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Review

Mycotoxins in food in West Africa: current situation and possibilities of controlling it

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This review presents the different mycotoxins (aflatoxins, fumonisins and ochratoxin A) produced in agricultural crops in the West African sub-region. The acute and chronic toxic effects of the various mycotoxins are presented. Maize and groundnuts have been found to be excellent substrate for aflatoxin contamination, while fumonisins are widely distributed in maize. Other food products for which mycotoxin contamination has been reported in the sub-region include dried yam chips, tiger nut, melon seeds and stored herbal plants. Mycotoxin contamination is favoured by stress factors during plant growth, late harvesting of crops, high ambient humidity preventing thorough drying, unscientific storage practices and lack of awareness. Control measures include education of the populace on the danger of mycotoxin contaminated diet, early harvesting, rapid drying, sorting, sanitation, use of improved storage structures, smoking, insect control, the use of botanicals and synthetic chemicals as storage protectants, fumigation, biological control, the use of resistant varieties and detoxification of mycotoxin contaminated grains.

Key words: Mycotoxins, aflatoxins, food, fumonisins, ochratoxin A, surveillance, toxicology, prevention, control, West Africa.

INTRODUCTION

The safety of food and feed for human and animal consumption should be of topmost priority with regards to the regulation of agricultural and food industries. Those involved in farming in sub- Saharan Africa constitute about 70% of the population, and food commodities are the major items of international trade for many West African countries (Conway and Toenniessen, 2003) . The quality and safety of food is of importance so that markets are not compromised by the sale of low quality or unsafe food. For the safety of human food, food-borne bacteria constitute the greatest hazard, followed by mycotoxins. Conversely in terms of livestock feeds, mycotoxins pose the greatest threat. Mycotoxins are low molecular weight compounds that do not produce immediate symptoms, unlike the bacteria toxins that are macromolecular proteins that produce symptoms in only a few hours, because the body recognizes them as antigens and produces antibody-mediated reaction. Mycotoxins are toxic secondary metabolites of fungal origin, which when ingested, inhaled or absorbed through the skin cause lowered performance, sickness or death in human and animals.

Mycotoxins have attracted worldwide attention due to the significant losses associated with their impact on

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human and animal health, and consequent national economic implications (Bhat and Vashanti, 1999). Mycotoxicosis is the consequence or effect (disease or pathological abnormalities) of ingesting toxin-contaminated foods by man and animals. It may also result indirectly from consumption of animal products such as milk from livestock exposed to contaminated feed. Though mycotoxins have impacted mankind since the beginning of organized crop cultivation, but until the past 40 years, their effects have largely been ignored. The scientific study of mycotoxins began in 1960 when a large number of turkey poults died in England due to consumption of contaminated groundnut meal imported from Brazil (Blount, 1961) . A toxigenic fungus identified as *Aspergillus flavus* was isolated from the groundnuts and the toxic principle was named aflatoxin meaning *A. flavus* toxins. Over 300 'mycotoxins' have been reported (Coker, 1979). However, based on extensive analytical studies (IARC, 1993) and detailed study of the distribution of fungi in nature, the five agriculturally important toxins from fungi are aflatoxins, fumonisins, ochratoxin A, zearalenone and deoxynivanelol. Fungal toxins can cause acute or chronic intoxications, depending on the animal, sex, breed and dosage (Coker, 1979). The only toxin that has gained prominence in scientific literature in food products from the west African sub-region is aflatoxin, while there are few studies conducted on fumonisin and ochratoxin A.

There is ample evidence that the inhabitants of sub-Saharan Africa are experiencing heavy dietary exposure to food-borne mycotoxins particularly aflatoxins and fumonisins. According to the World Development Report (1993), diseases caused by mycotoxins lead to reduced life expectancy in developing countries (Miller, 1996). In many parts of Africa, the need to eat outweighs other considerations such as food safety, and as such, this has made food-borne intoxications to be a serious problem in many parts. According to Miller (1996), 40% of the productivity lost to diseases in developing countries is due to diseases exacerbated by aflatoxins. Regrettably, many of the people in the region are not even aware of the effect of consuming mouldy products. Due to the poor education levels and other socio-economic factors, even if steps are taken to make food products safe the consumers will be unwilling to pay the extra costs, and will still prefer to buy the cheap commodities.

