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FOOD SAFETY IN THE RAPID TRANSFORMATION OF FOOD SYSTEMS IN AFRICA: AFLATOXINS ALONG THE MAIZE VALUE CHAIN IN NIGERIA – CONCEPTS AND FUTURE RESEARCH DIRECTIONS

By

Oluwatoyin Ademola, Saweda Liverpool-Tasie and Adewale Obadina

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Background/Motivation

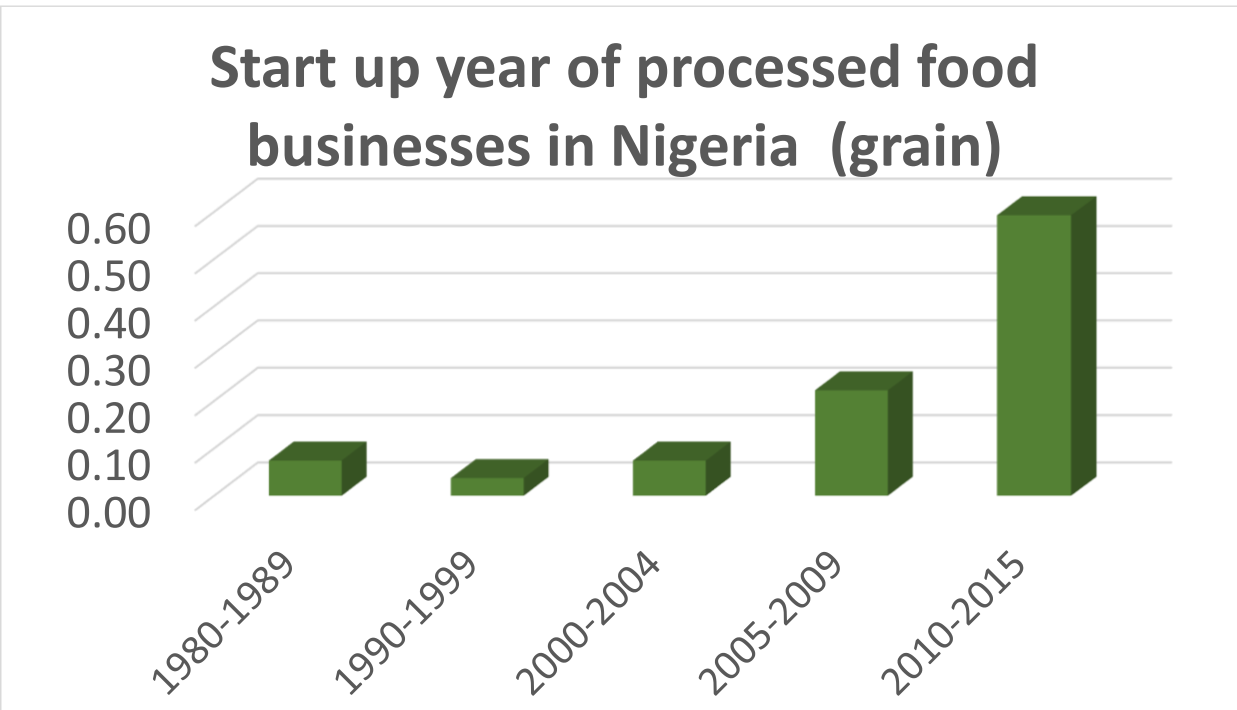
Over the past two decades, food systems in Sub Saharan Africa (SSA) have transformed rapidly. This transformation is driven by several factors including increased incomes and rapid urbanization rates which have caused consumption patterns to change significantly (Tschirley et al. 2017). Two characteristics of this transformation are the rise in food purchases (particularly by rural households) and the consumption of processed and packaged foods. In Nigeria for example, nationally representative data in 2015 reveals that almost 75% of foods consumed are purchased with over 65% processed in some form (Liverpool-Tasie et al., 2016). These high and increasing rates of purchased and processed foods are revealed broadly across the continent and in both rural and urban areas within countries (Tschirley et al., 2015; Liverpool-Tasie et al., 2016).

