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Risk mitigation of aflatoxin contamination in maize and its food and feed products in developing countries: a review

[2]WANJIRU J W., [2]NJUE J G., OKOTH M W., [1]KARAU G M*

[1]Kenya Bureau of Standards
[2]University of Nairobi, Department of Food Science, Nutrition and Agriculture

***Corresponding Author**: joywangeshi22@gmail.com

Abstract

Food safety is key to a health population in the developing countries along the whole value. Maize and its products' safety from aflatoxin is a concern taking into consideration that they are highly consumed in these countries as their staple food by individuals from different socio- economic levels and upbringings. It's used to manufacture human foods which include maize flour, grits, porridge, beers among others and animal feeds where their consumption show health benefits such as provision of vitamin B-complex for skin, heart, brain, hair and improved digestion in humans. Aflatoxin exposure from maize products and feeds consumption have been so frequent in alarming rates leading to Aflatoxicosis which is a serious health risks to consumers and livestock, maize grain scarcity and global trade impact therefore nations have set strict threshold limits. Google Scholar database was used in the research of the literature articles that are recent and related to aflatoxin in maize grains. Great emphasis is based on maize grains and feeds' safety from aflatoxins thus this review is focused on the aflatoxin in maize in terms of research on recent toxicity data, maize contamination impacts, mitigation measures research on safe methods that can't lead to risks due to further contamination with harmful residuals and the future interventions from the literature that should be installed considering that maize is the main food in Sub- Saharan Africa. Therefore, available mitigations are applicable and hence the government relevant bodies are required to enforce strict measures on their application while enhancing a favorable environment to partners who would be available in installation of the future predicted measures.

Keywords: *Aflatoxin, Threshold, Sub-Saharan Africa, Mitigation, Maize, value chain*

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Introduction

Aflatoxins are toxic carcinogens and mutagens which are released by some molds that are known for their extreme toxicity and their availability in food and feed is highly poisonous. Aflatoxins are highly detected in poorly stored cereal foods which include millet, cottonseeds, peanuts, cassava, rice, sesame seed, pepper, chili, sweet corn, sunflower seed, tree nuts, sorghum, wheat and spices. Consumption of aflatoxin from feed and food, bring about the exposure of naturally occurring aflatoxin B_1, B_2, G_1, and G_2 which are the dominant aflatoxin types which act as strong carcinogens which are assigned into Group 1 "human's carcinogens" by the International Agency for Research on Cancer (IARC) (Ostry *et al.,* 2017). Aflatoxin M1 is the metabolite of AFB1 found in milk due to consumption of feed containing aflatoxin which is considered to be a possible carcinogenic agent. Apart from their carcinogenicity, these types of aflatoxins have been reported to have genotoxic, hepatotoxic, immunosuppressive, mutagenic, nephrotoxic, teratogenic and cytotoxic effects (Afshar *et al.,* 2020). Having been classified as the largest mycotoxin group produced by the species of *Aspergillus flavus* and *A. parasiticus* which are secondary metabolites, they have low molecular weight and they are extremely carcinogenic compounds classified as the largest group of mycotoxins that are responsible for the grains' spoilage. Under extreme stress and low maintenance which include low nitrogen content, drought and high temperature, fungal presence cause aflatoxin accumulation to the stored grains (Pickova *et al* 2021). Other conditions that lead to difficulty in aflatoxin growth control are climatic which include the combination of high temperature and high moisture content above 7% (Awuchi *et al.,* 2020). In Sub- Saharan Africa, aflatoxin prevalence is high because of the hot-humid conditions that are found to accelerate fungal growth (Wild *et al.,* 2010). Due to its high preference, global food safety concern has increased as the World Health Organization report demonstrated, where the rural small scale subsistence farmers in developing countries are ranked to have high risk of exposure to aflatoxin (WHO, 2015). Globally, maize is characterized as the leading feed, food and industrial crops to reduce the food security crisis (Erenstein *et al.,* 2021) although, it has often been found to be highly contaminated by aflatoxin, this being contributed to low application of the mitigations of prevention and reduction. Several cases have been discovered from Sub- Saharan Africa on maize and feed consumption where loss of lives have been continually witnessed due to their aflatoxin levels that were above threshold to both human, livestock and also the negative effect on the economy has been addressed. Safe maize grains free from aflatoxin has therefore proven to be an important food item to improve food security therefore this literature review focuses on its aflatoxin safety in developing countries as the staple food which is overwhelmingly consumed, the contamination levels, aflatoxin mitigations expounding the future interventions that need to be addressed in pre- and postharvest handling of maize grains and animal feeds taking into consideration on its negative effects due to its exposure to both human and the livestock. The aim of this literature review is to pull the mitigations for aflatoxin reduction together and hence the data may be available for application and further research.

Materials and methods

Literature search in this study was conducted by the use of Google Scholar database. All the literature articles that are recent and relevantly related to aflatoxin in maize grains, the importance of maize grains to the developing countries taking the hinderances of their growth into consideration and also the impact of aflatoxin exposure to human, livestock and to the economy and the efforts that have been put in place to reduce levels on food and feed were conducted. The relevant reports that belong to country's profiles were consulted where websites of Governments' institutions including the Kenya Bureau of Standards, Kenya National Bureaus of Statistics, Ministry of Health, Ministries of Agriculture, Food and Agriculture Organization of the United Nations (FAO) and Joint Committee on Food additives were obtained including the search from the Google literature.

Results

Studies that have been conducted in many developing countries globally showing different exposure levels to aflatoxin from the maize and the products' consumption being the staple food. Also, there are a number of incidences of aflatoxin contamination from the food and feed manufactured from maize grains and the health risks reviewed specifically from these developing countries. Intense review on mitigations of aflatoxin and the predicted activities that should be installed strictly in future were discussed.

