Mycotoxins; a burden in Africa

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Abstract— Food shortage and contamination of the little available had been a challenge facing the African continent for centuries. Mycotoxins produced by fungi on agricultural produce all over the world are poisonous compounds, and these metabolites are stable under most food processing stages, and responsible for reduced food quality and value in addition to causing mycotoxicosis and other health conditions in man and animals, while the farmer loses huge profit due to rejected produce. It is generally accepted that the best way to eliminate the problems caused by mycotoxins is to engage in an effective prevention technique, while other methods such as detoxification and deactivation of already contaminated agricultural goods is another route that must be charted so as to be able to halt fungal infections and the resulting mycotoxicoses from the consumption contaminated feed, crops, and food products by animals and man. The use of high technique molecular equipment though ensures dependable results but are not readily accessible in quantifying the resulting outcomes in the African continent. The review is to raise the need for concerted effort at mitigating the losses and wastages resulting from fungal contamination.

Keywords: Africa, Contamination, Food-shortage, Fungi, Health, Metabolites, Mycotoxins, Rejection

1 Introduction

Mycotoxins are biologically active, low molecular weight toxic secondary metabolites produced under favourable environmental conditions by some strains of filamentous fungi on food crops, agricultural produce and products. These chemical substances are produced everywhere as long as fungi growth and proliferation is encouraged, and they elicit lethal effects in human and animals when consumed. Over 300 mycotoxins has already been characterized with structures conferring different toxic actions and food quality reducing capabilities on the different analogues. Mycotoxins reduce the quality of food crops, and results in devastating health conditions in human and animal consumers. They are produced in minute quantities when the environmental conditions favour fungal proliferation and toxins' production. *Aspergillus, Fusarium, Penicillium* are the major genera known to produce fungal toxins with health implications such as cancer (aflatoxin B1), mental retardation and nephrotoxicity (ochratoxin A), nerve degradation, abortion and disease of reproduction system (zearalenone), cardiotoxicity (fumonisin) [1].

Several factors facilitate mycotoxin production on agricultural produce before harvesting referred to pre-harvesting contamination, and after harvesting known as post-harvesting contamination. Poor post-harvesting handling of food crops such as storage, drying, processing, transportation lead to more contamination because the food crops are exposed to nature and other contamination sources than the pre-harvesting processes. Contamination and infection of agricultural crops and produce by toxigenic fungi occur during cultivation, harvesting, transportation, processing, storage, and preparation; and they produce mycotoxins when the environmental conditions are favourable [2].

Atanda et al. [3] reported that climatic condition, nutrient and substrate availability, soil type, farming method, time of harvest, pest infestation, storage and drying conditions coupled with sanitary and food processing techniques can contribute to fungal infection and toxin production. Mycotoxins' production factors according to Megan et al. [4] can be divided into;

a) Intrinsic properties of the food crop: These are natural inherent properties in the food materials that cannot be modified easily but can make the crop susceptible to fungal infection and production of mycotoxins. The properties include moisture content, water activity, substrate composition, pH and nutrient type.

b) Extrinsic factors: These include climate, high environmental temperature, oxygen level; natural disasters like drought, fire outbreaks, erosion and flooding. Extrinsic factors are extraneous and foreign conditions that can promote toxin formation. The food substance cannot control being exposed to these alien factors. Warm and humid climates, climate change, and poor agricultural management practices promote fungal proliferation which leads to more production of mycotoxins and contamination.

c) Processing factors: Food and other consumables are exposed to contamination as they move along the food chain [2]. Poor and unhygienic drying practices observed by farmers in Africa increases fungal contamination [5], blending, addition of preservatives, poor fermentation and post fermentation procedures [6], poor handling of grains and seeds management could introduce fungi with capacity to produce mycotoxins into the food materials or crop.

d) Implicit factors: These are associated factors that can lead to the production of mycotoxins. Insects such as *Mussidia nigrivenella*, *Sitophilus zeamais* and *Carpophilus dimidiatus* have been implicated as promoting production, contamination and spreading of mycotoxins in agricultural crops [7]. The strain of a fungus could also determine if mycotoxin would be produced. Individual strain of a fungal species is defined by specific genetic pattern which could require a different set of environmental conditions for the fungal survival.