The West African countries have tropical climate with an all year round high ambient temperature and relative humidity that provide optimal condition for the growth of toxigenic moulds. The sub-region also has poorly developed infrastructures such as processing facilities, storage, transportation and skilled human resources.

Fungi that produce toxins in food are classified into field fungi and storage fungi based on their ecological requirements for growth (Bankole, 1994). The first group requires grain moisture above 20% in cereals and often causes ear rot diseases and toxin production before harvest, when the crop is still in the field. The important genera of field fungi include *Fusarium*, *Cladosporium* and *Alternaria*. The storage fungi usually grow in grain with moisture content in equilibrium with 70-90% relative humidity, which corresponds to less than 18% moisture content in cereals, and the most important genera are *Aspergillus* and *Penicillium*. They are infrequently associated with crops in the field, but are also associated with plant debris, plant surfaces, atmosphere and other surfaces where the water activity is relatively low.

FUMONISINS

The most important field fungi of maize in Africa and worldwide are *Fusarium* spp, and they are known to produce over 100 secondary metabolites that can adversely affect human and animal health (Visconti, 2001) . *F. verticillioides* (sny *F. moniliforme*) has been found to be the most widespread. Many studies in Nigeria have found this fungus to be the most frequent in preharvest and stored maize (Ekpo and Banjoko, 1994; Essien, 2000). This fungus is so intimately associated with maize that it was frequently observed in symptomless maize kernels in Nigeria (Thomas and Buddenhagen, 1980).

Fumonisins discovered in South Africa in 1988 (Marasas, 1995), and produced by *F. verticillioides* and *F. proliferatum* are recently receiving increasing attention in scientific literature because they have been implicated in a number of animal diseases, such as leucoencephalomalacia in equines, which involves a massive liquefaction of the cerebral hemisphere of the brain with neurological manifestations such as abnormal movement, aimless circling, lameness, etc (Marasas, 1995), porcine pulmonary oedema, rat liver cancer and haemorrhage in the brain of rabbits (Marasas, 1995). It can cause hepatotoxicity, and nephrotoxicity in many animals (Howard et al., 2001). In a 2-year study conducted by the US Food and Drug Administration, it was shown that at high exposure, fumonisin B_1 produced liver cancer, decreased the life span in female mice, and also induced liver carcinoma in male rat, but did not decrease the life span. (NTP, 1999).

There is not enough conclusive evidence of the human health hazards associated with fumonisin contaminated food, though human health risks associated with fumonisin are possible (FDA, 2001). However, some correlation studies have suggested a link between the consumption of maize with high incidence of *F. verticillioides* and fumonisins and the high incidence of human oesophageal carcinoma in certain parts of South Africa and China (Yoshizawa et al., 1994; IPCS, 2000)). Fumonisin has been demonstrated to induce apoptosis in cultured human cells and in rat kidneys (Tollenson et al., 1996). IARC (1993) evaluated the carcinogenicity of grains contaminated with *F. moniliforme*, containing fumonisins and fusaric acid, and found them to be possible human carcinogens. So far, Switzerland has a

provisional tolerance value of 1 ppm for fumonisin B_1 and B_2 in maize products (FAO, 1997). The United States FDA has proposed a guideline of tolerance level of 2 mg/kg total fumonisins in corn for human consumption (FDA, 2001).

Hell et al. (1996) found that the levels of fumonisins detected in maize samples decreased from south to north in Benin, and that the fumonisin levels significantly correlated with aflatoxin levels. Doko et al. (1995) reported average fumonisin levels of 640 g/kg in maize from Benin, while in our survey conducted from 2000 to 2001 in Nigeria, fumonisin B_1 was detected in 55 of the 108 maize samples (Bankole et al., 2003). The concentrations of fumonisin B_1 in the Nigerian samples varied from 65 to 1830 g/kg with mean levels in positive samples of 390 g/kg. Linear correlation analysis showed a significant positive correlation between the number of samples positive to fumonisin B_1 and those infected by *F. verticillioides*. It was found that the fumonisin level in samples did not correlate with the extent of visible mouldiness in samples (Bankole et al., 2003).

The level of insect damage in grains influences the extent of fumonisin contamination. Avantaggio et al. (2002) found that insect damage of maize is a good predictor of *Fusarium* mycotoxin contamination, and can serve as early warning of fumonisin contamination. Insects carry the spores of *Fusarium* from plant surfaces to the interior of the stalk or kernels or create infection wounds due to the feeding of the larvae on stalks or kernels (Munkvold and Hellminch, 2000).