Increased consumption of processed foods can be met from two sources; domestically processed foods and imports. In addition to foreign exchange savings, domestically produced processed foods create numerous opportunities for domestic entrepreneurs and farmers; the potential source of inputs for these industries. However, they also raise key concerns related to food safety and nutrition. Consequently, regulations are necessary to ensure that these new products meet necessary food safety and nutrition standards. Similarly, incentives need to be aligned properly for economic agents along food supply chains for food safety considerations to be widely incorporated into these supply chains. Domestic production of substitutes for previously imported items (to meet increasing local demand for processed foods) in any developing country should be an area of key policy concern. Though there is evidence of a rise in domestic processed food production and consumption (Liverpool-Tasie et al. 2016; Tschirley et al., 2015) the extent to which standards exist and are enforced for domestic processed foods is not well understood in many countries in Sub Saharan Africa. Consequently, this paper explores one particular issue related to food safety in Nigeria; the presence and potential effects of aflatoxins along Nigeria's maize value chain.

Nigeria is the most populous country in Africa with one of the two largest economies on the continent (World Bank, 2017). Nigeria dominates in terms of exports' values among West African countries (ECOWAS, 2016) and is a major market for goods from other countries such as China, United States and Netherlands (OEC, 2015). Furthermore, there has been a recent expansion in domestic processing firms across the country. Liverpool-Tasie et al. 2017b found that approximately 60% of largely medium scale packaged food companies surveyed in their 2016 study were established between 2010 and 2015. (See Figure 1). Consequently, understanding the extent to which processed foods in Nigeria meet necessary national and international regulatory standards for health and safety has implications for the country and the entire continent.

Maize was selected because of the longstanding and growing importance of the crop in the food and feed industry in Africa, and Nigeria in particular. Though introduced to the African continent in the 1500s, maize has become one of the continents' dominant food crops (IITA 2013). The continent accounts for 7% of global production with Nigeria in the lead (IITA, 2013). Nigeria's maize production was around ten million tons in 2014 (FAOSTAT, 2017) and seventy-eight percent of maize in Nigeria is said to be cultivated for human consumption (USDA, 2012). With higher incomes and increased animal protein consumption, Nigeria's demand for maize for feed has also dramatically increased. Between 2003 and 2015, the volume of feed used in Nigeria increased from 300 thousand to 1.8 million tons; a 600% increase (Liverpool-Tasie et al. 2017a). This increase in direct and indirect demand for maize raises old and new challenges related to food safety in Nigeria and beyond. The old challenges center around ever-increasing quantities of staple crop consumed fresh, boiled/roasted and in low level processed form (in flour and in wet form for a traditionally fermented maize cereal called pap or Ogi). The new challenges include those posed by maize as a key ingredient in animal feed (to serve rapidly growing livestock sub sectors) and those associated with increasing consumption of more commercially processed maize products such as cereals (cornflakes, golden morn etc). Within this rise in commercially processed and packaged maize products, the discussion of challenges with domestically produced versus imports is key. In a study conducted in 2 Nigerian cities (Ibadan, South West Nigeria and Kaduna, North West Nigeria) Liverpool-Tasie et al. (2017b) found that domestically produced maize products dominate in retail volume terms across retail outlets in Nigeria. These retail outlets include independent supermarkets, grocery stores and non-services stores. In wet markets (where majority of shopping is conducted by the average Nigerian) the share of domestically produced maize based products is much higher accounting for over 80% of the volume of maize based products in both cities. Consequently, ensuring that these products are safe and healthy for human consumption is imperative.

