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Review on impacts of aflatoxicosis in human and animal health in Ethiopia

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Abstract
The objectives of the paper are to review about effect of aflatoxicosis on animal and human health, its economic significant, and to point out the control and prevention strategies. Aflatoxins are a group of related fungal secondary metabolites; primarily produced by the fungi, Aspergillus flavus and Aspergillus parasiticus. The production of aflatoxins within the fungus depends on the substrate and the particular enzymes and other environmental factors. Hence, the extent of contamination by aflatoxins varies according to geographic location and storage condition of crops and more importantly processing of food materials under favourable temperature and humidity conditions. The four major types of aflatoxin are aflatoxin B1 (AFB1), AFB2, AFG1andAFG2.Of these, AFB1is the most prevalent form and also the most potent of these toxins. The toxicity and potency of aflatoxins make them the primary health hazard as well as responsible for losses associated with contaminations of processed foods and feeds. Aflatoxicosis have a greatest negative impact, in animal and human health. The toxicity may range from acute sickness or death to chronic problems. They can induce stunted growth in young and fertility reduction in adults. Aflatoxins can also undermine child nutrition and development. They are carcinogenic, mutagenic, teratogenic and immunosuppressive in most mammalian species. The economic impact of aflatoxins derives directly from crop and livestock losses as well as indirectly from the cost of regulatory programs designed to reduce risks to animal and human health. Ethiopia is considered to provide a favourable situation, for the proliferation of aflatoxigenic fungi. Aflatoxin exposure can be reduced by proper pre-harvesting, drying and post-harvest sorting in a controlled environment. Hazard analysis and critical control point (HACCP) protocol to identify the source of intoxication and overcome the hazard conditions should be adopted.

Keywords: Aflatoxicosis, Aflatoxin, animal health, economic impact, Ethiopia, human health

Introduction
Aflatoxins are a group of related fungal secondary metabolites primarily produced by the fungi, *Aspergillus flavus* and *Aspergillus parasiticus* [1], which are frequently contaminate foods such as groundnuts and maize [2]. Aflatoxins were initially isolated and identified as the causative toxins in Turkey X-disease (necrosis of the liver) in 1960 when over 100,000 turkeys died in England [3]. Among all mycotoxins and polypeptide compounds synthesized by fungal species, aflatoxins (the most potent hepatotoxic and carcinogenic metabolites) continue to receive major attention [4].

Aflatoxin contamination of grains causes several damages to human and animal health and economic losses [5]. It is largely associated with commodities produced in the tropics and subtropics, such as maize, rice, sorghum, barley, rye, wheat, groundnut, groundnut, soybean and cottonseed [6]. Maize and groundnuts (peanuts), the two crops most conducive to aflatoxin contamination, are staples in the diets of many people worldwide, increasing aflatoxin exposure where dietary variety is difficult to achieve [7].

Developing countries located in the tropical regions, are at greatest risk given their reliance on these commodities as their staple food source [1]. An estimated 500 million of the poorest people in sub-Saharan Africa, Latin America, and Asia are exposed to mycotoxins at levels that substantially increase mortality and morbidity. It is estimated that up to 25% of the world's food crops are contaminated with mycotoxin and over 4.5–5.0 billion people around the world, especially in less developed nations, are at the risk of chronic exposure to mycotoxins [8].

Aflatoxins are acutely toxic, immunosuppressive, mutagenic, teratogenic and carcinogenic compounds targeting mainly the liver for toxicity and carcinogenicity [9].

Aflatoxin exposure contributes to between 4.6 and 28.2% of all liver cancer cases, most of which occur in Sub-Saharan Africa, Southeast Asia, and china, the regions with the highest aflatoxin exposure [10]. Ethiopia is considered to provide a favourable situation for aflatoxigenic mould proliferation of agricultural commodities. Previous reports have been made of aflatoxin contamination in cereals and cereal products and spices taken from silos, ware-houses, shops and market places in Addis Abab [11]. In Eastern Ethiopia, aflatoxin levels ranging from 5 to 250 ppb was reported in groundnut samples [12]. Its effect on human and animal health and occurrences particularly in Ethiopia was not summarized well. Therefore; the objectives of this seminar paper are: -

- To review about the impact of aflatoxicosis on animal and human health with its economic significant.
- To review about the status of aflatoxin in Ethiopia and to point out the control and prevention measures.

General overview of mycotoxin and mycotoxicosis

Mycotoxins are biologically active, toxic metabolites produced by toxigenic fungi mainly belonging to *Aspergillus, Fusarium* and *Penicillium species,* which invade crops in the field and may grow on foods during storage under favourable conditions of temperature and humidity [13].