Maize as a staple food in developing countries

The developing countries cover a total of 64% of the world's maize area (Dowswell *et al.,* 2019). Maize has different production and trading patterns depending on the geographical regions and also the end uses. In USA, humans consume of about 12% maize and the remaining is used for animal feeds manufacturing and in production of ethanol fuel. In Africa, maize is more considered the staple food for human consumption. In many countries, the highest number of foods consumed daily are based on maize and its products. Figure 1 shows the parts of the maize grains which upon processing, several parts of the grain produce a different product hence the maize grains usage is wide which include processing of the corn oil.

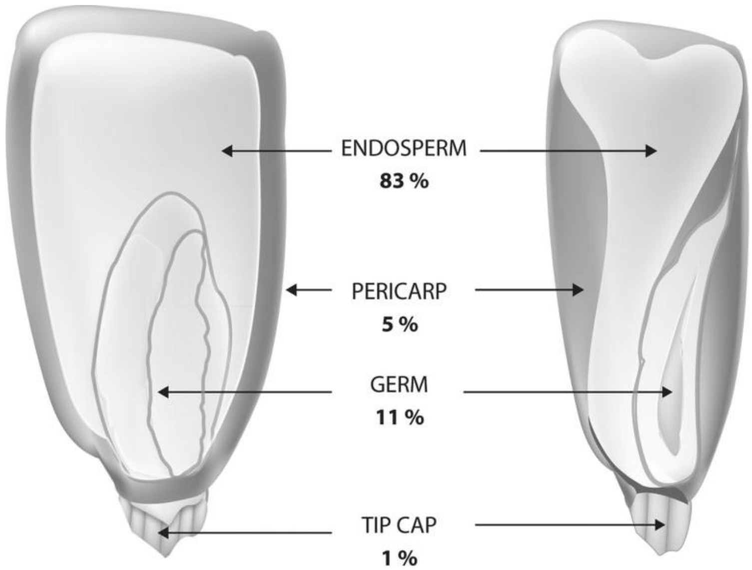

Figure 1: Parts of the maize grains (Gwirtz et al., 2014).

Moreover, it is the main crop and the main source of minerals and calories for most populations as shown in figure 1 from different socio- economic levels. It has health benefits including vitamin B-complex for brain, skin, hair and heart (Amudalat *et al.,* 2015). A 50% increase in price of maize has shown stagnation in calorie intake for both urban and rural households leading to a sharp significant decline in its consumption (Rudolf *et al.,* 2019). It contains essential fatty acids (Rouf Shah and Kumar, 2016), which include linoleic acid. Kenya has been consistently been producing less maize with per-capita consumption of about 125 kg/year (Ombuki *et al.,* 2018).

Vitamin	Unit / 100 g	Corn, whole	Corn, bran	Corn, starch
Thiamin	mg	0.39	0.01	0
Riboflavin	mg	0.20	0.10	0
Niacin	mg	3.63	2.74	0
Pantothenic acid	mg	0.42	0.64	0
Vitamin B6	mg	0.62	0.15	0
Folate	µg	19.00	4.00	0
Choline	µg		18.10	0.40

Table 1: Nutritional content of the maize grains

Source: U.S Department of Agriculture

The three main primary categories of maize use include; Human consumption, animal feed and ethanol for fuel. Maize has a wide range of products which include porridges, bread, tortillas, couscous and cornbread. Flour and grits are commonly used as raw material used in breweries. Corn starch, corn oil and sweeteners among products, are among food products that are produced from the maize.

Production of maize and utilization in Kenya

In Kenya, maize is an important crop where about 2.1 million ha out of 5.3 million Kenya's ha of the crops that were cultivated between 2011 and 2013 was maize which is the leading staple food in Kenya slowly replacing the indigenous food crops. The major areas that maize is produced includes; Uasin Gishu, Trans- Nzoia, Kakamega, Embu, Nyeri, Taita-Taveta, Nakuru, Kwale and Kirinyaga (De Groote *et al.,* 2020). In addition, its farming has become a source of income for many farmers making its production a sensitive subject in the country.

The maize importation policies from the government have been inconsistent and have caused excessive importation without the set control. Due to this, there has been an outcry from farmers in the last few years due to lack of markets and poor payments to the farmers after their sales to the National Cereal and Produce Board through the merchants, brokers and cartels has delayed payments to genuine farmers. Having that maize is produced by the small -scale farmers, they face very difficult conditions and challenges during the cultivation time. These challenges include weather variation, poor soils, seeds of low-yield and losses during post-harvest due to traditional storage techniques that are in use which are found to be ineffective in reducing food safety hazards to consumers (Cairns *et al.,* 2021).

Globally, machineries of farming have played a crucial role of enhancing agricultural production by improving land productivity. In developed countries, use of machinery in farming is being highly incorporated while in other parts like in Kenya; farm machinery use is almost negligible leading to low maize output (Zhou *et al.,* 2020).

The unreliable and low rainfall, diseases and pests and inherently infertile soils which is highly caused by low soil nutrients levels has also caused low harvests of maize in Kenya leading to scarcity (MANG'ENI *et al.,* 2022). The cultivation has also led to employment creation through the contribution of the gross domestic production to the households while the poor climate of cultivation has led to decline of the output lowering the employment level hence decreasing the per capita consumption (Mumo *et al.,* 2018).

Processing of Maize products

Some of the most important nutraceuticals known to enhance health are sourced from maize. The components of the maize include the phenolics compounds, carotenoids from the yellow maize, the nonpolar and the polar lipids obtained from the insoluble and the soluble dietary fiber, anthocyanin from the blue maize and phlobaphene that is found in the red maize (Serna-Saldivar *et al.,* 2016). Therefore, it can be consumed in different forms after being processed and by doing so, its consumption level to the population increases. When maize flour is mixed with other ingredients which salt, egg, sugar, spices, groundnut and vegetables, different types of bread and snacks are produced (Palacios-Rojas *et al*., 2016).

