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Aflatoxin Contamination in Foods and Feeds: A Special Focus on Africa

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1. Introduction

A groan can almost be audible from scientists who work or have an interest in the field of mycotoxicology (fungi and mycotoxins) to the effect of “not another review publication on AF”. It is true that since the discovery of AF in the early 1960s, a huge literature on AF has developed. In one way, this literature can be considered appropriate, as these mycotoxins set the scene for a new burst of activity in the contamination of feeds and foods with mycotoxins, those produced by filamentous fungi, which has shown that these substances are not merely academic novelties, but have important effects in questions of food quality and human and animal health. Further, the principal member of this mycotoxin group, AFB₁, one of the most carcinogenic natural products formed in nature (D’Mello, 2003), a major cause of hepatocellular carcinoma (liver cancer) in both animals and humans is rated as a Class IB carcinogen by the International Agency for Research on Cancer (IARC) (IARC, 1993) meaning that it is a proven cancer-inducing agent. It also occurs ubiquitously in the environment contaminating many different food and feed commodities. Rather interestingly, critics of the excessive focus on AF may perhaps, point out that one of the reasons it is intensely investigated is the ease with which it can be detected and measured due to its strong fluorescence and ultra violet (UV) light absorbing properties (Bhatnagar and Ehrlich, 2002) which skews attention away from other important mycotoxins not containing a chromophore such as the trichothecenes (TH) and fumonisins (FB). Another irony of the kudos given to AF is because of its discovery stemming mainly from the condition observed in Britain called Turkey X disease, where it was associated with deaths of tens of thousands of turkey poults (Blount, 1961) is that many of the symptoms of the disease fit those of cyclopiazonic acid (CPA) and later analysis of the groundnut used to produce feed for these birds was found to contain (CPA) in addition to AFB₁.

Whatever the merits and demerits of again reviewing literature on AF, this review has a specific purpose which has not been thoroughly explored in the past. This is to look at the ravages that this toxin has caused in Africa, not only from an animal and human health point of view, but also from the economic consequence of having agricultural commodities contaminated with these toxins. Although most countries of the world can be affected by AF, it is sub-Saharan Africa (SSA) that has suffered the most. It is difficult to defend this statement because of the lack of detailed information on the occurrence of AF in African crops. This is because, much of SSA agriculture occurs in impoverished rural areas and the lack of technical infrastructure in many African countries does not allow for routine quality control of even commercially produced commodities, never mind those produced by rural populations for their own consumption. Much of the data on the incidence of mycotoxins in SSA countries is generated by non-African agencies (e.g., IARC) (IARC 1993) or by academic institutions. This review attempts to bring together information from studies conducted over the years and attempts to discuss it in a way that will give some idea on the mycotoxin problem in the continent both from an agricultural, economic and health points of view. For reasons already highlighted, occurrence and effects of AF, principally AFB₁, is the best representative in doing this.

2. Factors enhancing the prevalence of aflatoxigenic fungi and aflatoxins in Africa

Prior to AF contamination, the food material must be infected with fungi that have the genetic capacity to synthesize and deposit the toxins on the foods and feeds before or after harvest. Only species of the genus *Aspergillus* are endowed with the 23 genes responsible for synthesis of AF. Members belonging to this genus are most abundant in the tropics and as such, are major food spoilage agents in warmer climates. The genus is metabolically versatile producing over twenty mycotoxins. Of the over 180 species of *Aspergillus*, only a few are aflatoxigenic. After the discovery of AF in the 1960s, *A. flavus* and *A. parasiticus* of the section *Flavi* were the only known AF producers producing the B and B/G types of AF, respectively (Blount, 1961). Other aflatoxigenic species that subsequently emerged are *A. nomius* (B and G types), *A. bombycis* (B and G AF), *A. ochraceoroseus*, and *A. pseudotamarii* (B type), but they occur less frequently (Peterson *et al.*, 2001, Ito *et al.* 2001)). *A. tamarii*, *A. paroisclerotigenus* (B types), *A. rambellii* and certain members of *Aspergillus* subgenus *Nidulantes* namely: *Emericella venezualensis* (Frisvad *et al.*, 2005) and *E. astellata* (Frisvad *et al.*, 2004), have now been included in the growing list of aflatoxigenic species. *A. arachidicola* sp. Nov. and *A. minisclerotigenes* sp. Nov that produce both forms of the toxin, are the latest emerging aflatoxigenic species (Pildain *et al.* 2008). The unexpected new comer is *A. niger*, an ochratoxin (OT) producer which was discovered over four decades ago but was never associated with AF synthesis. However, in a search for aflatoxigenic fungi in Romanian medicinal herbs, Mircea *et al.* (2008) showed the capacity of some strains of *A. niger* to produce AFB₁. All these known AF producing fungi particularly *A. flavus* are common and widespread in nature, and have been shown as fungal contaminants of African foods and feeds according to Atehnkeng *et al.* (2008), Essono *et al.* (2009), Njobeh *et al.* (2009) and Makun *et al.* (2011).

Despite the fact that a strain of mould has the genetic potential to produce a particular mycotoxin, the level of production would in part be influenced by the nutrients available.

Typically, moulds require a source of energy in the form of carbohydrates or vegetable oils in addition to a source of nitrogen either organic or inorganic, trace elements and available moisture for growth and toxin production. Cereals particularly oilseeds adequately provide all these nutrients and so are considered ideal substrates for growth of fungi and consequently, toxin synthesis (FAO, 1983). However, even amongst the cereals, mycotoxins contamination varies with size and integrity of seed the coat with the small, compact grains (wheat, rice, oat, sorghum) and those encapsulated in hard seed coats (beans and soybeans) being less susceptible to fungal infection and mycotoxin formation than larger grains such as maize (Stössel, 1986). In Africa, grains contribute about 46% of the total energy intake (FAOSTAT, 2010), this figure may even be higher in rural SSA, where cereals and tubers and roots are virtually the sources of nutrition. This over dependence on grains, an ideal substrate for AF synthesis in rural Africa is a major reason for the high AF load in the continent.

Probably the two most important environmental components favouring mould growth and AF production are hot and humid conditions. Although the optimum temperature and moisture content for growth and toxin production for the various aflatoxigenic fungi varies, many of them achieve best growth and toxin synthesis between 24°C and 28°C (Schindler *et al.*, 1977) and seed moisture content of at least 17.5% (Trenk and Hartman, 1970; Ominski *et al.*, 1994). These conditions approximate the ambient climatic conditions in most parts of Africa and hence also account for the high prevalence of the toxins in the continent. As to how climate change will alter the AF situation in the continent, is still a matter of public debate. However, in an attempt to predict how extreme climatic conditions associated with climate change can affect AF contamination, Paterson and Lima (2010) adduced that while anticipated warmer (33°C) and more humid conditions might increase AF prevalence in Europe, perhaps the reverse might be the case in tropical Africa as most aflatoxigenic fungi will not survive the expected 40°C. Even though this prediction is plausible, it is pertinent to state herein that if there will be a rise in temperature and a rainfall reduction in all parts of Africa except for East Africa where an increase in mean annual rainfall is expected (IPCC, 2007), it is only reasonable to assume that many regions of the continent will experience droughts while East Africa would be hotter and more humid and given that these conditions favour AF production (Mutegi *et al.* 2009), climate change might exacerbate the AF crisis in Africa. In agreement with this deduction, Paterson and Lima (2010) also speculated that if temperature does not increase as envisaged, then droughts might be more frequent. Drought conditions actually constitute stress factors to plants rendering them vulnerable to *Aspergillus* infection (Robertson, 2005; Holbrook *et al.*, 2004) with ensuing increase in AF pollution. An indelible sign that droughts prop up AF contamination is the fact that these conditions preceded the fatal outbreak of acute human aflatoxicosis that occurred in Kenya in 2004 (Afla-guard, 2005; CDC, 2004).

Soil is another natural factor that exerts a powerful influence on the incidence of fungi. Crops grown in different soil types may have significantly different levels of AF contamination. For example, peanuts grown in light sandy soils support rapid growth of the fungi, particularly under dry conditions, while heavier soils result in less contamination of peanuts due to their high water holding capacity which helps the plant to prevent drought stress (Codex Alimentarius Commission, 2004). Produce harvested from land on which groundnut has been planted the previous year were more highly infested by *A. flavus* and

contained more AF than crops grown on land previously planted with rye, oats, melon or potatoes (Martin and Gilman, 1976). Likewise, previously fungicide treated soil has been shown to reduce incidence of *A. flavus* in groundnuts to very low levels. Accordingly, it might also be useful to add recommendations on appropriate crop rotation programmes and soil treatments in order to reduce the hazards from mycotoxins.

The presence of other microorganisms either bacteria or other fungi may alter AF elaboration on food materials. When *A. parasiticus* was grown in the presence of some bacteria; *Streptococcus lactis* and *Lactobacillus casei*, AF production was reduced (Ominski *et al.*, 1994). Meanwhile, fungal metabolites such as rubratoxins from *Penicillium purpurogenum*; cerulenin from *Cephalosporium caerulens*; and *Acrocyndrium oryzae* enhance AF production even though they repress growth of AF producing fungi (Smith and Moss, 1985). This type of positive interaction between fungi in the same food matrix with regards to AF synthesis couple with multi-occurrence of mycotoxins from the different fungi which could at the least have additive if not synergistic health impact on the host (Speijer and Speijer, 2004) worsen the AF plight in Africa because such simultaneous co-occurrence of fungi and mycotoxins in African agricultural commodities is very common phenomenon as indicated by many workers including Makun *et al.* (2007), Makun *et al.* (2009) and Njobeh *et al.* (2009).

Much more than in other parts of the world, insects, termites, rodents and birds constitute a major problem to food safety and availability in Africa. The accessibility of these pests and predators to crops is made possible by the available deplorable storage facilities (bags, 'rhumbu') and traditional postharvest preservation techniques (drying grains on rocks and bare floor) applied in the region. Besides eating up parts of the human rations, they boost the susceptibility of crops to microbial infestation and infection with a correlating swell in AF occurrence (Hell *et al.* 2000). In the course of feeding on crops in the field or during storage, these animals physically wound kernels and tubers. Mechanical damage resulting from such actions of pests disrupts the seed coat and facilitates the penetration of fungal inoculum into the interior of the grains. In addition to the physical damage, these animals transmit spores from other plants and environmental surfaces to inoculate the already defective kernels and tubers and as such, help to distribute moulds widely throughout a bulk mass of grain or feed. The metabolic activities of pests especially insect larvae also produce metabolic water and heat (Sinha, 1984) that are beneficial for mould growth. The activities of these insects and birds occasioned by poor storage amenities (Hell *et al.*, 2000; Udoh *et al.*, 2000) provoke fungal growth and toxin production (Agboola, 1992; Wagacha and Muthomi, 2008). According to the review of Bankole and Adebajo (2003) on the mycotoxin situation in West Africa, the commonest insects that spread *A. flavus* in preharvest maize in the region are lepidopteran ear borer *Mussidia nigriovenella*, *Sitophilus zeamais* and *Carpophilus dimidiatus*.

Agricultural practices have profound impact on AF contamination of foods. Population drift from agrarian rural areas to urban settlements in search for employment has led to reduced workers on the farm and so 'off season' harvesting during early rains is increasingly common. Also because farmers have improved varieties of grains particularly maize, crops are now grown and harvested twice during the planting season and so harvesting of the first set of these crops is done in the wet months of July and August. Such 'off season' harvesting promotes growth of aflatoxigenic fungi and toxin synthesis (Kaaya and Warren, 2005). Harvesting methods that enhance seed breakage would also increase the degree of

mycotoxin formation. *Aspergillus flavus* was observed to be more abundant in kernels from pods gathered by combined harvesting than from hand harvested pods and the respective AFB₁ content were 1780 and 140ppb (Martin and Gilman, 1976). This is in agreement with the suggestion that certain modern agricultural management practices may create unique ecological niches which select toxigenic fungi (Bilgrami et al., 1981). Meanwhile, as Africa is experiencing a boost in mechanized farming, there are no commiserate control measures put in place to reduce the negative impact of this agricultural revolution on mycotoxin pollution.

Fungi are generally aerobic organisms; therefore storage atmosphere deficient in oxygen would lead to reduced metabolism and consequently mycotoxin production. Jarvis (1971) and Agboola (1992) reported that a reduction in oxygen content of storage environment from 5% to 1% and increase in carbon dioxide content to above 20% dramatically reduced the growth of *A. flavus* and AF production. Commodities are better stored anaerobically with the addition of organic acids such as propionic acid as preservatives in storage systems which do not absorb moisture or enhance moisture migration (Ominski et al. 1994). Unfortunately traditional storage facilities in Africa are devoid of such standard storage environments (Hell et al., 2000; Udoh et al., 2000).

Unwholesome trade practices have become problematic in guaranteeing food safety in the developing world. Since fungal proliferation and mycotoxin formation increase with duration of storage (Hell et al. 2000) when favourable conditions prevail, the hoarding of commodities under poor storage circumstances from October to July/ August for sale during period of scarcity in order to maximize profits which has become a common practice in rural Africa exaggerates AF contamination problem. Similarly, the tradition of mixing grains of different grades in order to improve the quality of contaminated grains especially when one contains a large number of fungi spores will provide inoculum for the good grade and probably contaminate the toxin-free grain with AF. Other compelling factors that worsen the AF burden in Africa are public ignorance of the existence of the toxins; complete absence or lack of enforcement of regulatory limits; and introduction of contaminated food into the food chain which has become inevitable due to shortage of food supply caused by drought, wars and other socioeconomic and political insecurity (Wagacha and Muthomi, 2008).

3. Occurrence of AF in foods and feeds

AF producing fungi particularly *A. flavus* are common and widespread in nature and most often found when certain grains are grown under stressful conditions such as drought. The moulds occurs in soil, decaying vegetation, hay and grains undergoing microbiological deterioration and invades all types of organic substrates when the conditions are favourable for growth particularly in hot and humid situations (Ominski et al., 1994). Under such a suitable environment, aflatoxigenic fungi contaminate foods and feeds directly or indirectly. In direct contamination, the product is infected with aflatoxigenic fungi with subsequent toxin production. Indirect contamination occurs when food or feed was previously contaminated with AF producing fungi and although the fungi has been removed or killed during processing, AF still remains in the final product. Such contamination of cereals and oilseeds is the main point of entry of many mycotoxins in the human and animal dietary systems particularly in Africa (Smith and Moss, 1985). Fungal infection of agricultural

produce is inevitable but while in developed countries, they get removed from the food chain, in most parts of Africa, moulded foods are part of the daily diets. All foods and feedstuffs are vulnerable to fungal contamination but the nature and degree of aflatoxigenic fungal contamination will depend on the presence or absence of AF in the product. Whereas the identification of toxigenic fungal contaminants is an undoubted pointer to a potential risk, positive conclusions can only be made with certainty by quantifying the suspected toxins which is why this critical review of levels of AF in food commodities is an empirical assessment of Africa's health condition with regards to mycotoxicoses. The crops that frequently support growth of AF producing fungi and subsequent toxin production are thus principal sources of exposure to AF that include but not limited to cereals (maize, sorghum, pearl millet, rice, wheat), oilseeds (peanut, soybean, sunflower, cotton), spices (chile peppers, black pepper, coriander, turmeric, ginger), and tree nuts (almond, pistachio, walnut, coconut, brazil nuts) (FAO, 1983). The other possible sources of entry of mycotoxin into animal and human systems include fruits, vegetables, animal tissues and animal products and fermented products (Jarvis, 1976).

There are at least 14 natural occurring AF known to exist, however, only six have public health and agricultural significance and they include AFB₁, B₂, G₁ and G₂. The other two are AFM₁ and M₂ which are the hydroxylated forms of AFB₁ and B₂, respectively that are secreted in animal (including humans) tissues and fluids. There is no region of the world that is free from AF problem but the strict food and feed quality control programmes put in place in the developed countries greatly reduce the AF burden in those countries. This however, is not the case in Africa and to some extent, in Asia. Besides the lack of regulation of mycotoxins in the continent, the prevailing hot, humid climate and subsistence on foods suitable for AF contamination and other factors discussed in Section 2.0, make Africa the most AF vulnerable region in the world. Hence, a current overview of its natural occurrence in different raw and processed food commodities that are major sources of the toxins in the continent which will not only reflect the disparity in human exposure to AF worldwide, but also contributes to a better understanding of Africa's health afflictions is the primary objective of this section.

3.1 Raw agricultural products

3.1.1 Nuts and oilseeds

These products are the most investigated of all foods and feeds with regards to AF contamination. The reasons being that they are the most susceptible to AF in addition to their high protein content particularly in the case of groundnut which has made them priceless components of many animal and human diets. Data on AF incidence and concentrations in groundnut are consistently incriminating with several reports regularly accounting for extremely high levels of the toxins (Table 1) in all regions of the continent. Table 1 shows over 60% prevalence of AF across Africa at very critical levels. The incidence and levels reported vary with season. Highly contaminated samples were obtained during the rainy season (90% frequency at 12-937 µg/kg) than in the dry season (53.2% prevalence at 15-390 µg/kg) (Kamika and Takoy, 2011). The highest contaminations noted in Malawi (ICRISAT, 2010) were in districts that were prone to late session rains which enhance favourable conditions for post harvest contamination. Similarly, Mutegi *et al.* (2009)

demonstrated that wet and humid weathers are associated with severe AF contamination than drier locations. Serious contamination of Nigerian groundnut is a recurring problem since the 1960s when up to 8000 µg/kg were reported in 1976 (Opadokun, 1992) from the Northern region of the country. Even after heat treatment that should reduce AF levels in contaminated samples (Ogunsanwo *et al.* 2004), dry-roasted groundnuts from South Western part of the country contain as high as 165 µg/kg (Bankole *et al.* 2005). Bankole and Adebajo (2003) reviewed the AF contents in groundnut cake (range: 20 - 455 µg/kg) and snack (30 µg/kg) from Nigeria and concluded that the levels of contamination in these products were toxicologically unsafe. Homemade and unrefined groundnut oil contains AF at levels ranging between 20 and 2000 µg/kg in Nigeria (Obidoa and Gugnani, 1992). It is pertinent to state herein that in 1988, the deaths of some primary school children in Nigeria were associated with incriminating levels of AF in groundnut cake 'kulikuli' (Fapohunda, 2011). The AF problem of peanuts persists even in South Africa where food safety standards are adhered to. This came to limelight in 2001 when the South African Primary School Nutrition Programme received substantial media coverage on unacceptably high AF content in sandwich containing peanut butter given to school children. The government then established a national monitoring programme to survey AF in groundnuts and peanut products. Between July, 2003 and March 2004, 1140 peanut and groundnut products samples were analyzed and accordingly, about 30% of analyzed samples did not comply with the legal limit of 10 µg/kg (5 µg/kg for AFB₁) and concentrations as high as 560µg/kg were obtained (MRC, 2006).