Mycotoxins could be inhaled (as spores or dust), ingested (infected food materials, contaminated animal), parenterally or absorbed through the skin (dust, contact) into the blood and then locate the target organs. Mycotoxins being mostly stable

to heat, and not readily altered by different food processing procedure applied, coupled with the likely presence of more than one type of the metabolite in food substances which might synergistically interact calls for attention and action. The African society suffers from a host of problems amongst which is food shortage and food contamination, which emanated from poor agricultural practices embarked upon by the local farmers, unstable and unfriendly government policies, war, corruption, herdsmen/farmers clashes, and climate change. Other factors such as poor preservation methods, lack of storage facilities, local farming techniques, lack of incentives, lack of linking roads, poor sanitary adherence all culminate to threaten food safety in Africa [8], [9].

Food supply and security issues consists of contending variables to include public health, rural incomes, worker productivity, water supply, sanitation, government policy on food supply, land legislation, and nutrition which is not viewed in Africa as a major problem presently [10], [11]. Food safety is generally classified as a public health issue especially in Africa where it is related to nutrition and route for infectious diseases. It is a mix involving trade (local and international), policymakers (government policies, legislations on land and food), consumers (purchasing power and trust), industries (policy statement, finance drive, workers productivity), middle men (transportation and storage), farmers (mechanization of farming, preservation, farming methods, natural disasters, soil fertility), nutrition and health. Food safety concerns regulation, surveillance and monitoring, and control which is presently difficult and in most cases unavailable in many Africa countries. Africans bear huge and grave burden of food associated diseases [12].

While researches on mycotoxin is increasing and more people are delving into the problems caused by the contaminants, very little and in most cases no significant efforts is made to stem mycotoxins' contamination especially by farmers and government on the one hand, and secondly, health givers who seems to be oblivious of the grave consequences inherent in consumption of contaminated food materials on health. The government in Africa is majorly bothered by exchange earnings, while paying no attention to the effects of these dangerous metabolites. Huge number of illnesses coupled with hospitalizations were recorded each year in Europe, with associated cost of hospital stays and reduced productivity as a result of mycotoxin contamination. Other consequences on animals and plants include reduced output and fertility and reduced crop yield and quality.

2 Common mycotoxins with devastating effects on man and animals in Africa

Below are some commonly encountered mycotoxins which negatively impact agricultural, health and economy in Africa

a) Aflatoxin

Aflatoxins are a naturally occurring potent by-product of *Aspergillus flavus* and *Aspergillus parasiticus* on grains and other crops, particularly maize and groundnuts [13]. Adegoke and Letuma [14] also reported the capacity of *A. nomius, Aspergillus toxicarius* and *A. parvisclerotigens* to produce aflatoxin. These metabolites are oxygenated heterocyclic compounds with substituted coumarin with acutely toxic, immunosuppressive, mutagenic, teratogenic and carcinogenic potentials [15]. Aflatoxin is metabolized in the liver, though absorption in the blood and extra-hepatic organs also occur; and has been classified by the International Agency for Research on Cancer (IARC) as Group 1 carcinogens [16]. They are the most potent mycotoxins known with capacity of causing cancer of the liver, suppressing the immune system, and death. The metabolite could be found as aflatoxins B1 and B2, aflatoxins G1 and G2, while aflatoxins M1 and M2 are produced when temperature is between 24 and 35 °C, and moisture content exceeds 7%.