Mycotoxins are nearly all cytotoxic, disrupting various cellular structures such as membranes, and interfering with vital cellular processes such as protein, RNA and DNA synthesis. They have adverse effects on humans, animals, and crops that result in illnesses and economic losses. Mycotoxins come in the organism of animal or human by contaminated food infested with spores, conidio-spores and/or with fragments of mycelium. Alimentary ingestion of these fungal toxins in organism of animal or human cause intoxication called mycotoxicosis [14].

Mycotoxins commonly occur in human and animal food derivatives and can appear in the field before harvest, post-harvest or during processing, storage and feeding, adversely affecting the quality of the food [15]. Mycotoxins are toxic to human beings and other animals even in very low concentrations. Mostly, mycotoxins occur more frequently in areas with a hot and humid climate that favours the growth of moulds in the substrate. The diseases caused by exposure to mycotoxins are known as mycotoxicosis. Mycotoxins such as Aflatoxin B1 (AFB1), fumonisin B1 (FB1) and Ochratoxin A (OTA) which are toxic to mammals causing one of the most toxic effects on them leading to hepatotoxicity, mutagenicity, tetragenicity resulting in diseases like hepatitis, oedema, haemorrhage, oesophageal cancer and kidney failure [16].

Aflatoxicosis

Aflatoxins are a group of mycotoxins produced by the strains of *Aspergillus flavus* and *Aspergillus parasiticus* in the feedstuffs [3]. The aflatoxins were initially isolated and identified as the causative agent in Turkey X disease that caused necrosis of the liver in 1960 and over 100,000 turkeys died in England and the death was attributed to the consumption of a mould-contaminated peanut meal [17].

Aflatoxicosis is a form of mycotoxicosis arising from toxin ingestion of spoiled feed contaminated with *Aspergillus* fungus [18]. Aflatoxin can cause both acute and chronic aflatoxicosis [19]. Acute aflatoxicosis results in death, whereas chronic aflatoxicosis results in more prolonged pathologic changes, including cancer and immunosuppression [20].

Four major aflatoxins produced naturally are known as aflatoxin B_1, B_2, G_1, and G_2. "B" and "G" refer to the blue and green fluorescent colours produced under UV light on thin layer chromatography plates [21]. The primary and major disease associated with aflatoxin consumption is hepatocellular carcinoma (HCC) or liver cancer [22]. Aflatoxin B1 is found widely and in greater concentrations than other naturally occurring forms of AF throughout the world in foods such as maize, peanuts and peanut products, cottonseed and its extractions, and to some extent, chillies, peppers, and pistachionuts [23]. It is, contaminate both, animal and human feed, particularly by intermediate cereals. The ingestion of AFB1 by milk producing animals leads to the metabolism of the toxin, which is found in milk in the form of toxic hydroxylated derivative commonly called Aflatoxin M1 (AFM1) [24]. Aflatoxin B1 is the most potent carcinogen in humans and animals and has been classified as class-one human carcinogen [25].

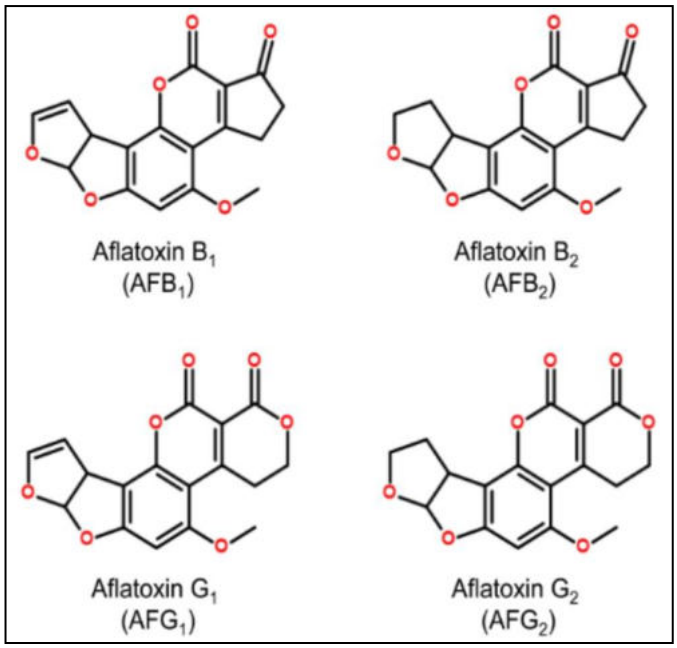

Fig 1: Molecular structures of the four primary aflatoxins: (source: [26].

Epidemiology

Natural occurrence and source of intoxication

The production of mycotoxins within the fungus depends on food sources and the particular enzymes of the fungus and other environmental factors. The extent of contamination by aflatoxins also varies with different geographic location, agricultural and agronomic practices, storage condition of crops and more importantly processing of food materials under favourable temperature and humidity conditions [27]. The relative humidity that is higher than 85% is a very supportive environment for *Aspergillus flavus* growth [28].