AFLATOXINS

The fungi *A. flavus*, *A. parasiticus* and *A. nominus*, produce aflatoxin. *A. flavus*, however, is the most common producer (Bradburn et al., 1993). These fungi occur principally in soil and decaying vegetation. The four major aflatoxins are B_1, B_2, G_1 and G_2. Aflatoxins M_1 and M_2 are hydroxylated metabolites of aflatoxins B_1 and B_2, respectively in animals. Exposure to aflatoxin is widespread in West Africa, probably starting in the utero, and blood tests have shown that very high percentage of West Africans are exposed to aflatoxins. In a study carried out in the Gambia, Guinea Conakry, Nigeria and Senegal, over 98% of subjects tested positive to aflatoxin markers (Wild, 1996). Aflatoxin is a very powerful hepatocarcinogen, and naturally occurring mixtures of aflatoxins has been classified as a class 1 human carcinogen (IARC, 1993). The IARC also concluded that there was inadequate evidence for the carcinogenicity of aflatoxin M_1.

Aflatoxin contaminated diet has been linked with the high incidence of liver cancer in Africa (Oettle, 1964; Bababunmi et al., 1978) . In a recent study in China, Li et al. (2001) found that the levels of aflatoxins B_1, B_2, and G_1 were significantly higher in corn from the high incidence area for human hepatocellular carcinoma, and the average daily intake of aflatoxin B_1 from the high risk area was 184.1 g. Aflatoxin synergies other agents such as hepatitis B in the causation of liver cancer (Turner et al., 2000). Though, the etiology and pathogenesis of kwashiorkor still remain obscure, but much higher aflatoxins have been found in the blood, urine and livers of children with the disease than similar age-matched children (Hendrickse, 1983, 1984), and the presence of the toxin was established in the autopsy brain tissue of some Nigerian children (Oyelami et al., 1996) . Nutritional deficiencies are quite prevalent in populations consuming high quantities of cereals. Aflatoxin positive kwashiorkor children showed significantly greater severity of edema, increased number of infections, lower haemoglobin levels and longer duration of hospital stay than aflatoxin-negative kwashiorkor children (Adhikari et al., 1994; Ramjee, 1996). It seems that the protein deficiency reduces the capacity of the liver to detoxify aflatoxins. Thus, the conclusion is that aflatoxin may be a contributory factor in increasing the morbidity of children suffering from the disease (Ramjee, 1996).

In a recent study in Nigeria Uriah et al. (2001) found that blood and semen aflatoxin levels ranged from 700 to 1393 ng/ml and 60 to 148 ng/ml, respectively in infertile men and were significantly higher than that in fertile men. Gong et al. (2002) demonstrated that children in Togo and Benin who ate foods contaminated with aflatoxins showed the kind of stunted growth and being underweight, which are symptoms normally associated with malnutrition. Aflatoxins have also been shown to be immunotoxic to both livestock and man. Turner et al. (2003) detected aflatoxin albumin adducts in 93% of sampled children (6-9 years) in Gambia and provided evidence that IgA in saliva may be reduced because of high dietary levels of aflatoxin exposure. The study confirmed that children in rural areas of Gambia are frequently exposed to high levels of aflatoxin. In the US, the FDA uses an action level of 20 g/kg as the maximum residue limit allowed in food for human consumption, except for milk (FAO, 1996). For overall sanitary precaution principle, the European Union has enacted in 1998 very severe aflatoxin tolerance standards of 2 g/kg aflatoxin B_1 and 4 g/kg total aflatoxins for nuts and cereals for human consumption (CEC, 1998), and this has come into effect from January, 2001 (Dimanchie, 2001).

Consumers in the developed world are now well aware of the carcinogenic effect of aflatoxins, and will thus shy away from a product from any supplier that has aflatoxin beyond the acceptance level. Exports of agricultural products particularly groundnuts from developing countries have dropped considerably in recent years resulting in major economic losses to producing countries (Bhat and Vashanti, 1999; Otzuki et al., 2001). According to the World Bank estimate, the policy change by the EU will reduce by 64% imports of cereals, dried fruits, and

nuts from nine African countries: Chad, Egypt, Gambia, Mali, Nigeria, Senegal, South Africa, Sudan and Zimbabwe, and this will cost African countries about US $670 million in trade per year (Kellerhals, 2000). Though, the new EU rule has been criticized as excessively too rigorous, because the difference between the EU limits and the Codex limits would only save two lives for every one billion people (WHO, 2000).