The maize flour functional properties, nutritional value and the commercial properties can be improved by adding protein producing products which include; chick pea, sunflower seed, soybeans, sesame seed, cowpea, peanuts, melon seed, lentil seeds, sweet potato flour and shea nut. Maize-based flour bread was observed to yield acceptable bread after being mixed with composite flour which is a non- wheat with the ratio of maize starch 40%, xanthan gum 0.5% soybean flour 19.5% and sweet potato flour 40% (Julianti, *et al.,* 2017). In baking, maize flour has been in use and has been more productive when the flour is used together with other cereal products and has been found to improve the properties. Maize is also used in making of maize porridge. In Kenya, 46% of consumers of maize porridge take it as the breakfast (uji) if its thin for economic reason due to its high density (Ohna *et al.*,2012) while when is thick (ugali), 67–71%, they consume it for lunch or dinner (De Groote *et al.*,2012). 64% population across Eastern/Southern Africa consumes *Ugali* 5 to 7 times in a week (Muzhingi *et al.,* 2008).

The low dry matter content of between 6–10 g/100 ml of the thin porridge makes it nutritionally inadequate to about 0.40 Kcal/ml that is lower than 0.68 Kcal/ml that of breastmilk to infants who has the highest number of consumers consisting of about 70% (AM *et al*., 2015) but the protein, energy and the density levels can be improved by adding of legumes viscosity favorable for infant foods (Nout *et al*., 2009). Therefore, in Kenya, maize flour is the most highly consumed maize product across the economic levels of the population.

Products such as liquid corn syrup, corn sugar also use maize as the raw material. The process of malting and fermentation of alcoholic beverages by use of maize flour is achieved by the use of lactic acid bacteria including the *Lactococcus, Lactobacillus, Pediococcus* and *Leuconostoc*, fungi (e.g., *Aspergillus*) and yeast (e.g., *Saccharomyces*) while the nonalcoholic ones, are produced through soaking with light fermentation (Dabija *et al.,* 2021). Traditional Alcoholic beverages that are brewed traditionally are found to contain the highest alcohol percentages in Africa, which is made from maize fermentation and has low cost of manufacturing (Motlhanka *et al*., 2018). Animal feeds, silage and the fuel production in developing countries has been highly produced from the maize leading to the increase of maize production by 40% but also the high population that depends on the maize consumption has lowered the energy production (Ranum *et al*., 2014).

Aflatoxin contamination of maize and its products

Incidences of aflatoxin contamination in maize in Kenya

Aflatoxin is produced by the *Aspergillus flavus* and *Aspergillus Parasiticus*. Smallholder farmers produce maize under conditions that are sub-optimal, increasing the vulnerability to contamination by toxigenic fungi in Kenya. Large masses of grains stored in the silos are hard to control and monitor the conditions increasing the chances of vulnerability to contamination with time (Mutiga *et al.,* 2019).

Small-scale farmers from regions with high contamination vulnerability to mycotoxin, produce approximately 75 percent of total maize in Kenya (Wagacha *et al*., 2008). Several factors have been assessed due to aflatoxicosis outbreak in the year 2004 and 2005 in eastern Kenya (Lewis *et al*., 2005b; Onen *et al*., 2021). Maize handling along the food chain is the biggest contributor of the aflatoxin accumulation as its shown in Figure 2.

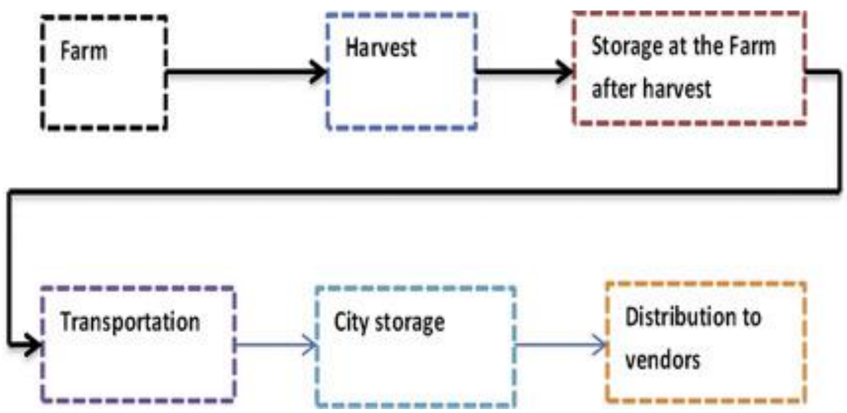

Figure 2: Maize grain handling chain

Maize was found to be contaminated by aflatoxin which led to death of over 200 people (Probst *et al.*, 2007).

In Nandi and Makueni counties, it was observed that 68.3 and 80.4% of the maize that were respectively sampled contained aflatoxin levels above 10 ppb level which is the national threshold. Sorghum was also contaminated with aflatoxin where 66.7% and 88.9%, were found positive and 37.1 and 29.9% had the levels above the threshold in the same counties. This showed that maize was highly invaded by aflatoxin compared to other cereal products (Kang'ethe *et al.,* 2017) . Another study which was done in south-western and eastern regions of Kenya, AFB1 levels of 68 ppb, 22 ppb respectively, were found where from both regions, aflatoxin B1 were above the 5 ppb limit for AFB1 (Kenya Bureau of Standards, 2014).

Maize grains were sampled from Western Kenya storage facilities of the farmers and the milled maize flour was obtained from hammer mills locally known as "posho" mills. The fact that the surrounding households use the same "posho mill", chances of cross contamination of maize from different households was present. Aflatoxin levels were detected in 49% of the total samples which were found to contain aflatoxin and 15%, were above the threshold of 10 ppb.