b) Fumonisin

Fusarium species produce diesters of propane-1, 2, 3-tricarboxylic acid naturally as fumonisin B1 (FB1), FB2 and FB3 into food materials especially cereals, while other analogues are produced in the course of metabolism and biochemical reactions [17], [18]. FB1 is the most abundant and potent of the metabolites contaminating maize, rice, sorghum and wheat. *Fusarium proliferatum* and *F. verticillioides* are the two major producers of the toxins. A provisional maximum tolerable daily intake 2 μg/g has been recommended [19]. Fumonisin halts the synthesis of sphingosine by inhibiting conversion of sphinganine to dihydroceramide with the resultant effect that signal transduction and cell recognition, regulation of cell growth, differentiation, senescence, and apoptosis are altered [20].

c) **Zearalenone.**

Zearalenone (ZEN) also referred to as F-2 toxin are produced by Fusarium species; *F. graminearum, F. culmorum, F. cerealis, F. equiseti, F. crookwellense* and *F. semitectum*, as a non-steroidal oestrogenic toxin on cereal crops such as barley, oats, wheat, sorghum, millet and rice [21]. ZEN causes reproductive problems in human by mimicking 17β-estradiol, and so bind oestrogen receptors in mammalian cells [22]. It is produced in grains and it is heat stable in nature.

d) Ochratoxins

Ochratoxins are produced by a wide range of *Aspergillus* and *Penicillium* species. They are post-harvest metabolites produced mostly at the point of storage of food crops and agricultural products. Ochratoxins are made up of a dihydroisocumarin nucleus attached to a phenyl alanine unit by an amide bond. Toxicity is conferred by either the chlorine, hydrogen, or

ethyl atoms that is attached at the isocumarin moiety junction. They are easily absorbed at the gastrointestinal tracts. The carboxylic and phenolic moieties aid ochratoxin A absorption which could be against concentration gradient or the passive transport system [23], [24]. Ochratoxin A binds plasma protein (albumin) which inadvertently aids its absorption [25].

e) Tricothecenes

Trichothecenes are a large group of related chemical mycotoxic sesquiterpene compound produced by some species of *Fusarium, Myrothecium, Trichoderma, Trichothecium, Cephalosporium, Verticimonosporium*, and *Stachybotrys* [26]. These mycotoxins contain the 12, 13-epoxy ring with hydroxyl or acetyl groups in their structures that confers biological activities on them. They are produced on cereal and produces devastating effect on human and animal health when consumed. The toxins produced are divide into groups according to the position of their functional group into Type A (T-2 toxin, HT-2, and Diacetoxyscirpenol (DAS)), Type B (Deoxynivalenol (DON), NIV, FUS-X, 3-acetyl-deoxynivalenol (3-ADON), 15-acetyl-deoxynivalenol (15-ADON)), Type C (crotonin and bacchirin), and Type D (Satratoxin G, and H, roridin A, verrucarin A). Toxicity is conferred by the presence of either an acetyl or hydroxyl on individual mycotoxin in the class, and the structure and position of the side-chain. Trichothecenes causes cell death by inhibiting synthesis of protein in the ribosome by reacting with specific site on the ribosomal RNA (rRNA), and thereby reducing glutathione levels which is accompanied by symptoms such as vomiting, diarrhoea, weight gain haemorrhage and death.

f) Citrinin

This is a nephrotoxic, hepatotoxic and cytotoxic toxin produced by *Penicillium* and *Aspergillus* species into grains and ceral crops. It has antimicrobial and ant-protozoal properties, while it vasodilation and renal damage in animals. It reduces cytokine production, induces reactive oxygen species, inhibit synthesis of nucleic acid, and activation of apoptotic cell death via signal transduction pathways and the caspase-cascade system [27].

g) Patulin

It is a heat-stable polyketide compound produced by *Penicillium, Aspergillus,* and *Byssochlamys.* The toxin induces apoptosis and causes severe immunological, neurological, and gastrointestinal symptoms.