AF contamination of cottonseed has been a major concern worldwide as extremely high contents ranging between 200,000 to 300,000µg/kg were reported much earlier in samples exported to the European markets (Smith and Moss, 1985). A survey of cottonseed for AF during such periods (between 1976 and 1979) when Nigeria was a major exporter of the crop, revealed over 60% (17/28) incidence rate with mean value of 105µg/kg recorded (Opadokun, 1992). Gbodi (1986) subsequently showed moderate contamination of the cash crop grown in the semi temperate climate of Plateau State, Nigeria (Table 1). Mycotoxin research on cottonseed in Nigeria has since ceased to exist as the country no longer depends on agriculture as its main source of revenue. When AF contaminated cottonseed is processed into oil, the toxins are concentrated in the residual cottonseed meal and cake which are often used as feed components of livestock feeds. The cottonseed oil also contains residual amount of the toxins at certain levels but this usually depends on the extent of contamination of the seeds from which it was obtained.

Aside from cottonseed, its products are also very important sources of human and animal exposure to AF. Abalaka (1984) found 26.1µg/kg and 12.6 µg/kg of AF in groundnut and cottonseed oil samples from the Guinea Savannah region of Nigeria. All cottonseed meal samples investigated for AF in South Africa (Table 1) contained the toxins in which 42 of the 60 samples analyzed exceeded the maximum level for feeds. The AF menace in cottonseed is not limited to the sub-Saharan region of the continent as aflatoxigenic fungi and the two B forms of the toxin were found naturally contaminating cottonseed, cottonseed meal and cake from Egypt (Mazen *et al.* 1990). Melon seed another important oilseed in West Africa has been shown to be prone to fungal and AF contamination (Table 1) at largely unsafe levels (Bankole *et al.* 2006). Also Opadokun (1992) reported high incidence (73%) of AF in Nigerian melon seed at mean content of 19µg/kg.

Commodity	Country	Type of Aflatoxin	Incidence rate	Range ($\mu\text{g}/\text{kg}$)	Mean level \pm SD ($\mu\text{g}/\text{kg}$)	Reference
Barley	Tunisia	AFB1	11/25	3.5-11.5	18.4 \pm 27.3	Ghali <i>et al.</i> (2008)
Cheese	Libya	AFM ₁	15/20	0.11-0.52		Elgerbi <i>et al.</i> (2004)
Cow milk	Nigeria	AFM ₁	3/22	-	\leq 2.04	Atanda <i>et al.</i> (2007)
	Sudan	AFM ₁	42/44	0.22 - 6.90	2.07	Elzupir and Elhussein, (2010)
	South Africa	AFM ₁	42/42	0.04 - 1.32	0.12	Dutton <i>et al.</i> (2010)
	Kenya	AFM ₁	474/613	0.005-0.78	0.064	Kang'ethe and Lang'a (2009)
	Cameroon	AFM ₁	10/63	0.006-0.527	-	Tchana <i>et al.</i> (2010)
Cowpea	Benin	AFB1	3/92		3.58	Houssou <i>et al.</i> (2009)
	Cameroon	AF	5/15	0.2-6.2	2.4	Njobeh <i>et al.</i> (2010)
Dried Beef	Nigeria	AFB	10/10	0.003		Oyero and Oyefolu (2010)
		AFG	10/10	0.004		
Dried Chilli	West Africa	AFB1	1/30	3.2	3.2	Hell <i>et al.</i> (2009)
	Morocco	AFB1	1/20	0.28	0.28	Juan <i>et al.</i> (2008)
Dried okra	West Africa	AFB1	3/30		5.4	Hell <i>et al.</i> (2009)
		AFB2	1/30		0.6	
Dried raisins	Morocco	AFB1	4/20	3.2-13.9	10.7 \pm 2.3	Juan <i>et al.</i> (2008)
Egg	Cameroon	AF	28/62	0.002-7.68	0.82 \pm 1.71	Tchana <i>et al.</i> (2010)
Fresh Beef	Nigeria	AFB	10/10	0.02		Oyero and Oyefolu (2010)
		AFG	10/10	0.03		
Groundnut	DR Congo	AFB1	43/60	1.5-937	229.07	Kamika and Takoy, (2011)
Groundnut	Malawi	AFB1	/1189	0-3871		ICRISAT (2010)
Groundnut	Kenya	AF	170/769	0-7525	< 4	Mutegi <i>et al.</i> (2009)
Local beer	Malawi	AF	5/5	8.8-34.5	22.3 \pm 4.93	Matumba <i>et al.</i> (2011)
Maize	Malawi	AFB		0.0-1335		ICRISAT (2010)
Maize	Nigeria	AFB1	55/55	0-1874	257.82	Atehnkeng <i>et al.</i> (2008)
		AFB2		0-608		
		AFG1		0-937		
		AFG2		0-286		
		AF	30/30	6.20-29.50	13.596	
Maize	Uganda	AF	22/49	1.00-1000		Kaaya and Warren, (2005)
Maize flour	Morocco	AFB1	16/20	0.23-11.2	1.57 \pm 0.78	Zinedine <i>et al.</i> (2007) ^b
Melon seed	Nigeria	AFB1	37/137	2.3-47.7	14.2	Bankole <i>et al.</i> (2006)
Milk ^c	South Africa	AFM ₁	98/114	Max: 2.07	0.15	Lishia <i>et al.</i> (data unpublished)
Milk ^d	South Africa	AFM ₁	85/85	Max: 2.48	0.14	
Millet	Nigeria	AFB1	12/49	1370.28-3495	2587.47 \pm 78.23	Makun <i>et al.</i> (2007)
Mouldy Sorghum	Nigeria	AFB1	93/168	0-1164	199.51-259.90	Makun <i>et al.</i> (2009)
Pasteurized milk	Morocco	AFM ₁	48/54	0.001-0.117	0.018	Zinedine <i>et al.</i> (2007) ^a
Powdered milk	Nigeria	AFM ₁	19/100	0.02-0.41	0.136	Makun <i>et al.</i> (2010)
Powdered soymilk	Nigeria	AFB1	30/30	4.58-19.76	11.53	Adebayo-Tayo <i>et al.</i> (2009)
		AFB2		2.57-11.54	6.04	

Commodity	Country	Type of Aflatoxin	Incidence rate	Range ($\mu\text{g}/\text{kg}$)	Mean level \pm SD ($\mu\text{g}/\text{kg}$)	Reference
Raw cow Milk	Egypt	AFM ₁	19/50	0.023 - 0.073	0.049 \pm 0.017	Amer and Ibrahim (2010).
Rice	Nigeria	AF	21/21	27.7-371.9	82.5 \pm 16.9	Makun <i>et al.</i> (2011)
Roasted Groundnut	Nigeria	AFB ₁	68/106	5-165	25.5	Bankole <i>et al.</i> (2005)
		AFB ₂	28/106	6-26	10.7	
		AFG ₁	12/106	5-20	7.2	
		AFG ₂	3/106	7-10	8.0	
Smoke-dried fish	Nigeria	AFB ₁	11/11	1.505-8.11	3.46	Adebayo-Tayo <i>et al.</i> (2008)
		AFG ₁	11/11	1.810-4.51	2.94	
Sorghum	Tunisia	AFB ₁	58/93	0.34-52.9	9.9 \pm 11.5	Ghali <i>et al.</i> (2009)
		AFB ₂	45/93	0.11-3.7		
		AFG ₁	3/93	0.45-0.7		
Sorghum	Malawi	AFB ₁	2/15	1.7-3.0	2.35 \pm 0.65	Matumba <i>et al.</i> (2011)
Sorghum	Ethiopia	AFB ₁			0-26	Ayalew <i>et al.</i> (2006)
Soybean	Cameroon	AF	2/5	0.2-3.9	2.1	Njobeh <i>et al.</i> (2010)
Wheat	Kenya	AFB ₁	23/50	0-7	1.93	Muthomi <i>et al.</i> (2008)
	Tunisia	AFs	15/51	4.0-12.9	6.7 \pm 2.4	Ghali <i>et al.</i> (2008)
	Nigeria	AFB ₁		17.10-20.53	19.00 \pm 1.67	Odoemelam and Osu, (2009)
Wheat & products	Algeria	AFB ₁	30/53	0.13-37.42	>5	Riba <i>et al.</i> (2010)
	South Africa	AFB ₁	13/238	0.5-2.0	>2	Mashinini and Dutton, (2006)

^cMilk obtained from rural communities in South Africa. ^dMilk obtained from commercial farms

Table 1. Some reports of aflatoxin levels in some foods commodities from Africa

Low AF contamination of cowpea, soybean and their products is reported in many parts of the world. The data on these nuts from Cameroon and Benin (Table 1) showed only trace amount of AF in few samples. Similarly, only 3 positive samples were demonstrated in 268 cowpea samples analyzed between 1975 and 1983 from Nigeria (Opadokun, 1992). In the same review, it was shown that all two samples of soybean oil assayed did not contain AF while 41 of 55 palm kernels were contaminated with low amount of the toxin. High seed coat integrity, ensuring limited access and low moisture content are responsible for the low susceptibilities of these nuts to aflatoxigenic fungi (Stossel, 1986) with consequent rare occurrence of the toxins in them. In spite of the low presence of AF in soybean, intolerable levels of these carcinogens were found in branded and unbranded powdered soymilk, a processed product of soybean in Nigeria (Adebayo-Tayo *et al.* 2009). Soymilk has become a popular infant recipe in Africa because it is a cheap source of water soluble protein, carbohydrates and oil and so human exposure to AF can arise in countries using it for human consumption. Although producing fungi particularly *Aspergillus flavus* are considerably natural contaminants of cocoa bean (Sanchev-Hervas *et al.* 2008), AF are rarely detected in cocoa bean and at very low concentration. In a survey for mycotoxins in cocoa and cocoa products sponsored by the Foundation of German Cocoa and Chocolate Industry, Hamburg, Beucker *et al.* (2005) screened over 200 samples and found AFB₁ at concentrations below 2 $\mu\text{g}/\text{kg}$. Literature search for data on high AF in cocoa from Africa was unsuccessful and that could be a clear indication that these toxins are not problematic in this cash crop. However, ochratoxin A is the mycotoxin of interest to the cocoa (Arogeun and Jayeola, 2005) and soybean (Smith and Moss, 1985) industries.

3.1.2 Cereals

Cereals are rich sources of minerals, vitamins, carbohydrates, oils and proteins but when refined majority of the nutrients are lost leaving mostly carbohydrates and are therefore grown mainly for energy. Grains as they are sometimes called provide more food energy worldwide than any other crop and thus are staples. They are staple for two third of the earth's population, providing 85% of the world's food energy and protein intake (FAOSTAT, 2006). Cereal consumption is moderate in developed countries however in Africa and Asia, it is a daily sustenance. In Africa, cereals contribute 46% of the total energy intake; however, this figure could be as high as 78% in some African countries (FAOSTAT, 2010). According to figures made available by the afore mentioned statistics division of FAO, the six most cultivated and hence consumed grains worldwide in order of decreasing production are maize, rice, wheat, barley, Sorghum and millet, and of these major grains maize, wheat and rice together account for 87% of all cereal production worldwide and 43% of all food calories. Because of their rich nutrient composition, cereals support fungal growth and mycotoxin production excellently on the farm, during storage and after processing into foods and feeds with the small grains (sorghum, rice, wheat, millet and rice) being less susceptible to fungal and toxin contaminations than the larger grains like maize. And since these ideal substrates for mycotoxin contamination are highly consumed globally, they constitute the most remarkable sources of mycotoxins (especially the most prevalent of mycotoxins; AF) to animals and human beings. While there are other cereals (oats, rye, triticale, fonio, buckwheat and quinoa) of global significance, this review will focus on the six major ones which are pertinent to Africa.

Maize is one of the important staple foods in Africa and is now widely grown for animal feeds. It is the third most cultivated food commodity in the continent after cassava and sugar cane but it ranks the first in term of food energy supply in Africa. AF are regularly detected in maize throughout the world and the recent serious contamination which was associated with drought led to fatal human aflatoxicosis in Kenya (Afla-guard, 2005; CDC, 2004) as previously stated in Section 2.0. The natural occurrence of AF in maize from some African countries has been reviewed (Table1). A regional effect on the incidence of the toxins has been demonstrated with lower contents observed in the drier North African countries (Morocco; 0.11-11.2 $\mu\text{g}/\text{kg}$) than amounts reported for such SSA countries as Uganda, Nigeria, Ghana and Malawi having up to 1874 $4\mu\text{g}/\text{kg}$. Monitoring for AF in maize samples from different regions of Africa showed disturbingly high levels of contamination above 1000 $\mu\text{g}/\text{kg}$ with many of the samples containing AF contents exceeding the CODEX regulatory limit of 20 $\mu\text{g}/\text{kg}$ (five times more lenient than the EU guideline of 4 $\mu\text{g}/\text{kg}$). Over 77% of the tested samples from Malawi were contaminated with AF with 90% of the positive samples not qualified for the EU export market (ICRISAT, 2010). Atehnkeng *et al.* (2008) previously analyzed 55 samples of maize from 11 districts across three agro-ecological zones of Nigeria for AF and mean values ranging between 30.9 -507.9 $\mu\text{g}/\text{kg}$ were recovered from the 10 districts, which were far beyond all known acceptable levels. Maxwell *et al.* (2000) also found AF at alarming concentrations of between 3,000-138,000 $\mu\text{g}/\text{kg}$ in Nigerian pre-harvest maize samples. In a survey for AF in Ghana which spanned for a decade, the toxin had over 50% prevalence with more than half of the investigated samples having levels exceeding the EU maximum limit (Akrobortu, 2008). Similarly, stored maize from Uganda contain unsafe AF levels (Kaaya and Warren, 2005; Kaaya and Kyamuhangire, 2006). Very high AF level of 46,400 $\mu\text{g}/\text{kg}$ was found in samples from Kenyan local markets (CDC, 2004).

There is a general paucity of reports on mycotoxin in African indigenous rice. Opadokun (1992) reported AFB₁ in only 13 of the 279 rice samples analyzed in Nigeria with only one having a level above 5 µg/kg. One reason why mycotoxicologists are not attentive to local African rice relative to other crops such as maize and peanuts for example is due to the fact that it is entirely consumed within the continent and not available in the European markets. Makun *et al.* (2011) demonstrated a 100% prevalence of AF in Nigerian rice at unsafe levels (range: 28 - 372 µg/kg) (Table 1), and also showed critical contamination by ochratoxin A (OTA) and presence of deoxynivalenol (DON), fumonisins (FB) and zearalenone (ZEA) at trace levels. Although, AF were not found in Ugandan grown rice, however, they have been reported in rice from Cote D'Ivoire (1.5 - 10 µg/kg) and Kenya (294-1050 µg/kg) (Kaaya and Warren, 2005). Data from these few studies underscore the need for more mycotoxin surveys of indigenous rice in Africa.

Wheat does not thrive well in tropical climates so African wheat production is concentrated in the narrow strip along the Mediterranean coast from Morocco to Tunisia, in the Nile valley (Egypt), and in parts of South Africa, Kenya, Ethiopia, Zimbabwe and Sudan. Very little is grown in West Africa however, there is an increase in wheat production in Nigeria and the Democratic Republic of Congo in recent years. The grain is produced mainly for bread making but its bran is increasingly used as component of animal feeds. In spite of the limited production (18.6 million tonnes per year) of the cereal in Africa, 50.4 million tonnes is consumed yearly in the continent (FAOSTAT, 2010). Data on AF in local African wheat (Table 1) reveal moderate contamination across the continent with the highest level of contamination occurring in Nigeria. Over 57% incidence rate of AFB₁ in 53 Algerian pre-harvest and stored wheat samples was established by Riba *et al.* (2010), with only 5 analyzed samples having contents above the EU legal limit. The Tunisian grown wheat had safe levels of AFB₁ (Ghali *et al.* 2008). Of the 51 samples screened from the country, 37% were positive for AFB₁ at levels below 3.4 µg/kg. Similarly, with regards to AFB₁, all South African wheat samples analyzed by Mashinini and Dutton (2006) qualified for the EU market, though it occurred simultaneously with DON, ZEA, OT and FB in some of the samples. Although AFB₁ contents in the Kenyan wheat were low (<7 µg/kg), most of the samples were also concurrently contaminated with low but significant levels of DON, T-2 toxin, ZEA and AFB₁ (Muthomi *et al.* 2008). Such co-occurrence of mycotoxins could result in additive or synergistic effects in the host animal (Miller, 1995) as will be discussed in-depth subsequently. Considering the EU and other international and national legal limits, the Nigerian wheat with AFB₁ levels above 17 µg/kg (Odoemelam and Osu, 2009) is of low quality and thus, unfit for human consumption. Makun *et al.* (2010) also found extremely high AFB₁ contaminations of wheat marketed in Minna, Nigeria at unacceptable levels (range: 40-275 µg/kg) in 27 of the 50 tested samples. The severe contamination levels of this crop in Nigeria making it a principal source of mycotoxins raise public health concerns and underscore the need for the regulation of mycotoxins in SSA.

