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Assessment of Maize Contamination by Aflatoxin in Burkina Faso: A Review of Methods of Control

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Abstract

Aflatoxin contamination of crops is frequent in warm regions across the globe, including large areas in sub-Saharan Africa and Burkina Faso. Aflatoxins and fumonisins are among the mycotoxins that have been increasingly reported to affect health and productivity of livestock globally. It cuts across the value chain, affecting farmers, markets, and finally consumers. However, aflatoxin contamination is a threatening issue in these staples and its negative effects on human health, most especially on infants and young children, are very alarming. Among the cereals in Burkina Faso, the maize is more vulnerable to contamination by *Aspergillus sp.* The contamination of maize by the aflatoxin is the main cause affecting production of agricultural sector, food security and regularity. Many factors are responsible for its proliferating. Therefore aflatoxins reduction in cereals such as maize is a serious concern for quality and safety. This review aimed to highlight the factors influencing aflatoxins contamination, and methods of reduction.

Keywords

Maize, Aflatoxin, Quality, Health Risk, Burkina Faso

1. Introduction

Mycotoxins exposure is particularly problematic in low-income populations in the sub-Saharan countries that consume relatively large quantities of staples, particularly maize and groundnuts. It is estimated that 26,000 Africans living south of the Sahara die annually of liver cancer associated with mycotoxins exposure. Mycotoxins are detected in a wide range of food products such as oilseeds, cereals, meat, spices and milk from mammals fed on contaminated foods Cho *et al.* [1]. Mycotoxins are secondary metabolites produced by some fungi under specific, favorable climate conditions. Aflatoxins and fumonisins are two classes of mycotoxins with widespread prevalence in cereal crops and feeds. Aflatoxins and fumonisins are a concern for public and animal health worldwide [1].

In Africa, mycotoxin contamination of commodities and animal feeds causes significant risk to the health and productivity of livestock consuming affected feed. Additionally, it causes a risk to humans that consume affected grain of cereals and animal source foods [2]. The contamination of maize with fungi and mycotoxins represents a major problem for its use in human and animal nutrition. Infection of grains in the field by fungi could result in the production of mycotoxins during cultivation, harvesting, storage, transport and processing. The most important species of fungi and mycotoxins that could contaminate maize grains are *Aspergillus flavus* and aflatoxins, *Fusarium verticillioides*, *F. proliferatum and fumonisins* and *F. graminearum* and trichothecenes and zearalenone [3]. Aflatoxin causes serious problem in many foods, but it is most abundant in maize and maize products, because it could be infected even in the field under specific environmental conditions. Contamination of maize depends on the co-existence of susceptibility of hybrids and environmental conditions favourable for proliferation of mycotoxigenic fungi [4].

Burkina Faso is a predominantly agricultural country with approximately 86% of the population deriving their income from the agricultural sector. Among its main plant species, maize occupies a prominent place [5]. Unfortunately, locally produced maize is very often contaminated with aflatoxins (especially aflatoxin B1). This is linked to a lack of capacity in terms of good practices related to production, harvesting and post-harvesting which favors the proliferation of molds responsible for the production of aflatoxins. There is an urgent need to take action to control and manage the aflatoxin contamination problem as this can lead to exposure of the population to health hazards as well as a decrease in income in the value chain [5].

Unfortunately, locally produced maize is very often contaminated with aflatoxins at doses that in most cases exceeded the regional and international recommended limits. Recently, there have been reports of aflatoxin contamination of food and feed with maize as one of the most contaminated agricultural products (more than 50% of the samples samples analyzed are contaminated) with levels ranging from 3.4 - 636 µg/kg for aflatoxin B1 that constitute the most toxic and carcinogenic. The detected total aflatoxin was an average of 67 µg/kg [6]. This would be due to current agricultural practices including those related to production, harvesting and post-harvest activities; this favors the infection and proliferation of molds responsible for the production of aflatoxins. There are no direct measures for prevention of infection of maize grains with ear rot fungi. However, unfavourable conditions for the development of fungi and toxinogenesis could be provided by implementation of appropriate agricultural practices as preventive measures in the field [7].

The proven knowledge of the harmful effects of aflatoxin on health, justified by on the one hand by health events linked to the consumption of cereals contaminated by aflatoxin in Africa, have increased the institutional and scientific fight against aflatoxin in cereals in this continent. Despite this political and scientific will, the presence of aflatoxin, sometimes in doses, is noted in the African and Burkina cereals production to the point that one wonders the effectiveness of the control methods used [8].