3 CHALLENGES AND BURDEN OF MYCOTOXIN CONTAMINATION IN AFRICA

i) Climate change and food safety

Climate change in Africa presently is increasing the span of desertification (land not suitable for agricultural activities), higher temperature and more heat wave recorded (decreasing farm yield and fewer mycotoxins), heavy precipitation (crop damage, soil erosion, increased pre- and post-harvest toxin contamination recorded). Fewer crops means reduced incidences of mycotoxins and increase in malnutrition. Climate change is a stress factor that is already creating more and new mycotoxins thus increasing the burden of contamination [28].

ii) Detection and quantification of mycotoxins

About half of world agricultural production is prone to mycotoxins contamination presently [29]. Detection, quantification, and monitoring of mycotoxins is an integral part of solving the challenge of food security and food sufficiency in the African continent. High cost implications are involved in testing using sophisticated equipment such as HPLC and LC-MS. While research in Africa is seriously lagging behind, most available research institutions and facilities do not have working and up-to-date instruments thus requiring samples to be shipped to laboratories outside the country for analysis. The use of HPLC and LC-MS while being sensitive, is time consuming and unnecessary for low level contaminations, hence the introduction of on-site rapid test such as lateral flow devices and ELISA tests. These on-site test kits are less costly, easy to use, fast, sensitive and sufficient for high throughput with the disadvantage of being used for just a type of mycotoxin.

iii) Economic and trade impact of contamination

Enormous losses accompanies rejection of food materials and other agricultural products at the point of export. This resulted in the loss of West African groundnut export market and Kenyan maize market. Rejection stems from increasing concentration of mycotoxins in products for export [30], [31]. Mycotoxins ranks as the third threat to food security after bacteria and pesticide contamination in agricultural produce [32]. Economic impacts of rejection has been classified as direct losses (reduced crop yield, death of animals or crop, weight loss, reduction in productivity, rejection at international market) and indirect losses – reduction in value, extra cost of managing contamination [2], [33]. The deleterious effects of mycotoxins' contamination is evidenced in Nigeria, Malawi and other West African countries where groundnut export has been grossly decimated due to aflatoxin contamination with a loss of about $1.2 billion [34], [35]. Africa loses US$450 million each year due to aflatoxin contamination.

Food security legislation and government regulations using institutions in tandem with International laws and regulations could have high cost implications when food substances and food products are meant for export. Surveillance and control, rejection of food materials not meeting safety standards automatically results in reduced income and re-use of the rejected good which ultimately still find its way to the food chain [8], [36]. Rejected agricultural crops and products usually lead to inefficient food use because such materials are diverted to other industrial use of less significance and shortage in supply.

The challenge of product rejection at the point of export results in increased production cost, losses incurred from reduced volume of acceptable products for export, reduced food availability, and reduced product value, inaccessibility of international market, farmers earning less which culminate to threatening food security.

iv) Government regulation and legislation

While few African countries are making concerted efforts through policy formulation, passage of legislations, setting up regulations and institutions to enforce compliance according to international laid down standards as it affects food security, other African states are yet to come to terms with the devastating effects foodborne contaminants can have on the people. Establishment and implementation of mycotoxins' legal limits is variously determined by availability of toxicological data, presence of affordable sufficient food, presence of up-to-date analytical methods, availability of data on mycotoxin contamination levels in various commodities, legislation and regulations, surveillance and institutions to monitor amongst many others [37].