Because it was replaced by maize as a staple food commodity in many rural settlements in Africa (Bandyopadhyay *et al.* 2007), sorghum (also known as guinea corn) is another cereal that has been neglected for some time. However, its rising industrial profile as a suitable raw material for beer brewing has seen to its re-emergence at the world market such that as of 2007, sorghum production in Africa increased significantly even to the detriment of rice and wheat production (FAOSTAT, 2010). The renewed focus on sorghum is also because it is one of the most drought tolerable crops and such high water-use efficient characteristics

makes it the crop of choice to boost food security in drought stricken regions of Africa and for the future against the anticipated water scarcity in the world. Sorghum is a staple grain for over 750 million people in Africa, Asia and Latin America (CODEX, 2011) that is traditionally grown mainly in the semi-arid tropics for human consumption and production of local alcoholic drinks is now a component of animal feeds. Regardless of its inherent resistance to mould infestation due to its high composition of fungicidal principles; phenols and tannin (US Grain Council, 2008), fungal contamination constitutes a major biotic constraint to sorghum improvement and production worldwide. It is estimated that annual economic losses in Asia and Africa due to mould are in excess of US \$130 million (Chandrashekar *et al.* 2000). AF is the most investigated mycotoxin in this crop being reported in nine countries at levels of up to 3,282 µg/kg in Brazil (CODEX, 2011). A few reports from some major sorghum producing countries (Table 1) generally reveal a moderate prevalence and low concentrations of AF in the northern part of the continent though many of the contaminated samples from Tunisia (62.50%) had higher contents than the EU limit (Ghali *et al.* 2009). Meanwhile all the samples from Malawi met the EU standard (Matumba *et al.* 2011). The samples analyzed by Makun *et al.* (2009) were mouldy which might explain the observed increased incidence and levels of contamination. The relevance of such biased data cannot be overemphasized as mouldy grains do normally enter the human and animal food chain in Africa. In another unbiased study using representative samples, Odoemelam and Osu (2009) supported the findings of Makun *et al.* (2009) by reporting unacceptable levels of AFB₁ (between 27 to 36 µg/kg with a mean value of 31±3.4) in Nigerian grown sorghum. Twenty six of 69 sorghum samples from Uganda contained the toxins of which 10 of the positive ones had levels over 100µg/kg (Kaaya and Warren, 2005). Besides the entry of AF into human foods via contaminated sorghum, the carryover of substantial amount of these toxins from contaminated sorghum into traditional beer and beverages (Okoye, 1987; Matumba *et al.* 2011) poses additional risk of AF exposure. This should attract much attention to toxic contaminants of the grain but the reality is that there is limited information on mycotoxins in sorghum from Africa which is not commensurate to the escalating economic value of the cereal. Thus, the decision taken by the Codex Committee on Contaminants in Foods at her 5th session held in The Hague, The Netherlands in March, 2011, to prepare a discussion paper on 'mycotoxin in sorghum grain' is a very laudable initiative.

Millet (*Pennisetum* spp.) is the other traditional cereal replaced by maize in Africa in the last three decades. It is resistant to drought and so has been extensively cultivated in arid and semi arid regions. Millet ranks the sixth most important grain in the world, sustaining a third of the world's population and is the fifth most cultivated crop in Africa after maize, sorghum and wheat (Obilana *et al.* 2002). The occurrence of AF in this grain has largely been reported in West Africa particularly in Nigeria, its principal producer in the continent. In a review on chemical safety of traditional grains, Brimer (2011) reported that the average AF content of freshly harvested millet from West Africa was 4.6µg/kg. Odoemelam and Osu (2009) found higher values (range: 34 - 40 µg/kg; mean content: 37.5±2.5 µg/kg) in samples from the forest region of Nigeria. Makun *et al.* (2007) obtained the highest value of 3,495 µg/kg (Table 1) in wet season samples of millet that have been stored for over a year in Niger State, Nigeria. A 1971 report on AF contamination of Ugandan millet as reviewed by Kaaya and Warren (2005) revealed a low incidence (9/55) and AF level of 9 µg/kg. The limited reports on mycotoxins in millet in Africa are understandable as it is one of the 'lost

crops of Africa' and that it is not an export crop. However, the anticipated 4 and 8 times reduction in risks of AF related problems if sorghum and millet, respectively, replace maize as primary staples (Bandyopadhyay *et al.* 2007), should bring these two African traditional crops to the front burner of mycotoxin research worldwide.

There is generally low natural incidence of AF in barley and derived products around the world. The levels reported in Tunisian grain (Table 1) is not an exception to this observation. Very low levels (<3.9 µg/kg) were also observed in barley from South Africa (Maenetje and Dutton, 2007). Because barley is grown in Africa for foods and lager beer production, good agricultural and manufacturing practices along with strict quality control measures are usually put in place in order to gain acceptability in competitive markets and this therefore accounts for the low prevalence of toxic substances in the grain as evident in these few reports. This sort of monitoring should be extended to all other foods and feedstuffs.

3.2 Animal feeds

A majority of animals reared in Africa are free ranged. During the dry season, pastoralists and their flocks travel hundreds of kilometres in search of greener pastures. Invariably, most domesticated African animals are raised on low grade cereals, informal pasture and domestic wastes. Commercially produced animals on the other hand, are essentially fed compounded feeds that are composed primarily of cereals, oilseeds and their by-products including those of animal origin. Even though the main ingredients of the diets of both the roaming and farm animals have been shown in subsection 3.1.1 and 3.1.2 to be heavily loaded with AF in the continent, a review on the occurrence of AF in animal feeds is still appropriate as processing might alter AF levels in the final product. More so, commercial livestock farming is now a major industry in Africa and thus feeds have become a major source of exposure of humans to food borne toxins via consumption of food products obtained from animals fed AF contaminated feeds. In view of the anticipated disparity in toxin content between the feed ingredients used and the compound feed produced, Mngadi *et al.* (2008) analyzed South African animal feeds and the raw ingredients used in manufacturing them for AF, FB, ZEA and OTA. Accordingly, data revealed 17 of the 23 samples tested positive for AF (Table 2) and over 7 of these samples having levels equal or exceeded the legislated limit of 20µg/kg for animal feeds. The raw ingredients namely cottonseed cake, sunflower oil cakes, molasses meal and bagasse were between 4 to 8 times more contaminated than the animal feeds and this disparity was attributed to the heat and other physical and chemical treatments (Rahana and Basappa, 1990) employed during processing that might have eliminated some of the toxins. As shown in Table 1, there is a high prevalence (84.6%) of carcinogenic AF in animal feeds from Kenya with 455 of the tested 830 samples having levels exceeding 5µg/kg, the WHO/FAO limits for feeds destined for dairy animals. Poor storage facilities, use of moulded maize for feed production and the absence of monitoring for AF during processing were the reasons for the high frequency and levels of AF in Kenyan feeds (Kang'ethe and Lang'a, 2009). Data on AF in animal feeds from Nigeria (Table 1) clearly points out that while retailing from open bags provokes AF contamination, manufacturing of feeds using materials less susceptible to fungi including wheat offal and palm kernel limits contamination (Adebayo-Tayo and Ettah, 2010). The 6 positive samples among the 13 feeds screened were mainly from retailed shops

by the aforementioned workers had no AF presence in the wheat and palm kernel base feeds. In accordance with EU regulations, poultry feeds from Morocco were safe for animal consumption (Zinedine *et al.* 2007). In light of the significant prevalence of AF in African feeds and feeding stuffs, it is recommended that the use of rapid and sensitive mycotoxin test kits by farmers, manufacturers and consumers to monitor the quality of products will largely lessen the AF burden in the continent.

Commodity	Country	Type of Aflatoxin	Incidence	Range ($\mu\text{g}/\text{kg}$)	Mean level \pm SD ($\mu\text{g}/\text{kg}$)	Reference
Animal feeds	South Africa	AF	17/23	0.8-156	38.9	Mngadi <i>et al.</i> (2008)
Animal feeds	Kenya	AFB1	703/830	0.9-595	8.9-46.0	Kang'ethe and Lang'a (2009)
Animal feeds	Sudan	AF	36/56	4.1-579.9	130.6	Elzupir <i>et al.</i> (2009)
Animal feeds ^b	South Africa	AF	99/108	3.2-950	112.54	Mwanza <i>et al.</i> (data unpublished)
Bush mango seeds	Nigeria	AFB1	20/20	0.2-4.0	1.5	Adebayo-Tayo <i>et al.</i> (2006)
		AFG1	20/20	0.3-4.2	1.5	
Cottonseed	Nigeria	AFB1	3/8	0.0-271		Gbodi (1986)
		AFB2	3/8	0.0-36.6		
		AFG1	2/8	0.0-183		
		AFG2	1/8	0.0-9.1		
Cottonseed meal ^a	South Africa	AFB1	60/60	13.4-75.7	24.90	Reiter <i>et al.</i> (2011)
		AFB2		1.0-5.4	1.84	
		AFG1		6.6-64.3	17.91	
		AFG2		0.3-3.3	0.90	
Pistachio	Morocco	AFB1	9/20	0.04-1430	158 \pm 6.3	Juan <i>et al.</i> (2008)
Pistachio	Tunisia	AF	21/40	0.24-122.4	21.8 \pm 38.0	Ghali <i>et al.</i> (2009)
Poultry feeds	Morocco	AFB1	14/21	0.05-5.38	1.26 \pm 0.65	Zinedine <i>et al.</i> (2007)
		AFB2		0.03-0.58	0.18 \pm 0.18	
		AFG1		ND	ND	
		AFG2		ND	ND	
Poultry/livestock feeds	Nigeria	AFB1	6/13	0.0-67.9	15.5	Adebayo and Etta (2010)

^aCottonseed cake was imported from Benin. ^bAnimal feeds from rural community of Limpopo province. ND: Not detected

Table 2. Some reports of aflatoxin levels in some animal feeds and fruits from Africa.

3.3 Vegetables

Reports on fungal and mycotoxin contaminations of vegetables are exceptionally uncommon. One of the most recent and novel works in this area is that of Hell *et al.* (2009) who studied 180 dried vegetable samples across three countries in West Africa including Benin, Mali and Togo. AF concentrations were determined in dried okra, hot chilli, tomatoes, melon seed, onion and baobab leaves. The results as seen in Table 1 is one of the very first few reports on AF in dried okra and hot chilli after that of Obidoa and Gughani (1992). AFs were not detected in the other dried commodities but however, the toxins have been detected in fresh vegetables elsewhere. For instance, Muhammad *et al.* (2004) found the toxins present in fresh tomatoes marketed in Sokoto, Nigeria. Similarly, Sahar *et al.* (2009) also showed the presence of AF in fresh tomatoes, pumpkin, powder chillies and coriander

(dry) grown in Pakistan. Other fruits and vegetables in which the toxins were found in that study include cucumber, persimmon, peanut and peach. Interestingly, Obidoa and Gugnani (1992) had earlier found AF in dried okra, onions, dry pepper and table foods sold at restaurants. The ready-to-eat dishes mainly “gari” (cassava products) and beans served with vegetable soups had AFB₁ at levels ranging between 8 and 61 µg/kg with total AF values ranging from 31.21 to 268µg/kg. The data suggest that AFs are common contaminants of most African table foods. Another vegetable that abhor aflatoxigenic fungi and consequently contain AF is oyster mushroom (Jonathan and Esho, 2010). The severe paucity of information on mycotoxins in vegetables necessitates increased research in the area.

3.4 Fruits

In a review of mycotoxins in fruits and fruit-processed products, Fernandez-Cruz *et al.* (2010) revealed that the commonest mycotoxin contaminants of fruits worldwide are patulin (PAT), OTA, AF and *Alternaria* toxins, and that natural AF contamination has been reported in oranges, apple and apple juices, dried apricots, dates, prunes, musts, dried figs and raisins. According to the review, AFs are most frequently reported in dried figs and raisins worldwide at significant levels of up to 550 and 63µg/kg, respectively. Furthermore, their occurrence was reported in apple juice from Egypt and dried raisins and figs from Morocco. Other reviewed literature of interest in this area is that provided by Trucksess and Scott (2008) and Barkai-Golan and Paster (2008). Reports on mycotoxins in fruits are not many in Africa with one reported in pawpaw and pineapple being contaminated by *Aspergillus flavus* in Maiduguri, Nigeria (Akinmusire, 2011). Baiyewu *et al.* (2007) showed the presence of the toxins in pawpaw from South Western Nigeria. Some data on AF incidence in Africa (Table 2) presented low occurrence of the toxins in African fruits. Juan *et al.* (2008) found AFB₁ at levels exceeding the EU limit of 2µg/kg in 5 and 20% of 20 samples each of pistachio and dried raisin, respectively, with the highest value of 1430 µg/kg detected in pistachio. While all dried fig samples were found fit for the EU market with regards to AFB₁ contents, 15% of them had AF levels above the 4 µg/kg, a maximum recommended limit of EU. The use of traditional processing and preservation methods for fruits in rural Morocco that provide optimal conditions for mould growth and mycotoxin formation was adduced as the cause for the increased prevalence of these AF in fruits. AF analysis in Tunisian pistachio performed by Ghali *et al.* (2009) found unacceptable (according to EU standards) concentrations of AF in 17% of the samples. Bush mango (*Irvingia* spp) is a sweet tasting fruit. The pulverized form of the dried seeds is used as condiment and thickeners for soups and stew in West Africa. Investigation into its AF content in Nigeria by Adebayo-Tayo *et al.* (2006) showed a 35% non compliance with the EU AFB₁ standard for fruits. There is need for AF surveys in commonly eaten fruits in Africa namely, oranges, banana, plantain, guava, dates, etc. in order to properly ascertain the extent to which fruits expose the African population to the toxins.

3.5 Roots and tubers

Roots and tubers are a major source of nutrition in the world after cereals. They are basic diets for about a billion people in the developing countries, providing 10% of world's food

energy and protein intake (Shewry, 2007). They account for 40% of food eaten by half the population of SSA, contributing 20% of total energy intake in the continent (FAOSTAT, 2010). Cassava, potatoes, yam and taro form the bulk of roots and tubers consumed worldwide. Cassava and yam are not vulnerable to AF contamination (Bankole *et al.* 2006) and even the processed products such as cassava and yam chips and their flour have low contamination rates. Analysis of cassava and yam chips from Benin showed no contamination by AF (Gnonlonfin *et al.* 2008) neither was the toxins found in cassava products from Tanzania (Muzanila *et al.* (2000), Nigeria (Jimoh and Kolapo, 2008) and Ivory Coast (Kastner *et al.* 2010). However, data obtained from Cameroon (Table 1) show low levels of the toxins in stored cassava chips at levels greatly dependent on processing practices, storage facilities and duration of storage (Essono *et al.* 2009). Higher prevalence and contents of AF are observed in yam based products than in cassava products. Apart from the 100% frequency (Table 1) shown in Yam chips from Benin (Bassa *et al.* 2009), 23% of the 107 samples analyzed by Mestres *et al.* (2004) from the same country had AF levels over the 15 µg/kg CODEX standard value for total AF. AFB₁ and G₁ were detected in yam chips from Nigeria at levels ranging from 5-27 µg/kg (Jimoh and Kolapo, 2008). AFB₁ was also found in 22% of samples from Nigeria (Bankole and Mabekoje, 2003) and a larger survey conducted later in same country found the toxin at a prevalence rate of 54.2% in the same products at toxicologically significant levels (range: 4-186 µg/kg; mean: 23 µg/kg), 32.3% with AFB₂ (range: 2-55 µg/kg), 5.2% were positive for AFG₁ (range: 4-18 µg/kg), while 2 samples contained AFG₂ (Bankole and Adebajo, 2003). The present unwholesome practice of storing and marketing high moisture cassava and yam products is responsible for the contamination in Africa (Essono *et al.* 2009) and should be discouraged.

3.6 Animal products

3.6.1 Milk and milk products

Animals fed AFB₁ and B₂ contaminated feeds excrete into their milk the less toxic AFM₁ and M₂, respectively. AFM₁ is of particular interest being the hydroxylated metabolite of AFB₁ and is known to have 2-10% of the carcinogenic potency of the parent compound (Zinedine *et al.* 2007). The carryover of this carcinogen in cow at a transfer ratio (consumed AFB₁ to excreted AFM₁) of 200:1 (Smith and Moss, 1985) which could be as high as 40:0.05 (JECFA, 2001) into human and animal milk that are the main sources of nutrition for infants whose vulnerability due to undeveloped immune system is obvious, poses serious health concern. Its stability to heat, cold storage, freezing and drying (Yousef and Marth, 1985) during processing makes dairy products another important source of AFM₁ exposure. Milk and milk products are traditionally staple food commodities for the nomadic population of Africa. They are recognized by the elites as natural balanced diet and so are increasingly consumed by the urban populace in the continent. Therefore, they can no longer be ignored as they are among the main entry routes of AFM₁ into the human dietary system in Africa.

The natural occurrence of AFM₁ in raw cow milk has been reported in quite a number of African countries as reflected in Table 1. A regional variation has been demonstrated in the data with lower concentrations occurring in the drier North Africa (Egypt and Morocco) than in the more humid SSA (Nigeria, Sudan, Kenya, Cameroon and South Africa). Many of the milk samples from the region (7.4, 18.7, 40, 52.6, 61.9 and 83.3 % of samples from Morocco, Kenya, Cameroon, Egypt, South Africa and Sudan, respectively, had AFM₁

contents above the legislated levels ($0.05\mu\text{g/L}$) of several countries including those in the EU. Similarly, their recorded mean levels according to JECFA (2001) are higher than those reported for European ($0.023\mu\text{g/L}$), Latin America ($0.022\mu\text{g/L}$), Far Eastern ($0.36\mu\text{g/L}$), Middle Eastern ($0.005\mu\text{g/L}$) and African diets ($0.0018\mu\text{g/L}$). Since AFM_1 content in milk is a good indicator of AFB_1 contamination in feeds, hence at a transfer rate of 200:1 for cows it can be estimated that dairy animals in Africa are exposed to between $3.6 - 414\mu\text{g/kg}$ of AFB_1 in their rations since the observed range of AFM_1 averages (Table 1) for Africa is 0.018 to $2.07\mu\text{g/L}$. Such high levels of AF in feeds in the continent have been shown in sections 3.1 and 3.2. The presence of AFM_1 in milk from breastfeeding mothers (Atanda *et al.* 2007) and other body fluids of diseased patients (Tchana *et al.* 2010) sometimes at above regulated levels, is confirmatory that humans are exposed to high AF levels in Africa and because milk is primary to infant nutrition it gives cause for considerable concern.

