International Journal of Multidisciplinary Research and Growth Evaluation.

Pre- and post- harvest evaluation of approaches in controlling aflatoxin-producing fungi in maize (*Zea mays* L.): A review

Adaeze Nnedinma Achugbu [1*], Jude Ejiofor Amadi [2], Kenneth Udeh Ekwealor [3]
[1-3] Department of Botany, Nnamdi Azikiwe University, Awka, Nigeria

* Corresponding Author: **Adaeze Nnedinma Achugbu**

Article Info

ISSN (online): 2582-7138
Volume: 03
Issue: 06
November-December 2022
Received: 08-11-2022
Accepted: 30-11-2022
Page No: 542-548

Abstract
Maize (*Zea mays* L.) commonly known as corn, is the third most important cereal grain worldwide after wheat and rice. It is referred to as the cereal of the future for its nutritional value and utilization of its products and by-products. To maintain high quality maize during storage, maize should be protected from weather (including relative humidity and temperature), growth of microorganisms, and insects. Major fungi associated with grain storage, including maize are *Aspergillus* spp. and *Fusarium* spp. Aflatoxin contamination in several foodstuffs in Africa has been a recurrent problem. In many parts, maize has become the preferred cereal for food, feed and industrial use, displacing traditional cereals such as sorghum and millets. However, it was significantly more heavily colonized by aflatoxin-producing *Aspergillus* spp. than either sorghum or millet. Pre-harvest measures that are efficient in reducing aflatoxin levels are the same as those that will enhance yields. Crop rotation tillage practices, fertilizer application, weed control are important in controlling *A. flavus* infection in the field while timely harvesting, grain sorting and proper storage are critical aflatoxin reducing steps in the post-harvest production chain. There are several methods appropriate to diminish contagious contamination and aflatoxin production in maize kernels during storage. This review gives approaches within the decrease of aflatoxin defilement in maize grains from planting to storage.

Keywords: Maize grains, aflatoxin, control

1. Introduction

Maize (*Zea mays* L.) commonly known as corn, is the third most critical cereal grain around the world after wheat and rice. It is alluded to as the cereal of the longer term for its dietary esteem and utilization of its items and by-products. The request for maize has been assessed to extend by 50% from 558 million metric tons in 1995 to 837 million metric tons in 2020, fueled by different employments, from nourishment preparing, creature bolster, to ethanol generation. It may be an essential staple nourishment grain for huge parts of the world counting Africa, Latin America and Asia (Yaouba *et al*., 2012) [56]. Maize can be developed in a number of situations from 58º North (Canada and the Russian Federation) to 40º South (Chile). This capacity to develop in a wide run of situations is reflected within the high differences of morphological and physiological characteristics (Paliwal, 2000c; Farnham *et al*., 2003) [38, 19].

To preserve high quality maize amid capacity, maize ought to be ensured from climate (counting relative humidity and temperature), development of microorganisms, and insects (Oyekale *et al*., 2012) [37]. Parasitic development in maize is encouraged by hot and humid conditions. Egal *et al*. (2005) [16], expressed that contagious pervasion in maize comes about in colour alter, diminishes in dietary values, and lessening of generally quality and amount of the maize. Major fungi related with grain capacity in maize are *Aspergillus* spp. *Fusarium* spp. Fungal development in maize presents a major hazard for people and animals, through generation of mycotoxins- particularly aflatoxins. Concurring to Manoch *et al*. (1988) [27], aflatoxin generation by the organisms within the grain depends on the capacity conditions, counting relative humidity, temperature and storage period. This survey proposes strategies in controlling aflatoxin generation in maize from planting to storage.

2. Aflatoxins

Mycotoxins that create from *Aspergillus flavus*, a common post-harvest organism in maize are called aflatoxins. These poisons are dangerous to creatures and human wellbeing, and constitute a figure in financial misfortunes in nourishment generation within the world (Lubulwa and Davis, 1994; Shamsuddeen *et al*., 2017) [25, 43]. Aflatoxins are auxiliary metabolites basically created by the organisms *Aspergillus flavus* Link, *A. parasiticus* Speare and to a lesser extent *A. nominus*. Ideal conditions for contagious advancement are 36 to 38ºC, with a high humidity of over 85% (Diener *et al*., 1987) [14]. Appropriate conditions for the development of the fungi toxin generation happen in most zones of Africa and aflatoxin contamination of nourishment may be a far reaching issue over the landmass, which has been surveyed by a few authors (Sibanda *et al*., 1997; Shephard, 2003; Bankole and Adebanjo, 2003; Bankole *et al*., 2006; Wagacha and Muthomi, 2008) [45, 44, 7, 8, 51].