Aflatoxin contamination of feeds

Feeds are formulated domestically or are bought from manufacturers and are sold through agro-chemicals outlets where maize is used as a component. Smallholder farmers tend to use supplements that are dairy diets together with feed concentrate in order to boost their products which include the oilseed plants that produce press cakes and also the seed cakes such for example cotton seeds, peanuts and sun flower seeds which are highly prone to aflatoxin contamination (Mmongoyo *et al.*,2017). The several by-products from the maize flour production used to manufacture feeds are also prone to aflatoxin contamination due to the germ which contains corn oil and aflatoxin is absorbed into it (Kimuli *et al.,* 2018).

Risks of aflatoxin contamination

Risk to human health

Aflatoxins exposure to human leads to aflatoxicosis which is a medical detrimental condition to reproductive organs, liver, kidneys, the immune system and cardiovascular system. These mycotoxins' toxicity main target organ is the liver which contributes to oxidation and nitration stress responses, lipids, RNA, proteins and DNA damage. These effects lead to Hepatitis, edema, vomiting, jaundice and eventually death (Mohajeri *et al.,* 2018). Worldwide, Hepatocellular carcinoma (HCC) is the sixth type of cancer caused by the exposure to aflatoxin where in developing countries the incidence rate is approximately 82% of 600,000 new cases in every year (Parkin *et al.,* 2005b). A study was conducted in Ghana and the report showed that higher levels of AFB_1–albumin in plasma blood were correlated with low levels of leuko-cyte immunophenotypes (Strosnider *et al.,* 2006). Saliva from children in Gambia showed an association between reduced secretory immunoglobulin A and serum aflatoxin–albumin levels (Turner *et al.,* 2003). Protein synthesis is inhibited by aflatoxin metabolites that react negatively to the cells where liver is the main target leading to its decrease of functioning capacity. Numerous studies have documented High aflatoxin prevalence associated with stunting in childhood from low-income countries who have been found to have increased disease estimation burden from blood aflatoxin albumin biomarkers (Rasheed *et al.,* 2021). Exposure to small doses of aflatoxin over a given period of time leads to its accumulation in the body.

Risk to livestock health

As in humans, exposure of aflatoxin-contaminated feed to livestock, leads to toxicity levels that are severe which eventually cause death. Aflatoxin exposure to poultry with high levels leads to liver damage, reduced growth, low egg production, feed conversion, compromised immune functions which is led by their reduced ability to metabolize vaccines affects economic costs to producers. The most sensitive animals known to AFB1 is Domestic turkeys (*Meleagris gallopavo* (Monson *et al.,* 2015).

Fish contamination by fungi colonization causing aflatoxin leads to a major health concern to animals where some clinical symptoms were reported from the fish which were infected naturally portraying yellow coloration and skin ulceration, patches that had ulcers that were hemorrhagic on skin and gills, corneal opacity, fin rot and distention in the abdomen (Mohamed *et al.,* 2017). Dogs are also highly susceptible to aflatoxins exposure causing acute dog illnesses and death (Vudathala *et al.,* 2021).

Economic outcomes of aflatoxin contamination in maize grains and feeds

Consequences of aflatoxin on trade

Different countries have adopted aflatoxin allowable limits for food products independently; European Union (EU) 4ppb, Food and Drug Administration (FDA) 20ppb, Kenya Bureau of Standards (KEBS) 10ppb. These standards have serious impacts on trade of food worldwide where their enforcement has largely reduced harmful exposures to consumers.

In developing countries, health impacts of aflatoxin exposure have accelerated due to the exposure to the staple foods largely to maize and its products.

Health and trade sectors are negatively affected by the contamination of feeds and maize based foods with aflatoxin leading to economic losses to agricultural produce. Several pre- and post-harvest techniques and technologies are capable of limiting the aflatoxin contamination though they may fail to reduce the toxin levels to below the thresholds (Moral *et al.,* 2020). Countries for example EU (4ppb) leads to importation challenge from aflatoxin prevalence areas. A study showed a reduction in imports in Europe from African countries to about 64% in cereal products because of strict allowable levels that they didn't meet and this led to economic loss (Wu *et al.,* 2015). It's discovered that most African countries don't implement surveillance exercise regularly for crop foods' aflatoxin levels frequently ending up with the consumption of maize products to a big population with levels that are higher than the threshold (Nelson *et al.,* 2020).

Effect of aflatoxin on economic planning

Speedily increased loss of foods due to aflatoxin contamination are witnessed together with the increase in costs of treating the food poisoning and the overall health maintenance which include increased pharmaceutical costs and high finances and the damage to the economy in agriculture and the livestock keeping sector. 20% of the worldwide foods' reports including for the maize grains according to Food and Agriculture Organization (FAO), annual produce is highly contaminated by mycotoxins (Eskola *et al.,* 2020). Cancer prevalence to humans and livestock's low production effects which include weakened immune system, low milk and eggs production are some of the damages to livestock and food industry caused by aflatoxin contamination. Due to contamination of feed and food to aflatoxin which has led to exposure of the general population and livestock, it has become a big problem in projecting the nation's growth in the cereals sector and its industrialization.