The fungi are capable of germinating at 15 - 17% moisture content, but infection and growth require higher moisture [29].

Factors such as prolonged drought, high temperatures, substrate composition, and storage time and storage conditions play an important role in fungal growth and the synthesis of aflatoxins [30].

Some other factors that affect aflatoxin contamination include the climate of the region, the genotype of the crop planted, the soil type, the minimum and maximum daily temperatures, and the daily net evaporation [31]. Foods utilized by humans and domestic animals are, good nutritional sources for *Aspergillus species* [32]. Aflatoxin contamination associated with food or feed is a global problem especially in the tropical and subtropical regions of the world, where warm temperatures and humidity favour the growth of the fungi [33].

Environmental factors such as soil moisture and temperature create the conditions under which *Aspergillus* can grow and produce toxins on crops or food. Animals and humans are exposed to aflatoxins through consumption of contaminated products such as meat [34] dairy products (milk, cheese, and yogurt) [35] or eggs [36].

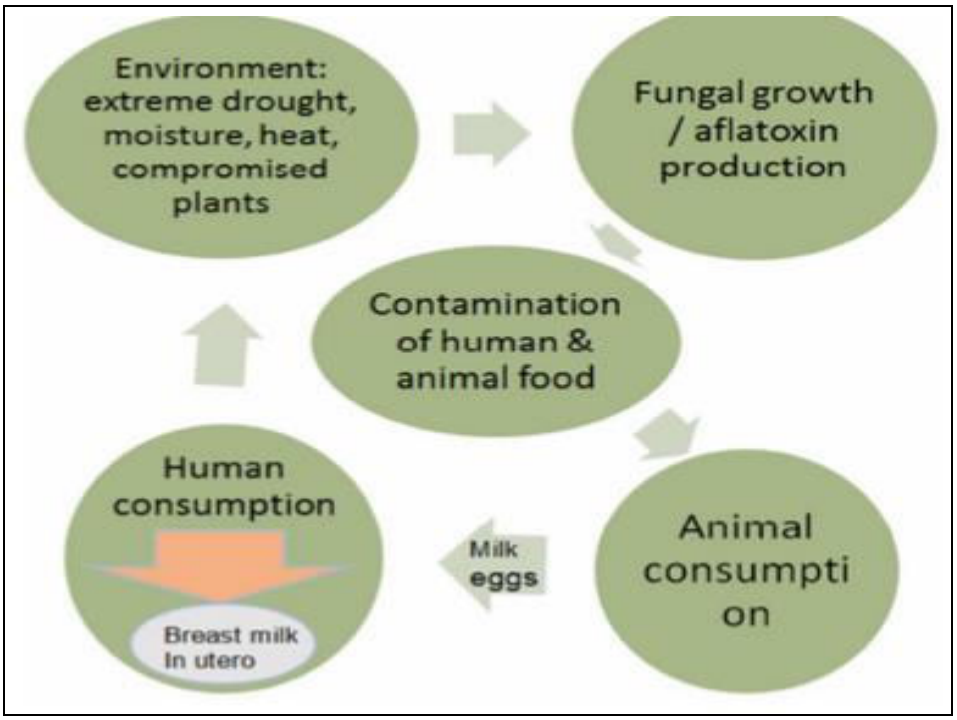

Fig 2: Human, animal, and environmental interaction [1].

Risk factors

The effects of aflatoxin contaminations are similar for all animals but the degree susceptibility varies with the species, age, sex and nutritional status of the animal, environmental factors, exposure level and duration of exposure. Young animals are particularly more susceptible to aflatoxin. Pregnant cows, calves, fattening pigs, mature cattle, and sheep fed low dosages of aflatoxin over long periods develop weakening, intestinal bleeding, debilitation, reduced growth, nausea, refusal of feed, predisposition to other infectious diseases, and may abort [37]. Males are more susceptible than females. There is considerable variation by species. A list of animals in order of decreasing sensitivity runs rabbits> ducks> turkeys> chicken> fish> swine> cattle> sheep [38].

Environmental stressors greatly impact the health and virility of crops. Drought stress is a major contributor to pre-harvest aflatoxin contamination [10]. The main predisposing factor in post-harvest aflatoxin accumulation in food is poor storage conditions; namely, excessive heat and moisture, pest-related crop damage, and extensive periods of time spent in storage [21].

Chronic excessive intake of alcohol is key risk factor of HCC. Cirrhosis may be developed with continuous intake of large amount of alcohol. Risk is increased by two folds when effect of alcohol is synergized with HBV or HCV [39].