The four major aflatoxins are called B1, B2, G1, G2 and to a lesser degree M1, M2 (Figure 1) based on their fluorescence beneath UV light (blue or green) and relative chromatographic versatility amid thin-layer chromatography. Aflatoxin B1 is the foremost strong characteristic carcinogen known (Squire, 1981; Bennett and Klich, 2003) [47, 10] and is ordinarily the major aflatoxin created by toxigenic strains. Aflatoxin defilement in maize grains has been a repetitive issue (Shephard, 2003) [44]. In numerous parts of the world, maize has gotten to be the favoured cereal for nourishment, bolster and mechanical utility, uprooting conventional cereals such as sorghum and millets. In any case, it was essentially more intensely colonized by aflatoxin-producing *Aspergillus* spp. than either sorghum or millet (Bandyopadhyay *et al*., 2007) [6].

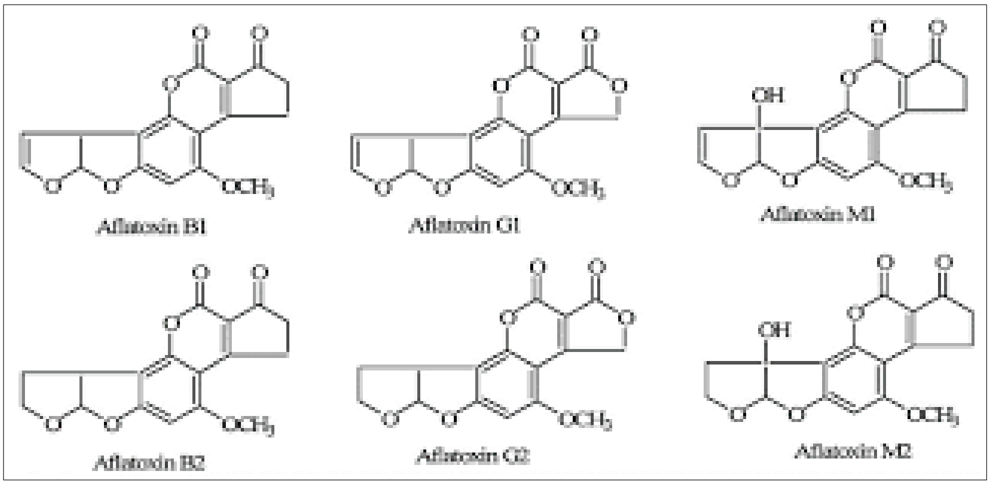

Fig 1: Structures of Aflatoxin B, G and M (Bennett and Klich, 2003) [10]

2.1 Pre-harvest approach to control aflatoxin in maize

Pre-harvest measures that are effective in lessening aflatoxin levels are the same as those that will upgrade yields. Crop rotation and administration of crop buildups are vital in controlling *Aspergillus flavus* infection within the field. Culturing practices like tillage, fertilizer application, weed control, late season precipitation, irrigation, wind and bug vectors all can influence the source and level of fungal inoculum keeping up the infection cycle in maize (Diener *et al*., 1987) [14]. In Africa, crops are developed beneath rain-fed conditions, with low levels of fertilizer and small or no pesticide application. These conditions advance *A. flavus* disease of fertility stressed plants, and any activity taken to diminish the likelihood of silk and kernel disease will diminish aflatoxin defilement. Insect's vector fungi can cause harm that permit fungi get to the grain and other crop tissues in this manner expanding the chances of aflatoxin defilement (Setamou *et al.,* 1998) [42].

a. Biological Control

A potential means for toxin control is the bio-control of fungal developments within the field. Various micro-organisms have been tried for organic control of aflatoxin defilement counting microbes, yeasts, and non-toxigenic (atoxigenic) strains of the causal micro-organisms (Yan *et al*., 2008) [55] of which as it were atoxigenic strains have come to the commercial stage. In Africa, two isolates of *A flavus* have been distinguished as atoxigenic strains to competitively exclude toxigenic organisms in maize grains. These strains have appeared to decrease aflatoxin concentrations in both research facility and field trials, diminishing toxin defilement by 70-99% (Atehnkeng *et al*., 2008) [5].