Raw milk is usually processed into dehydrated dairy products such as cream, butter, cheese and milk powder in order to extend its shelf-life. Yoghurt, another product of milk which has become part of human dietary system has a similar processing method as cheese making, only that the process is arrested before the curd forms. The separation of the components of milk during processing leads to distribution of AFM_1 into dairy products with consequent lower levels of the toxins in the individual products than in milk. In spite of this anticipated loss, AFM_1 has been found in African dairy products at unacceptable levels. High prevalence (75%) of AFM_1 with all positive samples having levels exceeding the legislated limit of $0.05\mu\text{g/L}$ was seen in Libyan cheese (Elgerbi *et al.* (2004). Amer and Ibrahim (2010) found AFM_1 in 50/150 Egyptian cheese samples at levels between 0.051 to $0.182\mu\text{g/L}$ and all the contaminated samples had levels beyond the EU regulated limit. Similarly, the toxin contaminates cheese, ice cream and yoghurt at intolerable amounts in Nigeria (Atanda *et al.* 2007). In order to determine how safe imported powdered milk samples are for human consumption, Makun *et al.* (2010) analyzed AFM_1 in 100 samples sold in the Lagos metropolis. As seen, 6 of the 19 positive samples had levels above the EU limit, however, all the tested samples were considered safe in Nigeria as levels of the toxin were below the country's maximum tolerable limit of $1\mu\text{g/kg}$. Clearly, the main strategy to reduce incidence of milk toxins is by feeding animals with AF free feeds.

3.6.2 Animal tissues

Relative to such mycotoxins as OTA, a much smaller proportion of AF is absorbed into animal tissues. The transfer ratios into tissues for AFB_1 can range between 1,000 and 14,000 (Smith and Moss, 1985). Any animal exposed to such high amount of mycotoxins would have shown some toxicity signs or even death and would likely not enter the human food chain in the developed world. Conversely, diseased animals are still eaten in Africa and as such, human exposure to AF via consumption of animal tissues can be a reality in the continent. There is a disparity between the AF content of beef and those of other edible organs with lower values obtained for the muscle tissue. This was shown by Oyero and Oyefolu (2010) when analysing fresh and sun-dried beef and edible organs (liver, kidney and heart). While, the dried animal tissues had lower levels of AFB_1 (beef: 2.9, liver: 3.1, heart: 27.9, kidney: 75.8 ng/kg) and AFG (beef: 4.4, liver: 3.1, heart: 55, kidney: 141.3 ng/kg) than for fresh samples whereby AFB_1 levels were for beef liver, heart, kidney were 21.7, 33.9, 55.9 and 85.2 ng/kg, respectively, and AFG levels in these organs recorded were

respectively, 27, 41.4, 74.1 and 70.7 ng/kg. Accordingly, the levels of the toxins in the edible organs were consistently higher than those in beef with kidney being the most vulnerable. It is therefore, suggested that withdrawal of animals from contaminated feeds onto mycotoxin free diets for 3-4 weeks could have allowed for sufficient withholding period to clear the muscles and organs from the toxins. Despite the low carryover rates of the toxins into animal tissues, AF contaminate fresh and processed meat (especially liver and kidney) at toxicologically significant levels of up to 325µg/kg in Egypt (Aziz and Youssef, 1991; Abdelhamid, 2008). It is only proper to indicate further herein that consumption of animal visceral organs (*kayan chiki*) may constitute a major source of AF exposure than muscle.

The garnishing of beef with peanut paste to produce dried beef product (*kilishi*) and roasted beef (*Suya*) is a common practice in West Africa that elevates the AF content of these processed meat products to over 194µg/kg (Jones *et al.* 2001; Chukwu and Imodiboh, 2009) which is beyond any known accepted maximum. Smoke-drying is the commonest method of preservation of fish, another major source of protein in the African continent. The inadequacy of the method with regards to preservation from contamination of smoke-dried fish by aflatoxigenic fungi and AF (Table 1) has been demonstrated (Adebayo-Tayo *et al.* 2009).

The carry-over of AF from feed to poultry by-products including meat and eggs has been investigated and found to be quite low varying with the product. In a feeding trial, Hussain *et al.* (2010) demonstrated AF transfer ratios of 1: 914 and 1: 1939 for the liver and muscle of broilers respectively. In hen, the transfer ratios are 1: 1103 for edible organs (gizzard, kidneys and liver) and 1: 33,100 for breast muscle (Wolzak *et al.* 1986). The carryover into eggs occurs at obviously high ratio of 1:6633 (Wolzak *et al.* 1985). The corresponding ratio of AFB₁ in feeds to residual levels in egg yolk and albumen were shown to be 1:4615 and 1:3846, respectively, in chicken hen (Bintvihok *et al.* 2002). In light of these high ratios, the presence of AF in eggs from Egypt (Abdallah *et al.*, undated) and Cameroon (Tchana *et al.* 2010) at levels of up to 7.68 µg/kg (Table 1) indicates that poultry animals consume AF in feeds at alarming concentrations. Although the reported AF levels in both meat and meat products, and eggs from Africa seem insignificant, with chronic intake of such amount simultaneously occurring with other food borne toxicants can have deleterious health impact (Speijers and Speijers, 2004).

3.7 Fermented products

Although fermentation reduces mycotoxins in contaminated food products (Hell and Mutegi, 2011), there is ample evidence to suggest that fermented products in Africa contain significant levels of AF. Kpodo *et al.* (1996) detected AF at levels as high as 289µg/kg in fermented maize dough in Ghana. The presence of AF was observed in all samples of fermented yams and plantains analyzed from the Southern region of Nigeria (Jonathan *et al.* 2011) at levels ranging between 37.67 - 96.34 µg/kg. Detectable (5.2 - 14.5 µg/kg) amounts of the toxins were also found in fermented cassava products from Cameroon (Essono *et al.* 2009). Sorghum based traditional opaque beer from Malawi contained AF at levels above the CODEX permissible limit of 10 µg/kg (Table 1) (Matumba *et al.* 2011). In their review on mycotoxin problem in Africa, Wagacha and Muthomi (2008) reported incriminating levels of AF (200, 000 - 400, 000 µg/l) in 33% of traditionally brewed beer in South Africa. Levels of up to 50µg/kg were found in sorghum based local beer from Lesotho (Sibanda *et al.* 1997).

With these unsafe levels in our fermented products, it will only be proper to adhere to the advice of Pietri *et al.* (2010) that if raw materials comply with the legislated limits, contribution of a moderate daily consumption of beer to AFB₁ intake will not contribute significantly to exposure of the consumer.

3.8 Other foods

Plants and plant products used as medicinal herbs, tea and spices may be commonly contaminated by AF at significant levels of up to 2,230 µg/kg especially in the case of liver curative herbal medicine sold in India (Trucksess and Scott, 2007). According to these authors, contamination of the toxins has been observed in ginger, garlic and capsicum. A survey conducted for aflatoxigenic fungi and AF in spices from Egypt (Aziz and Youssef, 1991) found black and white pepper contaminated with AF at unhealthy levels (range: 22-35 µg/kg). Zinedine *et al.* (2006) found natural presence of AFB₁ in black pepper, ginger, red paprika and cumin from Morocco at average levels of 0.09, 0.63, 2.88 and 0.03 µg/kg, respectively, with the highest level of contamination found in red paprika (9.68 µg/kg). Although moulds are frequently isolated from African herbal plants (Bankole and Adebajo, 2003), it seems the herbs are not prone to AF contamination (Katerere *et al.* 2008). Equally, a search on the literature failed to provide data on the incidence of AF in African tea.

An attempt is made in this chapter to provide an extensive review on AF contamination of commodities in Africa and further information on the subject is referred to the review of Sibanda *et al.* (1997), Shephard (2003), Bankole and Adebajo (2003) Bankole *et al.* (2006) and Wagacha and Muthomi (2008).

4. Human AF exposure

An important part in elucidating the health effects of AF in humans is the estimation of exposure to the toxin that they receive. A tedious and rather inaccurate estimate of exposure level can be established by determining mean toxin level in the food people eat/amount eaten, either in the basic commodity, e.g. maize kernels and rice as in the case for Nigeria, or in its ready-to-eat form, e.g. porridge for those leaving in the rural area of Limpopo in South Africa. In order to approximate the level of exposure of Africans to AF, let's assume a Nigerian that eats 138kg of cereals annually (Bandyopadhyay *et al.* 2007) as a representative of Africa and whose main staples are maize and rice consumed in a ratio of about 3:1. From Table 1, the AFB₁ mean values for indigenous maize and rice destined for human consumption in the continent are approximately 258 and 83 µg/kg, respectively. It can therefore be estimated that 29,500 µg/kg of AF is consumed yearly or let's say 81 µg/kg daily by the subject from the two cereals. Even though food processing such as sorting, cooking and others factors will reduce the content (Hell and Mutegi, 2011), what might be left will still be incriminating causing certain chronic intoxications which are discussed subsequently in this chapter. Again, if 350 µg/kg is the mean level of AF in foods that can elicit acute symptoms (Azziz-Baumgartner *et al.*, 2005), it can rationally be deduced that Africans are exposed to sub acute doses of AF in maize and rice amongst other food crops. While, the inferences made herein are generalized for Africa with regards to AF intake, it is not without flaws and exceptions, as it can also be reasonably inferred that Africans are exposed to the toxins from virtually all the foods they consume as seen in Table 1. This corroborates with high incidence of the toxin and its biomarkers in their body tissues and

fluids (Gong *et al.* 2003, Tchana *et al.* 2010). This is also in agreement with the fact that in many regions of the continent, the estimate on the frequency of human exposure to AF is about 98% (Wild, 1996).

More precise estimates of AF exposure among humans are best achieved by estimating the toxins and associated metabolites in bile, urine, faeces and hair as well as their distribution in blood, milk, liver, kidney and semen (Njobeh *et al.* 2010). Probably, the easiest one to use is the urine, which can conveniently be sampled and if a 24 hour sample is taken, it can give a fairly accurate content of AFB₁ ingested over a period from the measurement of levels of AFM₁ (Nyathi *et al.* 1987) or adducts (Groopman *et al.* 1992). Another useful method is to assay the amount in the blood and that bound to blood albumin. The latter can be regarded as a good biomarker for AFB₁ exposure (Wild *et al.* 1990) and in effect, removes AFB₁ from circulation. If one assumes that the half-life of albumin is about 20 days (Wild *et al.* 1990), then correlating the amount of conjugate with intake, an estimate of exposure that took place the previous week can be established. A similar case may be made for liver AFB₁-DNA adducts and this has been demonstrated in animals and by extrapolation, a relationship between the level of AFB₁ albumin and AFB₁-DNA conjugates is established (Wild *et al.* 1996).

5. Human health implications to AF exposure with reference to Africa

It is seen how there is extremely high degree of human exposure to AF in many parts of the African continent as previously stated in Section 4.0 of this chapter. Such level of exposure has enormous health and socioeconomic implications. Aspects of the effects of AF contamination of food and feed commodities in terms of the economy will also be highlighted in this review. In general, a disease caused by a mycotoxin is termed "mycotoxicosis" (aflatoxicosis in the case of AF). Aflatoxicosis seems a commoner in developing countries (Williams *et al.* 2004). Furthermore, for mycotoxins to exhibit disease symptoms of a chronic nature, they occur in feed or food at one part per billion (ppb)($\mu\text{g}/\text{kg}$), the exception being FB₁ which is present at three parts per million (ppm) (mg/kg) mark before symptoms in farm animals begin to be manifest (Bucci and Howard 1996). The difficulty when considering levels of mycotoxins for intoxication in human is that, except for "natural" cases of mycotoxicoses, disease causing levels of mycotoxins cannot be derived and hence, extrapolations from animal experiments have to be made. From known cases of human aflatoxicosis (Azziz-Baumgartner *et al.* 2005), it would seem that acute symptoms are found when levels in food ingested were at a mean value of 350ppb. Again the difficulty with such estimates, however, is gauging the exact amount of the toxin ingested per kg body weight, because this will depend not only on how much is ingested at a specific time, but for how long. Acute doses of mycotoxins may be ingested at one time or over a short period, whilst chronic levels may be consumed over long periods. An example in point of the latter is AFB₁ in groundnut, a staple where rural people ingest this mycotoxin most of their life time and as a consequence, this may increase the incidence of liver cancer (hepatocarcinoma) proportionately (Peers and Linsell, 1973) in the region. A similar situation is found where FB₁ from maize as a staple is ingested but the consequence of a lifetime of exposure to this toxin is not as clearly defined as that of AFB₁, because FB₁ has a much lower toxicity but there are indications that it has a role in various diseases conditions (Dutton 2009). This is discussed subsequently in detail.

5.1 Toxicology of AFB₁

AFB₁ created great interest amongst the medical profession once it was established as a powerful carcinogen (Wogan, 1973). In fact it is claimed to be the most powerful naturally occurring carcinogen known. The toxin is also mutagenic and teratogenic (Raisuddin *et al.* 1993). Because of these toxic properties, several investigations have been carried out over the years since its discovery both *in vitro* and *in vivo* to elucidate its mode of action as a carcinogen, perhaps to the detriment of studying other toxic properties it exhibits as well as those of its congeners AFB₂, AFG₁ and AFG₂. To justify this obsession with AFB₁, it is fair to point out that it is the most commonly occurring and at the highest levels as well as being the most potent when compared with the other AF. However, it might be worthwhile investigating the toxic properties of AFB₂ more closely, as this has all the molecular attributes of AFB₁ apart from the bishydro-furano double bond that confers the carcinogenic property. This double bond makes all the difference, as it allows detoxifying systems (cytochrome P₄₅₀) in the body to convert it to an epoxide by cytochrome P₄₅₀S, specifically CYP3A4, CYP3A5, and/or CYP1A2 (Gallagher *et al.*, 1994; Wang *et al.*, 1999) to the *exo*-8, 9-epoxide, which ironically is the "activated" form of the molecule that can form adducts with deoxyribonucleic acid (DNA) leading to guanine nucleotide substitutions (Lilleberg *et al.*, 1992). In passing it is also important to note that cytochrome P450 types also convert AFB₁ to other derivatives e.g., AFM₁, AFP₁ and Q₁ (Campbell and Hayes 1976). The epoxide is a good alkylating agent and can react with bases such as those in DNA and RNA to form the AF-alkylated form. Obviously other factors are involved, as not all alkylating agents are carcinogens and further, AFB₁ has a tendency to specifically attack guanine, one of the four DNA bases (Taylor 1992). Because AFB₁ is somewhat non-polar, it passes through membranes and other lipid barriers easily and also has a slight water solubility so it passes from the aqueous phase at low concentrations and accumulates in fat soluble phases such as adipose tissues. Furthermore, the molecule itself, because it is primarily aromatic in nature, the main core is a coumarin structure, which is rather flat and therefore, can intercalate into DNA (Jones *et al.* 1998). The epoxide of course can react with other nucleophiles, including those acting as part of the detoxification system, e.g., glutathione (Gopalan *et al.* 1992) and proteins such as blood albumin.

Because of the interaction of AFB₁ with DNA, it is reasonable to ascribe it to be its main toxicological action, certainly at low chronic level of exposure. AFB₁ can form AFB₁-DNA adducts, DNA strand breaks, DNA base damage and oxidative damage that can lead to cancer (Wang and Groopman, 1999). This damage can be repaired by various mechanisms, e.g. base excision repair (Wood, 1999). However, certain mutations that occur due to AFB₁'s action may interfere in these repair mechanisms, in particular, the xeroderma pigmentosum complementation gene group D (XPD) which is one of the groups encoding for groups in the nucleotide excision repair pathways. Recent findings suggest that two loci in this group are of particular importance in modulating the AFB₁ related development of liver cancer (Long *et al.* 2009). Probably of more direct importance is the action of AFB₁ on the p53 gene where it causes an AGG to AGT transverse mutation at codon 249 (Bressac *et al.* 1991). Gene p53 is responsible for producing the p53 protein which has an important role in the regulation of cell cycle and in suppressing genome mutation (May E. and May P., 1999).

5.2 Disease conditions in Africa linked to AF exposure

When considering mycotoxins and their effects in Africa there is a tendency to concentrate on those countries in SSA. The assumption being that those countries constituting the Sahara desert and border areas of the Mediterranean Sea are either more like European countries in terms of commercial food production and consumption; or the countries are so dry and unsuited to mass agrarian exploitation that they do not have the same problems of human mycotoxicoses as the rest within the continent. This is an erroneous supposition, as all foodstuffs at some stage may be contaminated with fungi and mycotoxins in these countries (Mokhles *et al.*, 2007, Ghali *et al.*, 2010) but it is fair to say that in SSA, apart from the major cities, the African population is rural, mainly relying on subsistence agriculture. Because this type of activity is unregulated and often is insufficient to maintain a proper nutritional supply to these populations, it is not unreasonable to suppose that they are exposed routinely to mycotoxins and often have little natural resilience to their effects. Consequently, several diseases, which can be correlated to exposure to mycotoxins or can be in part attributed to them, are known. As AF is ubiquitous in African commodities (Nyathi *et al.* 1989), it is not surprising that several of such conditions are caused or exacerbated by these toxins. However, as indicated above, the main problem is AFB₁ and these diseases will be discussed in terms of this toxin.

5.2.1 Acute toxicity

Although most naturally occurring cases of acute toxicity caused by AFB₁ are observed mainly in animals such as one that lead to the discovery of AF in turkey poults (Blount, 1961), there are several cases of human acute aflatoxicoses (most of which often go unnoticed). Since 1982, deaths caused by AF-contaminated maize have repeatedly occurred in the Eastern Province of Kenya (Probst *et al.* 2007). Similar cases have also previously been recorded at various times in India (Krishnamachari *et al.* 1975) and Malaysia (Lye *et al.* 1995). A recent case reported in Kenya is as a result of consuming contaminated maize (Nyikal *et al.* 2004) with 125 deaths out of 317 cases (Azziz-Baumgartner *et al.*, 2005) being recorded. The symptoms are anorexia, malaise and low grade fever leading to acute jaundice and lethal hepatitis. This outbreak was associated with high levels of AF in maize for human consumption (mean concentration of 355ppb) that led to increased levels of AF B₁ albumin adduct and higher hepatitis B titres in the patients than controls (Azziz-Baumgartner *et al.*, 2005). There seems to be little in the way of treatments for these cases, apart from straight forward strategies of antimicrobials and support for the damaged organs (Mwanza *et al.*, 2005) as the toxin acts rapidly and can be lethal.