Clinical Findings

Aflatoxins can cause acute and chronic toxicities depending on the concentrations present; are immunosuppressive, mutagenic, teratogenic, genotoxic and carcinogenic compounds produced mainly by *A. flavus* [40]. Acute aflatoxicosis is produced when moderate to high levels of aflatoxins are consumed. Specific, acute episodes of disease include haemorrhage, acute liver damage which manifests as severe hepatotoxicity with a case fatality rate of approximately 25%, oedema, absorption and/or metabolism of nutrients and alteration in digestion. The early symptoms of hepatotoxicity from aflatoxicosis can include anorexia, malaise, and low-grade fever. Acute high-level exposure can progress to potentially lethal hepatitis with vomiting, abdominal pain, jaundice, fulminant hepatic failure and death [31].

Chronic aflatoxicosis results from ingestion of low to moderate levels of aflatoxins. The effects are usually subclinical and difficult to recognize. Some of the common symptoms are impaired food conversion and slower rates of growth with or without the production of an overt aflatoxin syndrome [41].

In cattle, aflatoxin has been reported to cause decreased rumen motility and function, changes in the gastrointestinal tract physiology and blood coagulation defect (impairment of prothrombin, factors VII and X and possibly factor IV) while in poultry, aflatoxin can result to decreased feed consumption, body weight, testes weight and semen volume and decreased plasma testosterone value and reproduction [42]. Acute aflatoxicosis is associated with high doses of aflatoxin. It is characterized by haemorrhage, acute liver damage, oedema, and death in humans [21]. In humans, *Aspergillus flavus* aflatoxin consumption can lead to acute

hepatitis, immunosuppression, hepatocellular carcinoma, and neutropenia. The absence of any regulation of screening for the fungus in countries that also have a high prevalence of viral hepatitis highly increases the risk of hepatocellular carcinoma [43].

Post-mortem findings revealed pale, firm and fibrosed liver. The kidneys are yellow and surrounded by wet fat [44]. Other pathological features in cattle are blood coagulation defects, which may involve impairment of prothrombin, factors VII and X and possibly factor IX. A single dose of aflatoxincauses increases in plasma enzymes (aspartate aminotransferase, lactate dehydrogenase, glutamate dehydrogenase, gamma-glutamyltransferase and alkaline phosphatase) and in bilirubin, probably reflecting liver damage. Other abnormal clinical findings are proteinuria, ketouria, glycosuria and haematuria [45].

Toxicokinetics

Absorption

Aflatoxins are highly liposoluble compounds and are readily absorbed from the site of exposureusually through the gastrointestinal tract and respiratory tract into blood stream [46]. Aflatoxins, once ingested (because of their low molecular weight), are rapidly adsorbed in the gastro-intestinal tract through passive mechanism, and then quickly appear as metabolites in blood after just 15 minutes and in milk as soon as 12 hours post-feeding [47].

Biotransformation

Specific P450 enzymes in the liver metabolize aflatoxin into a reactive oxygen species (aflatoxin-8, 9-epoxide), which may then bind to proteins and cause acute toxicity (aflatoxicosis) or to DNA and induce liver cancer [48]. Aflatoxin may be transformed by certain P450 enzymes (CYP1A2, 3A4, 3A5, 3A7) in the liver, to its DNA reactive form aflatoxin-8, 9-epoxide. This molecule may bind to liver proteins and lead to their failure, potentially resulting in acute aflatoxicosis. Alternatively, it may bind to DNA to form adduct, a step that is a precursor for aflatoxin-induced hepatocellular carcinoma (liver cancer) [21]. Bioactivation is required for AFB1 to be toxic and this processing predominantly occurs inhepatocytes [49]. AFB1 is initially absorbed in the small intestine, especially the duodenum [50]. The majority of the toxin is metabolized in the liver, where AFB1 is converted by hepatic cytochromes P450 (CYP) enzymes into the reactive and electrophilic *exo*-AFB1-8,9-epoxide (AFBO) [51]. In humans and susceptible animal species, aflatoxins especially AFB1are metabolized by cytochrome P450 (CYP450) microsomal enzymes to aflatoxin-8,9-epoxide, a reactive form that binds to DNA and to albumin in the blood serum, forming adducts and hence causing DNA damage [52].

Excretion

Proportions of ingested aflatoxins B1 and B2 is hydroxylated and excreted in the milk as aflatoxins M1 and M2 [3]. Absorbed AFB1 and its metabolites are excreted in urine, while elimination to faeces is a route for both the unabsorbed AFB1 and biliary excretion of metabolites formed from the absorbed toxin [53].

Aflatoxicosis in Animals

Mycotoxins are fungal metabolites that can reduce the performance and alter the metabolism of livestock and poultry [54].