Commodities susceptible to aflatoxin contamination

Maize provides an excellent substrate for mould growth and mycotoxin contamination. Bouraima et al. (1993) found aflatoxin B_1 level up to 14 g/kg and aflatoxin G_1 level up to 58 g/kg in stored maize from Benin. Setamou et al. (1997) found that the percentage of samples contaminated with aflatoxin was 42.5% in 1994 and 30% in 1995 in preharvest maize from Benin. Udoh et al. (2000) reported that 33% of maize samples from different ecological zones of Nigeria were contaminated with aflatoxins. Hell et al. (2000a) found that the percentage of maize samples with more than 5 g/kg aflatoxin levels was between 9.9% and 32.2% in the different ecozones of Benin before storage, but that this increased to 15.0% and 32.2% after six months storage. All the maize samples collected from silos and warehouses in Ghana contained aflatoxins at levels ranging from 20 to 355 g/kg, while fermented maize dough collected from major processing sites contained aflatoxin levels of 0.7 to 313 g/kg (Kpodo, 1996). The role of insects in the spread of *A. flavus* and in increasing aflatoxin contamination has also bee stressed. Setamou et al. (1998) reported that the percentage of grains infected with *A. flavus* and samples contaminated with aflatoxin as well as the mean aflatoxin content of samples increased with increasing insect damage in preharvest maize in Benin. Hell et al. (2000b) found that no aflatoxin was detected in maize that was free of insect damage, whereas in maize with more than 70% of cobs damaged by insects, 30.3% were aflatoxin positive. The most important insects that spread *A. flavus* in preharvest maize was found to be the lepidopteran ear borer *Mussidia nigrivenella*, *Sitophilus zeamais* and *Carpophilus dimidiatus* (Setamou et al., 1998; Hell et al., 2000b). Preharvest aflatoxin production in maize is dependent on weather conditions during crop maturations. The risk of aflatoxin contamination before harvest is highest when environmental conditions are characterized by soil moisture stress with elevated temperatures (Payne, 1992).

Groundnuts cultivated in Northern Nigeria were contaminated with aflatoxin levels up to 2000 g/kg (McDonald, 1964) . The conditions of the shells was found to be of importance in relation to fungal contamination, and *A. flavus* was commonly associated with kernels from broken pods, and that most toxic samples come from this grade of pod (McDonald and Harkness, 1965). Damage to shells, which occur while the crop is in the ground, was found to predispose the kernels to contamination with aflatoxins (McDonald and Harkness, 1964). Akano and Atanda (1990) found aflatoxin B_1 concentrations in the range of 20- 455 g/kg in groundnut cake ('kulikuli') purchased from markets in Ibadan, Oyo State, Nigeria. Adebajo and Idowu (1994) reported that most of the corn-groundnut snack ('donkwa') contained aflatoxins above 30 g/kg immediately after preparation. Yameogo and Kassamba (1999) reported that seeds of groundnuts from Burkina Faso inoculated with *A.flavus* excreted all the four major aflatoxins, which peaked at 170 ppb after 6 days. Aflatoxin formation in groundnut is favoured by prolonged end of season drought and associated elevated temperature (Rachaputi et al., 2002).