Figure 1



Source: Liverpool-Tasie et al. (2017b)

Aflatoxin incidence and growth along the maize value chain

Aflatoxins are highly toxic metabolites produced by the toxigenic fungi species of *Aspergillus;* they usually contaminate agricultural produce such as maize, on the fields, in stores, and in the final products. Aflatoxin contamination poses a global problem though its impact is more prevalent in tropical climatic regions throughout the entire continent of Africa (ECOWAS, 2013; Wild et al., 2016). Four common aflatoxins have been reported as present in agricultural produce: Aflatoxin B1 (AFB1), Aflatoxin B2(AFB2), Aflatoxin G1 and Aflatoxin G2. However, AFB1 and AFB2 are the two most important with AFB1 proven to be the most toxic (Bhat and Vasanthi, 2003; Da Costal et al., 2010). The *Aspergillus sp* that contaminates grains are storage mold; their infestation typically starts during the postharvest period and further proliferates in improper storage conditions. Chatterjee et al. (1990) established that Aspergillus species might invade and attack maturing kernels in the fields before harvest. This suggests that aflatoxin contaminated grain can leave the farmers' fields and proliferate further in the store. The storage fungi usually grow in grain with moisture content greater than 14%, relative humidity between 70-90%, pH 4-6 and temperature of about 30-40^{0}C (Bankole and Adebanjo, 2003; Whitlow and Hagler, 2013). In Nigeria, aflatoxins have been found to be present in several key staples including maize and peanuts (Bankole and Mabekoje, 2004; Adetunji et al., 2014; Ezekiel et al., 2013; Afolabi et al., 2015). Other cereals such as sorghum and millet are also affected by aflatoxins (Makun et al., 2009; Apeh et al., 2016).

Aware of the serious effects of aflatoxins on humans and other animals, several countries have established regulations on the levels of aflatoxin in food and feed. These moves are to safeguard the health of residents, and the economic interests of producers and traders (SON, Code of practice and commodities standards, 2017). Nigeria as a member of Codex Alimentarius Commission, a joint FAO/WHO Food Standard Program, has regulations modelled on those of the international body. A standard approach to the control of aflatoxin in Nigeria is in place through the Standards Organization of Nigeria (SON). SON, the Federal Standardization body in Nigeria was established by Act No. 56 of 1971. The 1971 Act has been replaced by the SON Act No. 14, 2015. SON has adopted all relevant, existing Codex Codes of practice for the prevention and elimination of aflatoxin and has therefore set standards for aflatoxins in Nigerian maize products. The maximum limits for total aflatoxin (AFB1+AFB2+AFG1+AFG2) in maize grain is 4 ppb; 2 ppb for AFB1 (SON - NIS 253:2003), 2ppb for AFB1 in maize grit (SON - NIS 718:2010). These standards are the same as the maximum limits set by European Union Commission (EU, 2006), for aflatoxin B1 (2 ppb) and total aflatoxins (4 ppb) as well as the standard set by the United States for total aflatoxin in foodstuff at (20 µg/kg = 20ppb). National Agency for Food and Drug Administration and control (NAFDAC) is a Nigerian regulatory body with the mandate to enforce and monitor the standards set by SON throughout the food chain. The strength of enforcement is not certain and limited to packaged foods sold where present.

As preliminary evidence of this concern, we tested the levels of aflatoxins in three maize products available in the domestic market in Nigeria in a toxicology lab on the Michigan State University Campus. The first was a locally processed and packaged maize cereal (ogi). The second was a locally produced custard (produced with imported corn starch) and the third, a locally produced cereal product from a multinational food and beverage company. The products were tested for the presence and level of aflatoxin using Liquid chromatography mass tandem spectrometry (LC-MS/MS). LC-MS/MS involves the coupling of liquid chromatography techniques to mass-spectrometry which results in detecting and quantifying a single mycotoxin, a group of the same type of mycotoxin and the analysis of many concurrent mycotoxins (Li et al., 2013). It was used because of its efficiency, improved detection limits and spectrum of metabolites it can detect. Eight mycotoxins were detected in all the three samples, namely aflatoxin B1, B2, G1, G2, vomitoxin, T-2 toxin, DAS and Zearalenone. The result revealed that the mycotoxins detected in the locally produced custard and the cereal from the international beverage company were below limit of detection (i.e. less than 2ppb) while the locally produced *Ogi* had a high level of aflatoxin B1 of 15ppb, higher than the SON standard of 2ppb. The high level of aflatoxin B1 in the locally produced Ogi could be as a result of high levels of contamination of the maize grain and/or inefficient processing in terms of the fermentation process. This confirms that more attention needs to be paid to issues of food security generally and even among processed and packaged foods in Nigeria.