It is urgent to take action to control and manage the problem of contamination by aflatoxin in Burkina Faso. This serious deterioration quality and commodity of maize products are ignored by the main actors of agriculture as well as consumers and public who consume maize even contaminated with aflatoxin and thus exposing themselves to serious sanitary dangers and public health.

Also, this low quality of maize is not competitive on the international market, and is limited to less lucrative markets which are often markets, and informal, especially at the national and regional levels, so that agricultural producers do not get a good return on their production.

It is necessary to develop an integrated approach to control and reduce aflatoxin contamination, focusing on the ownership and management capacity of the main actors in the value chain, including agricultural producers. This review article aims to make a general review of production, using, factors contributing to maize contamination by aflatoxins and mains methods of control deployed to reduce it in Burkina Faso.

2. Production, Use and Constraints

Maize is the second most important cereal produced in Burkina Faso. Its production has increased from 1,133,480 tons in 2011 to 1,710,898 tons in 2019. However, despite the efforts made to develop the sector and the results achieved, it still faces many challenges, including the low level of organization of stakeholders [5].

The main producing regions concern western area (Hauts-Bassins, Boucle du Mouhoun, Cascades…) where many maize varieties have been developed and popularized in such as Espoir, Bondofa, Obatanpa, Massongo, Wari, Komsaya and Barka [9] [10].

Maize is the second most important cereal crop in terms of area, production and consumption. Indeed, maize is grown by nearly 78.6% of Burkinabe farm households in the rainy 0.8% in the dry season [11]. Several varieties of maize (*Zea mays* L.) have been developed and popularized in Burkina Faso. According to Traore [12] varieties are developed according to the ecological zone, the needs of consumers and the level of producers. Constraints related to maize production vary according to the different links in the chain. These constraints are presented in **Table 1**.

The majority of Burkinabe farmers grow maize for self-consumption, but also for sale [13]. It is one of the main cereals on which stakeholders and the governments have high hopes for improving their income and combating food insecurity [14]. According to using of maize, the cooked paste constitutes the most widespread common culinary preparation. The grain whether or not it is hulled, ground and the resulting flour can be cooked and consumed in the form of dough fermented and consumed as a paste or porridge. Other dishes, such as gritz or semmolia, are the result of steaming grains, consumed as couscous or porridge [13]. When still fresh, it is best consumed roasted or boiled. Fresh grilled maize is widely sold and can be found on every street in urban areas. It offers very interesting specificities, especially for the breeding of hens and laying hens [15].

3. Factors Affecting the Maize Quality

3.1. Physical Factors

The physical factors that can lead to the alteration of maize grains are temperature and humidity. The temperature is the first factor of alteration of the grains because this factor plays an important role in the conservation of the grains. It controls the speed of degradation of the grains, but also the speed of development of microorganisms and insects. Heating of grains by respiration is a self-accelerating phenomenon that can lead to grain death at 50˚C and above [16].

The researchers reported that food products such as cereals and legumes were more prone to *Aspergillus* species than any other toxin-producing fungi, more

Table 1. Constraints of maize production.

Step	Constraints
Production, inputs and equipment specific	-Low availability of pre-basic and basic seeds; -Low availability of specific fertilizer formulas and doses; -Low availability of pre-harvest equipment -High cost of mechanizing maize production -Lack of standards for the manufacture of post-harvest equipment -Low adoption of improved post-harvest equipment. -Low availability of efficient varieties; -Low availability of adapted technical itineraries; -Low adoption of improved varieties and technical itineraries Low adoption of improved varieties and efficient technical itineraries; -High pest pressure.
Storage and conservation	-Low use of improved storage and conservation techniques; -Insufficient training of actors (producers) on improved post-harvest improved post-harvest technologies

so at storage due to the temperatures involved [17]. However, fungal activity and toxin production have been reported elsewhere to be optimum at 25˚C - 37˚C in the presence of other favoring conditions [18]. Abdel-Hadi *et al.* [19] reported maximum *Aspergillus* growth rate of 6.9 mm/day at 35˚C and maximum aflatoxin production rate of 2278 - 3082 mg/g at 37˚C in maize. Nonetheless, the effect of temperature and that of moisture are inseparable [20].

Moisture in stored grains is the most important deterioration factor. It is the site of heating, mold development, and sometimes germination. Any of these phenomena is clear evidence of poor storage. Wet or warm spots in the grain promote fungal growth, which leads to additional heat and moisture production additional heat and moisture production, creating a self-generating process [21] [22].