Aflatoxin was detected in 98% of samples of dried yam chips surveyed in Benin with levels ranging from 2.2 to 220 g/kg and a mean value of 14 g/kg (Bassa et al., 2001) . Aflatoxin B_1 was detected in 22% of yam chips in Ogun and Oyo States of Nigeria (Bankole and Mabekoje, 2003), while in a larger survey conducted later, 54.2% of dried yam chips were contaminated with aflatoxin B_1 (4–186 g/kg; mean = 23 g/kg), 32.3% with aflatoxin B_2 (2-55 g/kg), while 5.2% were positive for aflatoxin G_1 (4-18 g/kg), and two samples tested positive for aflatoxin G_2 (Bankole and Adebanjo, 2003). Adebajo (1993) reported the presence of aflatoxins in tiger nut (*Cyperus esculentus*) at toxicologically unsafe levels. Bankole and Eseigbe (1996) detected aflatoxins in 35% of tiger nut with concentrations ranging from 10-120 g/kg collected from different parts of Nigeria, and the incidence of *A. flavus* and aflatoxin contamination was found to be correlated. Efuntoye (1996) reported the fungal contamination of herbal drug plants stored for sale in Ibadan, and demonstrated the mycotoxin producing ability of the isolates on artificial medium (Efuntoye, 1999). The problem with mycotoxin contamination in herbal plants is that they are consumed directly, unlike other products such as maize and groundnuts, which may undergo some processing before eating. In a recent survey, 27% of melon seed samples from farmers' stores contained aflatoxin B_1 with mean levels of 14 g/kg in the forest and 11 g/kg in the savanna of Nigeria (Bankole and Adebanjo, 2004). Rice, which is widely consumed in the country, has also been reported by various authors to favour aflatoxin production. A recent survey in UK shows that retail rice was contaminated with aflatoxins, though at toxicologically 'safe levels' (FSA, 2002).

OCHRATOXIN A

Ochratoxin A (OTA) is a mycotoxin produced by different species of *Aspergillus* and *Penicillium*, though it was first isolated from cultures of *Aspergillus ochraceus* (Van der Merwe et al., 1965). OTA is found as natural contaminants in many foodstuffs including cereals, dried

fruits, cocoa, wine poultry eggs and milk. OTA is immunosuppressive, teratogenic, genotoxic and mutagenic, and IARC has classified it in-group 2B as possibly carcinogenic to human (IARC, 1993). It was concluded by the Committee on Toxicity of Chemicals in Food, Consumer Products and Environment (COT) that OTA is a genotoxic carcinogen, and proposed that levels in foods be reduced to the lowest level that can be technologically attained (COT, 1997). The joint expert Committee on Food Additives of the WHO and FAO set a provisional maximum intake of 100 ng/kg body weight (bw), while the Scientific Committee on Food of the European Union proposed that the maximum daily intake of OTA should not exceed 5 ng/kg bw (WHO, 1996). Sedmikova et al. (2001) found that ochratoxin A can increase the mutagenic ability of aflatoxin B_1 in the case of the two simultaneously occurring in the same crop. It is frequently associated with crops grown in semi-arid and temperate regions, and it is not considered a major problem under the tropical climate. However, OTA has been found as a contaminant in tiger nut (Adebajo, 1993), while Kpodo (1996) reported the detection of OTA in five out of 20 samples of fermented maize dough at levels less than 6.1 g/kg. OTA has also been established to be a problem in cocoa beans exported from West Africa. The EU is presently contemplating on introducing regulatory limits in cocoa and cocoa products, and industries have been mandated to implement preventive measures to reduce OTA (CABI, 2001). Scientists at CABI have collected samples from all stages of cocoa production from the tree through to the finished product to determine those points at which OTA enters food (CABI, 2001). Grapes and wines, which have been found to contain ochratoxin A elsewhere in the world, have not been in the sub-region for the possible presence of OTA.

MYCOTOXIN CONTROL AND PREVENTION STRATEGIES

Mycotoxin control programs will result in economic gains as well as health improvement in the region. It is now realized by many developing countries that reducing mycotoxin levels in foods will confer international trade advantages as well as offer long-term health benefit to the local population. The new European standards of aflatoxin level in groundnuts and cereals means that effective control must be found by developing countries for them to continue to export to the attractive European Union markets. Mycotoxin researchers have proposed many solutions against aflatoxin production in food, and some of the strategies, which may be applicable in West Africa, are highlighted as follows.

Education and Extension

Since the problem posed to the health and economy by mycotoxins is only popular among researchers, and is not known to a larger percentage of the populace including even the educated ones. Therefore the National agency in each country such as the National Agency for Food and Drug Administration and Control in Nigeria should initiate a program to educate people. Unfortunately in Nigeria, NAFDAC is presently confronted with a much serious issue, which is the large-scale importation of fake drugs into Nigeria. Private non-governmental organizations should also join in the spread of information especially to the most remote villages. There should be regular programs on radio and televisions on mycotoxin hazards and discussion on the issue should also feature regularly on daily newspapers and magazines.