Development of risk mitigation of aflatoxin contamination

There are different strategies designed to mitigate and manage the levels of aflatoxin in Sub- Saharan Africa food value chains. These include;

Good agricultural practices (GAP)

There are strategies that are possible to implement which include planting of tolerant and resistant breeds. Also, sorting of the grains physically at the farm, controlling aflatoxin causing fungi both chemically and biologically, tillage, land preparation, drying, crop rotation chemical decontamination and appropriate storage will reduce aflatoxin contamination (Kang'ethe *et al.,* 2017c). Low-input farming practices lead to fungal and aflatoxin contamination of crops thus affecting the food security and the economic status in sub-Saharan Africa posing a risk to aflatoxin exposure (Hell *et al.,* 2011). The critical stages in aflatoxin contamination prevention of maize include pre-harvest practices, harvest timing, handling of produce during harvesting, levels of moisture content at the harvesting time, drying methods and techniques, packaging materials used, storage conditions, pest control, and local milling facilities and conditions (Mahuku *et al.,* 2019). Hermetic bags and silos used to store maize grains are some of the emerging technologies for maize storage including the use of mobile grain drying equipment before storage (Walker *et al.,* 2018). The technology of mobile grain dryers is yet to be adopted largely by farmers in Kenya due to high investment and operation costs. (Hoffmann *et al.,* 2021).

In western Kenya, a study was done to determine the social economic factors affecting a technology that reduces maize contamination by aflatoxin, involving the intercropping system which includes the maize rows, and the *Desmodium* legume which is the intercrop between Napier grass which is a border crop planted around the plot (Njeru *et al.,* 2019). This technology is known as push- pull farming that is highly adopted in western Kenya for the control of maize diseases (Owuor *et al.,* 2018). Maize samples from farms cultivated by push- pull methods, were found to contain low aflatoxin levels. Such GAP interventions have been shown to reduce levels significantly and hence to the risk of exposure.

Physical methods; Sorting methods can be either electronic or manual and they hinders aflatoxin contamination where the shriveled, moldy and discolored seeds are discarded (Hell *et al.*, 2011b). Artificial drying is highly practiced in developed countries where moisture content is reduced up to 12% for maize grains hindering aflatoxin producing fungi. Drying is by sun-drying on mats. Metal bins are used as new improved method of storage adopted by small scale manufacturers and their use is limited because of their high cost of operation and maintenance (Hell and Mutegi, 2011c). Crop storage is improved by the use of airtight hermetic triple bags which prevent grains from aflatoxin contamination and mold growth. The prices of the produce are determined by their quality which is an added advantage economically to high quality produces hence proper storage is highly encouraged (Kimatu *et al.,* 2012).

Radiation treatment

Gamma (γ) radiation produced from the Electromagnetic radiations is highly used in food preservation which is used in maintaining the agricultural products' in good quality (Indiarto *et al.,* 2020) where the high energy photons produced by the rays acts by damaging the DNA fungal cells. UV radiation has shown to reduce levels of aflatoxin substantially (Wanjiru *at al.,* 2020) where during the degrading; the safety or toxicity of the residue product has not been clearly determined (Mao *et al.,* 2016). Static hot air roasting that was used as a tradition method of aflatoxin decontamination used together with the infra-red rays roasting of maize were applied at the 140 °C temperature and 40 minutes time of exposure which was found to reduce aflatoxin substantially (Siciliano *et al.,* 2017).

Chemical methods

Aflatoxin has been found to be degraded by the use of citric acid in maize grain (Oryza *et al.,* 2021). (Sipos *et al.,* 2021) found that, during the reduction of aflatoxin G1, G2, B_1 and B_2 by the use of sodium hydrosulphite ($Na_2S_2O_4$) there was no damage of the black pepper's outer layer thus making the method effective. On the other hand, these chemical methods end up making the food products unpalatable due to physiological changes. The development of encapsulated delivery system technology has led to the improvement of propionic acid anti- fungal used for postharvest farm products (Feng *et al.,* 2020).

Neutral electrolyzed oxidizing water

Electrolysis of pure water produces acidic electrolyzed water (AEW) and the Neutral electrolyzed oxidizing water (NEW). The oxidation-reduction potential (ORP), the available chlorine concentration (ACC) and pH level, leads to antimicrobial ability where chlorine oxidants and ORP acidity which is more than in neutral electrolyzed water, has been found to detoxify aflatoxin in maize and also its health-friendly. NEW was found to reduce the levels of AFB1 in peanuts to allowable levels (Jardon-Xicotencatl *et al.,* 2015). Maize grains that were found to contain levels of aflatoxin above the set limits was treated with NEW and it was concluded that the treated maize had levels below the set limits (Gómez-Espinosa *et al.,*2017).

Biological methods

The biological methods that have been tested to reduce aflatoxin have been found to be affected by the *A. flavus* population which is diverse and its unknown ability to survive for prolonged periods after the biocontrol is applied. Second, the selection of the biocontrol strains that are suitable for food safety management has been a great issue (Ehrlich *et al*., 2014). Many African countries, have been in the forefront of the biocontrol agents to be applied commercially based on the non- aflatoxigenic strain's ability to reduce levels of aflatoxin in peanuts, cotton seeds and maize (Bandyopadhyay *et al.,* 2016). In Kenya, and other African countries, a bio control agent by the trade name "Aflasafe" has been tested and has shown substantial impact on the levels of aflatoxin reduction. (Mutegi *et al.,* 2018b). The method has shown to reduce aflatoxin by 70–90% in maize however; more studies need to be done to determine the levels of toxic residues to the environment while used in large scale, inefficacy against other mycotoxins and long-term effect to the farms (Pitt *et al.,* 2019). Lactic acid bacteria and yeasts species have shown to prevent the growth fungi producing aflatoxin through binding in milk, maize, silage and other cereal products (Wacoo *et al.,* 2020). For fodder conservation, microbial starters are used to control aflatoxin in silage. Many countries have successfully embraced the method (Ogunade *et al.,* 2018), though the technology is yet to be implemented in Kenya at a large scale. Also, the application of microbial agents in human foods is yet to be introduced in the country. Currently, the usefulness of their application is critically assessed (Ahlberg *et al.,* 2019b). Studies has been done in East African countries and was shown that fermentation of milk with a *Lactobacillus rhamnosus* probiotics (Wacoo *et al.*, 2019) and natural fermentation with *Lactobacillus* monocultures, has shown to reduce levels of aflatoxin M1 (Shigute and Washe, 2018).