b. Plant Fungicides

The proceeding improvement of fungicide resistance in plant and human pathogens requires the disclosure and advancement of unused fungicides. Subsequently, a wide run of chemicals has been assessed for their potentials and utilized as elective to synthetic fungicides, e.g. plant extracts and a few compounds gotten from plants (Wedge and Smith, 2006) [53]. Beneath this circumstances there have been examined unused strategies to control plant diseases as an elective way to chemical fungicide application either eliminating these chemical compounds from horticulture or selfishly controlling their use beside natural fungicide substances in a special procedure called Integrated Plant Management-IPM (Juan, 2012) [22]. This has brought about the use of botanical fungicides for the control of seed-borne pathogens of nourishment crops that are viable and have small or no antagonistic impact on the environment (Abdulsalam, 2011; Usman and Bawa, 2018) [1, 50]. Usman and Bawa (2018) [50], explored the adequacy of plant extracts in controlling the pathogens fungal seed-borne pathogens of farmer-saved seed maize (*Zea mays* L.). The result appeared that neem seed and lemon grass plant extracts had the potential within the protection of seed maize decay by fungi.

c. Crop Management Strategies

Controlling or diminishing contamination and directing the components that increase the hazard of defilement within the field for maize will go a long way in controlling aflatoxins. Administration practices that diminish the incidence of mycotoxin contamination within the field incorporate convenient planting, ideal plant densities, legitimate plant nutrition, drought stress, controlling other plant pathogens, weeds, insect pests and appropriate harvesting (Bruns, 2003) [12]. Crop rotation and administration of crop buildups also are critical in controlling *A. flavus* contamination within the field. Tillage practices, crop rotation, fertilizer application, weed control, late season precipitation, water system, wing and pest vectors all can influence the source and level of contagious inoculum, keeping up the disease cycle in maize (Diener *et al.,* 1987) [14]. Lime application, use of cultivate yard excrement and cereal crop buildups as soil alterations have appeared to be successful in decreasing *A. flavus* contamination as well as aflatoxin levels by 50-90% in maize seeds, as depicted by Waliyar *et al*. (2008) [52].

d. Timely Harvesting

Amplified field drying of maize might result in serious grain losses during storage (Borgemeister *et al*., 1998; Kaaya *et al.*, 2006) [11, 24], and as such collecting quickly after physiological development is prescribed to combat aflatoxin issues. Kaaya *et al*., (2006) [24], noted that aflatoxin levels expanded by almost 4 times by the third week and more than 7 times when maize harvest was deferred for 4 weeks. Be that as it may, after early harvesting, maize grains have to be dried to safe levels to halt fungal development. Clearing out the collected crop within the field earlier to storage, advances fungal contamination and insect pervasion. This can be a common practice in Africa and the need to let the crop dry totally earlier to harvest (Udoh *et al*., 2000) [49].

e. Rapid Drying

Dampness and temperature impact the development of toxigenic fungi in stored maize. Aflatoxin defilement can increase 10-fold in a 3-day period, when field harvested maize is put away with high dampness content (Hell *et al*., 2008) [17]. The common suggestion is that harvested commodities ought to be dried as rapidly as conceivable to secure dampness levels of 10-13% for cereals. Accomplishing this through basic sun-drying beneath the high humidity conditions of numerous parts of Africa is troublesome. Indeed, when drying is done in the dry season, it isn't completed before stacking grains into the stores as observed by Mestre *et al*. (2004) [29], and products can be effectively contaminated with aflatoxins. There are a few advances to extend the viability of grain drying and diminish the chance of toxin contamination even beneath low-input conditions; these are the utilize of drying stages, drying in the field and drying on mats (Hell *et al*., 2008) [17].

2.3 Post-harvest approach in controlling aflatoxin production in maize

Aflatoxin contamination of maize grains increases with capacity period (Kaaya and Kyamuhangire, 2006) [24]. It is compounded in Africa through excessive heat, high humidity, need of air circulation within the stores and insect/rodent harm coming about within the proliferation and spread of fungal spores. In this way, procedures to reduce quantitative and subjective post-harvest losses have been created (Hell *et al*., 2008) [17]. These progressed postharvest technologies have been utilized effectively to diminish aflatoxin-adducts level in populaces in Guinea, where presentation was more than halved 5 months after harvest in people from the intervention towns (Turner *et al.*, 2005) [16].

a. Disinfestation Methods

Smoking is a productive strategy of lessening moisture substances and securing maize against pervasion by parasites. The viability of smoking in protecting against insect invasion was found to be high. Around 4 to 12% of agriculturists within the different biological zones in Nigeria utilized smoke to protect their grains, and this practice was found to be related with lower aflatoxin levels in farmers' stores (Udoh *et al*., 2000) [49]. Agriculturists utilize local plant items for controlling insect invasion, past studies have looked at the use of these substances for the control of organisms for the most part demonstrating their viability *in vitro* (Hsieh *et al*., 2001) [21], but these items have not demonstrated their productivity in farmers stores. There is need to audit the efficacy of the different items utilized by farmers and tried by analyst to get a total picture approximately their potential in lessening toxin contamination. Use of pesticides to control mycotoxins and their efficacy, have been looked into by D'Mello *et al*. (1998) [15], but their use by farmers in Africa is not continuously well practiced and deaths due to pesticide use have been detailed.