Seminars and workshops

Seminars and workshops provide avenues to exchange discoveries, and get information on work going on in other laboratories. In 1995, a workshop was organized by the International Institute of Tropical Agriculture in Cotonou to review the progress made on mycotoxin research in Africa. The meeting enabled scientists to assess the past and present work, and streamline the areas of future studies. More of this gathering is needed in the sub-region and in Africa as whole.

Adoption of good agronomic practices

Agronomic practices have been shown to have profound effect on mycotoxin contamination of crops in the field. Avantaggio et al. (2002) found that extremely high fumonisin contamination levels were found in maize ears visibly damaged by insects, and recommended field control of insects to reduce fumonisin contamination.

Early harvesting

Early harvesting has been advocated as a means of reducing the risk of aflatoxin contamination. Though, many farmers are aware of the need for early harvesting, however, labour constraints, unpredictable weather, the need for cash and the threat of thieves, rats and other animals often compel farmers to harvest at inappropriate time (Amyot, 1983). McDonald and Harkness (1967) found that the common practise of allowing the groundnuts to dry out in the field predispose the kernels to *A. flavus* infection. However, Rachaputi et al. (2002) demonstrated the importance of assessing aflatoxin risk on a site-by-site basis to make appropriate decisions on the timing of harvest to minimize aflatoxin levels and obtain maximum returns. Early harvesting and threshing under high aflatoxin risk conditions resulted in lower aflatoxin levels and higher gross returns of 27 than in delayed harvesting in groundnut. On the other hand, it

was also shown that early harvest under low aflatoxin risk resulted in lower gross returns because of lower yields and poor seeds grades.

Rapid drying

Among the recommendation for solving mycotoxin problem, rapid drying of agricultural products to low moisture is often emphasized, because all scenarios leading to mycotoxin contamination relate to non-maintenance of stored products at safe moisture content. Dry grains keep longer, safe from insects and moulds because the water activity required for their growth is not met. Drying harvested maize to 15.5% moisture content or lower within 24 to 48 h will reduce reduce the risk of fungus growth and consequent aflatoxin production (Hamilton, 2000). Most African farmers spread their harvests to dry under the sun, which often require longer durations for the product to attain 'safe' moisture level. The grains are spread out on rock surfaces or on nylons spread on the flour, and the stirring or turning is done manually till the product is dry. Due to the high rainfall at the time of harvest, farmers take some steps such as stacking the products to shield it from rain, bringing grains in under cover, drying grains over the fire and mixing of moist and dry grains (Amyot, 1983; Begum 1991). The efficacy of drying was demonstrated in the report of Awuah and Ellis (2002) when groundnut kernels with 6.6% moisture were free of fungi regardless of the storage protectant used for 6 months, whereas at 12% moisture, only jute bags with *S. aromaticum* effectively suppressed the cross infection of healthy kernels. However, when the moisture content was increased to 18.5%, the latter treatment was not as effective. In addition to ensuring that grains going into store have 'safe' moisture content, efforts should be made to prevent moisture migration into grains through leaking roofs and condensation resulting from inadequate ventilation.

Since sundrying may be a difficult task due to the high rainfall at the time of harvest, a lot of work has been done on the design of solar and mechanical dryers for use by farmers in the tropics (Axtell and Bush, 1991; Carruthers and Rodriquez, 1992). However, these dryers are not in use by farmers because large capital investment is involved. Other methods of drying that are much effective and rapid include microwave or sonic drying, but these could not be implemented in the sub-region because farmers do not have the requisite facilities. Mechanical dryers could be set up in strategic locations, which farmers can utilize if sundrying is proven difficult.

Physical separation

Sorting out of physically damaged and infected grains (known from colourations) from the apparently healthy ones is an efficient and feasible method of reducing mycotoxin contamination. This could be done manually or by using electronic sorter. Infection of seeds or grain often imparts colourations or changes some other physical characteristics. Udoh (1997) identified sorting of damaged maize cobs and cobs with poor husk covering as a practise that led to a significant reduction in aflatoxin contamination. This was corroborated by the report of Hell et al. (2000a) who advocated the removal of insect damaged cobs at harvest to reduce aflatoxin contamination. Martin et al. (1999) recommended the final sorting either by hand or by colorimetry as the only possible remedial technique against aflatoxin contamination of groundnut in Senegal, and that the efficacy of this depends on the extent of seed contamination. Aflatoxin was found to be concentrated in the mouldy and stained peanut, and its physical separation could result in overall reduction of aflatoxin in whole samples (Hirano et al., 2001). Schatzki and Haddon (2002) asserted that presently, there is no sorting mechanism that meets commercial needs of adequate reduction and product preservation, and suggested a rapid, non destructive selection of peanuts for high aflatoxin content by soaking and tandem mass spectroscopy. When this method was used to examine over 65,000 nuts, it yielded approximately 120 nuts, each having aflatoxin in the range of 250 to 43000 g/kg.