Awareness creation

Training of farmers and regular surveillance enforcement of aflatoxin in feed and food chain are some of the awareness strategies to aflatoxin management to stakeholders that are already recommended and should be used as tools for information dissemination to the farmers (James *et al.*, 2005). Kenya's Ministry of Health and Food and Agriculture Organization created awareness campaign program in eastern part of Kenya upon the aflatoxicosis outbreak in 2005 on drying of maize and its storage and it was found that those who received the information had lower aflatoxin in their serum compared to those who did not (Daniel *et al.*, 2011). A need for awareness creation on aflatoxin to maize handlers in Nandi County was emphasized so as to manage the levels of aflatoxin after it was discovered that there was a high level of exposure to consumers (Sirma *et al.*, 2015). It has been observed that the aflatoxin levels significantly positively correlated with the use of diammonium phosphate fertilizer during planting after the farming inputs awareness programs were disseminated to them to farmers showing a positive relationship between levels of aflatoxin and the damage due to stem borer maize damage after an awareness program was presented to the maize farmers implying that sensitizing farmers through training is key to mitigation of maize diseases and mycotoxin contamination where adopting of appropriate pre harvest agronomic practices play an important role (Owuor *et al.*, 2018b). The level of knowledge to farmers on the causes, contamination consequences and prevention measures were examined in Congo and they observed that crop management practices are highly effective measures to control aflatoxin contamination where most farmers who applied them, were from the more educated households who were knowledgeable about aflatoxins (Udomkun *et al.*, 2018). Therefore, proper creation of awareness to the farmers on strategies to control the growth of aflatoxin in their maize produce results in less risk of exposure.

Future interventions in reduction of aflatoxin in maize; Mobile drier technology. The technology of mobile grain dryers is yet to be adopted by Kenyan farmers and those in other developing countries largely due to high investment and operation costs (Pretari *at al.*, 2019). In Kenya, the Trans-Nzoia region produces maize on a large scale and studies have shown that the region is highly affected by the storage conditions which include the temperature inside the store, humidity and grain moisture content leading to heavy losses. The intervention of the government to introduce mobile grain driers to the farmers will reduce the losses hence reducing the maize scarcity in the country. Through the funding from the government, the farmers can reduce the level of the losses that they undergo due to aflatoxin contamination.

Development of other potential bio- controls. The level of aflatoxin risk exposure in developing countries requires the increase of the number of potential and possible biocontrol methods that include the chemical binders and microorganisms to decontaminate the mycotoxins from livestock feeds and human foods. For fodder conservation, microbial starters are used so as to control aflatoxin in silage where many countries have successfully embraced the method (Jiang *et al.*, 2021) though the technology has not been established fully for large scale production in Kenya. The same applies to the inclusion of microbial agents in human foods in Kenya. Therefore, the researchers need to identify the gap that needs to be filled for appropriateness of these decontaminants for consumption to humans and animals. A survey was conducted recently to access the use of the commercially available mycotoxin- binding products in Kenyan markets (Mutua *et al.*, 2019). Though, their efficacy and regulatory status to manage the mycotoxin has not been extensively evaluated in the country.

Enhancement of the awareness campaign

Information should be distributed through awareness campaign using multiple means to organizations and parties taking into consideration on the cultures and villages remoteness of the farmers and the users of the maize- based products. Groups that do not receive information from the current campaigns on maize aflatoxin exposure require the formulation of a method to reach those populations. The unwilling group to adopt the set recommendations need to be identified and the reasons why they turn down. There are some traditional maize production practices which often act as factors to accumulation of aflatoxin at the farm field level. Primarily, lack of training and knowledge about aflatoxin control measures has led to some predisposing factors to aflatoxin exposure. Majority of Kenyan small-scale maize farmers have weak or no knowledge of aflatoxins exposure according to studies that have been conducted recently (Kagera *et al.*, 2019). They tend to consume their maize crops as home-made foods with no monitoring of aflatoxin content in them. They also sell the maize without carrying any regulatory action towards aflatoxin where recently a series of policy briefs from EAC aiming at cubbing the aflatoxin exposure problem by setting strict measures to enforce the recommendations and standards of aflatoxin are published (Mutegi *et al.*, 2018c).

Appropriate laboratory methods for developing countries

The use of the current methods of aflatoxin analysis in feed and food within developing countries is limited because of lack of sufficient resources and infrastructure even if the methods are rapid in detecting very low aflatoxin levels (Stepman *et al.*,2018). Adaption of testing methods to feeds and maize for epidemiologic and surveillance purposes to biological specimens is needed to the developing countries. Simplified screening methods and enhancement of the adaption of the methods of analysis to the developing countries are found to benefit the subsistence farmers in ensuring that they know the levels of aflatoxin in their produces and also this would empower the public health and agriculture institutions from reliable and sustainable confirmatory methods to the centralized laboratories.

