associated with decrease in the carbohydrate content of the stored grains, while resulting in a relative increase in the proportion of protein and fibre [45]. Similar findings on impact of aflatoxin on maize nutritional properties have been previously reported. For instance, Worku *et al.* [27] demonstrated that the oil and protein contents of maize grains with aflatoxin reduced from 8.0 - 30.2%, 5.8–12.0%, and 0–66.7%, respectively when compared to clean maize grains. Jimma zone of Ethiopia showed a reduction of up to 37.5% and 20.0% protein and oil contents, respectively, in stored maize. Aflatoxins can decrease the nutritional value of maize grains, making them less suitable for human consumption [27].

The health effects of aflatoxins on humans have been largely discussed regarding exposure during ingestion and manifestation of signs of illness [13, 31]. For instance, ingestion of large quantities of aflatoxin within a short time may cause acute aflatoxicosis which is largely associated with increased weariness, jaundice, vomiting, liver damage, enlarged bile duct and ultimately death [8], whereas chronic exposure can lead to immunosuppression, oesophageal cancer and growth retardation in foetus and infants [13]. Aflatoxins can decrease the nutritional value of maize grains, making them less suitable for human consumption. However, evidence on the effect of aflatoxin on produce in terms of nutritional value is limited.

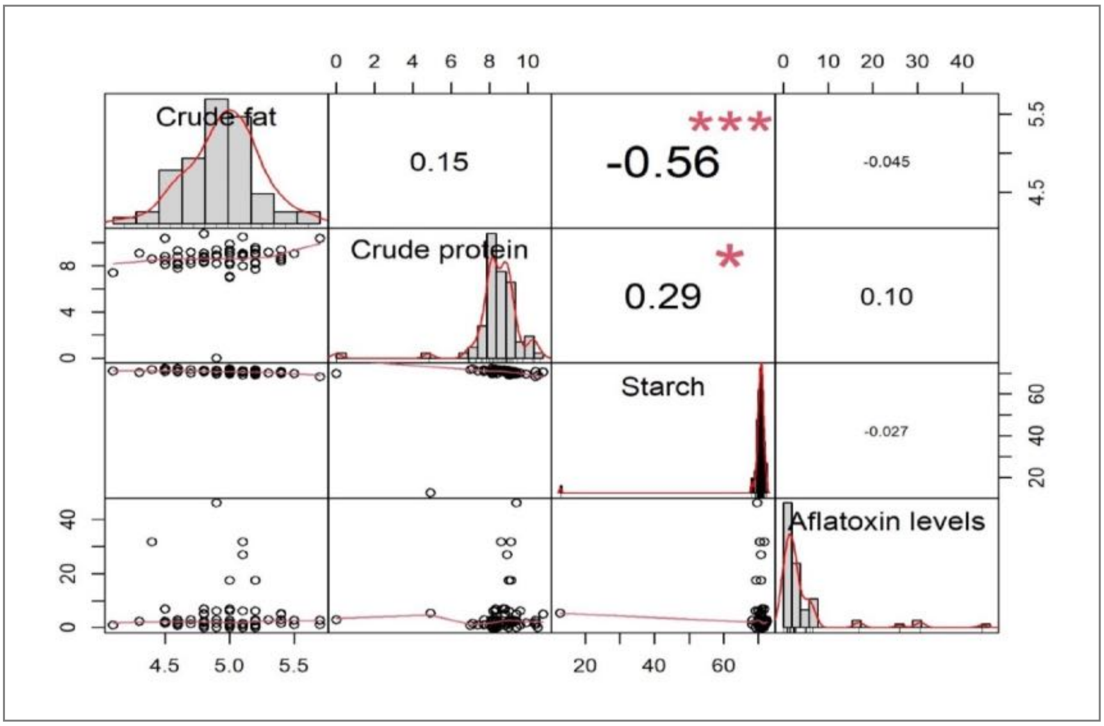

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Figure 3: Illustration of relationship of nutritional properties and aflatoxin levels of maize grains

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The study found that approximately 17% of maize grain samples in Meru County especially from Tigania East, Tigania West, Imenti Central, and Igembe South sub-Counties had high aflatoxin levels (>10ppb), and were unsuitable for human consumption. Additionally, aflatoxin contamination decreases the nutritional value of maize grains, making them less suitable for human consumption. It emphasizes the need for enhanced surveillance of aflatoxin poisoning and testing of maize grains to detect and prevent outbreaks of aflatoxicosis. Strict regulations enforcement of aflatoxin levels in food products and raising awareness among stakeholders about aflatoxin risks and prevention methods are recommended.