The situation is also of concern for many unpackaged foods where regulation of aflatoxin levels is largely nonexistent. Most maize based products get into the open market without being tested. In cases where subsistence farming is practiced, farmers produce and consume maize without testing for aflatoxin. The regulation of the product is essentially non-existent. According to field research carried out by (Abt Associates Incorporates, 2013), farmers revealed that there was no evidence of testing for aflatoxin in maize before consumption or sales. Prevalent practice in some markets is that farmers voluntarily separate moldy from clean grains while traders/sellers wash, sun dry and re-bag any maize grains that appear moldy. In a country as food insecure and populous as Nigeria, crops are rarely discarded. When contaminated crops are rejected by one player, another poorer market base is ready to buy and use the crop at a lower cost.

The risk associated with human and animal aflatoxin exposure is dire. Over fifty-five billion people worldwide suffer from uncontrolled exposure to aflatoxin (Strosnider et al., 2006), and there are different diseases associated with this exposure. (Bandyopadhyay et al., 2016) reported a case of aflatoxicosis among humans in Kenya which resulted in death because of frequent ingestion of maize contaminated with aflatoxin. Liver cancer from chronic exposure to aflatoxin (especially AFB1) known as Hepatocellular carcinoma (HCC), has been well documented, (particularly in poor nations) (Plymoth et al., 2009; Wild and Gong 2010; Liu and Wu, 2010). Nigeria has recorded the highest estimated annual global burden of HCC cases as a result of aflatoxin exposure (Liu and Wu, 2010). Long term exposure to aflatoxins is associated with child stunting, immune system suppression and reduction of life-expectancy (Bandyopadhyay et al., 2007; Hernandez-Vargas et al., 2015; Williams et al., 2004). Women and children are more susceptible to aflatoxin exposure; women can expose their unborn child to aflatoxin during pregnancy and through breast feeding because of consuming aflatoxin contaminated foods (Gong et al., 2003; Oluwafemi and Ibeh, 2011).

A study carried out on risk assessment of aflatoxin in the maize grain consumed by adults (Adetunji et al., 2014) and infant and young children (IYC) (Adetunji et al., 2017) in different agro ecological zones of Nigeria, showed higher exposure levels to aflatoxins among IYC compared to the adult group. A separate study revealed that the Derived Savannah Zone (Ondo, Oyo, Ekiti, Osun and Nasarawa states) had the highest exposure for IYC and adults while the Sudan Savannah Zones (Kano and Sokoto states) had the least exposure. Generally, these studies revealed that the mean exposure levels in Nigeria exceeded the 0.017 ng/kg body weight/day permissible exposure threshold by more than 45,000-fold. This obtained for all categories of maize consumers of aflatoxin across all the agro ecological zones and that infants and children are more at risk than adults. These studies further revealed that 152.7 Nigerian infants and 61.1 Nigerian children per 100,000 of the population are at risk of primary liver cancer as against 25.5 for Nigerian adults. Across the agro ecological zones, 240 infants out of every 100,000 people in the derived savannah zone are more at risk of HCC than infants and children in other agro ecological zones. A national value of about 7,761 liver cancer cases per year out of 10,130 total liver cancer cases annually, was recorded as due to consumption of aflatoxin contaminated maize and groundnuts in Nigeria resulting into a total burden of 100,965 disability adjusted life years lost (Abt Associates Incorporated, 2013).

Problems associated with aflatoxin extend beyond human consumption. They could potentially affect the welfare of animals, productivity of livestock and fish. As incomes increase and diets change (as has been seen historically in most of Europe and North America, and later by Asia and Latin America and more recently now in Africa) the demand for animal proteins increase. This typically is accompanied by a rise in the volume of the domestic livestock sector. For example, in Nigeria, Animal proteins alone account for about 15% and 20% of the food budget in rural and urban areas respectively (Liverpool-Tasie et al. 2017). As incomes rise, it is expected that Nigerians will eat more red meat, chicken, and fish Thus, it is important to understand the implication of aflatoxin on animal health (e.g. Livestock and poultry). Aflatoxin exposure affects animals because grains (contaminated by aflatoxins) are typically compounded as feeds for animal consumption. Furthermore, aflatoxins have been more frequently associated with products such as corn silage that include not just grains but a high percentage of stalks and stover (Mekuanint Gashaw, 2015).