Sanitation

Clearing the remains of previous harvests and destroying infested crop residues are basic sanitary measures against storage deterioration. Cleaning of stores before loading in the new harvests was correlated to reduced aflatoxin levels (Hell et al., 2000a). Disposing heavily damaged ears, those having greater than 10% ear damage, also reduced aflatoxin levels in maize (Setamou et al., 1998). Wild hosts, which constitute a major source of infestation for storage pests, should be removed from the vicinity of stores.

The use of improved storage structures

Traditional storage structures used by farmers for on the farm storage include containers made of plant materials (woods, bamboo, thatch) or mud placed on raised platforms and covered with thatch or metal roofing sheet. Essentially the stores are constructed to prevent insect and rodent attack and to prevent moisture from getting into the grains. The adoption of high yielding varieties (mostly with poor storability) by farmers has made the traditional storage systems to become inadequate. However, it has been very difficult to promote the new storage technologies such the use of metal bins to small-scale farmers due to their high cost. Research is needed to develop and refine suitable storage systems that are not capital intensive.

Smoking

Smoking is also an efficient method of protecting maize against infestation by fungi. The efficacy of smoking in protecting against insect infestation was found to be comparable to that of the chemical Actellics (primiphos–methyl) (Daramola, 1986). About 3.6 and 12% of farmers in various ecological zones in Nigeria used smoke to preserve their grains, and this practise was found to decrease aflatoxin levels in farmers' stores. The efficacy of smoking was also confirmed by Hell et al. (2000a) in the survey conducted in Benin. However, the problem with smoking is that if not carefully applied, it may discolour the product and change the taste.

Use of plant products

Some traditionally useful plants have been shown to exhibit fungitoxic properties. Awuah (1996) reported that the following plants *Occimum gratissimum*, *Cymbopogon citratus*, *Xylopia aethiopica*, *Monodera myristica*, *Syzigium aromaticum*, *Cinnamum verum* and *Piper nigrum* are effective in inhibiting formation of nonsorbic acid, a precursor in aflatoxin synthesis pathway. Leave powder of *Occimum* has been successfully used in inhibiting mould development on stored soybean for 9 months (Awuah, 1996). The essential oil and powder extracts of *Cymbopogon citratus* inhibited the growth of fungi including toxigenic species such as *A. flavus* and *A. fumigatus* (Adegoke and Odelusola, 1996). Adegoke et al. (2000) found that the minimum inhibitory concentration of the essential oil monoterpenes of the spice *Aframomum danielli* for the aflatoxigenic mould *A. parasiticus* was 78 ug/ml. It was found that the terpenoid had a damaging effect on biological membranes of susceptible organisms. Awuah and Ellis (2002) reported the effective use of powders of leaves of *O. grattisimum* and cloves of *Syzygium aromaticum* combination with some packaging materials to protect groundnut kernels artificially inoculated with *A. parasiticus.*

Essential oils from *Azadirachta indica* and *Morinda lucida* were found to inhibit the growth of a toxigenic *A. flavus* and significantly reduced aflatoxin synthesis in inoculated maize grains (Bankole, 1997). Bouda et al. (2001) reported that the essential oils of some weed species such as *Ageratum conyzoides*, *Chromolaena odorata* and *Lantana camara* effectively controlled *Sitophilus zeamais* , and suggested that they could be exploited for insect control in stored products.