5.2.2 Conditions of the liver

As the liver is the main organ of detoxification and the first major organ to be exposed to dietary intake of xenobiotics, it is not surprising to find that several liver conditions have been associated with AF, particularly in under developed countries, especially in Africa. The fact that many African crops, in particular, the staples such as ground nut and maize, can be routinely contaminated with AF, leads to an intuitive feeling that many diseases, including those of the liver, can be linked directly or indirectly, to AF, especially AFB₁. As already intimated, this is a dangerous supposition, as many chronic diseases are multi-factorial in nature, and as in any scientific hypothesis, needs strong evidence of support. This is not

easily gathered in the rural areas of Africa where infrastructure is poor, health services varying from none to basic clinics and health centres with little time or inclination to gather usefully directed statistics. Even the analysis and quality control of staples is dependent upon external scientific studies, which often are one of investigations that merely provide a snapshot of a true situation. Consequently, the information available to investigators attempting to correlate disease conditions to mycotoxin exposure is sparse and patchy with respect to various African countries. In addition, the practise of comparing these conditions in Africa to those in developed countries may highlight interesting differences that can give clues to the aetiology of African disease but may also lead to western scientists dismissing explanations of such chronic diseases in Africa, because of well researched conditions in their own countries, which have explanations other than dietary ones. Clearly, people living in African rural areas have an environment that is completely different to those living in western cities and hence, elevated incidence of certain medical conditions may be explained by factors other than those appertaining let's say for example, in Europe or North America. In any case, there are readily available systems in developing countries particularly in Africa that could provide natural environments for human experimentations as it is in theory, possible to compare the chronic diseases in rural populations against those of urbanized populations of the same race group (Njobeh *et al.*, 2010) elsewhere.

5.2.2.1 Hepatitis

Hendrickse (1991) lists five possible roles for AFB₁ in human disease including fatal AFB₁ poisonings that can "masquerade as hepatitis". This condition is an inflammation of the liver cells caused by various agents including viruses e.g., hepatitis B virus, (HBV) and may be self healing or in extended chronic cases, lead to cirrhosis. Several cases of hepatitis have been reported in the literature including one in India that was attended by high mortality (Krishnamachari *et al.* 1975). The outbreak was associated with maize contaminated by AF and it was concluded that it was as a result of aflatoxicosis.

5.2.2.2 Cirrhosis

Cirrhosis of the liver is a well known disease condition usually related to alcohol consumption. However, it may be caused by exposure of the organ to toxic principles other than ethanol and can often be found in children because of their higher susceptibility to toxin exposure. In certain countries in Africa (e.g. Ethiopia) (Tsega, 1977) and India (Yadgiri *et al.*, 1970), the condition has been described and efforts made to correlate it with AF intake (Tandon *et al.*, 1978). The whole issue is somewhat clouded because of the commoner occurrence of hepato-cellular carcinoma (HCC) together with cirrhosis, in areas of high AF exposure and hence, a relationship has been suggested by the two conditions; simply this would be that the onset of childhood and other cirrhoses leading to liver cancer (Lata, 2010). There is no real evidence, however, that there is a link (Kew and Popper 1984) and further, that the roles of HBV, hepatitis C (HVC) or AFB₁ is by no means clear. In some cases of cirrhosis, there is an over expression of the p53 gene and this has been related to simple cellular stress or mutation of the gene, which occurs in many of the subjects exposed to HBV and/or AFB₁ (Livni *et al.*, 1995). More recent work on cirrhosis in The Gambia (Kuniholm *et al.* 2008) tentatively concludes that health effects due to exposure to AFB₁ could include this disease. It would seem that, because of various factors that African populations face, including alcohol abuse, it is difficult to tease out any particular one and ascribe a role to it, other than it does make a contribution to the overall condition.

5.2.2.3 Hepatocellular Carcinoma (HCC)

This chronic disease is a major global health problem, causing over 600,000 cases per annum (Ferenci *et al.* 2010) and accounts for over 70% of all liver carcinomas (Lata, 2010). In Africa, the most likely cause or promoter of such a cancer is AFB₁ (it has been estimated that AFB₁ may play a causative role in 4.6-28.2% of all global HCC cases) (Liu and Wu, 2010), which is a primary carcinoma in the case of areas where factors such as hepatitis and AF are found. In other situations, the cancer may be of secondary type, i.e., an infiltration of a metastasised type from other parts of the body. Thus the situation is, not as clear cut as might have been thought. Areas in Africa where groundnut is consumed regularly, which is one of the principal sources of the mycotoxin, such as Sudan (Omer *et al.* 1998); Mozambique and Kenya, have high levels of liver cancer which have been shown to be correlated to AFB₁ levels (van Rensburg *et al.*, 1985). These areas also have a high incidence of viral diseases that can also affect the liver, e.g., the highly contagious HBV plus HIV infection (Kew, 2010a); HCV (Ashfaq *et al.* 2011); and iron over load (Kew and Asare, 2007) which tends to cause the issue. Hence it has been argued that these viruses are the cause of the high liver cancer incidence with other factors such as alcoholism and mycotoxins being of secondary importance (Stoloff, 1969; Perz *et al.*, 2006). Given the multi-factorial nature of cancer, these claims are dangerous ones to make and also apply to the school of thought that says HCC is mainly due to AFB₁. Nevertheless, hepatitis viruses do seem to play a major role in the development of HCC in African countries (Kirk *et al.*, 2004; Ocama *et al.*, 2009). It is, however, known that the risk posed by AFB₁ is independent of that of HBV (Blondski *et al.* 2010) although where both factors occur together, the risk is increased. It has been suggested, for example that cirrhosis of the liver, as previously discussed, may be a precursor to liver carcinoma (Kew, 2010a; Lata, 2010). It seems, therefore that HCC is multi-factorial, although some factors may contribute more than others, depending upon circumstances, e.g., in Africa where AFB₁ is commonly found in food, it may play a bigger role here than elsewhere, where it is not found to any extent. Further, in simple terms one thinks of a cancer initiator and a cancer promoter. It may well be that the highest liver cancer areas have a combination of both cancer forming factors plus others such as genetic ones. This certainly is the case for AFB₁ as it has been seen that AFB₁ needs to be activated by the cytochrome P₄₅₀ system in particular the CYP 3A4 version plus CYP3A5 and 3A7 (Kamdem *et al.*, 2006). Hence those persons with genetics dictating less expression of these forms of cytochrome P₄₅₀ would, in theory, have less chance of developing the cancer and vice versa. As earlier mentioned, AFB₁ may cause a missense mutation, where a guanine residue is converted to a thymine in the 249 codon of the p53 gene and this is considered to be an important marker in the promotion of HCC by AFB₁ (Bressac *et al.*, 1991). In a study that was conducted on Chinese subjects, this mutation was detected in the blood and liver of HCC patients (Jackson *et al.*, 2001). However, not all the patients had this mutation in their livers, indicating yet again a multi-factorial situation, although some of the liver negative subjects did have the mutation in their plasma samples. It was concluded that the detection of the codon 247 mutation may present a method of an early diagnosis of HCC.

5.2.3 Kwashiorkor

Kwashiorkor is a malnutrition condition which is in essence a protein deficiency of the young like marasmus but unlike it, the patient has sufficient calories. It is characterized by oedema, anorexia, dermatitis and an enlarged liver with fatty infiltrates (Bhattacharyya,

1986). Because of the liver's involvement, it was suggested that AFB₁ may be involved (Hendrickse *et al.*, 1983). This appeared to be supported by other observation, e.g., relating peak prevalence for kwashiorkor with climatic conditions such as high humidity (de Vries and Hendrickse, 1988); general occurrence of AFB₁ in children's excreta (de Vries *et al.* 1987, 1990); liver (Lamplugh and Hendrickes, 1982); serum (Coulter *et al.*, 1986; Hatem *et al.*, 2005); and its reduced product, aflatoxicol, in livers of Ghanaian children (Apeagyei *et al.*, 1986).

Other work, however, does not support the hypothesis that AF have a role in Kwashiorkor (Househam and Hundt, 1991). What AFB₁ exposure seems to influence in kwashiorkor patients is that their recovery time in hospital is lengthened and this is linked to a difference in the way AFB₁ is metabolised as compared to control non-kwashiorkor infants (Ramjee *et al.*, 1992). It could, therefore, be argued that kwashiorkor is protein deficiency in children who are receiving sufficient carbohydrate such as diet on maize gruel given to weaned children. Maize is not a balanced source of protein but has plenty of starch and hence its use as a staple would fit this hypothesis. Oedema would arise due to lack of sufficient blood proteins, i.e., hypoalbuminemia (Waterlow, 1984). This view has been questioned as it has been observed that the oedema symptoms can disappear before the blood albumin levels return to normal (Golden *et al.*, 1980). An alternative mechanism suggested was that the condition was caused by oxidative species not being regulated by anti-oxidants, e.g., vitamin E, which were depleted because of the poor diet (Golden and Ramdath, 1987). In order to test this, children in Malawi were treated with antioxidants such as riboflavin, vitamin E and selenium (Ciliberto *et al.*, 2005) but both the treated and control group given placebos showed similar levels as kwashiorkor as evidenced by oedema. More recent work seems to suggest that the incidence of kwashiorkor in Africa may be dropping, as evidenced by a Nigerian study (Oyelami and Ogunlesi, 2007). This was put down to better management of diarrhoeal diseases. An interesting point that was made in an earlier publication (Enwonwu, 1984) is that protein deficiency affects the cytochrome P₄₅₀ system, which would allow for the accumulation of AFB₁ in kwashiorkor children due to lack of conversion products. Because of the lack of the AFB₁ epoxide production, its carcinogenic property would be lost, which, ironically, would be re-instituted if protein supplementation was given. It would seem that the underlying causes of kwashiorkor still remains a mystery, is multi-factorial (Oyelami *et al.*, 1995) and unrelated to the lack of any particular food or nutrient (Lin *et al.*, 2007) although potassium supplement appeared to help (Manary and Brewster, 1997). However, it is still tempting to evoke some toxic factor in the diet of children that interacts with other factors to produce the condition. Kwashiorkor has been referred to at a certain time as a "maize disease" (Adhikari *et al.*, 1994). This label has been used in other circumstances with reference to *Fusarium* mycotoxins, in particular the FB, i.e., FB₁ (Dutton, 2009). It is not impossible that these mycotoxins rather than AFB₁ have some role in the development of kwashiorkor.

5.2.4 Miscellaneous

5.2.4.1 Reye's syndrome

This can be a fatal disease that affects mainly children and is typified by fatty liver, swelling of the brain (encephalopathy) and hypoglycemia. The liver becomes enlarged and firm but with no jaundice. There is also evidence of kidney damage. It is not particularly associated with Africa and indeed many cases were reported in first world countries (Harwig *et al.*,

1975). When first described (Reye *et al.*, 1963), the cause was unknown but it often occurred after a mild respiratory tract infection and, because of involvement of the liver, as in kwashiorkor and similar cases in Thailand, it was suggested that AFB₁ may be involved (Becroft, 1966; Olson *et al.*, 1971). This was supported by further studies where materials resembling AF were isolated from the liver of a girl of 8 months of age (Becroft and Webster, 1972) and AFB₁ in the livers of 5 children (Stora *et al.* 1983) but other investigations showed that the presence of AF in Reye's syndrome livers was variable and probably, the syndrome was the result of multiple interrelated factors (Ryan *et al.*, 1979; Rogan *et al.*, 1985). Nevertheless, concern was raised with respect to the presence of AF in the serum and urine of children with Reye's syndrome and it was concluded that this was of general public health importance (Nelson *et al.*, 1980). Because there was no clear cut evidence that AF played a central role in Reye's syndrome, other factors were considered. One of these *inter alia*, was the use of salicylates (Aspirin) in treating children with various infections, e.g., respiratory viral infections (Trauner, 1984). It has been claimed that since aspirin was abolished as a medication for influenza and similar diseases for patients under 18 years old, Reye's syndrome has become very rare (Kimura, 2011) and is considered a secondary mitochondrial disease.

5.2.4.2 Lung cancer

Oyelami and co-workers (1997) found that children with various diseases, including pneumonia in Nigeria had high levels of AF in their lungs. The route of acquisition of this toxin was not clear but there is evidence to suggest that the lung can be exposed to AFB₁ by inhalation (Hayes *et al.*, 1984) and that this may give rise to lung cancer (Dvorackova *et al.* 1981). Human lung microsomes cytochrome P₄₅₀ does not seem to be well expressed, the CYP1A2 form is not expressed at all (Wheeler *et al.* 1990) although some CYP1A2 activity is (Kelly *et al.* 1997). The exposure of lung cells, however, to polycyclic aromatic hydrocarbons induces cytochrome P₄₅₀s that may activate AFB₁ (van Vleet *et al.*, 2001). A study (Donnelly *et al.*, 1996) was conducted on human lung tissue fractions to investigate the possible role of other oxidative systems in the activation of AFB₁ and its deactivation by glutathione S-transferase. The study concluded that AFB₁ activation in human lung was primarily due to lipoxygenase and prostaglandin H synthase activity and that low conjugation activity contributed to human pulmonary susceptibility to AFB₁. Similar studies (van Vleet *et al.*, 2002a) showed that cytochrome P₄₅₀ in lung was capable of activating AFB₁ (van Vleet *et al.*, 2002b) and CYP1A2 has greater importance in lung tissue in activating AFB₁. Later work has indicated that cytochrome P₄₅₀ CYP2A13 is highly expressed in human bronchial cells, indicating that this cytochrome may be responsible for AFB₁ activation in the lung (Zhu *et al.*, 2006). Irrespective of what activates AFB₁, it seems that exposure of humans to AFB₁ inhalation may result in an increased risk of lung cancer (van Vleet *et al.*, 2002b). In the case of rural Africans, this is then a possibility as they process their maize manually (partly by winnowing), often in enclosed conditions where they may be exposed to dust from contaminated cobs.

5.2.4.3 Immuno-suppression and reproductive problems

An often neglected aspect of chronic mycotoxin exposure in humans is the effect of these on the immune system. With the arrival of infections such as HIV, which also attacks this system and is a major problem in SSA, the extra burden of immuno-suppressors may affect

the course of the immune deficiency syndrome (Bondy and Pestka, 2000; Dutton, 2004; Jiang *et al.*, 2008). There is a strong evidence to show that mycotoxins can promote “secondary infections” of organisms that are generally commensal in an animal due to immuno suppression, e.g. OTA in pigs (Stoev *et al.*, 2000). Several mycotoxins have been shown to be immuno-suppressive or have a potential to be so (Sharma, 1993) and these include AFB₁ (Cusumano *et al.*, 1996). These effects may be compounded by the interaction of more than one mycotoxin, which may occur in substrates (Hussein and Brasel, 2001) that may cause synergism, although doubts have been expressed on assessing these effects (Speijers and Speijers, 2004). There is, however, evidence from *in vitro* experiments that this may occur (Creppy *et al.*, 2004, Luongo *et al.*, 2006; Del Rio Garcia *et al.*, 2007; Orsi *et al.*, 2007; Smith *et al.*, 1997) and it is reasonable to suppose that these effects may be extrapolated to humans.

The action of AFB₁ on the human reproductive system and gestation and birth defects is experienced by animals (Ibeh and Saxena, 1997) so it not unreasonable to suppose that these may occur in humans and, from a recent review on the subject, it would seem that AFB₁ exposure in humans has several effects on reproduction (Shuaib *et al.*, 2010a). Several studies have measured the blood albumin-AFB₁ conjugate levels in pregnant African women and have found substantial levels as might be expected (Turner *et al.*, 2007). In one study, there was a correlation between these levels and anaemia in pregnant women in Ghana, if iron deficiency anaemia was excluded (Shuaib *et al.*, 2010b). In the case of men, sperm abnormalities have been associated with AFB₁ in their semen (Ibeh *et al.*, 1994). Other effects are low birth weight (de Vries *et al.*, 1989) and jaundice in neonates (Abulu *et al.*, 1998) which was correlated with AFB₁ in cord blood and effects on their immune system (Turner *et al.*, 2003). AFM₁ is a cytochrome P₄₅₀ mediated hydroxylated product of AFB₁ found in most mammal secreted milks, previously exposed to AFB₁ (Motawee *et al.*, 2009). It does have toxic and carcinogenic properties, although not as marked as AFB₁ (Hsieh *et al.*, 1984). It has been found in breast milk of women from several African countries (Coulter *et al.*, 1984; Zarba *et al.*, 1992). Its presence in cow's milk, particularly in that produced in African rural areas (Mwanza, 2007; Tchana *et al.*, 2010) is of great concern, considering its use in the nutrition of children.

To summarize on the health implications associated with human exposure to AF from the African viewpoint, it is but normal to state that of the AF, AFB₁ is considered to be the most important and much likely to be involved in human diseases. Although most work has concentrated on its role, sight must not be lost of the fact that its congeners, AFG₁ and M₁, which are also present in the environment, are capable of being converted to the active epoxide derivatives by the cytochrome P₄₅₀ system. AFM₁ is of particular importance, because of its occurrence in milk from dairy cattle fed feeds contaminated with AFB₁. With AFB₁ itself, as discussed herein, it is very difficult to tease out its exact role in various human disease conditions. In animal trials, it has been shown to be a powerful carcinogen and there is no reason to suspect that it does not have a carcinogenic effect in humans. A strong claim that the role of mycotoxins in human disease has been ignored was recently made (Wild and Gong, 2010) and interestingly, AFB₁ and FB₁ were cited as major culprits, because of their common occurrence in staple foods, often in combination. However, because of the complicating issues in the human environment and lack of direct experimentation on humans, it is difficult to assign a definitive role in any disease condition. In the case of HCC for example, at best we can claim that AFB₁ is responsible for 5-28% of all

cases in Africa, although the detection of specific point base mutations in liver cancer cells may allow for an estimation of the contribution of AFB₁ to human liver cancer. Whatever the precise medical role of mycotoxins in human diseases is, one cannot help but have a strong empathy with the pleas of Wild and Gong (2010) that they should be taken very seriously in Africa and other developing parts of the world.