b. Physical Separation and Hygiene

Aflatoxin is unevenly dispersed in a seed parcel and may be concentrated in a really little rate of the product (Whitaker, 2003) [54]. Sorting out of physically harmed and infected maize grains (known from colourations, odd shapes and size) from the intact commodity can result in 40-80% diminishment in aflatoxin levels (Park, 2002; Fandohan *et al*., 2005; Afolabi *et al*., 2006) [39, 18, 3]. The advantage of this strategy is that it diminishes toxin concentrations to secure levels without generation of toxin degradation products or any lessening within the dietary esteem of the nourishment. This might be done physically or by utilizing electronic sorters. Clearing the remains of past harvests and pulverizing infested crop buildups are fundamental sterile measures that are moreover viable against capacity disintegration (Hell *et al*., 2008) [17]. Isolating heavily harmed ears i.e. those having more noteworthy than 10% ear harm moreover decreases aflatoxin levels in maize (Setamou *et al*., 1998) [42]. Wild hosts, which constitute a major source of infestation for storage pests, ought to be expelled from the region of stores (Hell *et al*., 2008) [17].

c. Reduction through Food Processing Procedures

Sorting can expel a major portion of aflatoxin contaminated units, but levels of mycotoxins in contaminated commodities may moreover be decreased through nourishment preparing strategies which will include forms such as sorting, washing, damp and dry processing, grain cleaning, de-hulling, simmering, baking, frying, nixtamalization and explusion cooking. These strategies and their impact on mycotoxin diminishment have been looked into by Fandohan *et al*. (2008) [17]. The impact of expulsion cooking on mycotoxins in cereals was looked into by Castells *et al*. (2005) [13]. De-hulling maize grain can decrease aflatoxin defilement by 92% (Siwela *et al*., 2005) [46]. The impact of nixtamalization in lessening aflatoxin defilement (Park, 2002) [39] has recently been addressed with Méndez-Albores *et al*. (2004) [28], detailing that nixtamalization is reversible. Fermentation can increase the security of a few nourishment items sullied with mycotoxins. In any case, the accessible reports are conflicting, with a few appearing exceptionally proficient diminishments in mycotoxins related with aging, though others discover lesser or no impacts. Fandohan *et al*. (2005) [18], found that handling maize into makume (a strong maize fermented maize based product) brought about 93% diminishment of aflatoxin, whereas lessening levels were 40% for 'owo' which may be a non-fermented dry processed maize porridge. The authors distinguished sorting, winnowing, washing, smashing combined with de-hulling of maize grains as the basic mycotoxin diminishing steps within the generation chain, whereas fermentation and cooking showed up to have immaterial impact. There are diverse preparing strategies for the exceedingly inclined commodities (maize and groundnuts) in different parts of Africa and examinations of the impact of these handling methods will distinguish those strategies that uncover buyers to less aflatoxins (Rushing and Selim, 2019) [40].

3. Traditional methods of maize preservation and storage

Food grains are the foremost commonly stored durable nourishment commodities within the tropic and subtropics as a rule put away to supply nourishment and nourish reserves as well as seed for planting. Postharvest losses are a major cause of concern around the world where below 5% investigate subsidizing has been designated (Mobolade *et al*., 2019) [31]. A significant amount of food maize grain is being harmed after harvest due to lack of satisfactory capacity and processing facilities. Additionally, critical agricultural production can be affected due to varieties in periodicity and escalated of climatic events likes floods and dry seasons, temperature and rainfall patterns (Arun *et al*., 2017) [4].

3.1 Open fire place

In most rural cultivating communities, the larger part of the agriculturists put away maize grains close to the kitchen where the warm and smoke of burning kindling enter to keep the maize grains free from insect pest invasion (Sarangi *et al*., 2009) [41]. Within the occurrence where large amounts of maize grains are required to be stored, extraordinarily raised horse shelters are developed; a moderate burning fire is lit and hot air is controlled to permit grains to stay dry (Sarangi *et al*., 2009) [41]. Whereas smallholder ranchers ordinarily store nourishment grain crops over the kitchen fire within the cultivate cabin or in open where the high temperature due to coordinate sun powered radiation may moreover kill the developing larvae within the seeds (Mobolade *et al*., 2019) [31].