Water content is an important factor that affects both the grade and storability of grains and legumes as it significantly influences microbial growth and toxin production [20]. It is thus, a key determinant of aflatoxin development in food crops. Storage fungi like *Aspergillus* require about 13% moisture or relative humidity of 65% (water activity, aw, of 0.65) for growth and toxin production [17]. Water activity is however shown to increase with storage time; this coupled with improper drying predisposes stored cereals and legumes to fungal infestation, growth and aflatoxin development [19].

3.2. Chemical Factors

The chemical factor of alteration of the grains is the composition of the gases of the environment during storage. The grains in mass constitute a porous material with 30% to 50% of the volume in place occupied by the interstitial air. It is the composition of this atmosphere that determines the aerobic or anaerobic metabolism of the grains [16]. The air is composed of 78% nitrogen of nitrogen, 21% of oxygen and 1% of other gases including carbon dioxide. In an airtight enclosure the grains' own respiration depletes the environment of oxygen and enriches it with carbon dioxide. This modification of the composition of the gases in the medium generally blocks the development of mold growth and causes the death of predatory insects, thereby extending the shelf life of the grains [16].

3.3. Biological Factors

Several factors can influence or cause a loss of quality of the maize especially during storage. According to Sharma *et al.* [23], insect or pest infestation remains a major problem in the production, storage and marketing of cereals. This is a major concern for the grain industry because it affects cereals both quantitatively and qualitatively. Post-harvest losses caused by insects, mites, rodents, and microbes in stored grain have been estimated at 10% worldwide of total food grain losses, 5% are caused by insects, 2% by rodents, and 5% - 30% by molds and mycotoxins [24].

The main rodent predators of grain stocks are the gray or Norway rat (*Rattus norvegicus*), black rat (*Rattus rattus*), and mouse (*Mus musculus*) [25].

Regarding insects, they are very small beetles (weevils, bostrychids, bruchids) and some lepidopterans or butterflies (alucite, moths, moths), whose biological activity depreciates the commodity and whose larvae are harmful because they consume the interior of the grains [25]. Contamination of maize by fungi (molds) and their secondary metabolites (mycotoxins) represents a serious hazard to humans and animals [26].

3.4. Soil Properties Factors

Soil is factor that has a key influence on fungal contamination in agricultural produce [27]. Thus, crops cultivated in different soil types may have significantly varying levels of aflatoxin prevalence. According to Codex Alimentarius [28], light sandy soils accelerate growth of the fungi in peanuts, particularly under dry conditions, whereas heavier soils result in less contamination owing to their high water retention capacity that helps in the reduction of drought stress. It also reported that light sandy soils promote the rapid proliferation of *Aspergillus flavus* especially in adverse dry conditions [29].

3.5. Storage Factors

The quality of stored foods markedly depends on the storage conditions subjected. However, methods and duration of storage of food commodities seem to differ from one agro-ecological area or ethnic group to another [20]. Most of the storage structures commonly used by farmers in Burkina Faso are traditional and may not provide the right internal atmosphere; give maximum protection from water, insects and rodents; and be easy to clean. All these conditions promote growth of fungi and aflatoxin production in stored legumes and cereals [30]. The increased aflatoxin concentration could be attributed to microbial infestation stemming from the invasion of insects and rodents during storage due to the general deplorable nature of the storage facilities used. Mechanical damage caused during harvesting and shelling of groundnuts also makes them susceptible to *Aspergillus* species invasion both on the field and during storage [20].

4. Methods of Control of Aflatoxin Contamination

4.1. Cultural Control

To be effective, the control of aflatoxin contamination in crops must take into account all the agronomic and environmental factors that influence seed infestation by toxigenic fungi. Aflatoxin contamination can occur during pre-harvest, post-harvest, or peri-harvest periods [31]. Several attempts have been made to control or reduce seed infestation by *Aspergillus flavus* and *Aspergillus parasiticus*, by application of fungicides to seedlings, during cultivation or after harvest [32].

4.2. Chemical Control

4.2.1. Chemical Compounds

A large number of chemicals include acids, bases and oxidizing agents can react with aflatoxins and convert them to non-toxic or less toxic compounds. some chemical compounds have been brought to test their effectiveness on detoxification of aflatoxins and other mycotoxins including hydrochloric acid, citric acid, lactic acid, ammonium persulphate, calcium hydroxide, sodium bicarbonate and potassium carbonate formaldehyde, hydrogen peroxide, sodium bisulfite, ozone gas (O_3), sodium hydroxide and sodium hypochlorite. More Aflatoxins reduction was reported when food and feed were treated with more concentrated citric acid and other chemicals [33].