6. Possible intervention control strategies for AF in Africa

Considering the action and toxic nature of AF, it may have been thought that attempting to completely eliminate their actions in humans or perhaps, animals would be rather futile. However, several approaches have been or can be taken, either during pre or post-exposure that can assist in alleviating or moderating the actions of AF, particularly those of AFB₁. Whatever actions are taken or have been adopted, do require financial considerations and because the current global financial situation is not in a good stead, make this even much more difficult, but of great importance. In order to assess "overall disease burden" (ODB), the concept of "disability-adjusted life year" (DALY) is used (Murray, 1994). It is defined as the number of years lost due to early death, ill health or disability and this is deduced by the addition of two variables, i.e. "years of life lost" (YLL) to "years lived with disability" (YLD). It follows that one DALY is equal to one year of healthy life lost. In order, therefore, to calculate the cost effectiveness of a programme to prevent HCC for example, the DALYs for this disease must be determined followed by computing the likely lowering of this figure. Against this, is the cost of reducing mycotoxins like AFB₁ and FB₁ in a food staple such as maize. This in turn depends upon regulations governing the health risk factors, which in order to reduce risk to health, must become more stringent resulting in economic losses in the crop due to it not meeting the recommended standard. For example, it is claimed that export losses from AF in groundnut may exceed US\$ 450 million, if the level were 4ppb AF (European Union regulation) as opposed to the level imposed in USA of 20ppb which would result to about \$100 million loss (Wu, 2004). An important aspect of this approach is the fact that WHO has in the past not recognised AF as a high priority problem within the top 6 health problems but it has been argued that AF not only has an impact on HCC, but probably modulates several of the other top 6 problems (Williams *et al.*, 2004). In order to determine the cost effectiveness of various interventions, it is necessary to establish the cost effectiveness ratio (CER), which is the gross domestic product (GDP) multiplied by DALY saved per unit cost. In a study involving AF in maize in Nigeria and groundnut in Guinea, two strategies were compared viz: pre-harvest control; and post harvest interventions (Wu and Khlangwiset, 2010a). Accordingly, it was shown that the cost of both interventions exceeded the monetised values of lives saved and quality of life gained by reducing HCC, if applied nationwide. Furthermore on this study of Wu and Khlangwiset (2010a), CER for biocontrol in Nigeria ranged from 5.1 to 24.8 and for post harvest intervention for groundnut in Guinea from 0.21- to 2.08. Any intervention with a CER <1.0 is considered very cost effective and more that >0.33 as just simply cost effective (Wu and Khlangwiset, 2010a). The implications of such calculations cannot be underestimated, as they do not only indicate to governments and world bodies their value, but also have an ethical dimension in terms of human and animal sufferings.

When considering interventions, several routes may be taken (Wu and Khlangwiset, 2010b). The best approach is that of prevention which is always better than cure. One such intervention is that of releasing non-aflatoxigenic strains of *Aspergillus flavus* into the agricultural environment and such a commercial product called Afla-Guard® is available commercially. This results in suppression of naturally occurring aflatoxigenic strains (Abbas *et al.*, 2011). Another is the introduction of genetically modified variety of crops, e.g., genetically modified (GM) Bt maize which inhibits insect damage and hence fungal infection (Wu, 2006). Another preventive measure is feeding of animals with amino acids and vitamins particularly lysine and vitamin C that have protective actions against mycotoxins (Obidoa and Gugnani, 1992; Smith *et al.*, 2000). A more traditional way is the use of fungicides and pesticides, although current preference is not in favour of this. The use of natural predators (cats and dogs) at fields and storage sites to deter rodents, birds and monkeys is a very practicable preventive control strategy for Africa.

Post harvest treatments are a little more difficult due to the persistence of AF in commodities even after processing. Early harvesting, effective drying (to moisture level of less than 14%), cleaning, removal of damaged produce (sorting), e.g., small and discoloured groundnuts (Chiou *et al.*, 1994); good storage facilities with controlled humidity (Kew, 2010b) and packaging can all contribute to lowering the level of the mycotoxin in the final product. While these remain the most effective post harvest control measures for Africa, other alternative but less effective measures include reduction of storage time, use of chemical and botanical preservatives, and detoxification of contaminated produce. The most commonly used chemical preservatives are the organic acids; formic, acetic, propionic, sorbic and benzoic acids. Nonetheless, they are ineffective in foods that contain basic components that neutralize these acids (Smith and Moss, 1985). Alkalis, strong acids and oxidizing agents are quite effective in detoxifying AF but because they could drastically change the properties of the products, ammoniation is still the most preferred and developed detoxification procedure. But the changes in chemical compositions and organoleptic properties of ammoniated meals makes them unfit for human consumption nevertheless good enough for animals. Commercialization of the ammoniation procedure in Africa by governments and private companies as has been successfully done in the USA, could help provide livestock farmers in developing countries with relatively safer feeds in the face of highly contaminated feedstuffs and shortage of feeds.

The toxic and 'off flavour' products of chemical preservation and detoxification processes has led scientists to search for natural, safer and environment-friendly fungicidal products. Among such African based studies, *Lippia multiflora* leaf extract has been shown to have fungistatic effect on *A. flavus* (Anjorin *et al.*, 2008). More intense field trials of such promising plant products and their subsequent formulation into botanical fungicide would be impressive for the continent. Gamma irradiation of AF contaminated foods lowers both the toxicity (Ogbadu and Bassir, 1979) and production (Ogbadu, 1979; Ogbadu, 1980a; Ogbadu, 1981; Ogbadu, 1988) of the toxin in irradiated foods and so this could be a good post harvest, processing and packaging treatment option for African countries if suitable infrastructures are put in place. Hazard Analysis Critical Control Point (HACCP), a proactive management system in which food safety is maintained through the analysis and control of biological, chemical, and physical hazards from raw material production, procurement and handling, to manufacturing, distribution and consumption of the finished product has become a priceless tool for mycotoxin control (FAO, 2003).

Clinical applications in the control of conditions such as HCC have been applied with varying degree of success. This range from preventative measures such as the use of Novasil clay being added to the diet to bind AF (Afriyie-Gyawu *et al.*, 2008); and HVB immunisation (Kew 2005). The use of drugs can be considered in two parts, one that blocks cytochrome P_{450s} responsible for the activation of AFB₁ to an active (its epoxide) form, e.g. oltipraz (Langouet *et al.*, 1995; Wang *et al.*, 1999) and natural foods, e.g. Brassicas (Manson *et al.*, 1997); and those which may have some other non-clear cut effect such as the use of plant extracts as protective agents (Kotan *et al.*, 2011); boric acid (Turkez and Geyikoglu, 2010); sorafenib, a blocker for signalling pathways involved in HCC (Dank, 2010).

7. Legislation

In order to protect consumers against the hazards of mycotoxins, many countries including 15 of those from Africa (Sibanda *et al.*, 1997; Fellingner, 2006; Njobeh *et al.*, 2010) have instituted legislation against some mycotoxins notably AF. According to these authors, the maximum tolerable limits for AF in human foods in Africa is between 5-20 ppb, while for animal feeds is from 5 to 300 ppb with infant foods having the least regulated levels (0.05-10 ppb) (0.05 ppb for AFM₁ in the case of South Africa). While these maximum allowable limits would protect citizens from the dangers of AF, the biggest challenge in regulating mycotoxins in the continent is the lack of enforcement of legislation partly attributed to the presence of informal food market systems operating in most countries. Under this market structure, raw agricultural produce from farms and storage barns are sold directly to consumers without being screened for mycotoxins neither are they subjected to inspection for spoilage. Furthermore, government agencies charged with the responsibility to regulate mycotoxins are non-existent in many of these countries and even when available, they are dysfunctional as they are composed of deplorable infrastructures and logistics. An effective mycotoxin surveillance and food quality control unit which ensures that all foods and feeds destined for human and animal consumption are devoid of mycotoxins at harmful levels must be in place to implement mycotoxin legislation in the continent.

8. Prevention by surveillance and awareness campaign

Assessing the levels of mycotoxins and indeed other food toxicants is paramount to evaluating food safety. In line with the recommendation for effective mycotoxin survey and food and feed inspection for implementation of legislation for food safety, African governments must build or strengthen already existing regional laboratories to monitor mycotoxins in foods and feeds on regular basis. And to ensure that they are in compliance with set standards. Invariably, Africa must reinforce its food quality control agencies and this can only be achievable if professionals working in such establishments possess the academic as well as technical capacity for mycotoxin management which calls for the inclusion of courses on mycotoxins in the curricula for training of agriculturists, medical personnel and laboratory based scientists. Awareness on the adverse impact of mycotoxins should not be limited to professionals in the food and feed related industries, but to the entire consumers. Public awareness campaign on impact and prevention of mycotoxins especially the notorious AF via electronic and print media and other information dissemination modes is therefore an imperative. Such scientific and public enlightenment interventions require concerted national and international multidisciplinary strategies (WHO, 2006). It is but imperative to engage both national and

international bodies to partner with one another to effectively manage mycotoxins. For example in Nigeria, experts in diverse but related fields from academia and research institutions formed the Nigerian Mycotoxin Awareness and Study Network in 2005 (NMASN-www.ngmycotoxin.org) with a common goal of offering scientific and technical support towards managing mycotoxins in the country. In doing so, the network organizes annual workshops for stakeholders. Similarly this year (2011), the International Society of Mycotoxicology organised a world conference in Cape Town, South Africa on mycotoxin reduction (www.mycoredafrica2011.co.za) which brought scientists from all over the globe to not only share knowledge and expertise but to establish research collaborations towards strengthening the capacity of the African mycotoxicologists and laboratories. European Union (Leslie *et al.*, 2008) and World Health Organisation (WHO, 2006) had earlier organized such international conferences in 2005 and 2006 in Ghana and Congo Brazzaville, respectively. It is only pertinent now to encourage scientists and institutions involved in mycotoxin research in Africa to collaboratively seek accessible research grants from the AU, EU and other foreign funding agencies for more effective investigations and control of mycotoxins.

9. Summary

Aflatoxins are toxic secondary metabolites produced notably by *Aspergillus flavus* and *A. parasiticus* that frequently invade foods and feedstuffs before and after harvest. The four major aflatoxins include aflatoxin B₁, B₂, G₁ and G₂ with aflatoxin B₁ recognized as the most prevalent and toxic of all aflatoxins. Their presence in foods and feeds is inevitable and as such, humans and animals are exposed to them on a continuous basis leading to a wide array of health complications. Particularly aflatoxins B₁, they have been directly linked to hepatocarcinoma and deaths among humans and animals. Although this may be the case worldwide, the situation in sub-Saharan Africa is very severe as increased levels of exposure to this group of mycotoxins is a common phenomenon since it presents suitable environmental conditions for aflatoxin concentration in various food and feed materials. Again, the problem is further exacerbated by increased prevalence in the continent, of such endemic diseases as malaria, hepatitis and HIV/AIDS. In Africa recently, we have experienced the most fatal aflatoxin-poisoning outbreaks including two episodes in Kenya and one in Nigeria. In view of the significance therefore, of aflatoxin exposure, this chapter reviews the disparity in aflatoxin contamination of food and feeds worldwide with particular emphasis on Africa. It has also expounded briefly on those factors that influence the distribution of aflatoxins in various food and feeds. Additionally, an in-depth review is provided on the negative public health problems and the impact in the economy associated with this notorious group of secondary metabolites with particular reference made from the African context, while also discussing those control strategies possible within the continent's technological capacity.

10. Keywords

Aflatoxins, Occurrence, Agricultural commodities, Health, Control, Africa.

11. References

Abalaka, J.A (1984). Aflatoxin distribution in edible oil-extracting plants and in poultry feed mills. *Food and Chemical Toxicology* 22 (6): 461-463

- Abbas, H. K., Zablutowicz, R. M., Horn, B. W., Phillips, N. A., Johnson, B. J., Jin, X. and Abel, C. A. (2011) Comparison of major control strains of non-toxicogenic *Aspergillus flavus* for the reduction of aflatoxins and cyclopiazonic acid in maize, *Food Additives and Contaminants Part A* 28, 198-208.
- Abdallah, M.I.M.; Manal, M.A.*; Dawoud, A.S. And Marouf, H.A. Occurrence of aflatoxins in table eggs sold in Damietta City regarding its health significance. Retrieved on 15th July, 2011 from www.nu.edu.sa/uploads/sss/2/7/1/3/7.pdf
- Abdelhamid, A.M (2008). Thirty Years (1978 - 2008) of Mycotoxins Research at Faculty of Agriculture, Almansoura University, Egypt. Retrieved on 1st June, 2011 from www.engormix.com
- Abulu, E.O., Uriah, N., Aigbefo, H.S., Oboh, P.A. and Agbonlahor, D.E. (1998) Preliminary investigation on aflatoxin in cord blood of jaundiced neonates *West African Journal of Medicine* 17, 184-187.
- Adebayo-Tayo, B. C., Adegoke, A. A. and Akinjogunla, O. J. (2009). Microbial and physico-chemical quality of powdered soymilk samples in Akwa Ibom, South Southern Nigeria. *African Journal of Biotechnology* 8 (13): 3066-3071
- Adebayo-Tayo, B. C. and Ettah, A E. (2010). Microbiological quality and aflatoxin B1 level in poultry and livestock feeds. *Nigerian Journal of Microbiology*, 24(1): 2145 - 2152
- Adebayo-Tayo, B.C., Onilude, A.A., Ogunjobi, A.A., Gbolagade, J.S. and M.O. Oladapo (2006). Detection of fungi and aflatoxin in shelved bush mango seeds (*Irvingia* spp.) stored for sale in Uyo, Nigeria *African Journal of Biotechnology* 5 (19):1729-1732
- Adebayo-Tayo, B.C., Onilude, A.A. and Ukpe, G.P. (2008) Mycofloral of Smoke-Dried Fishes Sold in Uyo, Eastern Nigeria *World Journal of Agricultural Sciences* 4 (3): 346-350
- Adhikari, M., Ramjee, G. and Berjak, P. (1994) Aflatoxin, kwashiorkor and morbidity *Natural Toxins* 2, 1-3.
- Afla-guard, (2005). Aflatoxin in Africa. Retrieved on 11th May, 2011 from www.circleoneglobal.com/aflatoxin_africa.htm.
- Afriyie-Gyawu, E. Ankrah, N.A., Huebner, H.J., Ofosuhene, M., Kumi, J., Johnson, N.M., Tang, L., Xu, L., Jolly, P.E., Ellis, W.O., Ofori-Adjei, D., Williams, J.H., Wang, J.S., Phillips, T.D. (2008) Novasil clay intervention in Ghanaians at high risk for aflatoxicosis. I. Study design and clinical outcomes *Food Additives and Contaminants Part A* 25, 76-87.
- Agboola S.D (1992). Post harvest technologies to reduce mycotoxin contamination of food crops. In Z.S.C Okoye (ed) Book of proceedings of the first National Workshop on Mycotoxins held at University Jos, on the 29th November, 1990, 73-88.
- Akinmusire, O.O. (2011). Fungal species associated with the spoilage of some edible fruits in Maiduguri, Northern Eastern Nigeria *Advances in Environmental Biology* 5(1): 157-161
- Akrobortu, D.E. (2008). Aflatoxin contamination of maize from different storage locations in Ghana. An M.Sc. Thesis submitted to the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Ghana. 27-32
- Amer, A.A. and Ibrahim, M.A.E. (2010) Determination of aflatoxin M1 in raw milk and traditional cheeses retailed in Egyptian markets *Journal of Toxicology and Environmental Health Sciences* 2 (4): 50-53
- Anjorin, S.T, Makun, H.A, and Ihenecho, H.E (2008). Effect of *Lippia Multiflora* leaf extract and *Aspergillus flavus* on germination and vigour indices of *Sorghum Bicolor* [L] (Moench). *International Journal of Tropical Agriculture and Food System*, 2 (1): 130 - 134.

- Apeagyei, F., Lamplugh, S. M., Hendrickse, R. G., Affram, K. and Lucas, S. (1986) Aflatoxin in the livers of children with kwashiorkor in Ghana *Tropical and Geographical Medicine* 38, 273-276.
- Aroyeun, S.O and Jayeola, C.O (2005). Mycotoxins in cocoa. A paper presented at the Regional Workshop on Mycotoxins organized by National Agency for Food and Drug Administration and Control (NAFDAC) in collaboration with International Atomic Energy Agency (IAEA), Held at Meidan Hotels, Victoria Garden City, Lagos, Nigeria between 7th and 11th February, 2005.
- Ashfaq, U. A., Javed, T., Rehman, S., Nawaz, Z. and Riazuddin, S. (2011) An overview of HCV molecular biology, replication and immune response *Virology Journal* 8, In Press.
- Atehnkeng, J., Ojiambo, P.S., Donner, M., Ikotun, K., Sikora, R.A., Cotty, P.J. and Bandyopadhyay, R. (2008). Distribution and toxicity of *Aspergillus* species isolated from maize kernels from three agro-ecological zones of Nigeria. *International Journal Food Microbiology*. 122, 74-84.
- Atanda, O., Oguntubo, A., Adejumo, O., Ikeorah, J. and Akpan, I. (2007). Aflatoxin M1 contamination of milk and ice cream in Abeokuta and Odeda local governments of Ogun State, Nigeria *Chemosphere* 68, 1455-1458
- Aziz, N.H. and Youssef, Y.A (1991). Occurrence of aflatoxins and aflatoxin-producing moulds in fresh and processed meat in Egypt *Food Additives and Contaminants*. 8 (3):321-31
- Azziz-Baumgartner, E., Lindblade, K., Gieseke, K., Rogers, H. S., Kieszak, S., Njapau, H., Schleicher, R., McCoy, L. F., Misore, A., DeCock, K., Rubin, C. and Slutsker, L. (2006) Case control study of an acute aflatoxicosis outbreak, Kenya 2004 *Environmental Health Perspectives* 113, 1779-1783.
- Baiyewu, R.A., Amusa, N. A., Ayoola, O.A. and Babalola, O.O. (2007). Survey of the post harvest diseases and aflatoxin contamination of marketed pawpaw fruit (*Carica papaya* L) in South Western Nigeria *African Journal of Agricultural Research* 2 (4):178-181.
- Bandyopadhyay, R., Kumar, M. and Leslie, J.F. (2007). Relative severity of aflatoxin contamination of cereal crops in West Africa *Food Additives and Contaminants* 24 (10):1109-14.
- Bankole, S.A and Adebajo, A. (2003). Mycotoxins in food in West Africa: current situation and possibilities of controlling it. *African Journal of Biotechnology* 2 (9): 254-263.
- Bankole, S.A. and Mabekoje, O.O (2004). Mycoflora and occurrence of aflatoxin B1 in dried yam chips from markets in Ogun and Oyo States, Nigeria *Mycopathologia*. 157(1):111-5
- Bankole, S.A., Ogunsanwo, B.M. and Esegbe, D. A (2005). Aflatoxins in Nigerian dry-roasted groundnuts. *Food Chemistry* 89: 503-506.
- Bankole, S.A., Ogunsanwo, B.M., Osho, A. and Adewuyi, G.A (2006). Fungal contamination and aflatoxin B1 of egusi melon seeds in Nigeria. *Food Control* 17: 814-818.
- Bankole, S Schollenberger, M. and Drochner, W. (2006). Mycotoxins in food systems in Sub Saharan Africa: A review *Mycotoxin Research* 22 (3): 163-169
- Barkai-Golan, R. and Paster, N. (2008). Mycotoxins in Fruits and Vegetables. Academic Press, San Diego, USA. 3-11
- Bassa, S., Mestres, C., Champiat, D., Hell, K., Vernier, P. and Cardwell, K. (2009) First report of aflatoxin in dried yam chips in Benin. *Plant Disease* 85 (9): 1032
- Becroft, D.M.O. (1966) Syndrome of encephalopathy and fatty degeneration of viscera in New Zealand children *British Medical Journal* 2, 1351.