3.1.1 Open air/aerial storage

Unshelled maize cobs and other un-threshed cereals are suspended in bunches or stacks, utilizing rope or plant fabric, beneath roof, from the branches of trees or the best shafts driven into the ground (Ofor, 2011) [35]. The grain dries within the discuss and the sun until it is required by the rancher for utilization or marketing. When the grains are put away within the open air, the farmers continuously guarantee to ensure that the grains are being kept from precipitation by covering with polythene. The drawback of open-air capacity is that the grain is uncovered to the environment and pests. The farmers do moreover hold the un-threshed nourishment grains tied in more hands beneath cross ventilated shade absent from precipitation. The un-threshed maize grains are commonly put away beneath the roof of residences, hanging from the roof timbers or spread out on a framework within the ceiling where high temperature due to coordinate sun oriented radiation warms up the maize grains to diminish the dampness substance and may moreover kill the developing larvae within the seeds hence preventing insect infestation (Mobolade *et al*., 2019) [31].

3.1.2 Metal or plastic drums

Plastic or metal utilized for the natural solvents, petroleum items, vegetable or palm oil capacity and transportation or water capacity tanks are other materials utilized to supply airtight capacity of nourishment grains in both nations after intensive washing in case the modern one isn't being utilized. Maize grains meant for storage are to begin with sun dried to diminish the dampness substance to 12% or less, from there on the drums are filled with the grains (threshed or un-threshed) and fixed with the oil screw cap for simple opening afterward (Mobolade *et al*., 2019) [31]. The filled drums are kept on a bed beneath shade protected with a layer of straw or in a storage facility absent from coordinate sun powered radiation to dodge the grains from getting to be caked due to dampness alter and warming of the stored grains. In the event that the drums are closed air tight, the grains can be stored for a year or more without utilizing bug sprays. One major drawback of grain storage in a drum is that the drum must remain sealed for it to be viable since insects are inclined to continue physiological action at the scarcest channel of oxygen when opened aimlessly (Murdock *et al*., 1997; Makalle, 2012) [32, 26].

3.1.3 Storage bags

Short duration storage of maize grains in sacks is broadly utilized in farms, towns and commercial storage centers. Sacks made of woven jute, sisal, neighborhood grass, and cotton depend on the materials that are accessible within the region. These were prior utilized broadly in both Nigeria and India until the presentation of the polypropylene sacks, be that as it may; farmers still utilize jute or sisal bags. They more often than not come in several sizes extending from 25kg sacks to 100kg sacks. Polyethylene storage packs make a profoundly proficient, airtight storage environment for all crops. Polyethylene sack is placed inside conventional storage packs for an extra layer of security to make multi-layer polyethylene storage packs to guarantee water safe and totally air tight storage condition (Mutungi *et al*., 2015; Ng'ang'a *et al*., 2016) [33, 34].

3.1.4 Silo

Silo is more often than not utilized for storing threshed food grains and paddy in most nations due to its long life expectancy and insect/pest resistance. There are diverse sorts of silo: metal, mud, concrete, and plastic, though none has demonstrated to be completely a constructional material over others (Mijinyawa, 1999; Adejumo, 2013) [30, 2]. Storage time in silo changes between 6 months to a couple of few years and storage capacities too changes with the estimate of the silo, at some point between 0.5 to a few millions of metric tons (Omobowale *et al*., 2015) [36]. The silo ought to be put on an establishment comprising of a free coarse gravel embankment, resting on the ground level, within the way; it is protected from dampness fleeting water (Barbari *et al*., 2014) [4].

4. Conclusion

Some of the potential solutions to controlling mycotoxins in maize grains incorporate: halting the contamination handle (have plant resistance, biocontrol); control of natural components (temperature, precipitation, relative humidity); crop management techniques (good agricultural practices, pre- and post-harvest management); post-harvest strategies (harvesting, drying, storage, use of plant extracts) and cleaning (sorting, processing). During the pre-harvest stage, the appropriate agronomic practices may depend on the use of crop varieties or hybrids, which are resistant to fungal infections, the application of pesticides and fungicides, adequate management of weeds and crop residues, the use of appropriate crop rotation, tillage, fertilization and irrigation and the application of biocontrol agents. During the harvest stage, the foremost imperative variables that ought to be taken into thought are appropriate harvest timing (maturity stage) and cutting height (to play down soil defilement), as well as quick storage in collected maize grains.