In Africa presently, only few countries have regulation for recommended tolerance levels for mycotoxin contamination in food materials and food products. Kenya (peanuts and peanut products, vegetable oil), Malawi (all food materials), Nigeria (all food materials and infant food), South Africa (all food materials), Zimbabwe (groundnut, maize, and sorghum), Mauritius (groundnut and others), and few others are the countries with recommended tolerance levels for mycotoxins contamination in food materials (which is mostly to aflatoxins only). Despite rising health implications to man and animals and losses due to rejection, most African countries are not doing enough to mitigate the challenge of mycotoxins' contamination [12], [38], [39], [40], [41], [42]. Legislation of food production processes and distribution is the concern of individual country and varies from country to country [43], [44].

v) Health implications of mycotoxin contamination

As at the first quarter of 2017, increases in contamination rates were noted for aflatoxin, DON, fumonisins with over 70 % of the sampled food substances containing multiple form of mycotoxins [32). Mycotoxins' effects are usually significant and long lasting, and could be hepatotoxic, nephrotoxic, teratogenic, immunotoxic, mutagenic, carcinogenic coupled with other associated mycotoxicoses. Sterigmatocystin, ochratoxin A, aflatoxin have been classified by the National Toxicology Program (NTP) and the International Agency for Research on Cancer (IARC) as carcinogenic substances, and are among the most studied mycotoxins [17], while others with negative health implications include T-2 toxin and ZEA [44].

Reports suggests interaction occur mycotoxin exposure and disease conditions. HIV/AIDS, malaria, malnutrition, immunosuppression, impaired growth and tuberculosis transmission and progression have been reported to be modulated by mycotoxin (such as aflatoxin and fumonisin) contamination [45], [46). The other associated outcomes are exacerbation in vitamin deficiencies, maternal anaemia, stunting, and edema in malnourished people [47], [48]. Mycotoxin contamination of food materials increases disease burden, reduce productivity, and increases morbidity and mortality in Africa. It reduces market value of farm animals, reduce their productivity, increases disease burden of animals, and bring huge losses to farmers.

4 MANAGEMENT AND CONTROL OF MYCOTOXINS' CONTAMINATION

As a result of the environmental factors which favour mould growth and proliferation, adequate preventive and management measures are to be put in place to reduce fungi growth in the field and at harvest, and at the stage of storage to prevent mycotoxin production.

a) Pre-harvest management

i) Breeding and planting of mycotoxin resistant crop varieties

Planting of mycotoxin resistant crops (conventional and transgenic breeding) will go a long way in reducing mycotoxin contamination. Mycotoxins such as aflatoxins produced by *Aspergillus flavus* is produced along with ten other metabolites using the aflatoxin metabolic pathway, and are all pre-harvest contaminants [49], [50]. Research advocates development of resistant germplasm, designing crops reduce fungal infection and prevent toxin accumulation, and planting of crops with enhanced host resistance to fungal infection and mycotoxin production, and breeding crops with resistant genotypes [49], [51].

ii) Field management

It is important that plants be grown under sanitary conditions to reduce contamination and prevent infections. Diseased plant should be removed and burnt. Application of compost and manure, planting cover crops, crop rotation practices all promote the diversity of soil microbial communities, and suppresses microbial infection and transmission. Organic farming systems lowers the risks of strains becoming pathogenic. The system facilitates competition and increases diversity amongst microorganism, and reduces dominance among a particular group.

iii) Application of biological and chemical control agents

The use of biological agents have been advocated for the control of pathogenic strains of microorganisms. Since mycotoxins are not easily deactivated or detoxified, the best control method recommended is to prevent fungi continued production. Biological agents such as fungus *Clonostachys rosea* strain IK726 and some aflatoxigenic *Aspergillus flavus* have successfully prevented Zearalenone and Deoxynivalenol production by *Fusarium graminearum* and *F. culmorum,* while the non-aflatoxigenic *A. flavus* competitively reduce aflatoxin-producing strains and in so doing, reshapes the fungal community [52], [53], [54], [55]. Competitive exclusion of toxigenic moulds with non-toxigenic strains in the field have been adopted in the United State of America, Nigeria, and Kenya [56], [57], [58], [59]. The use of fungicide is also advised.

b) Post-harvest management

i) Drying

Harvesting should be done at maturity when the crop is ripe. Harvesting before maturity or the practice in some African countries where maize is left to dry after maturing and not harvested should be discouraged as it exposes the crop to fungal contamination. Drying to reduce moisture level should be fast, and if possible hot sunlight rays should be avoided. Safe moisture level of 12% and 0.70 water activity is recommended because it reduces mould growth during storage [14], [60]. Artificial drying is encouraged as it allows dry air to pass freely over the produce [61], [62]. Solar and tarp drying help to improve storage conditions, though it is advised to check the moisture content before storage.