4.2.2. Ozonization

With a short half-time, at neutral pH and ambient temperature, ozone is able to inactivate microorganisms and decompose their toxic metabolites, leaving no traces of ozone in the treated commodity. Ozone, a powerful oxidant, reacts across the 8, 9 double bond of the furan ring of aflatoxin through electrophilic attack, causing the formation of primary ozonides followed by rearrangement into monozonide derivatives such as aldehydes, ketones and organic acids [34].

4.3. Physical Control

4.3.1. Cleaning

Cleaning is a multistep process such as removing dust, husks and products colonized by molds, mechanical sorting and washing. Proximately 80% of aflatoxin contaminations can be attributed to small, shrivelled seeds mouldy and stained seeds and damaged seeds [35]. Due to the low solubility of AFs in water, it is generally hard to remove aflatoxins by washing. But, it is very difficult to remove aflatoxin bonded or attached strongly to the inner texture of food [36].

4.3.2. Heating

Aflatoxins have high decomposition temperatures ranging from 237˚C to 306˚C. Solid AFBl is quite stable to dry heating at temperatures below its thermal decomposition temperature of 267˚C. However it has been reported all heat treatment (boiling, roasting, baking and steaming) still provides a feasible mechanism for reducing the AFs concentration in foodstuffs [33]. The efficacy and extent of reduction method is depends on several factors, including aflatoxins concentration, the extent of binding between aflatoxins and food constituents, heat penetration, moisture content, pH, ionic strength, processing conditions and source of contamination (naturally or artificially) [37].

4.3.3. Ionization

In general radiation can be classified into two categories: ionizing and non-ionizing. Gamma radiation, considered a cold temperature process, has been applied by many researchers to extend the storage life of certain foods by reducing microbial populations. Some researchers believe that the gamma ray is not effective on reduction of aflatoxins and others reported different level of decontamination in different food by gamma irradiation [38].

4.3.4. Adsorption

Adsorption, a very common treatment of mycotoxin reduction, involves binding the toxin to absorbent compound during the digestive process in the gastrointestinal tract. The absorption of aflatoxins requires polarity and suitable position of functional groups. Some more common aflatoxin absorbents include active carbon, diatomaceous earth, alumino (clay, bentonite, montmorillonite, sodium and calcium aluminum silicates mainly zeolite, phyllosilicates and hydrated sodium calcium aluminosilicate (HSCAS)), complex carbohydrates (cellulose and olysaccharides) present at cellular wall of yeasts and bacteria (such as glucomannans, peptidoglycans), and synthetic polymers (such as cholestyramine, polyvinyl pyrrolidone, and its derivatives) [33] [39].

4.4. Biological Control

4.4.1. Bacteria

Several bacterial species, such as *Bacillus subtilis*, *Lactobacilli* spp., *Pseudomonas* spp., *Ralstonia* spp. and *Burkholderia* spp., have shown the ability to inhibit fungal growth and production of aflatoxins by *Aspergillus* spp. One of the effects of the LAB is protection against toxins produced in foods, such as heterocyclic amines, polycyclic aromatic hydrocarbons, reactive oxygen species, and mycotoxins [40]. The L. *casei* was a stronger binder of AFB1 compared to others bacteria [41].

The *L. plantarum* was the most efficient organism in degrading AFB1 [42]. Reduction of mycelial growth of *A. parasiticus* as a result of co-inoculation of the four bacteria (*Leuconostoc mesenteroides*, *Lactobacillus plantarum Lactobacillus casei*, *Bacillus subtilis*) was observed to range between 20.9% to 86.2% while reduction of aflatoxin production ranged from 21.6% to 70.4% [43].

4.4.2. Yeast

Some saprophytic yeast species (such as *Candida krusei* and *Pichia anomala*) have shown promise as biocontrol agents against *A. flavus*. However, binding of aflatoxins by yeast strains is also a fast and reversible process, their binding ability is generally lower than bacterial strains. AFB1 binding by *S. cerevisiae* was a rapid process in liquid medium and it involved the formation of a reversible complex between the toxin and yeast cell wall surface [44]. The esterified glucomannan (EGM) and mannanoligosaccharide (MOS) have been proposed to be responsible in yeast cell wall [45] (Guan *et al.* 2011). All types of yeast showed promising effect on AFs reduction. The order of AFs reduction was AFB1 > AFB2 > AFG1. Furthermore, the instant dry yeast was the most effective yeast [46].