Enhancement of the field aflatoxin screening methods. Inexpensive and portable field screening methods should be made available so as to ensure that consumers are giving out maize products that are safe from aflatoxins. These methods should be practiced with little training or the equipment should be portable to the site including in to the storage facilities for example the silos or on the farm site where they should have the ease of use, user friendly and should not use the electricity. These methods are necessary for rapid confirmation of the levels of aflatoxin at an affordable cost hence allowing stakeholders to quickly take the decision on site and hence will allow further evaluation and intervention for decision making (Strosnider *et al.*, 2006b). The main advantage of these portable field screening methods is that they would benefit the developing countries mostly to the remote farmers in the villages and make the work easy from long distances to the centralized laboratories for analysis then travel back to deliver the results hence it is important to ensure that these methods are fully enhanced. However, there is no direct application of these strategies in developing countries. The bottom line is that there should be efforts of reducing the cost and improving the durability, ease of transport, and usability of field methods to limit aflatoxin exposure in developing countries. The governments in these countries should ensure that they have put enough support through the Ministry of Agriculture so as to empower farmers and also as a way of reduction of waste of the maize grains due to accelerated levels of aflatoxin making the maize unsuitable for consumption.

Laboratory methods. Laboratory methods are effective in confirming the field tests in that they are more precise, efficient and accurate but also, they are more costly and labor intensive in that they require techniques that are not appropriate to analyze on site. Instrumentation regular maintenance, reagents supply and materials and the training of personnel increases the cost of laboratory analysis expenses. Speed of analysis, accuracy of the results with limitations in resources and infrastructure, are some of the factors that need to be favorable to the users so as to choose the best laboratory method. In developing countries, laboratory methods that are currently used, require more refurbishment to improve usability and friendliness. Thin-layer chromatography is reliable and simple hence has become a well- suited laboratory analysis method for food samples (Bucar *at al.,* 2017), but it is labor intensive and limiting with regard to the number of samples that can be tested in a day. Aflatoxin testing kits that are commercially available used for food analysis are faster and less labor intensive but also expensive. Therefore, these laboratory methods can be unfriendly to the user.

Developing countries early warning system

The early warning systems should be designed to detect aflatoxin contamination which is a benefit to developing countries in preventing the future outbreaks of aflatoxicosis so as to create effective health surveillance, sustainable system, food and biological monitoring strategies (Wang *et al.,* 2022). Early warning signs should be validated and developed to put the response protocols in place. The surveillance activities by the public health need to intensively collect the data, analyze, interpret and disseminate it and use in proper designing of the warning system of the aflatoxicosis outbreak. By doing so, there will be reduction of morbidity and mortality rate and increase of health to the consumers of maize-based products. Factors which include deaths of livestock, feeds with high levels of aflatoxin, poor weather conditions and modeling of aflatoxin contamination during postharvest could serve as the indicator of aflatoxin exposure to consumers where the validation and refinement of these systems is needed so as to set a proper monitoring from different information sources and triggers that would set necessary responses in order to prevent the outbreak of aflatoxicosis and proper information dissemination (Schwartzbord *et al.,*2017). There should be a response protocol that is needed to be formulated so as to prevent further exposure to aflatoxin from an already identified contaminated food source. The government agencies, the public and private health care sector including the nongovernmental organizations need to be highly and sufficiently involved in the development and implementation of the effective communication and strategies response.

Discussion

Maize is ranked as a staple food in the developing countries and its safety is a serious concern. In this study, the review on aflatoxin accumulation in maize grains is clearly emphasized which is showing the importance of safety of the maize grains from aflatoxin invasion. In Sub Saharan Africa, the area coverage for the maize cultivation has increased to about 60% (Santpoort *et al.,* 2020) where it is estimated that by the year 2030, maize farms will increase by 5% due to maize consumption demand (Erenstein *et al.*, 2021b).

This study outputs shows clearly that the need for maize cultivation has increased gradually in the developing countries and in the entire world. The agro-ecological zone where maize is grown is diverse adapting to different systems of farming (Olaniyan *et al.,* 2015). Maize production has better productivity and has led to increase of food for the growing population but has been limited by the shortages of the areas of cultivation in developing countries (Obi *et al.,* 2020). In a daily diet, maize provides about 30 per cent of total calories in the body. Its oil is greatly important to the body as it regulates the blood pressure, blood cholesterol preventing the cardiovascular diseases (Aya *et al.,* 2019). This implies that 40% of all crop area in Kenya has been occupied by maize plantations (Abate *et al.,* 2015). The required bags of maize in Kenya in 2017 were 52.8 million bags to feed the population in the same year reversing the trend where the domestic demand is higher than the overall production, the country being one of the sub- Saharan that have been facing the scarcity of gain produced turning to an importer (Tarus *et al.,* 2019).

The use of farm inputs which include the use of fertilizers has shown a rise in the level of production of maize in the growing areas (Kätterer *et al.,* 2022) where their prices influence either positively or negatively in the yields; when the price is favorable, farmers tend to purchase high amount of the inputs. There has been a great urge for the government to reform the fertilizer policy so as to subside the prices which has been too escalated making many of the farmers not to afford for maize cultivation and to other crops leading to constrained economic growth due to decrease in crop yield (Boulanger *et al.,* 2022). Due to reduced local technology in maize- based bread production, use of maize flour in bread making has reduced. Staling susceptibility, substitute grains dominance, low shelf life due to maize high lipids and lack of functional gluten in maize flour has also been characterized as a reason that has led to less use of maize flour in baking due to lack of elasticity characteristics in the bread dough and the lack of spongy characteristics leading to low volume and a dry heavy, fibrous and a crumb which is brittle with traces of strong fermented flavor (Nkhabutlane *et al*., 2014). There has been found a positive correlation between the *Aspergillus* fungi in the soil and aflatoxin levels in maize which relate positively with the risk factors observed during cultivation, environmental and conditions of climatic and postharvest management (Muthomi *et al*., 2009). The increase of aflatoxin outbreaks in Kenyan locations, have increased the awareness levels of aflatoxin preference in feed and maize, and other food products which include milk. Due to this, stakeholders have taken actions heightening public health concern, research efforts, interventions and policy changes for mitigation to reduce the levels to allowable limits hence reducing the levels of exposure to its risks (Mutegi *et al*., 2018). (Mutiga *et al*., 2015) conducted a survey on fumonisins and aflatoxin contamination in maize from different Western Kenya agro-ecological zones was conducted and about 75 per cent of maize produced was found to contain levels of aflatoxin that were higher than the threshold. The health effects are accelerated by high solubility of aflatoxin in lipids absorbed into the gastro intestinal tract to then to the blood vessels (Javanmardi *et al*., 2022) leading to great concern on aflatoxin exposure. Poultry animals has shown to be highly affected by the consumption of feeds containing aflatoxin levels that are beyond threshold while Ruminants' livestock animals are found to have high tolerance towards feeds that are contaminated by the toxins because they possess an ability to detoxify it due to presence of microorganisms found in the rumen destroying the toxic secondary metabolites improving the basis for the preventative probiotic's development (Loh *et al.,* 2020).