There are several methods appropriate to diminish contagious contamination and aflatoxin production in maize kernels during storage. Hand sorting based on visible fungal contaminations could be an exceptionally valuable apparatus to diminish the aflatoxin in maize grains. Size partition by sieving and density partition are valuable measures as the lighter, smaller and broken kernels and the little components of heap may be infected or harmed by fungi. Their expulsion essentially diminishes aflatoxin contamination in maize. This review gives approaches within the decrease of aflatoxin defilement in maize grains from planting to storage. It is hence prescribed that farmers and investigates can utilize this review as a guide in the control of aflatoxin-producing fungi in maize.

5. References

1. Abdulsalam S. Seed Borne Pathogens on Farmer Saved Sorghum (*Sorghum bicolor* L.) seeds. Journal of Stored Products and Postharvest Research. 2011;2(2):24-28.
2. Adejumo BA. Development of a 350 kg Double-walled Insulated Metallic Silo for Tropical Climate. Greener Journal of Science, Engineering and Technology Research. 2013;3(6):195-204.
3. Afolabi CG, Bandyopadhyay R, Leslie JF, Ekpo EJA. Effect of Sorting on Incidence and Occurrence of Fumonisin and Fumonisin-producing *Fusarium* species on Maize (*Zea mays* L.) in Nigeria. Journal of Food Protection. 2006;69:2019-2023.
4. Arun KC, Aggarwal PK, Joshi PK, Vyas S. Farmers' Prioritization of Climate-smart Agriculture (CSA) Technologies. Agricultural Systems. 2017;151:184-191.
5. Atehnkeng J, Ojiambo PS, Ikotun T, Sikora RA, Cotty PJ, Bandyopadhyay R. Evaluation of Atoxigenic Isolates of *Aspergillus flavus* as Potential Biocontrol Agents for Aflatoxin in Maize. Food Additives and Contaminants: Part A. 2008;25:1264-1271.
6. Bandyopadhyay R, Kumar M, Leslie JF. Relative Severity of Aflatoxin Contamination of Cereal Crops in West Africa. Food Additives and Contaminants. 2007;24(10):1109-1114.
7. Bankole SA, Adebanjo A. Mycotoxins in Food in West Africa: Current Situation and Possibilities of Controlling it. African Journal of Biotechnology. 2003;2(9):254-263.
8. Bankole SA, Schollenberger M, Drochner W. Mycotoxin Contamination in Food Systems in Sub-Saharan Africa: A Review. Mycotoxin Research. 2006;22:163-169.
9. Barbari M, Monti M, Rossi G, Simonini S, Guerri FS. Self-built Silos for Storage Cereals in African Rural Villages. African Journal of Agricultural Research. 2014;9:1384-1390.
10. Bennett JW, Klich M. Mycotoxins. Clinical Microbiology Reviews. 2003;16(3):497-516.
11. Borgemeister C, Adda C, Sétamou M, Hell K, Djamamou B, Markham RH, *et al*. Timing of Harvest in Maize: Effects on Post-harvest Losses due to Insects and Fungi in Central Benin, with Particular References to *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Agriculture, Ecosystems & Environment. 1998;69(3):233-242.
12. Bruns HA. Controlling Aflatoxin and Fumonisin in Maize by Crop Management. Journal of Toxicology: Toxin Reviews. 2003;22(2-3):153-173.
13. Castells M, Marin S, Sanchis V, Ramos AJ. Fate of Mycotoxins in Cereals during Extrusion Cooking: A Review. Food Additives and Contaminants: Part A. 2005;22(2):150-157.
14. Diener UL, Cole RJ, Sanders TH, Payne GA, Lee LS, Klich MA. Epidemiology of Aflatoxin Formation by *Aspergillus flavus*. Annual Review of Phytopathology. 1987;25(1):249-270.
15. D'Mello JPF, Macdonald AMC, Postel D, Dijksma WTP, Dujardin A, Placinta CM. Pesticide Use and Mycotoxin Production in *Fusarium* and *Aspergillus* Phyto-Pathogens. European Journal of Plant Pathology. 1998;104:741-751.
16. Egal S, Hounsa A, Gong YY, Turner PC, Wild CP, Hall AJ, *et al*. Dietary Exposure to Aflatoxin from Maize and Groundnut in Young Children from Benin and Togo, West Africa. International Journal of Food Microbiology. 2005;104(2):215-224.
17. Fandohan P, Hell K, Marasas WF. Food Processing to Reduce Mycotoxins in Africa, Pre and Post-harvest Management of Aflatoxin in Maize. In: Leslie JF, Bandyopadhyay R, Visconti A, editors. Mycotoxins: Detection Methods, Management, Public Health and Agricultural Trade. Wallingford, UK: CABI Publishing; c2008. p. 302-309.
18. Fandohan P, Zoumenou D, Hounhouigan DJ, Marasas WF, Wingfield MJ, Hell K. Fate of Aflatoxins and Fumonisins during the Processing of Maize into Food Products in Benin. International Journal of Food Microbiology. 2005;98(3):249-259.
19. Farnham DE, Benson GO, Pearce RB. Corn Perspective and Culture. In: White PJ, Johnson LA, editors. *Corn Chemistry and Technology*. 2nd ed. St. Paul, MN: American Association of Cereal Chemists, Inc.; c2003. p. 1-33.
20. Hell K, Fandohan P, Bandyopadhyay R, Kiewnick S, Sikora R, Cotty PJ. Pre- and Post-harvest Management of Aflatoxin in Maize. An African Perspective: Management of Aflatoxin in Maize. 2008;19:219-229.
21. Hsieh PC, Mau JL, Huang SH. Antimicrobial Effect of