4.4.3. Nontoxigenic Aspergillus Strains

In general, nontoxigenic *Aspergillus* strains (*A. niger*, *A. parasiticus*), *Trichoderma viride*, *Mucor ambiguus* and few other fungi have been reported to show significant AFB1 degradation abilities. The success of this method is depending on some factors such as, formulation (the combination of competitive strain and carrier or substrate), inoculum rate, Herbicide application and soil temperature.

Application of nontoxigenic strains to soil should be delayed until soil temperature reaches at least 20˚C [47]. Atehnkeng *et al.* [48] in Africa showed that non-toxigenic strains of *A. flavus* reduce aflatoxin concentrations in both laboratory and field trials by 70% to 99%.

4.4.4. Aflasafe Product

Aflasafe™ consists of a mixture of four native atoxigenic strains specifically targeted for a particular country or agroecosystem. Multistrain products such as Aflasafe™ may be superior to single-strain products because they display both immediate and long-term efficacy in diverse environments [49]. Product development is currently also underway in Ghana, Mozambique, Tanzania, Zambia and Burkina Faso. Aflasate BF01 has been tested successfully for 3 years in Burkina Faso [50]. The products in each country contain unique strains native to the target country and are developed in close collaboration with national institutions.

5. Conclusion

Many factors after post-harvest could be responsible for maize contamination by aflatoxin. This review showed that several methods of control would reduce aflatoxin contamination.

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Conflicts of Interest

Authors have declared that no competing interests exist.

References

[1] Cho, S.H., Lee, C.H., Jang, M.R., Son, Y.W., Lee, S.M., Choi, I.S., Kim, S.H. and Kim, D.B. (2008) Aflatoxins Contamination in Spices and Processed Spice Products Commercialized in Korea. *Food Chemistry*, **107**, 1283-1288. https://doi.org/10.1016/j.foodchem.2007.08.049

[2] Kangethe, E.K., Sirma, A.J., Murithi, G., Mburugu-Mosoti, C.K., Ouko, E.O., Korhonen, H.J., Nduhiu, G.J., Mungatu, J.K., Joutsjoki, V., Lindfors, E. and Ramo, S. (2017) Occurrence of Mycotoxins in Food, Feed, and Milk in Two Counties from Different Agro-Ecological Zones and with Historical Outbreak of Aflatoxins and Fumonisins in Kenya. *Food Quality and Safety*, **1**, 161-169. https://doi.org/10.1093/fqsafe/fyx018

[3] Chulze, S.N (2010) Strategies to Reduce Mycotoxin Levels in Maize during Maize during Storage: A Review. *Food Additives and Contaminants*, **27**, 651-657. https://doi.org/10.1080/19440040903573032

[4] Blandino, M., Reyneri, A., Colombari, G. and Pietri, A. (2009) Comparison of Integrated Field Programmes for the Reduction of Fumonisin Contamination in Maize Kernels. *Field Crops Research*, **11**, 284-289. https://doi.org/10.1016/j.fcr.2009.01.004

[5] MARAH (Ministry of Agriculture and Fishery Resources) (2020) The Maize Sector in Burkina Faso: An Inter Profession to Better Meet the Challenges. 50 p.

[6] Warth, B., Parich, A., Atehnkeng, J., Bandyopadhyay, R., Schuhmacher, R., Sulyok, M. and Krska, R. (2012) Quantitation of Mycotoxins in Food and Feed from Burkina Faso and Mozambique Using a Modern LC-MS/MS Multitoxin Method. *Journal of Agricultural and Food Chemistry*, **60**, 9352-9363. https://doi.org/10.1021/jf302003n

[7] Lee, K.J., Dabrowski, K., Blom, J.H., Bai, S.C. and Stromberg, P.C. (2002) A Mixture of Cottonseed Meal, Soybean Meal and Animal Byproduct Mixture as a Fish Meal Substitute: Growth and Tissue Gossypol Enantiomer in Juvenile Rainbow Trout (*Oncorhynchus mykiss*). *Journal of Animal Physiology and Animal Nutrition*, **86**, 201-213. https://doi.org/10.1046/j.1439-0396.2002.00375.x

[8] Lewis, G.P., Schrire, B., Mackinder, B. and Lock, M. (2005) Legumes of the World. Royal Botanic Gardens, Kew, 577 p.