Lappa et al. [63] reported that manipulation of environmental factors such temperature and water activity did not adversely affect toxin formation in *Aspergillus carbonarius* which has been corroborated by other authors but, such manipulations led to early detection of the capacity of a fungus to produce mycotoxin; though both studies reported inductions of regulatory genes responsible for the production of the different mycotoxin respectively.

ii) Sorting

Sorting to remove and discard defective, damaged, infected and insect eaten or infested crops is important and should be emphasized. Damaged crops could be conduit for fungal infections, while some insects are reported to promote mycotoxin production in crops.

iii) Application of natural and chemical agents

Use of fungicide like propionic acid will prevent growth though large quantity will be needed for large volume of storage. While it will not deactivate already produce mycotoxin, it has not been validated for human consumption and at the concentration that is most safe for use. Chemical agents drastically reduces damaged recorded from pest and insect attack and so prevent mycotoxin contamination but leave behind non-biodegradable metabolites in the environment. These are presently discouraged because of their ecological unfriendly nature [64]. Application of irradiation also kill microbial cells and prevent mycotoxin contamination [65].

iv) Handling and transportation

Handling of agricultural produce should be carefully done to prevent contamination. Contamination can be at the point of packaging, processing, sorting, and other stage of contact with the product. At the point of transportation, properly packaged product should be transported from place to place while strictly maintaining an atmosphere where contamination, infection and proliferation of fungi strains is inhibited [66].

v) Instituting a workable HACCP plan

Instituting a practicable a Hazard Analysis and Critical Control Points (HACCP) is key to preventing and controlling contamination by mycotoxins of agricultural produce. Institutions and bodies to implement the basic principles of the HACCP plans should be established and empowered to meet the goals for which they were set up [67]. It is important for food and agricultural sector participants involved in trade, manufacturing and production, regulatory agencies collaborate to promote safe food and products for consumption.

vi) Trade

The necessity of embracing agro-dealer education, conducting multi-sectorial food safety campaigns, advocacy campaigns cannot be quantified. Each country should have standards set for animal feed and commodities for human consumption that is built on Codex Alimentarius, and should be enforced to reduce rejections, income loss to farmers and traders, and losses in foreign earnings.

vii) Food additives

Several type of food additives have been developed to help remove mycotoxins from food for animal consumption. While some additives have the advantage of being able to effectively bind some mycotoxins, they bind weakly to others. A good additive should not bind to minerals, vitamins and other nutrients in the feed. Another problem is its applicability as it requires monitoring

4 Conclusion

Susceptibility of agricultural produce to fungal infection, production of toxins, and stability of the toxic compounds despite food treatment procedures, and ease at which the mycotoxins form adducts with blood proteins calls for concern. Reduction of the toxic chemicals through the adaptation of better agricultural methods during growing, storage, processing and transportation should be encouraged. While partnership with the private sector such as Capacity and Action for Aflatoxin Reduction in Eastern Africa (AAREA) and Partnership for aflatoxin control in Africa (PACA) should be encouraged by governments in Africa to better strategize and evaluate how mycotoxins prevalence can be mitigated, Asemoloye [2] recommended capacity building aimed at analysing the economic and trade impacts of mycotoxin contamination. Modified mycotoxins, which are emerging new mycotoxic metabolite analogue of former mycotoxins have reported, hence African government should come up with workable strategic policies aimed at eliminating the mycotoxins' contamination [68], [69], [70].

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