Various Combinations of Plant Extracts. Food Microbiology. 2001;18(1):35-43.
22. Juan AM. Natural Fungicides Obtained from Plants. In: Dharumadurai D, editor. Fungicides for Plant and Animal Diseases. Rijeka, Croatia: InTech; c2012. p. 3-28.
23. Kaaya AN, Kyamuhangire W. The Effect of Storage Time and Agro-ecological Zone on Mould Incidence and Aflatoxin Contamination of Maize from Traders in Uganda. International Journal of Food Microbiology. 2006;110(3):217-223.
24. Kaaya AN, Kyamuhangire W, Kyamanywa S. Factors Affecting Aflatoxin Contamination of Harvested Maize in the Three Agro-ecological Zones of Uganda. Journal of Applied Sciences. 2006;6:2401-2407.
25. Lubulwa G, Davis J. Estimating the Social Costs of the Impacts of Fungi and Aflatoxins in Stored Products Protection. In: Proceedings of the 6th International Conference in Stored-Product Protection; c1994. p. 1017-1042.
26. Makalle M. Postharvest Storage as a Rural Household Food Security Strategy in Tanzania. ARPN Journal of Science and Technology. 2012;12(9):814-821.
27. Manoch L, Chana C, Sangchote S, Banjoedchoedchu R. Some Mycotic Fungi from Agricultural Products and Food Stuff in Thailand. Journal of the Japanese Association of Mycotoxicology. 1988;1:45-46.
28. Méndez-Albores JA, Villa GA, Del Rio-García JC, Martínez EM. Aflatoxin-Detoxification Achieved with Mexican Traditional Nixtamalization Process (MTNP) is Reversible. Journal of the Science of Food and Agriculture. 2004;84(12):1611-1614.
29. Mestres C, Bassa S, Fagbohoun E, Nago M, Hell K, Vernier P, *et al*. Yam Chip Food Sub-Sector: Hazardous Practices and Presence of Aflatoxins in Benin. Journal of Stored Products Research. 2004;40(5):575-585.
30. Mijinyawa Y. Wood Products for Grain Silo Construction. Journal of Engineering and Applied Sciences. 1999;1:25-29.
31. Mobolade AJ, Bunindro N, Sahoo D, Rajashekar Y. Traditional Methods of Food Grains Preservation and Storage in Nigeria and India. Annals of Agricultural Sciences. 2019;64(2):196-205.
32. Murdock LL, Shade RE, Kitch LW, Ntoukam G, Lowenberg-Deboer J, Huesing JE, *et al*. Post-harvest Storage of Cowpea in Sub-Saharan Africa. In: Singh BB, editor. Advances in Cowpea Research. Ibadan, Nigeria: IITA and JIRCAS; c1997. p. 302-312.
33. Mutungi C, Affognon HD, Njoroge AW, Manono J, Baributsa D, Murdock LL. Triple-layer Plastic Bags Protect Dry Common Beans (*Phaseolus vulgaris*) Against Damage by *Acanthoscelides obtectus* (Coleoptera: Chrysomelidae) during Storage. Journal of Economic Entomology. 2014;107:1998-2005.
34. Navale V, Vamkhede A, Ghoble A. Fumonisin: A Toxin Produced by *Fusarium* Species. International Journal of Current Microbiology and Applied Sciences. 2015;4:809-818.
35. Ojiambo PS, Ikotun T. Biological and Ecological Studies of Fungal Pathogens Associated with *Aspergillus* Fruit Rot of Fluted Pumpkin. Nigerian Journal of Plant Protection. 2002;19:41-51.
36. Oladiran JA. Incidence and Control of *Colletotrichum* Leaf Disease of Watermelon (*Citrullus lanatus* Thunb) in Nigeria. International Journal of Pest Management. 1987;33(3):282-285.
37. Olakojo SA, Ajala SO. Evaluation of Maize Cultivars for Reaction to Infestation and Damage by Larger Grain Borer, *Prostephanus truncatus* Horn and Weevil, *Sitophilus zeamais* Motschulsky. Journal of Central European Agriculture. 2007;8:307-312.
38. Oni A, Fagbohun TR. Preliminary Studies of Effect of Fungi on Nutrient Content of Four Soybean Cultivars during Storage. African Journal of Food Science. 2011;5:473-477.