[9] West and Central African Council for Agricultural Research and Development (CORAF/WECARD) (2018) Impact of the Adoption of Improved Maize Varieties on the Welfare of Maize Farmers in Benin, Burkina-Faso, Cote d'Ivoire and Mali. Regional Report. 59 p. http://coraf.org/wp-content/uploads/2018/04/Rapport_r%C3%A9gional_%C3%A9tude_impact_VF.pdf

[10] Traore, I.C., Konate, N.M., Faye, E., Gueye, H.M. and Dieng, H. (2019) Collection, Sorting and Characterization of Maize (*Zea mays* L.) Accessions Grown in the Upper and Middle Valley of the Senegal River (Mauritania). *Journal of Animal & Plant Sciences*, **42**, 7330-7339. https://doi.org/10.35759/JAnmPlSci.v42-3.5

[11] General Direction of the Promotion of the Farming Economy (DGPER) (2010) Final Results of the Permanent Survey Agricultural (EPA) of Burkina Faso. 104 p. http://cns.bf/IMG/pdf/masa_rdepa_2009-2010.pdf

[12] Traore, B.A. (2011) Improvement of the Maize Variety (*Zea mays* L.). Hope for the Intensification of Maize Production in Burkina Faso. Identification of Essential Components Master Thesis, IDR, UPB, Bobo-Dioulasso, 69 p. http://bibliovirtuelle.u-naziboni.bf/biblio/opac_css/docnume/idr/elevage2/IDR-2012-ELO-EVA.pdf

[13] Kaminski, J. and Christiaensen, L. (2014) Post-Harvest Loss in Sub-Saharan Africa. What Do Farmers Say? *Global Food Security*, **3**, 149-158. https://doi.org/10.1016/j.gfs.2014.10.002

[14] Sarr, B., Kafando, L. and Atta, S. (2011) Identification of Climatic Risks for Maize Cultivation in Burkina Faso. *International Journal of Biological Chemical Science*, **5**, 1659-1675. https://www.ajol.info/index.php/ijbcs/article/view/75932/66427 https://doi.org/10.4314/ijbcs.v5i4.28

[15] Guedou, M.S.E., Houndonougbo, F.M.C., Chrysostome, G.A. and Mensah, A. (2015) Grain Maize and Its By-Products in Poultry Feed in Benin: Review. *Annals of Agronomic Sciences*, **19**, 149-164. https://bec.uac.bj/uploads/publication/a6c4f5a88ea5303dde2a6130418e7fc6.pdf

[16] Cruz, J.F., Beavogui, F., Drame, D. and Diallo, T.A. (2016) Fonio, an African Cereal. CIRAD, Montpellier, 154 p. https://fonio.cirad.fr

[17] Atanda, S.A., Pessu, P.O., Agoda, S., Isong, I.U., Adekalu, O.A., Echendu, M.A. and Falade, T.C. (2011) Fungi and Mycotoxins in Stored Foods. *African Journal of Microbiology Research*, **5**, 4373-4382. https://doi.org/10.5897/AJMR11.487

[18] Medina, A., Rodriguez, A. and Magan, N. (2014) Effect of Climate Change on *Aspergillus flavus* and Aflatoxin B1 Production. *Frontiers in Microbiology*, **5**, 348-365. https://doi.org/10.3389/fmicb.2014.00348

[19] Abdel-Hadi, A., Schmidt-Heydt, M., Parra, R., Geisen, R. and Magan, N.A. (2012) Systems Approach to Model the Relationship between Aflatoxin Gene Cluster Expression, Environmental Factors, Growth and Toxin Production by *Aspergillus flavus*. *Journal of the Royal Society Interface*, **9**, 757-767. https://doi.org/10.1098/rsif.2011.0482

[20] Okello, D.K., Kaaya, A.N., Bisikwa, J., Were, M. and Olota, H.K. (2010) Management of Aflatoxins in Groundnut: Manual for Farmers, Processors, Traders and Consumers in Uganda. Makerere University, National Agricultural Research Organisation, Kampala, 27-60.