Aflatoxicosis in Poultry

Early investigations (1960) of the sudden death of 100 000 turkey or poultry consuming groundnuts in England linked AF (from *A. flavus*) to acute hepatic necrosis and hyperplasia of the bile ducts of the intoxicated birds [55]. Poultry, especially turkeys are extremely sensitive to the toxic effects of AFB1 [51]. Aflatoxin B1 has a high range of effects in poultry including acute hepatic toxicity, teratogenicity, carcinogenicity, mutagenicity, haematological problems, and immunosuppression [56]. There are numerous reports that feed-borne AFB1 contamination has a profound and negative impact on feed efficiency, which significantly reduces productivity in the poultry industry. For example, dietary AFs (2.5 mg/kg) significantly reduced the feed intake by 9–11% of poultry among all age groups (7–280 days old) [36]. Dietary exposure of broiler hens to AF (10 mg/kg) resulted in embryonic mortality and lowered the immunity in the progeny chicks [57]. As in other species, the liver is the most severely affected organ in poultry, primary consequences being hepatotoxicity and carcinogenicity [51].

Hepatic damage is manifested by enlarged and putty-coloured liver, petechial haemorrhages, marked vacuolation of hepatic cells and bile duct proliferation. Feed levels of AFB1 as low as 250-500 ppb given to New Hampshire chickens have been reported to result in liver damage, decreased haemoglobin, and hypoproteinaemia [58]. Apart from the health and quality of the chickens, there are concerns that aflatoxin contaminants may pass from processed chicken products to humans consuming such products. Several studies have noted the presence of aflatoxin residues in the eggs and muscles of chickens [59].

Aflatoxicosis in Monogastric Animals

Dogs exposed to aflatoxins contaminated feed develop severe depression, anorexia and weakness, and sudden death may occur [60], chronic aflatoxicosis induces jaundice as the predominant clinical sign and histopathology reveals shrunken livers with extensive fibrosis [61] with necropsy revealing haemorrhage and liver damage [62]. Equine aflatoxicosis has been characterized by depression, lameness, and death. Post-mortem examinations revealed subcutaneous and enteric haemorrhage, enlarged kidneys, enlarged necrotic livers, and hepatic, nephritic, and myocardial lesions [63].

Aflatoxicosis in Ruminant

Ruminants such as cattle, sheep, goats, and deer are less known for their sensitivity to the negative effects of mycotoxins than are non-ruminants [63]. The most threatening aspect of AF contamination of feed is related to carry-over of AFs in milk of dairy animals. The major AF metabolite excreted in milk is AFM1 [64]. The presence of aflatoxin M1 (AFM1) in milk and dairy products is an important issue, especially for developing countries [35].

Aflatoxicosis in Humans

Human exposure to aflatoxins is primarily from consumption of contaminated food directly like cereals, seeds and fruits, or indirectly by eating food products and by products obtained from animals consuming contaminated feeds [65]. Level of carcinogenicity is in the order of AFB1>AFG1>AFB2>AFG2 [66]. Hepatocellular carcinoma is the sixth most prevalent cancer worldwide with a higher

incidence rate within developing countries [67]. Chronic exposure to aflatoxin results to hepatocellular carcinoma (HCC) or liver cancer. HCC as a result of chronic aflatoxin exposure most often present in persons with chronic hepatitis B virus (HBV) infection [68]. Hepatocellular carcinoma risk is lower in HBV immune people [69]. Aflatoxin consumption raises the risk of liver cancer up to thirty-fold for individuals chronically infected with HBV, compared with either exposure alone. Unfortunately, these two risk factors – aflatoxin and HBV – are especially prevalent in poor nations worldwide [70].

The risk of liver cancer in individuals exposed to chronic hepatitis B virus infection and aflatoxin is up to 30 times greater than the risk in individuals exposed to aflatoxin alone [20]. In order to decrease the mortality and morbidity of HCC, early diagnosis and the expansion of novel systemic therapies for advanced disease, including gene, drug and immune therapies as well as primary HCC prevention are of great importance [71].