The susceptibility of animals to mycotoxins varies for different animals according to their age, species and exposure to a specific toxin (Pier et al., 2007) but ruminants such as goats, sheep and cattle are less sensitive to the negative effects of mycotoxins. (Ratcliff, 2002) reported that all species of domestic animals and poultry are susceptible to aflatoxin and the effects could be hepatoxic, carcinogenic and immune suppressive to death. Adverse effects of aflatoxin on animal health for swine, cattle, goats, sheep and poultry have been recognized and reported by several authors around the world. Aflatoxin can cause deleterious damage to animals through liver damage, gastrointestinal dysfunction, reduced productivity, decreased reproductive performance, decreased feed utilization and efficiency, birth defects, tumors and the suppression of their immune system even when low levels are consumed; their chances of being infected by various diseases are therefore increased. (Akande et al., 2006; Cortyl, 2008) Aflatoxin also causes increase liver fat (fatty liver syndrome) (Bakirdere et al., 2012).

Aflatoxins research in Nigeria has been carried out by biochemists and food scientists but the implications and effects of their research outputs are not well understood by consumers and social scientists. Ezekiel et al. (2013) reported that only 15% of consumers in five Nigerian states (Lagos, Ogun, Oyo, Niger, and Kaduna) were aware that groundnut cakes could be contaminated with aflatoxin. A study by (Ilesanmi and Ilesanmi, 2011) shows that 80.6% of health workers in Ibadan, Nigeria have good knowledge of aflatoxin contamination in groundnut while (Idahor and Ogara, 2010) reported that only 860 (32%) out of 2689 Tiv farmers in Benue State, Nigeria were aware of mycotoxins in food crops. Several studies have investigated the level of aflatoxins in pre-harvest maize, stored maize, and maize based products across different locations in Nigeria. (Bankole and Mabekoje, 2004) reported the level of aflatoxins in pre-harvest maize from farmers' fields in south west Nigeria (one out of five agro ecological zones where maize is predominant); they revealed that Aflatoxins B1, B2, G1 and G2 were present in all samples, and that the values ranged from 3 to 138 µg/kg with mean of 28 µg/kg which was above the standard set by the Standards Organization of Nigeria (SON). (Atenhang et al., 2008; Udoh et al., 2000; Adetunji et al., 2014) in different studies looked at the level of aflatoxin in stored maize across the agro ecological zones of Nigeria where maize is predominant. The authors observed different levels of aflatoxin contamination in maize and revealed that these levels varied in different ecological zones. The similarities in their report is the high level of aflatoxin above the international standard set for maize and foodstuff generally. Maize sold in open markets was investigated for the level of aflatoxins, and according to (Odoemulam and Osu, 2009; Arowora et al., 2012; Sule et al., 2015; Ifeanacho et al., 2017) in different studies, aflatoxins were found present in the maize, with AFB1 recording the highest levels. Other studies have focused on the level of aflatoxins in maize based products; (largely locally processed). A study by (Adebajo et al., 1994; Ezekiel et al., 2012) on street vended snacks (corn cake, kokoro) shows that aflatoxins were present in both samples but at varying levels. Ezekiel and Sombie (2014) investigated the level of aflatoxins in breakfast cereals (corn flakes and golden morn) in Ogun state, Nigeria. They found that aflatoxin was present but at a level below 20ppb which is recommended internationally for total aflatoxin in foodstuff. On the other hand, Oluwafemi and Ibeh (2011) reported high level of aflatoxins; above recommended maximum rates in some major weaning foods in Ibadan, Nigeria and concluded that exposure of infants to these foods is not safe for their development.