[21] Magan, N. (2006) Mycotoxin Contamination of Food in Europe: Early Detection and Prevention Strategies. *Mycopathologia*, **162**, 245-253. https://doi.org/10.1007/s11046-006-0057-2

[22] Los, A., Ziuzina, D. and Bourke, P. (2018) Current and Future Technologies for Microbiological Decontamination of Cereal Grains. *Journal of Food Science*, **83**, 1484-1493. https://doi.org/10.1111/1750-3841.14181

[23] Sharma, H.O. and Rathi, D. (2013) Assessment of Pre and Post Harvest Losses of Wheat and Soybean in Madhya Pradesh. In: Jabalpur, M.P., Ed., *Agro-Economic Research Centre for Madhya Pradesh and Chhattisgarh*, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, 102 p. https://pareshsarma.com/wp-content/uploads/2020/08/Tomato-Postharvest-lossess-1-1.pdf

[24] Rajendran, S. and Sriranjini, V. (2008) Plant Products as Fumigants for Stored-Product Insect Control. *Journal of Stored Products Research*, **44**, 126-135. https://doi.org/10.1016/j.jspr.2007.08.003

[25] Cruz, J.F., Hounhouigan, D.J. Havard, M. and Ferre T. (2019) The Transformation of Seeds. Agricultures Tropicales. 201 p. https://agritrop.cirad.fr/594973/1/ID594973.pdf https://doi.org/10.35690/978-2-7592-2784-6

[26] Pereira, P., Nesci, A., Castillo, C. and Etcheverry, M. (2011) Field Studies on the Relationship between *Fusarium verticillioides* and Maize (*Zea mays* L.): Effect of Biocontrol Agents on Fungal Infection and Toxin Content of Grains at Harvest. *International Journal of Agronomy*, **2011**, Article ID: 486914. https://doi.org/10.1155/2011/486914

[27] Makun, H.A., Dutton, M.F., Njobeh, P., Gbodi, T.A. and Ogbadu, G.H. (2012) Aflatoxin Contamination in Foods and Feeds: A Special Focus on Africa. In: Eissa, A.H.A., Ed., *Trends Vital Food Control Engineering*, IntechOpen, London, 188-234.

[28] Codex Alimentarius (2004) Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Peanuts. Codex Aliment Comm. 1-10. https://www.nicd.ac.za/wp-content/uploads/2018/05/Code_of_Practice_for_the_Prevention_and_Reduction_of_Aflatoxin_Contamination_in_Peanuts_CAC_RCP_55-2004.pdf

[29] Braimoh, A.K. and Vlek, P.L.G. (2004) The Impact of Land-Cover Change on Soil Properties in Northern Ghana. *Land Degradation and Development*, **15**, 65-74. https://doi.org/10.1002/ldr.590

[30] Hell, K., Cardwell, K.F., Setamou, M. and Peohling, H.M. (2000) The Influence of Storage Practices on Aflatoxin Contamination in Maize in Four Agro-Ecological

Zones of Benin, West Africa. *Journal of Stored Products Resources*, **36**, 365-382. https://doi.org/10.1016/S0022-474X(99)00056-9

[31] Dorner, J.W. and Cole, R.J. (2002) Effect of Application of Nontoxigenic Strains of *Aspergillus flavus* and *A. parasiticus* on Subsequent Aflatoxin Contamination of Peanuts in Storage. *Journal of Stored Products and Resources*, **38**, 329-339. https://doi.org/10.1016/S0022-474X(01)00035-2

[32] Aliabadi, M.A., Alikhani, F.E., Mohammadi, M. and Darsanaki, R.K. (2013) Biological Control of Aflatoxins. *European Journal of Experimental Biology*, **3**, 162-166.

[33] Jalili, M., Jinap, S. and Radu, S. (2011) The Effect of Chemical Treatment on Reduction of Aflatoxins and Ochratoxin A in Black and White Pepper during Washing. *Food Additives Contaminants*, **28**, 485-493. https://doi.org/10.1080/19440049.2010.551300

[34] Freitas-Silva, O. and Venancio, A. (2010) Ozone Applications to Prevent and Degrade Mycotoxins. A Review. *Drug Metabolism Reviews*, **42**, 612-620. https://doi.org/10.3109/03602532.2010.484461

[35] Bucheli and Taniwaki (2002) Research on the Origin, and on the Impact of Post-Harvest Handling and Manufacturing on the Presence of Ochratoxin A in Coffee. *Food Additives and Contaminants*, **19**, 655-665. https://doi.org/10.1080/02652030110113816

[36] Jard, G., Liboz, T., Mathieu, F., Guyonvarc'h, A. and Lebrihi, A. (2011) Review of Mycotoxin Reduction in Food and Feed: From Prevention in the Field to Detoxification by Adsorption or Transformation. *Food Additives and Contaminants—Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, **28**, 1590-609. https://doi.org/10.1080/19440049.2011.595377

[37] Hussain, A., Ali, J., Akther, S. and Shafqatullah, S. (2011) Degradation of Aflatoxins by Roasting in Contaminated Peanuts. *Pakistan Journal of Biochemistry Molecular Biology*, **44**, 56-59.