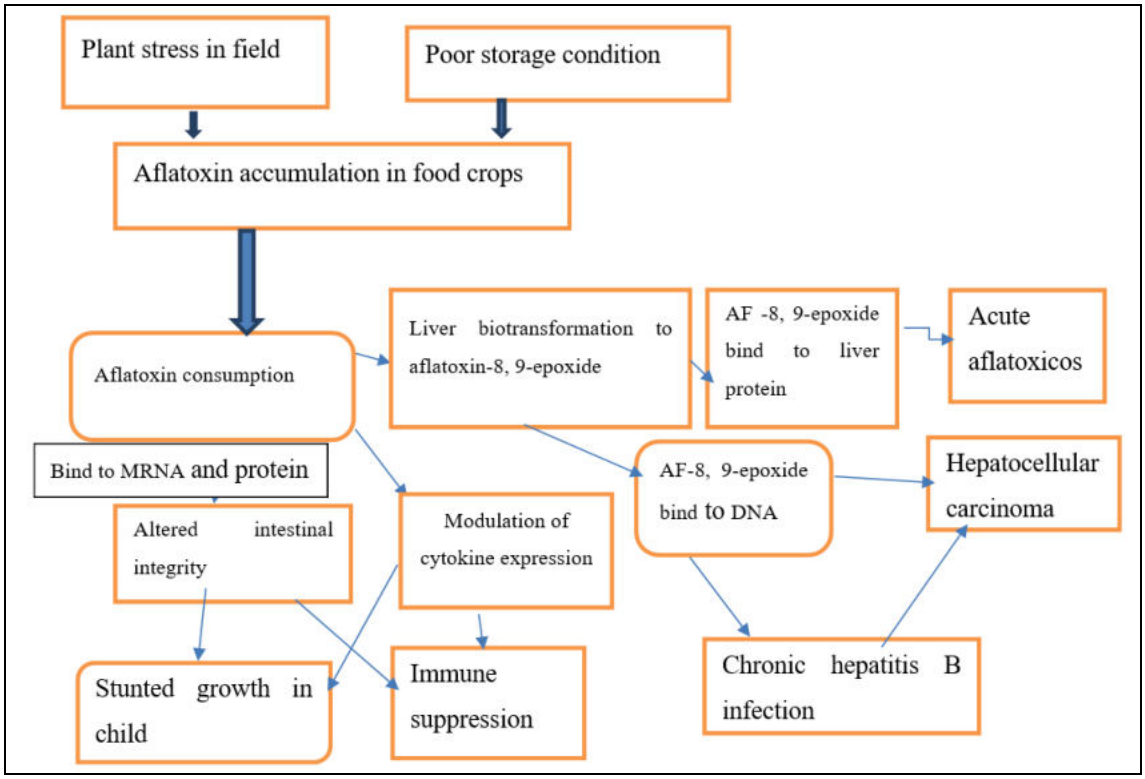

Fig 3: Aflatoxin disease pathways in humans [21].

Economic impact of aflatoxicosis

Aflatoxin contamination of agricultural commodities poses considerable risk to human and livestock health and has significant economic implication for the agricultural industry worldwide [4]. The economic impact of aflatoxins derives directly from crop and livestock losses as well as indirectly from the cost of regulatory programs designed to reduce risks to animal and human health, other adverse economic effects of aflatoxins include lower yields for crops. The high toxicity and carcinogenicity of these compounds and their ability to cause various pathological conditions has led to widespread screening of foods and feeds potentially contaminated with them [45]. The attendant economic impact of mycotoxicosis include: reduced productivity decreased weight gain and feed efficiency, increased disease incidence consequent upon immunosuppression, sdevitalizing body organs and reproductive abnormality, morbidity and mortality [29].

Aflatoxins contamination of crops possesses a serious threat to human and animal health as well as consider as danger in trade market [3]. Aflatoxin contaminations of major crops also influence food security by directly reducing the availability of foods. Producers of the affected crops may also earn less due to product rejection, reduced market value, lower yield and morbidity and mortality of animals [72].

Aflatoxins in Ethiopia

Ethiopia is favourable for the growth of aflatoxigenic fungi and hence aflatoxin contamination of grains has been documented [5]. Three different *Aspergillus species*, were found to be associated with the pre and post-harvest maize samples collected from West Gojam (Fig.6). The first species isolated from the collected samples was *A. flavus*. Colonies of this fungus were characterized by a velvety, yellow to green or the old colony was brown mould with a goldish to red-brown on the reverse (Fig. 5).

Aspergillus flavus is the most important mycotoxigenic fungi associated with cereal crops have been detected in sorghum grain at harvest prior to grain storage stored in underground pit [73]. The maize crop is third most important crop in Ethiopia after wheat and teff and accounts for largest share in total crop production [74]. Despite the fact that maize is a crucial food to Ethiopian population and is vulnerable to mycotoxins risk due to different geographical and climatic conditions and poor handling of crop and storage, limited surveys have been reported on the relation of fungal mycotoxinsin the crop and ways to protect the food from contamination in Ethiopia [75]. The average concentration of aflatoxins in pre-harvest and post-harvest maize was detected (Fig 4).

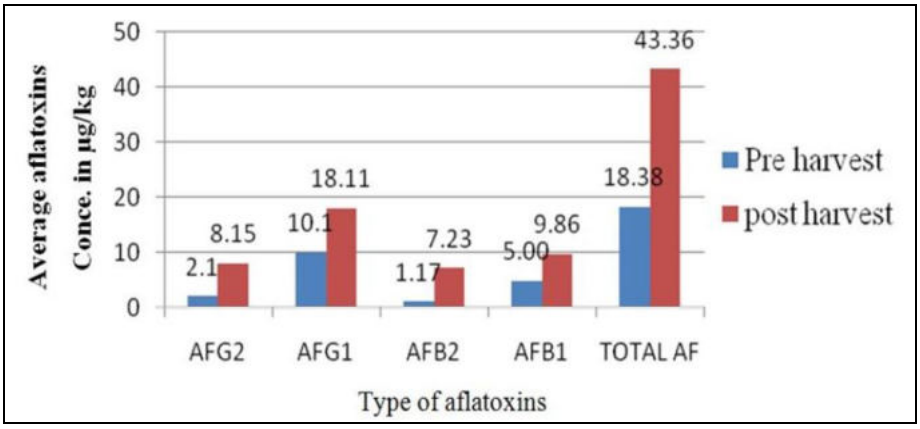

Fig 4: Average concentration of aflatoxin in pre and post-harvest maize [76].