- Becroft, D. M. O. and Webster, D. R. (1972) Aflatoxins and Reye's disease *British Medical Journal* 14th October, p117.
- Beucker, S., Raters, M. and Matissek, R. (2005). Mycotoxin Study III: MycoDONA Deoxynivalenol, Ochratoxin A and Aflatoxins in Cocoa and Cocoa-containing Products Analysis, Situation Assessment, and Monitoring. Retrieved on 15th July, 2011 from http://www.kakao-stiftung.de/pdf/Projekt_38e.pdf
- Bhattacharyya, A. K. (1986) Protein-energy malnutrition (Kwashiorkor-Marasmus syndrome): terminology, classification and evolution *World Review of Nutrition and Dietetics* 47, 80-133.
- Bilgrami, K.S., Prasad, T., Misra, R.S. and Sinha, K.K. 1981. Aflatoxin contamination in maize under field conditions. *Indian Phytopathology*. 34, 67-68.
- Bintvihok, A., Thiengnin, S., Doi, K. and Kumagai, S. (2002). Residues of aflatoxins in the liver, muscles and eggs of domestic fowls *Journal of Veterinary Medical Science* 64 (11): 1035-1037
- Blondski, W., Wojciech, Kotlyar, D. S. and Forde, K. A. (2010) Non-viral causes of hepatocellular carcinoma *World Journal of Gastroenterology* 16, 3603-3615.
- Blount W.P. (1961) Turkey X disease *Turkeys (Journal of the British Turkey Association)* 9, 55-58.
- Bondy, G. S. and Peska, J. J. (2000) Immunomodulation by fungal toxins *Journal of Toxicology and Environmental Health B* 3, 109-143.
- Bressac, B., Kew, M., Wanda, J. and Ozturk, M. (1991) Selective G to G mutations of p53 gene in hepatocellular carcinoma from southern Africa *Nature* 350, 429-431.
- Bucci, T. J. and Howard, P. C. (1996) Effect of fumonisin mycotoxins in animals *Journal of Toxicology Toxin Reviews* 15, 293-302.
- Brimer, L (2011). Chemical food safety of traditional grains. Retrieved on 1st June, 2011 from http://www.sik.se/traditionalgrains/workshop/proceedings/Leon_Brimer_proc.pdf
- Campbell, T.C. and Hayes, J.R. (1976) The role of aflatoxin metabolism in its toxic lesions *Toxicology and Allied Pharmacology* 35, 199-222.
- Center for Disease Control and Prevention (CDC), 2004. Outbreak of aflatoxin poisoning – Eastern and Central provinces, Kenya, January–July, 2004. Retrieved on 20th June, 2011 from <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5334a4.htm>.
- Chandrashekar, A., Bandyopadhyay, R., and Hall, A.J. (eds.). 2000. Technical and institutional options for sorghum grain mold management: proceedings of an international consultation, 18-19 May 2000, ICRISAT, Patancheru, India. (In En. Summaries in En, Fr.) Patancheru, 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi- Arid Tropics. 299 pp. ISBN 92-9066-428-2. Order code CPE 129.
- Chiou, R. Y. Y., Wu, P. Y. and Yen, Y. H. (1994) Color sorting of lightly roasted and de-skinned peanut kernels to diminish aflatoxin contamination in commercial lots *Journal of Agricultural Food Chemistry* 42, 2156-2160.
- Chukwu, O. and Imodiboh, L.I. (2009) Influence of Storage Conditions on Shelf-Life of Dried Beef Product (*Kilishi*) *World Journal of Agricultural Sciences* 5 (1): 34-39
- Ciliberto, H., Ciliberto, M., Briend, A., Ashorn, P., Bier, D. and Manary, M. (2005) Antioxidant supplementation for the prevention of kwashiorkor in Malawian children: randomised, double blind, placebo controlled trial *British Medical Journal* 330, 1109-1114.

- Codex Alimentarius Commission. 2004. Code of Practice for the Prevention and Reduction of Aflatoxin Contamination in Peanuts. Retrieved 13th May, 2011 from http://www.codexalimentarius.net/download/standards/10084/CXC_055_2004e.pdf.
- Codex Alimentarius Commission. (2011). Discussion paper on mycotoxins in Sorghum. Joint FAO/WHO Food Standards Programme CODEX Committee on contaminants in foods' 5th Session held in The Hague, The Netherlands on 21 - 25 March 2011.
- Coulter JB, Lamplugh SM, Suliman GI, Omer MI and Hendrickse RG. (1984) Aflatoxins in human breast milk *Annals of Tropical Paediatrics* 4, 61-66.
- Coulter, J. B., Hendrickse, R. G., Lamplugh, S. M., MacFarlane, S. B., Moody, J. B., Omer, M. I., Suliman, G. I., and Williams, T. E. (1986) Aflatoxins and kwashiorkor: clinical studies in Sudanese children, *Transactions of the Royal Society of Tropical Medicine and Hygiene* 80, 945-951.
- Creppy, E. E., Chiarappa, P., Baudrimont, I., Borracci, P., Moukha, S. and Carratu, M. R. (2004) Synergistic effects of fumonisin B₁ and ochratoxin A: are *in vitro* cytotoxicity data predictive of *in vivo* acute toxicity? *Toxicology* 201, 115-123.
- Cusumano, V., Rossano, F., Merendino, R. A., Arena, A., Costa, G. B., Mancuso, G., Baroni, A. and Losi, E. (1996) Immunobiological activities of mould products: functional impairment of human monocytes exposed to aflatoxin B₁ *Research in Microbiology* 147, 385-391.
- Dank, M. (2010) Treatment of primary hepatocellular carcinoma *Orv Hetil* 151, 1445-1449. (In Hungarian; abstract PubMed 20739261).
- Del Rio Garcia, J. C., Moreno, R., C., Pinton, P., Mendoza, E. S. and Oswald, I. P. (2007) Evaluation of the cytotoxicity of aflatoxin and fumonisins on swine intestinal cells *Rev Iberoam Micol* 24, 136-141. (In Spanish; abstract PubMed 17604433).
- de Vries, H. R. and Hendrickse, R. G. (1988) Climatic conditions and kwashiorkor in Mumias: a retrospective analysis over a 5-year period *Annals of Tropical Paediatrics* 8, 268-270.
- de Vries, H. R., Lamplugh, S. M. and Hendrickse, R. G. (1987) Aflatoxins and kwashiorkor in Kenya: a hospital based study *Annals of Tropical Paediatrics* 7, 249-251.
- de Vries, H.R., Maxwell S.M. and Hendrickse, R.G. (1989) Foetal and neonatal exposure to aflatoxins *Acta Paediatric Scandinavia* 78, 373-378.
- de Vries, H. R., Maxwell, S. M. and Hendrickse, R. G. (1990) Aflatoxin excretion in children with kwashiorkor or marasmic kwashiorkor - a clinical investigation *Mycopathologia* 110, 1-9.
- Donnelly, P.J., Stewart, R.K., Ali, S.L., Conlan, A.A., Reid, K.R., Petsikas, D. and Massey, T.E. (1996) Biotransformation of aflatoxin B₁ in human lung *Carcinogenesis* 17, 2487-2494.
- Dvorakova, I., Stora, C. and Ayraud, N. (1981) Evidence for aflatoxin B₁ in two cases of lung cancer in man *Journal of Cancer Research and Clinical Oncology*, 100 221-224.
- Dutton, M. F (2004) Chapter 13 Fumonisin B₁ in animal and human health. In *Recent Researches on Fungi* Ed. R.K.S. Kushwaha, Scientific Publishers (India) Jodhpur.
- Dutton, M. F. (2009) The African *Fusarium*/maize disease, *Mycotoxin Research* 25, 29-39.
- Dutton, M., Mwanza, M., de Kock, S., Khilosia, L. (2012). Mycotoxins in South African foods: a case study on aflatoxin in milk. *Mycotoxin Research* 28: 19-25
- Elgerbi, A. M., Aidoo, K. E. Candlish, A. A. G. and Tester, R. F. (2004). Occurrence of aflatoxin M₁ in randomly selected North African milk and cheese samples *Food Additives & Contaminants: Part A*, 21 (6) : 592 - 597

- Elzupir AO, Younis M.H, Himmat Fadul M, Elhussein AM (2009) Determination of Aflatoxins in Animal Feed in Khartoum State, Sudan. *Journal of Animal and Veterinary Advances* 8 (5): 1000-1003
- Enwonwu, C. O. (1984) The role of dietary aflatoxin in the genesis of hepatocellular carcinoma in developing countries, *Lancet* 2 (8409), 956-958.
- Essono, G., Ayodele, M., Akoa, A., Foko, J., Filtenborg, O. and Olembo, S. (2009). Aflatoxin-producing *Aspergillus* spp. and aflatoxin levels in stored cassava chips as affected by processing practice *Food Control* 20 648–654
- Fapohunda, S.O (2011). Impact of Mycotoxins on Sub-Saharan Africa : Nigeria as a Case Study. European Mycotoxin Awareness Network Retrieved on 7th July, 2011 from <http://www.services.leatherheadfood.com/mycotoxins/index.asp>
- F.A.O. (2003) Manual on the application of HACCP system to mycotoxin control. Retrieved on 13th May, 2011 from <http://www.fao.org/docrep/005/y1390e/y1390e00.htm>.
- F.A.O (1983). Post harvest losses in quality of food grains. Food and Agriculture Organisation (Food and Nutrition Paper No 29, pg. 103
- FAOSTAT (2006). Production statistics. Retrieved on July, 2010 from www.faostat.fao.org
- FAOSTAT, (2010) Crops primary equivalent. Retrieved on 16th May, 2011 from www.faostat.fao.org
- FDA (2011), Hazard Analysis Critical Control Point. Retrieved on 13th May, 2011 from <http://www.fda.gov/food/foodsafety/hazardanalysiscriticalcontrolpointshaccp/default.htm>)
- Fellinger, A. (2006). Worldwide mycotoxin regulations and analytical challenges. World Grain Summit: Foods and Beverages, September 17–20, 2006, San Francisco, California, USA.
- Ferenci, P., Fried M., Labrecque, D., Bruix, J., Sherman, M., Omata, M., Heathcote, J., Piratsivuth, T., Kew, M., Otegbayo, J.A., Zheng, S.S., Sarin, S., Hamid, S., Modawi, S.B., Fleig, W., Fedail, S., Thomson, A., Khan, A., Malfertheiner, P., Lau, G., Carillo, F.J., Krabshuis, J., Le Mair, A., World Gastroenterology Organisation Guidelines and Publications Committee (2010) World gastroenterology organisation guideline. Hepatocellular carcinoma (HCC): a global perspective, *Journal of Gastrointestinal Liver Disease* 19, 311-317.
- Fernández-Cruz, M.L., Mansilla, M.L. and Tadeo, J.L. (2010). Mycotoxins in fruits and their processed products: Analysis, occurrence and health implications *Journal of Advanced Research* 1, 113–122
- Frisvad, J.C. and Samson, R.A (2004). *Emericella venezuelensis*, a New Species with Stellate Ascospores Producing Sterigmatocystin and Aflatoxin B1 *Systematic and Applied Microbiology*, 27, 672-680.
- Frisvad, J.C., Samson, R.A. and Smedsgaard, J. (2004) *Emericella astellata*, a new producer of aflatoxin B1, B2 and sterigmatocystin. *Letters in Applied Microbiology* 38, 440–445
- Frisvad, J. C., Skouboe, P., and Samson, R. A. (2005). Taxonomic comparison of three different groups of aflatoxin producers and a new efficient producer of aflatoxin B1, sterigmatocystin and 3-O-methylsterigmatocystin, *Aspergillus rambellii* sp. nov. *Systematic Applied Microbiology*, 28, 442–453.
- Gallagher, E.P., Wickers, L.C., Stapleton, P.L., Kunze, K.L and Eaton, D.L. (1994) Role of human microsomal and human complementary DNA expressed cytochromes P450 1A2 and 3A4 in the bioactivation of aflatoxin B₁ *Cancer Research* 54, 101-108.

- Gbodi, T.A. (1986). Studies of mycoflora and mycotoxins in Acha, maize and cotton seed in plateau state, Nigeria. A Ph. D thesis, submitted to Department of Physiology and Pharmacology, Faculty of Veterinary Medicine, A.B.U, Zaria, pg. 1-213.
- Ghali, R., Belouaer, I., Hdiri, S., Ghorbel, H., Maaroufi, K. and Hedilli, A. (2009) Simultaneous HPLC determination of aflatoxins B1, B2, G1 and G2 in Tunisian sorghum and pistachios. *Journal of Food Composition and Analysis* 22, 751-755
- Ghali, R., Khlifa, K. H., Ghorbel, H., Maaroufi, K. and Hedilli, A. (2008). Incidence of aflatoxins, ochratoxin A and zearalenone in Tunisian foods. *Food Control* 19, 921-924
- Ghali, R., Khlifa, K. H., Ghorbel, H., Maaroufi, K. and Hedilli, A. (2010) Aflatoxin determination in commonly consumed foods in Tunisia, *Journal of the Science of Food and Agriculture* 90, 2347-2351.
- Golden, M.H.N., Golden, B.E. and Jackson, A.A., (1980) Kwashiorkor and nutritional oedema *Lancet* 1 (8180), 114-116.
- Golden, M.H.N. and Ramdath, D. (1987) Free radicals in the pathogenesis of kwashiorkor *Proceedings of Nutrition Society* 46, 53-68.
- Gong, Y.Y., Egal, S., Hounsa, S., Hall, A.J., Cardwell, K.F., Wild, C.P., (2003). Determinants of aflatoxin exposure in young children from Benin and Togo, West Africa: the critical role of weaning. *International Journal of Epidemiology* 32, 556-662.
- Gong, Y., Hounsa, A., Egal, S., Sutcliffe, A.E., Hall, A.J., Cardwell, K.F., Wild, C.P., (2004). Postweaning exposure to aflatoxin results in impaired child growth: a longitudinal study in Benin, West Africa. *Environmental Health Perspectives* 112, 1334-1338.
- Gopalan, P., Jensen, D. E. and Lotikar, P. D. (1992) Glutathione conjugation of microsome mediated and synthetic aflatoxin B1-8,9-oxide by purified glutathione S-transferase from rats *Cancer Letters* 64 225-233.
- Gnonlonfin, G.J.B., Hell, K., Fandohan, P. and Siame, A.B. (2008). Mycoflora and natural occurrence of aflatoxins and fumonisin B1 in cassava and yam chips from Benin, West Africa *International Journal of Food Microbiology*
- Groopman, J. D., Hall, A. J., Whittle, H., Hudson, G. J., Wogan, G. N., Montesano, R. and Wild, C. P. (1992) Molecular dosimetry of aflatoxin-N7-guanine in human urine obtained in the Gambia, West Africa *Cancer Epidemiological Biomarkers and Prevention* 1, 221-227.
- Harwig, J., Przybylski, W. and Moodie, C. A. (1975) A link between Reye's syndrome and aflatoxins? *Canadian Medical Association Journal* 113, 281.
- Hatem, N. L., Hassab, H. M., Abd Al-Rahman, E. M., El-Deeb, S. A. and El-Sayed Ahmed, R. L. (2005) Prevalence of aflatoxins in blood and urine of Egyptian infants *Food and Nutrition Bulletin* 26, 49-56.
- Hayes, R.B., Van Nieuwenhuize, J.P., Raatgever, J.W. and Ten Kate, F.J.W. (1984) Aflatoxin exposures in industrial setting: an epidemiological study of mortality *Food Chemistry and Toxicology* 22, 39-43.
- Hell, k. and Mutegi, C. (2011). Aflatoxin control and prevention strategies in key crops of Sub Saharan Africa. *African Journal of Microbiology Research* 5 (5):459-466
- Hell, K., Cardwell, K.F., Setamou, M., Poehling, H.M., (2000). The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *Journal of Stored Products Research* 36,365-382.
- Hell, K., Gnonlonfin, .G.J., Kodjogbe, G., Lamboni, Y. and Abdourhamane, I.K. (2009). Mycoflora and occurrence of aflatoxin in dried vegetables in Benin, Mali and Togo, West Africa *International Journal of Food Microbiology* 135, 99-104