Preventing and reducing the prevalence and growth of aflatoxins along the maize value chain

Several factors can cause aflatoxin incidence during maize production. Hot and humid climatic conditions common to tropical regions, that prevail in parts of Nigeria, are two important environmental factors favoring mold growth and aflatoxin production. Soil type is also a natural factor that influences aflatoxin incidence during maize production (Atanda et al., 2013). Farmers' practices such as delayed harvest (that is leaving mature maize to dry on the field) have been highlighted by FAO (1999) as a factor that increases aflatoxin contamination during production of maize. Drying of maize grains without the cob, on the ground, can cause contamination from the soil with molds and foreign bodies adversely affecting quality (Odogola and Henriksson, 1999). Exposing maize to moisture pick up after drying and insect infestation can lead to fungal infection and subsequent aflatoxin production. Preventing aflatoxin incidence during maize production requires that early harvesting should be practiced alongside drying to a safe moisture content level. Ensuring uniform drying of maize to a safe moisture level will keep it in a good state longer, is unfavorable for mold growth and makes the grain safe from insect infestation. Drying maize on a raised platform will also prevent contact with the soil and other foreign material that can contaminate it.

Proper storage is critical in the maize value chain. Storage at less than 13% moisture content, 65% relative humidity; and temperature of less than 25^{0}C prevents the growth of storage molds (Montross et al., 1999). Factors that predispose maize to aflatoxin contamination during storage include poor storage conditions and poor storage methods. Poor storage conditions such as high moisture level, temperature and humid environment can stimulate moisture uptake of maize even after drying to a safe moisture level. These conditions could be favorable for mold growth and subsequent aflatoxin production. Poor storage methods can promote insect and rodent infestation thereby predisposing the grains to fugal attack. The most important way to prevent aflatoxin incidence during maize storage is the use of good storage methods such as the use of improved granary or good polythene bags (in situations where granary is not affordable). Such action is effective in preventing insect and rodent damage. Sorting of the maize grains before storage to remove discolored, tainted and damaged grains also prevents further contamination of aflatoxins.

Another point of concern is the handling of maize during transportation, when maize grains do not get to their point of sale in one day. Poor storage conditions during transportation such as leaking roofs of vehicles and condensation arising from inadequate ventilation can stimulate mold growth. Dry containers free from foreign matter that contaminates maize should be used during transportation; vehicles should be covered with tarpaulin while adequate ventilation is provided to prevent condensation during transportation to reduce fungal growth which can lead to aflatoxin production during transportation.

Aflatoxin presence in animal feed is another source of concern in the maize value chain. This is because most feeds are produced from maize, (often the low-quality maize rejected by large commercial operators) sold to feed millers. Some feed millers, aware of aflatoxin and its implications for their animal feed, get aflatoxins tests conducted by a company laboratory or an outsourcing agent. (Abt Associates Incorporated, 2013). An approach that involves the use of a binder, widely adopted by feed millers to reduce aflatoxins in feeds is described by (Hell et al., 2008). The binder is a clay/mineral mix with animal feed which binds chemically to aflatoxins and prevent its absorption in the gastrointestinal tracts, thus eliminating the clay-aflatoxin complex from the body of the animal.

The importance of processing methods in reducing aflatoxin level in maize is critical. Several different processing methods to reduce aflatoxin levels in maize products have been reported. However, their effectiveness depends on the initial levels of contamination of the maize grain. For a significant reduction in contamination of the maize product, its initial contaminated condition must be reasonably low. Some processing methods in aflatoxin reduction such as sorting, winnowing, washing, crushing combined with dehulling of maize grain are presented in Fandohan et al. (2005). Fermentation, a biological process that involves breakdown of substrates by microorganisms have shown a significant reduction in aflatoxin level during production of Ogi (Okeke et al., 2013). Although aflatoxins are heat stable compounds, baking and boiling are reported to reduce the level of aflatoxin B1 in corn meal and corn grit (Stoloff and Trucksess, 1981). Extrusion, another processing method that employs high heat (120- 220^{0}C), reduces aflatoxins B1 in corn tortillas (Elias-Orozeo et al., 2002). Nixtamalisation a processing method that involves the use of calcium hydroxide (lime) is called alkaline cooking; it gives a significant reduction of aflatoxins in corn chips, tortillas and tortilla chips (Torres et al., 2001)