High levels of broken kernels, insect damage, and moisture contribute to increased aflatoxin contamination. The study recommends improving both pre-and post-harvest handling practices and encouraging local governments to educate the public on the link between these factors and aflatoxin infection, as well as enforce safe storage practices.

Nutritional contents such as fat, starch, and protein did not significantly associate with aflatoxin levels. However, frequent exposure to aflatoxins can impair nutrient absorption, highlighting the importance of both reducing aflatoxin levels and preserving the nutritional value of maize.

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COMPETING INTEREST

The authors declare that there were no competing interests regarding the publication of this paper.

Table 1: Percentage of Samples with Aflatoxin at different contamination categories per sub-County

sub-County	Aflatoxin range (ppb)	Average	Aflatoxin category (%)			Number of samples (n)
			<1ppb (low)	1-10ppb (medium)	>10ppb (high)	Total = 49
Buuri	0.00-3.42	1.1 ± 0.2^{d}	33.3	66.7	0.0	6
Igembe Central	0.00-6.86	2.4 ± 0.4^{d}	33.3	66.7	0.0	6
Igembe North	0.94-1.40	1.1 ± 0.1^{d}	100	0.0	0.0	2
Igembe South	2.29-46.19	11.1 ± 2.5^{bc}	0.0	83.3	16.7	5
Imenti Central	1.28-48.15	16.8 ± 4.0^{ab}	0.0	83.3	16.7	6
Imenti North	0.29-39.83	6.5 ± 2.4^{cd}	42.9	42.9	14.3	7
Imenti South	0.71-6.16	2.0 ± 0.3^{d}	87.5	12.5	0.0	8
Tigania East	1.09-33.87	25.0 ± 2.1^{a}	20.0	0.0	80.0	5
Tigania West	1.09-31.83	11.9 ± 1.8^{bc}	0.0	75.0	25.0	4
F-value		17.51				
p-value		<0.001				

Values with different superscripts in the column are significantly different at $p\leq0.05$

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Table 2: Grain Physical and Nutritional Properties per sub-County.

sub-Counties	Physical properties (%)				Nutritional properties (%)		
	Undamaged grains	Broken grains	Insect damaged grains	Moisture	Crude fat	Crude protein	Starch
Buuri	90±1[b]	4.4±0.5[ab]	4.7±1.2[ab]	12.7±0.1[a]	5.0±0.1[a]	8.7±0.2[a]	71.2±0.2[a]
Igembe Central	93±1[a]	3.9±0.4[ab]	2.7±0.7[b]	13.0±0.3[a]	4.9±0.1[a]	8.0±0.4[a]	70.9±0.2[a]
Igembe North	87±5[abc]	4.1±1.7[ab]	7.7±4.4[ab]	11.7±0.0[a]	4.7±0.0[a]	8.5±0.0[a]	71.8±0.0[a]
Igembe South	91±2[ab]	4.6±0.4[ab]	4.6±2.3[ab]	12.6±0.2[a]	4.9±0.1[a]	9.1±0.3[a]	70.8±0.3[a]
Imenti Central	87±3[abc]	6.3±0.9[ab]	5.8±3.0[ab]	13.0±0.6[a]	5.2±0.2[a]	9.1±0.3[a]	70.1±0.4[a]
Imenti North	88±3[ab]	3.7±0.5[b]	7.1±2.6[ab]	11.2±1.6	4.9±0.1[a]	8.9±0.2[a]	70.8±0.3[a]
Imenti South	92±1[ab]	4.9±0.4[ab]	3.0±0.8[ab]	12.8±0.3[a]	5.0±0.1[a]	8.5±0.2[a]	70.4±0.2[a]
Tigania East	85±2[c]	5.8±0.8[a]	7.9±2.5[a]	13.2±0.3[a]	5.1±0.1[a]	9.0±0.1[a]	70.3±0.5[a]
Tigania West	91±1[a]	3.7±0.4[b]	4.3±0.9[ab]	13.7±0.4[a]	5.0±0.2[a]	9.0±0.4[a]	70.5±0.4[a]
Average	90±1	4.4±0.5	4.7±1.2	12.8±0.2	5.0±0.0	8.6±0.2	70.7±0.1
F-value	2.09	2.49	2.20	1.14	0.69	1.01	1.68
p-value	0.036	0.012	0.029	0.347	0.711	0.445	0.113

Values with different superscripts in the same column are significantly different at $p \leq 0.05$. A total of 353 maize grain samples, collected from nine sub-Counties, were analyzed for physical and nutritional properties

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