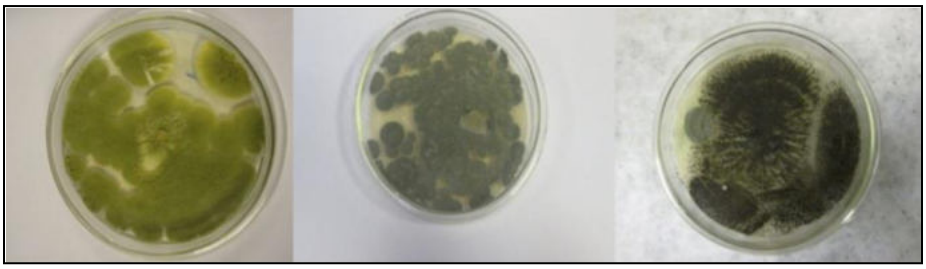

Fig 5: *Aspergillus species* isolated from maize sample [76].

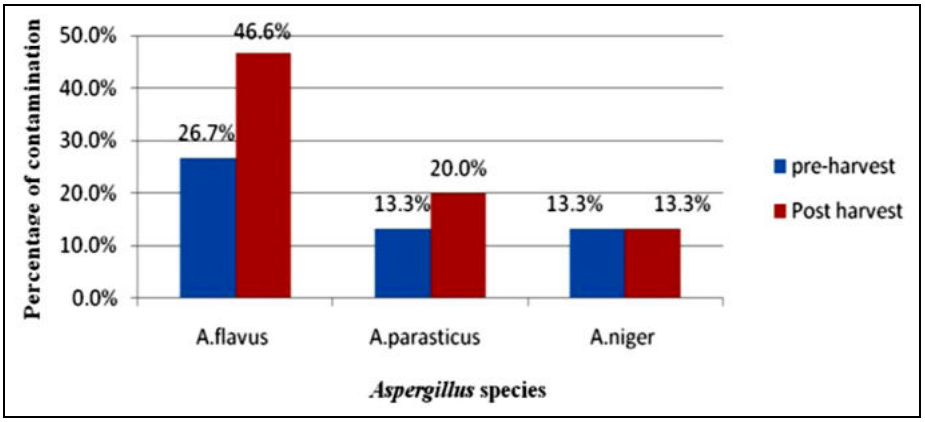

Fig 6: Percentage of Aspergillus species pre and post-harvest maize [76].

Diagnosis and Treatment

The detection and quantification of aflatoxins in food samples require an efficient extraction step. Aflatoxins are generally soluble in organic solvents such as either methanol or acetone mixed in different proportion with small amounts of water. Chromatographic techniques are based on the physical interaction between a mobile phase and a stationary phase. The most commonly used chromatography techniques for analysis of aflatoxins are thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), and gas chromatography (GC) [77]. A TLC analysis is a relatively economical method requiring little equipment but can be tedious and is time and labour consuming. The HPLC analysis requires an extensive clean up procedure and derivatization to improve the detection sensitivity; it also requires specially trained personnel to perform the analyses [78]. Fluid therapy and feeding of toxin binders, multivitamins and protein supplements are some of the treatment options. Antibiotic therapy was also used in remaining animals to diminish the threat of secondary infection in immunosuppressive conditions [79].

Prevention and Control

In a primary prevention trial, the goal is to reduce exposure to aflatoxins in the diet. In secondary prevention trials, one goal is to modulate the metabolism of ingested aflatoxin to enhance detoxification processes, thereby reducing internal dose and subsequent risk [41]. Interventions to reduce aflatoxin-induced illness can be roughly grouped into three categories: agricultural, dietary, and clinical. Agricultural interventions are methods or technologies that can be applied either in the field (pre-harvest) or in drying, storage and transportation (post-harvest) to reduce aflatoxin levels in food. Agricultural interventions can thus be considered 'primary' interventions, because they directly reduce aflatoxin in food. Dietary and clinical interventions can be considered 'secondary' interventions. They cannot reduce actual aflatoxin levels in food, but they can reduce aflatoxin-related illness; either by reducing aflatoxin's bioavailability in the body or by ameliorating aflatoxin-induced damage [31].