[38] Prado, G., Cruz-Madeira, J.E.G., Morais, V.A.D., Oliveira, M.S., Souza, R.A., Peluzio J.M., Godoy, I.J., Silva, J.F.M. and Pimenta, R.S. (2011) Reduction of Aflatoxin B1 in Stored Peanuts (*Arachis hypogaea* L.) Using *Saccharomyces cerevisiae*. *Journal of Food Protection*, **74**, 1003-1006. https://doi.org/10.4315/0362-028X.JFP-10-380

[39] Hasheminya, S.M. and Dehghannya, J. (2013) Strategies for Decreasing Aflatoxin in Livestock Feed and Milk. *International Research Journal of Applied and Basic Sciences*, **4**, 1506-1510.

[40] Fuchs, S., Sontag, G., Stidl, R., Ehrlich, V., Kundi M. and Knasmüller, S. (2008) Detoxification of Patulin and Ochratoxin A, Two Abundant Mycotoxins, by Lactic Acid Bacteria. *Food Chemistry and Toxicology*, **46**, 1398. https://doi.org/10.1016/j.fct.2007.10.008

[41] Yin, Y., Yan, L., Jiang, J. and Ma, Z. (2008) Biological Control of Aflatoxin Contamination of Crops. *Journal of Zhejiang University Science B*, **9**, 787-792. https://doi.org/10.1631/jzus.B0860003

[42] Oluwafemi, F. and Da-Silva, F.A. (2009) Removal of Aflatoxins by Viable and Heat-Killed Lactobacillus Species Isolated from Fermented Maize. *Journal of Applied Biosciences*, **16**, 871-876. https://www.biosciences.elewa.org

[43] Kim, J.G. (2007) Anti-Aflatoxigenic Activity of Some Bacteria Related with Fermentation. *Communicating Current Research and Educational Topics and Trends in Applied Microbiology*, **1**, 322-328.

[44] Bueno, D., Casale, C.H., Pizzolitto, R.P., Salano, M.A. and Olivier, G. (2007) Physical Adsorption of Aflatoxin B1 by Lactic Acid Bacteria and *Saccharomyces cerevisiae*: A Theoretical Model. *Journal of Food Protection*, **70**, 2148-2154. https://doi.org/10.4315/0362-028X-70.9.2148

[45] Guan, S., Gong, M., Yin, Y., Huang, R., Ruan, Z., Zhou, T. and Xie, M. (2011) Occurrence of Mycotoxins in Feeds and Feed Ingredients in China. *Journal of Food, Agriculture and Environment*, **9**, 163-167.

[46] Milani, J.S., Nazari, S.S., Bamyar, E. and Maleki, G. (2014) Effect of Bread Making Process on Aflatoxin Level Changes. *Journal of Chemical Health Risks*, **4**, 1-7. http://www.jchr.org/article_544078.html

[47] Rajani, P., Sridevi, V. and Chandana-Lakshmi, M.V.C. (2012) A Review on Biological Control of Aflatoxin Crop Contamination. *International Journal of Chemical Environmental and Pharmaceutical Research*, **3**, 83-86. http://ijcepr.in/vol-3/issue-1/13.pdf

[48] Atehnkeng, J., Ojiambo, P.S., Donner, M., Ikotun, T., Sikora, R.A., Cotty, P.J. and Bandyopadhyay, R. (2008) Distribution and Toxigenicity of Aspergillus Species Isolated from Maize Kernels from Three Agro-Ecological Zones in Nigeria. *International Journal Food Microbiology*, **122**, 74-84. https://doi.org/10.1016/j.ijfoodmicro.2007.11.062

[49] Probst, C., Bandyopadhyay, R., Price, L.E. and Cotty, P.J. (2011) Identification of Atoxigenic *Aspergillus flavus* Isolates to Reduce Aflatoxin Contamination of Maize in Kenya. *Plant Disease*, **95**, 212-218. https://doi.org/10.1094/PDIS-06-10-0438

[50] Bandyopadhyay, R, Ortega-Beltran, A, Akande, A., Mutegi, Atehnkeng, C., Kaptoge, J.L., Senghor, A.L., Adhikari, B.N. and Cotty, P.J. (2016) Biological Control of Aflatoxins in Africa: Current Status and Potential Challenges in the Face of Climate Change. *World Mycotoxin Journal*, **9**, 771-789. https://doi.org/10.3920/WMJ2016.2130