39. Paudyal S, Poudel S. Storage Practices in Tropical Maize Production Systems in Southern Africa. Tropical Agriculture. 2006;83:261-265.
40. Perrone G, Gallo A, Logrieco A. Biodiversity of *Aspergillus* section *Flavi* in Europe in Relation to the Management of Aflatoxin Risk. Frontiers in Microbiology. 2014;5:377.
41. Pingali PL, Pandey S. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector. In: Pingali PL, editor. World Maize Facts and Trends. Mexico City: CIMMYT; c2001. p. 1-24.
42. Plácido T, Yamashita T, Della Lucia SM, Abreu JD, de Paula SO, Fonseca ER, *et al*. Detoxification of Aflatoxin in Peanut Products by Trichoderma. Brazilian Journal of Microbiology. 2013;44(3):787-791.
43. Quezada MY, Moreno MA, Amaya MI, Lopez JD, Vazquez BI, Martinez AL, *et al*. Survey of Aflatoxins in Maize, Peanut and Soya from Mexican Markets. Food Additives and Contaminants: Part A. 2003;20:276-281.
44. Sanchis V. *Aspergillus*, Aflatoxins and Health. In: Bandyopadhyay R, editor. Aflatoxin Management in West Africa. Ibadan, Nigeria: IITA; c2014. p. 3-12.
45. Turner P, Sylla A, Gong YY, Diallo MS, Sutcliffe AE, Hall AJ, *et al*. Reduction in Exposure to Carcinogenic Aflatoxins by Postharvest Intervention Measures in West Africa: A Community-based Intervention Study. The Lancet. 2005;365(9475):1950-1956.
46. Van Egmond HP, Schothorst RC, Jonker MA. Regulations Relating to Mycotoxins in Food. Perspectives in Mycology. 2007;35:147-157.
47. Waliyar F, Reddy SV, Subramaniam K. Importance of Mycotoxins in Food and Feed in India. Aflatoxin Management in West Africa. Ibadan, Nigeria: IITA; c2008. p. 20-28.
48. Wenndt A, Valdivia C. Maize Storage Systems in Paraguay: The Role of Native Technical Knowledge and Farmer Preferences. Agriculture and Human Values. 1992;9:95-104.
49. Williams JH, Phillips TD, Jolly PE, Stiles JK, Jolly CM, Aggarwal D. Human Aflatoxicosis in Developing Countries: A Review of Toxicology, Exposure, Potential Health Consequences, and Interventions. The American Journal of Clinical Nutrition. 2004;80:1106-1122.
50. Zeringue HJ. Changes in *Aflatoxin* B1 Levels in Cottonseed and Corn Kernels upon Treatment with an Insect Sex Hormone. Phytopathology. 2000;90:647-650.
51. Wagacha JM, Muthomi JW. Mycotoxin Problem in Africa: Current Status, Implications to Food Safety, Health and Possible Management Strategies. International Journal of Food Microbiology. 2008;124:1-12.
52. Waliyar F, Kumar LP, Traore A, Ntare BR, Diarra B, Kodio O. Pre and post-harvest management of aflatoxin contamination in peanuts *In*: Leslie, L. F. (ed.)

Mycotoxins: Detection methods, management, public health and agricultural trade. CAB International, Cromwell Press, Trowbridge, UK; c2008.p. 209-218.
53. Wedge DE, Smith BJ. Discovery and Evaluation of Natural Product-Based Fungicides for Disease Control of Small Fruits. Biological Control of Plant Pathogens and Diseases. 2006;1:1-14.
54. Whitaker TB. Detecting Mycotoxins in Agricultural Commodities. Molecular Biotechnology. 2003;23:61-71.
55. Yan LY, Jiang JH, Ma ZH. Biological Control of Aflatoxin Contamination of Crops. Journal of Zhejiang University Science B. 2008;9:787-792.
56. Yaouba A, Tatsadjieu NL, Jazet DPM, Mbofung CM. Inhibition of Fungal Development in Maize Grains under Storage Condition by Essential Oils. International Journal of Biosciences. 2012;2(6):41-48.