Health impact of aflatoxin exposure is increased by the lack of technology, resources and appropriate infrastructure for aflatoxin control and routine monitor making these nations' produce lead in aflatoxin exposure (Ahlberg *et al.,* 2019). It's essential to neutralize and prevent the toxin from invading the products due to huge losses witnessed and for the sake of protection of the public health (Vabi *et al.,* 2018) for the maintenance of the economic planning.

To mitigate and manage aflatoxin contamination in food and feed along the value chains, complementing and applying novel methods of Good Agricultural Practices is highly recommended. GAP is comprised of pre- and postharvest practices and measures which are implemented differently at the farm level where it's the primary level of contamination (Kang'ethe *et al*., 2017b).

The physical methods used are less effective in reducing aflatoxin to allowable levels (Bahkali *et al.,* 2012). Heating has been repeatedly used with efforts of reducing the aflatoxin levels of the maize, but not substantially to allowable levels because its application depends on the humidity and the temperature levels where high temperatures may destroy the food structure (Javanmardi *et al*., 2022). There is a high chance of formation of other more toxic compounds from the chemical methods used in aflatoxin levels reduction leading to more problems that affect the safety of the food (Gibellato *et al*., 2021). Other methods that include Neutral Electrolyzed water and biological methods has shown to be effective in reduction of aflatoxin levels substantially. Training of the maize products handlers has been found to be the most effective method of awareness creation on aflatoxin exposure control. Future interventions require closer monitoring so as to ensure that they have been fulfilled maximumly. Maize products handlers require proper equipment with the knowledge and necessary tools to reduce the levels in the end products so that the food safety may be improved.

Recommendations

Maize grains are consumed overwhelmingly in developing countries as staple food. They are used in production of range of products which include the baby foods, composite and the sifted maize flour among other products hence its safety from aflatoxin invasion will save consumers from the negative health effects. Treatment of the maize grains prior to manufacturing is the best approach in reduction of the toxins and therefore, measures of treatment should be enhanced fully incorporating the Food Safety Systems in the manufacturing firms. The measures that are described in these systems allows the handler to identify the hazards that would lead to aflatoxin exposure and take the action of control. For the raw maize grains, the post- harvest practices should be observed before the storage which include proper drying. Measures should be taken by the government agencies which include the Ministry of agriculture to enable the farmers to grow safe maize and give them the necessary aid of harvesting measures that would reduce the aflatoxin accumulation in the maize grains. In maize growing areas in Kenya which include the western side of the country, a lot of cases has been observed where maize grains have been found to contain aflatoxins levels that are beyond the threshold. These cases have clearly shown that a big population is exposed to aflatoxin consumption. Public health and the ministry of agriculture should continuously conduct the surveys on the safety of the maize grains produced in these areas so as to enhance their activities of maize handling. More technology discoveries should be highly emphasized so as to ensure there are several ways of aflatoxin reduction in place at all times. Also, farmers and handlers along the chain should be enlightened on the importance of acquiring proper training of aflatoxin reduction measures. Animal feeds has shown to contain aflatoxin levels beyond the threshold and therefore, these levels are being observed in animal products which include milk and eggs. Treatment measures should be enhanced by the feeds manufactures which include the use of the binders and other safe methods of aflatoxin controls to animal feeds that include the use of safe microorganisms that are found to be effective. Animal feeds raw materials' handling is a critical step of manufacturing of safe feeds free from aflatoxin and therefore training is required to be disseminated to the manufacturers and farmers who compose their own feed materials. The health risks that are brought by aflatoxin exposure are carcinogenic and therefore, more studies need to be conducted so as to come up with a solution of extracting the toxin from the body after the exposure. Or else, strict measures of the decontaminations to be followed by the aid of the government agencies through mandatory ruling. Developed nations has strict limits when it comes to cereal trading or any other commodity that has a high preference of aflatoxin and therefore, products from developing countries are screened keenly before being traded out to developed countries. Since the developing nations have not strictly installed the mitigation measures of aflatoxin control, a lot of waste is witnessed and therefore, it is recommended that Food and Drug Act to enforce mandatory mitigation installation to farmers and maize grain and products manufacturers. The government in the developing countries should create the capacity of incorporating the future interventions that are relevant to aflatoxin reductions that may be discovered by the researchers. They should also make the environment favorable to any partner who would wish to work together with such nations to improve the food safety mostly in aflatoxin mitigation which has become a bother and health threat to consumers for decades.

Conclusions

Aflatoxicosis is preventable when the necessary strategies are put in to place. More commitment is required in the effort of reducing the aflatoxin exposure to the population where firm collaboration between the Ministry of Agriculture, government and non-government bodies, public health communities and the allocation of sufficient funds to researchers' and other bodies involved is highly encouraged. The incorporation of the discussed future interventions provides knowledge about their application with an aim of reducing aflatoxin exposure. New discoveries and strategies within developing countries are required to reduce the level of food insecurity.

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