One means of intervening to reduce aflatoxin exposure would be to alter agricultural practices such that crops like

rice, with a lower incidence of *A. flavus* infestation and aflatoxin level, are consumed. However, for many communities in developing countries a change in diet is simply not feasible and thus primary intervention (pre- and post-harvest) or chemoprevention methods may need to be employed. Pre-harvest would be the most effective point of control because this is the point at which the crop is first infected by the toxin-producing fungus. Interventions at this level involve measures to reduce crop stress (improved irrigation, use of fungicides, pesticides and insecticides, use of cereal strains resistant to fungal colonization, bio control by introduction of competitive non-aflatoxigenic strains of *A. flavus* and genetically modified crops that inhibit fungal colonization) [2].

Vaccination against hepatitis B virus in infancy is an effective approach to prevent HCC, particularly in developing countries where both incidence of hepatitis B virus and exposure to aflatoxins are high [20]. Pre-harvest interventions include choosing crops with resistance to drought, disease, and pests and choosing strains of that crop which are genetically more resistant to the growth of the fungus and the production of aflatoxins [80].

Table 1: Interventions for Preventing or Reducing Aflatoxin Exposure

Stage in Food Production	Interventions	References
Pre-harvest	Timing of planting crop; planted; Genotype of seed planted; Irrigation; Insecticides; Competitive exclusion, timing of harvest	[80]
Post-harvest: drying and storage	Hand sorting; drying on mats; Sun drying; Storing bags on wooden pallets or elevated off ground; Insecticides; Rodent control	[81]
Post-harvest: Food preparation	Hand sorting; Winnowing; Washing; Crushing and dehulling; Nixtamalization; Acidification; Chemo protectant; Enter sorption	[82]

The One Health Approach

Aflatoxin contamination of foodstuffs and its effects on human and animal health is a complex issue. Therefore, by understanding its epidemiology, holistic solutions can be found. A one health understanding of aflatoxicosis considers how human behaviours influence the environment to promoter or inhibit aflatoxin production. A one health approach recognizes that human impacts on the environment play an important role in Aspergillus growth and the production of aflatoxins. By understanding and educating stakeholders on the interconnectedness of humans, animals, and the environment, it becomes possible to find solutions that address each of the contributing factors [83].

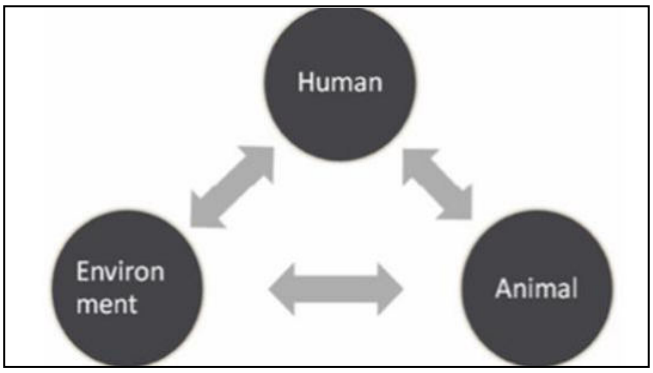

Fig 7: Interconnectedness of humans, animals, and the environment [1].

Conclusion and recommendations

Aflatoxins are toxic carcinogenic secondary metabolites produced predominantly by two fungal species: *Aspergillus flavus* and *Aspergillus parasiticus* and they are mainly occurred in tropical and subtropical regions where temperature and humidity are favourable for the growth of *Aspergillus species* and production of the toxins. Aflatoxins are highly toxic to livestock and people. Aflatoxins B1, B2, G1, and G2 are produced by *A. flavus* and *A. parasiticus* in grains or seeds before harvest and during storage. Among which aflatoxin B1 is the most potent and carcinogenic compound. Aflatoxins are not only a big problem at crop production level, but also it has become a global health issue because of the consequences that the consumption of this toxin generates in animals and human beings. Aflatoxicosis is a disease caused by the consumption of aflatoxins. The toxicity and potency of aflatoxinsmakes them the primary health hazard as well as responsible for losses associated with contaminations of processed foods and feeds. Ethiopia is most favourable for aflatoxicogenic fungi and aflatoxin contamination, especially AFB1.

Based on the above conclusion the following recommendations are forwarded

- It is necessary to implement awareness program to enhance the control and prevention of mycotoxin and mycotoxicosis in general for aflatoxicosis in particular.
- It is important to educating farmers on the need to ensure proper pre-harvest drying and post-harvest sorting in a controlled environment.
- Hazard analysis and critical control point (HACCP) protocol should be adopted to identify source of intoxication and overcome the hazard condition.
- It important to educating stakeholders on the interrelationship of humans, animals and the environment is the first step in preventing Aflatoxin related health issues.
- Mycotoxins levels regulation should be implemented in African countries particularly in Ethiopia by government jurisdictions.
- Farmers should be well informed about aflatoxins and its impact and sources.

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