Obviously strict regulation is another method to address the presence of aflatoxins in food. Regulation needs to be strengthened in Nigeria alongside efforts to minimize final consumer exposure to unsafe foods due to high aflatoxin incidence. The United States Food and Drug Administration (U.S. FDA) has set regulations on use of contaminated products that can be blended with uncontaminated products or other ingredients to make the composite feed safe for animal consumption (Dohlman, 2008; U.S. FDA, 2000; Rowe, 2007). This strategy has been employed by some Nigerian commercial feed companies as an economically efficient way of incorporating inexpensive protein sources (e.g., *kulikuli*- groundnut cake) into composite blends that are safe for animal consumption. Till date there are no regulations on aflatoxin in Nigerian animal and fish feeds, but commercial feed formulators are vigilant about aflatoxin levels because of the implications on health and productivity.

Research from the United States Department of Agriculture (USDA) shows that feeds with higher levels of contaminants can be used for 'finishing animals' bound for slaughter. The USDA has higher limits for aflatoxin contamination in 'finishing feed', which can be used up to 2 weeks before slaughter. Upper bounds for 'finishing feed' is set at 300 ppb for cattle; 200 ppb for swine; and less than 100 ppb for breeding cattle, swine, and mature poultry; it is set at less than 20 ppb for dairy cows and young animals (Dohlman, 2008; US FDA, 2000; Rowe, 2007).

The way forward?

It is clear that awareness about aflatoxins and its effects on human and animal health in Nigeria and other developing countries needs to be enhanced. Furthermore, to address the incidence and growth of aflatoxins in a sustainable way, further research is necessary to understand current practices of handlers of maize and maize based products and to compare them with best practices. There are costs and benefits associated with best agronomic and handling practices to deal with aflatoxins along the entire maize value chain. These have to be better understood so that necessary incentives are aligned to encourage their adoption.

Given how aflatoxin levels increase along the value chain with handling, storage and processing, a holistically approach to this issue is imperative. It is not possible to solve the problem by only focusing on one set of actors in the value chain. Research and policy interventions that support the development and provision of improved maize varieties that are resistance to fungal infection and use of biocontrol on maize fields are important. (Cotty et al., 2007; Dorne and Horn 2007). However, these efforts need to be accompanied by measures to prevent the exposure of grain to the fungi along the entire value chain. For example, the provision and use of drying equipment can reduce the moisture level of maize grains after harvest thus preventing mold growth at that stage. This compares to the common approach of using sun rays which leads to uneven drying of the grains and the accumulation of toxins when the fungi are mycotoxigenic in nature. Improved storage systems are also key. The use of well-structured storage systems (such as cribs recommended by FAO, 1979; NSPRI, 1982) by farmers and traders will better maintain the quality of maize grain during storage compared to the traditional methods of storing maize in compact rooms with poor ventilation. Storing maize in shelled form rather than on cobs is another potential approach. This lends to the use of loose grains that are easily handled, dried and maintained at a safe moisture level. Such action can reduce insect and rodent infestation. Strict compliance to good processing/manufacturing practices (cleaning, sorting, washing and use of proper packaging materials) and good hygienic practices (clean environment, use of clean equipment) is also necessary. Research to understand the factors affecting adoption of these practices (e.g. information, associated costs and profitability implications) is necessary. For example, sorting of the maize grain to remove damaged, discolored and moldy grains as well as cleaning before storage and processing are important but the extent to which they are practiced is not well documented.

In addition to a better understanding of the economic incentives associated with the necessary practices to reduce the levels and growth of aflatoxins along the maize value chain, practical health considerations and improved regulation are necessary. For example, vaccination against Hepatitis B virus to reduce aflatoxin related HCC is an effective clinical intervention (Li and Wu, 2010). In addition, constant inspection and monitoring of maize products throughout the value chain is necessary. All processed food should be monitored for aflatoxins. Guidelines and markets for the alternative use of contaminated maize products should be introduced. Furthermore, policies are needed to support an incentive structure that encourages all actors along the value chain to take into account their contribution to the problem or its solution.

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