It should be noted that despite the vast literature on the efficacy of plant material in controlling mycotoxigenic moulds, there has not been any concerted effort of a large- scale trial of these plants on the farmers' field. Udoh et al. (2000) was of the view that caution must be exercised in using plant materials to control mycotoxins, because some of these materials are natural media for *A. flavus* growth. Hell et al. (2000a) found that the use of *Khaya senegalensis* bark to protect maize against insects increased the risk of aflatoxin development, and that even the farmers in Benin were aware of the low efficiency of the indigenous products, but were being compelled to use them because of their inaccessibility to chemical products. Most of the plants being screened for ability to control storage fungi are used in traditional medicine. Toxigenic *A. flavus* have been found to grow and produce mycotoxins in herbal plants (Efuntoye, 1996, 1999). In our own experience here, *C. odorata*, which has been reported to be potent against insects, was found to be an excellent substrate for the growth of storage fungi.

Synthetic chemicals

When used in the right quantity, chemicals (insecticides or fungicides) can result in highly economic gains (Giga and Biscoe, 1989). The poor education background of the farmers often leads to misuse of pesticides. Farmers across the sub-region are still using pesticides such as gammalin that have for long been banned. Thus, hundreds of people died in Nigeria recently as a result of consumption of cowpea treated with inappropriate pesticides.

Use of resistant varieties

Differences exist in the storability of different crop varieties, and other things being equal, it is preferable for farmers to grow crop varieties that have long durability in store. In most cases, this is not practicable, as most of the high yielding varieties increasingly being introduced to farmers are more susceptible to storage deterioration than the traditional varieties. Reducing contamination by varietal screening is one possible way, but the multiplicity of varietal resistance parameters means that totally resistance varieties will not be available for some time to come (Martin et al., 1999). Scientists at USDA have identified two maize lines that are resistant to *A. flavus* and *F.moniliforme* infection (Hamilton, 2000).

Fumigation

Seed fumigation with ethylene oxide and methyl formate was found to significantly reduce the incidence of fungi including toxigenic species on store groundnuts and melon seeds (Bankole, 1996). Kavita and Reddy (2000) reported that sodium chloride (2.5, 5.0 and 10.0%), propionic acid (1.0, 2.5 and 5.0%), acetic acid (1.0, 2.5 and 5.0%) inhibited aflatoxin B_1 production in *A. flavus* inoculated groundnuts and maize kept in gunny bags. However, all treatments except sodium chloride have adverse effect on seeds germination and viability.

Biological control

Biological control by introducing atoxigenic strains of *A. flavus* and *A. parasiticus* to soil of developing crop is one strategy that has recently gained prominence in literature. The introduction of various combinations of atoxigenic *A. flavus* and *A. parasiticus* into soil resulted in 74.3 to 99.9% reduction in aflatoxin contamination of peanuts in the US (Dorner et al., 1998). The application of non-aflatoxigenic strain of *A. flavus* around developing cotton plant led to a 68-87% reduction in aflatoxin contamination (Cotty, 1994). Dorner and Cole (2002) have also shown that field application of non toxigenic strains of A*. flavus* and *A. parasiticus* had a carry-over effect and reduced postharvest aflatoxin contamination, and in one study reported a 95.9% reductions. Though, the results of Dorner and Cole (2002) have shown that postharvest spraying of crops prior to storage with atoxigenic strains of *A. flavus* and *A. parasiticus* cannot protect against aflatoxin contamination (Dorner and Cole, 2002), but workers at the International Institute of Tropical Agriculture (IITA), Cotonou, Benin, have found a less toxic strain of *A. flavus* that grows on grains stored under warm humid conditions which can displace harmful strains that produce large amounts of toxins (IITA, 2003a) . Under the German Development Agency (BMZ) funded programme, scientists at IITA are spearheading a new offensive to minimize the formation of aflatoxins by exploiting a strategy called competitive exclusion (IITA, 2003b) . The principle is to introduce and establish a benign strain to replace the toxigenic strain. The next challenge of the researchers is to test the atoxigenic strains in different parts of Africa and in different agricultural products where aflatoxins are a threat.

Detoxification

A novel detoxification technique that is currently under investigation is the possibility of introducing a harmless phyllosilicate clay (HASCAS), which is widely used as an anticaking agent in animal feed in to the diet of animals (Phillips, 1997). The HSCAS is capable of tightly and selectively absorbing aflatoxins *in vitro* and *in vivo.* The incorporation of 0.5% by weight of HASCAS into the diet protected young animals exposed lethal aflatoxin levels up to 750 ppb. The next challenge is to investigate the consequences of introducing the HSCAS into the diets of an 'at risk' population.

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