- Hendrickse, R. G. (1991) Clinical implications of food contaminated by aflatoxins *Annals of Academic Medicine Singapore* 20, 84-90.
- Hendrickse, R. G., Coulter, J. B., Lamplugh, S. M., MacFarlane, S. B., Williams, T. E., Omer, M. I., Suliman, M. I., and El-Zorganui, G. A. (1983) Aflatoxins and kwashiorkor. Epidemiology and clinical studies in Sudanese children and findings in the autopsy liver samples from Nigeria and South Africa *Bulletin of the Exotic Pathology Society* 76, 559-566
- Holbrook, C.C., Guo, B.Z., Wilson, D.M., Kvien, C., (2004). Effect of drought tolerance on preharvest aflatoxin contamination in peanut. Proceedings of the 4th International Crop Science Congress Brisbane, Australia, 26 Sep-1 Oct 2004
- Househam, K. C. and Hundt, H. K. (1991) Aflatoxin exposure and its relationship to kwashiorkor in African children *Journal of Tropical Pediatrics* 37, 300-302.
- Hsieh, D. P. H., Cullen, J. M. and Ruebner, B. H. (1984) Comparative hepatocarcinogenicity of aflatoxins B₁ and M₁ in the rat *Food and Chemical Toxicology* 22, 1027-1028.
- Hussain, Z., Khan, M.Z., Khan, A., Javed, I., Saleemi, M.K., Mahmood, S. and Asi, M.R. (2010). Residues of aflatoxin B₁ in broiler meat: Effect of age and dietary aflatoxin B₁ levels *Food and Chemical Toxicology* 48 (12): 3304-3307
- Hussein, H. S., and Brasel, J. M. (2001) Toxicity, metabolism and impact of mycotoxins on humans and animals, *Toxicology* 167, 101-134.
- International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (2010). Assessing occurrence and distribution of aflatoxins in Malawi. Project Final Report (Grant No. 08-598). Retrieved on 1st June, 2011 from http://mcknight.ccrp.cornell.edu/program_docs/project_documents/SAF_0642_groundnut_breeding/Assessing%20Occurrence%20and%20Distribution%20of%20Aflatoxin%20%20final2.pdf.
- Ibeh, I. N. and Saxena, B. N. (1997) Aflatoxin B₁ and reproduction. I. Reproductive performance in female rats, *African Journal of Reproductive Health* 1, 79-84.
- Ibeh IN, Uraih N, Ogonar JI. (1994) Dietary exposure to aflatoxin in human male infertility in Benin City, Nigeria. *International Journal of Fertility and Menopausal Studies* 39, 208-214
- IPCC, (2007) International Panel on Climate Change. Fourth Assessment Report. Retrieved on 16th May, 2011 from www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml
- Ito, Y., Peterson, S. W., Wicklow, D. T., & Goto, T. (2001). *Aspergillus pseudotamarii*, a new Aflatoxin producing species in *Aspergillus* section *Flavi*. *Mycological Research*, 105, 233-239.
- Jackson, P. E., Qian, G.-S., Friesen, M. D., Zhu, Y.-R., Lu, P., Wang, J.-B., Wu, Y., Kensler, T. W., Vogelstein, B. and Groopman, J. D. (2001) Specific p53 mutations detected in plasma and tumors of hepatocellular carcinoma patients by electrospray ionisation mass spectrometry, *Cancer Research* 61, 33-35.
- Jarvis, B (1971). Factors affecting the production of mycotoxins *Journal of Applied Bacteriology*. 34(1):199-213.
- Jarvis, B. (1976). Mycotoxins in food. In: Skinner, F.A and Carr, J.G (Eds), *Microbiology in Agriculture, Fisheries and Food*, Academic Press, London, pp. 251-267.
- JECFA, (2001). WHO Food additives series:47 safety evaluation of certain food additives and contaminants: Aflatoxin M₁. Joint FAO/WHO Expert Committee on Food Additives
- Jiang, Y., Jolly, P. E., Preko, P., Wang, J. S., Ellis, W. O., Phillips, T. D. and Williams, J. H. (2008) Aflatoxin related immune dysfunction in health and in human

- immunodeficiency virus disease, *Clinical and Developmental and Immunology* 2008, 12 pages. (On Line Free access).
- Jimoh, K.O. and Kolapo, A.L. (2008). Mycoflora and aflatoxin production in market samples of some selected Nigerian foodstuffs. *Research Journal of Microbiology* 3 (3): 169-174
- Jonathan, G., Ajayi, I. and Omitade, Y.(2011). Nutritional compositions, fungi and aflatoxins detection in stored 'gbodo' (fermented *Dioscorea rotundata*) and 'elubo ogede' (fermented *Musa parasidiaca*) from South western Nigeria. *African Journal of Food Science* 5(2): 105 - 110.
- Jonathan, S. G. and Esho E.O. (2010) Fungi and aflatoxin detection in two stored oyster mushroom (*Pleurotus ostreatus* and *Pleurotus pulmonarius*) from Nigeria *Electronic Journal of Environmental, Agricultural and Food Chemistry* 9 (11): 1722-1736
- Jones, W. R., Johnston, D. S. and Stone, M. P. (1998) Refined structure of the doubly intercalated d(TAT^{af}GCATA)₂ aflatoxin B₁ adduct *Chemical Research in Toxicology* 11, 873-881.
- Jones, M. J., Tanya, V. N., Mbofiing, C. M.F., Fonkem, D. N. and Silverside, D. E. (2001) A Microbiological and nutritional evaluation of the West African dried meat product, Kilishi *The Journal of Food Technology in Africa*, 6 (4), 126-129
- Juan, C., Zinedine, A., Molto, J.C., Idrissi, L. and Manˆes, J. (2008). Aflatoxins levels in dried fruits and nuts from Rabat-Sale' area, Morocco *Food Control* 19, 849-853
- Kaaya, N.A and Kyamuhangire, W. (2006). The effect of storage time and agroecological zone on mould incidence and aflatoxin contamination of maize from traders in Uganda. *International Journal of Food Microbiology* 110, 217-223
- Kaaya, N.A. and Warren, H.L. (2005). A review of past and present research on aflatoxin in Uganda *African Journal of Food Agriculture Nutrition and Development* 2005, 18 pages (On Line Free Access)
- Kamdem, L. K., Meineke, I., Godtel-Armbrust, U., Brockmoller, J. and Wojnowski, L. (2006) Dominant contribution of P450 3A4 to the hepatic activation of aflatoxin B₁ *Chemical Research in Toxicology* 19, 577-586.
- Kamika, I. and Takoy, L.L (2011). Natural occurrence of Aflatoxin B1 in peanut collected from Kinshasa, Democratic Republic of Congo. *Food Control*. In press.
- Kang.ethe, E.K. and Lang.a, K.A. (2009). Aflatoxin B1 and M1 contamination of animal feeds and milk from urban centers in Kenya. *African Health Sciences* 9 (4): 218-226
- Kastner, S., Kandler, H., Hotzb, K., Bleisch, M., Lacroix, C, Meile, L.(2010). Screening for mycotoxins in the inoculum used for production of attie'ke' a traditional Ivorian cassava product. *Food Science and Technology* 43: 1160-1163
- Katerere , D.R., Stockenstrom, S., Thembo, K.M., Rheeder, J.P., Shephard, G.S. and Vismer, H.S. (2008). A preliminary survey of mycological and fumonisin and aflatoxin contamination of African traditional herbal medicines sold in South Africa *Human and Experimental Toxicology* 27 (11): 793-798
- Kelly, J.D., Eaton, D.L., Guengerich, F.P. and Colombe (1997) Aflatoxin B₁ activation in human lung *Toxicology and Applied Pharmacology* 144, 88-95.
- Kew, M. C. (2005) Prevention of hepatocellular carcinoma, *HPB* 7, 16-25.
- Kew, M. C. (2010a) Hepatocellular carcinoma in African blacks: recent progress in etiology and pathogenesis *World Journal of Hepatology* 2, 65-73.
- Kew, M. C. (2010b) Prevention of hepatocellular carcinoma *Annals of Hepatology* 9, 120 - 132.
- Kew, M. C. and Asare, G.A. (2007) Dietary iron overload in the African and hepatocellular carcinoma *Liver International* 27, 735-741.

- Kew, M. C. and Popper, H. (1984) Relationship between hepatocellular carcinoma and cirrhosis *Seminars in Liver Disease* 4, 136-146.
- Kimura, A. (2011) Reye's syndrome and Reye-like syndrome, *Nippon Rinsho* 69, 455-459. (In Japanese, PubMed 21400838).
- Kirk, G. D., Lesi, O. A., Mendy, M., Akano, A. O., Sam, O., Goedert, J. J., Hainaut, P., Hall, A. J., Whittle, H. and Montesano, R. (2004) The Gambia liver cancer study: infection with hepatitis B and the risk of hepatocellular carcinoma in west Africa *Hepatology* 39, 211-219.
- Kotan, E., Alpsyoy, L., Anar, M., Aslan, A. and Agar, G. (2011) Protective role of methanol extracts of *Cetraria islandica* against oxidative stress and genotoxic effects of aflatoxin B₁ in human lymphocytes *in vitro Toxicology and Industrial Health* 2011, In press.
- Kpodo, K., Sorensen, A.K. and Jakobsen, M.(1996). The occurrence of mycotoxins in fermented maize products *Food Chemistry* 56 (2):147-153.
- Krishnamachari, K. A., Bhat, R. V., Nagarajan, V. and Tilak, T. B. (1975) Hepatitis due to aflatoxicosis. An outbreak in Western India *Lancet* 1(7915), 1061-1063.
- Kuniholm, M. H., Lesi, O. A., Mendy, M., Akano, A. O., Sam, O., Hall, A. J., Whittle, H., Bah, E., Goedert, J. J., Hainaut, P. and Kirk, G. D. (2008) Aflatoxin exposure and viral hepatitis in the etiology of liver cirrhosis in the Gambia West Africa *Environmental Health Perspectives* 116, 1553-1557.
- Lamplugh, S. M. and Hendrickse, R. G. (1982) Aflatoxins in the livers of children with kwashiorkor *Annals of Tropical Paediatrics* 2, 101-104.
- Lane, K.S, (2005). New support for FDA regulation of tobacco. Retrieved on July, 2006 from www.Tobacco.org.
- Langouet, S., Coles, B., Morel, F., Becquemonet, L., Beaune, P., Guengrich, P., F., Ketterer, B. and Guillouzo, A. (1995) Inhibition of CYP1A2 and CYP3A4 by olitpraz results in reduction of aflatoxin B₁ metabolism in human hepatocytes in primary culture *Cancer Research* 55, 5574-5579.
- Lata, J. (2010) Chronic liver disease as tumor precursors, *Digestive Diseases* 28, 596-599.
- Leslie, J.F., Bandyopadhyay, R. and Visconti, A. (2008), *Mycotoxins: Detection methods, management, public health and agricultural trade*. Cromwell Press, Trowbridge, UK. Pp 476
- Lilleberg, S. L., Cabonce, M. A., Raju, N. R., Wagner, L. M. and Kier, L. D. (1992) Alterations in the structural gene and expression of p53 in rat liver tumors induced by aflatoxin B₁ *Molecular Carcinogenesis* 6, 159-172.
- Lin, C. A., Boslaugh, S., Ciliberto, H. M., Maleta, K., Ashorn, P., Briend, A. and Manary, M. J. (2007) A prospective assessment of food and nutrient intake in a population of Malawian children at risk for kwashiorkor *Journal of Paediatric and Gastroenterological Nutrition* 44, 487-493.
- Liu, Y. and Wu, F. (2010) Global burden of aflatoxin-induced hepatocellular carcinoma: a risk assessment *Environmental Health Perspectives* 118, 818-824.
- Livni, N., Eid, A., Ilan, Y., Rivkind, A., Rosenmann, E., Blendis, L. M., Shouval, D. and Galun, E. (1995) p53 expression in patients with cirrhosis with and without hepatocellular carcinoma *Cancer* 75, 2420-2426.
- Long, X. D., Ma, Y., Zhou, Y. F., Yao, J. G., Ban, F. Z., Huang, Y. Z. and Huang, B. G. (2009) XPD codon 312 and 751 polymorphisms and aflatoxin B₁ exposure and hepatocellular carcinoma risk *BMC Cancer* 9, 400-409.

- Lubick, N (2010) Examining DDT's urogenital effects. *Environmental Health Perspectives* 118, A18
- Luongo, D., Severino, L., Bergamo, P., De Luna, R., Lucisano, A. and Rossi, M. (2006) Interactive effects of fumonisin B₁ and alpha-zearalenol on proliferation and cytokine expression in Jurkat T cells *Toxicology in Vitro* 20, 1403-1410.
- Lye, M. S., Ghazali, A. A., Mohan, J., Alwin, N. and Nair, R. C. (1995) An outbreak of acute hepatic encephalopathy due to severe aflatoxicosis in Malaysia *American Journal of Tropical Medical Hygiene* 53, 68-72.
- Maenetje, P.W. and Dutton, M.F (2007). The incidence of fungi and mycotoxins in South African barley and barley products *Journal of Environmental Science and Health, Part B*: 42, (2) 229 - 236
- Makun, H.A, Anjorin, S.T., Moronfoye, B., Adejo, F.O., Afolabi, O.A., Fagbayibo, G., Balogun, B.O. and Surajudeen, A.A. (2010). Fungal and aflatoxin contaminations of some human food commodities in Nigeria. *African Journal of Food Sciences*. 4 (4): 127 - 135
- Makun, H. A., Dutton, M.F., Njobeh, P.B., Mwanza, M. and Kabiru A.Y. (2011) Natural multi- mycotoxin occurrence in rice from Niger State, Nigeria *Mycotoxin Research*. 27 (2): 97-104.
- Makun HA, Gbodi TA, Akanya HO, Sakalo AE, Ogbadu HG (2007) Fungi and some mycotoxins contaminating rice (*Oryza sativa*) in Niger state, Nigeria. *African Journal of Biotechnology* 6(2):99-108
- Makun HA, Gbodi TA, Akanya HO, Salako EA, Ogbadu GH (2009) Fungi and some mycotoxins found in mouldy Sorghum in Niger State, Nigeria. *World Journal of Agricultural Sciences* 5(1):5-17
- Manary, M. J. and Brewster, D. R. (1997) Potassium supplement in kwashiorkor *Journal of Paediatric and Gastroenterological Nutrition* 24, 194-201.
- Manson, M. M., Ball, H. W. L., Barrett, M. C., Clark, H. L., Jumah, D. J., Williamson, G. and Neal, G. E. (1997) Mechanism of action of dietary chemoprotective agents in rat liver: induction of phase I and II drug metabolizing enzymes and aflatoxin B₁ metabolism *Carcinogenesis* 18, 1729-1738.
- Matumba, L., Monjerezi, M., Khonga, E. B., Lakudzala, D.D. (2011). Aflatoxins in sorghum, sorghum malt and traditional opaque beer in southern Malawi. *Food Control* 22, 266-268
- Mashinini, K. and Dutton, M.F. (2006) The incidence of fungi and mycotoxins in South Africa wheat and wheat-based products *Journal of Environmental Science and Health Part B*, 41:285-296
- Maxwell, D., Levin, C., Armar-Klemesu, M., Ruel, M., Morris, S., Ahiadeke, C. (2000). Urban Livelihoods and Food and Nutrition Security in Greater Accra, Ghana. IFPRI, Washington, p. 172.
- May, P. and May, E. (1999) Twenty years of p53 research: structural and functional aspects of the p53 protein *Oncogene*, 18 7621-36.
- Martin, P.M.D, and Gilman, G.A. (1976). A consideration of the mycotoxin hypothesis with special reference to the mycoflora of maize, sorghum, wheat and groundnut. *Rep. Trop. Prod. Inst.* G105, Vil=112pg. 1-63.
- Mazen, M.B, El-Kady, I.A and Saber, S.M (1990). Survey of the mycoflora and mycotoxins of cotton seeds and cotton seed products in Egypt. *Mycopathologia* 110 (3):133-138.
- MRC (Medical Research Council) (2006). Report on aflatoxins in groundnuts and peanuts products retrieved on 14th July, 2011 from

- www.doh.gov.za/department/foodcontrol/docs/nmp.html
- Mestres, C., Bassa, S., Fagbohoun, E., Nago, M., Hell, K., Vernier, P., Champiat, D., Hounhouigan, J. and K. F. Cardwell. (2004). Yam chip food sub-sector: hazardous practices and presence of aflatoxins in Benin. *Journal of Stored Products Research* 40 (5): 575-585
- Miller, J.D. (1995). Fungi and mycotoxins in grains: Implications for stored product research. *J. Stored. Prod. Res.* 31 (1): 1-16
- Miller, J.D. (1996). Mycotoxins. In: Cardwell, K.F. (Ed.), Proceedings of the Workshop on Mycotoxins in Food in Africa. November 6-10, 1995, Cotonou, Benin. International Institute of Tropical Agriculture, Cotonou, Benin, pp. 18-22.
- Mircea, C., Poiata, A., Tuchilus, C., Agoroae, L., Butnaru, E. and Stanescu, U. (2008) Aflatoxigenic fungi isolated from medicinal herbs *Toxicology Letters*. 180: 32-246
- Motawee, M.M., Bauer, J. and McMahon, D.J. (2009) Survey of aflatoxin M₁ in cow, goat, buffalo and camel milks in Ismailia-Egypt. *Bulletin of the Environmental and Contamination Toxicology*, 83, 766-769.
- Mokhles, M., Abd El Wahhab, M. A., Tawfik, M., Ezzat, W., Gamil, K. and Ibrahim, M. (2007) Detection of aflatoxin among hepatocellular carcinoma in patients in Egypt *Pakistan Journal of Biological Sciences* 10, 1422-1429.
- Mngadi, P.T., Govinden, R. and Odhav, B. (2008). Co-occurring mycotoxins in animal feeds. *African Journal of Biotechnology* 7 (13): 2239-2243.
- Muhammad, S., Shehu, K., Amusa, N.A., (2004). Survey of the market diseases and aflatoxin contamination of tomato (*Lycopersicon esculentum* Mill) fruits in Sokoto, northwestern Nigeria. *Nutrition and Food Science* 34, 72-76.
- Murray, C. J. L. (1994) Quantifying the burden of disease: the technical basis for disability-adjusted life years *Bulletin of the World Health Organisation* 72, 429-445.
- Mutegi, C.K., Ngugi, H.K., Hendriks, S.L. and Jones, R.B.(2009). Prevalence and factors associated with aflatoxin contamination of peanuts from Western Kenya *International Journal of Food Microbiology* 130, 27-34.
- Muthomi, J.W., Ndung'u, J.K., Gathumbi, J.K., Mutitu, E.W. and Wagacha, J.M. (2008). The occurrence of *Fusarium* species and mycotoxins in Kenyan wheat. *Crop Protection* 27, 1215- 1219.
- Muzanila, Y.C., Brennan, J.G. and King, R.D. (2000) Residual cyanogens, chemical composition and aflatoxins in cassava flour from Tanzanian villages *Food Chemistry* 70, 45-49
- Mwanza, M. (2007) A survey of fungi and mycotoxins with respect to South African domestic animals in the Limpopo Province. Master of Technology Dissertation, University of Johannesburg. <http://152.106.6.200:8080/dspace/bitstream/10210/884/1/Mwanza%20M%20tech%20dissertation.pdf>
- Mwanza, O. W., Otieno, C. F. and Omonge, E. (2005) Acute aflatoxicosis: case report *East African Medical Journal* 82, 320-324.
- Nelson, D. B., Kimbrough, R., Landrigan, P. S., Hayes, A. W., Yang, G. C. and Benanides, J. (1980) Aflatoxin and Reye's syndrome: a case study *Pediatrics* 66, 865-869.
- Njobeh, B.P., Dutton, M.F., Koch, S.H. and Chuturgoon, A. (2009) Contamination with storage fungi of human foods from Cameroon *International Journal of Food Microbiology* 135, 193-198.
- Njobeh B. P., Dutton F. M., Makun, H.A (2010). Mycotoxins and human health: Significance, prevention and control In: Ajay K. Mishra, Ashutosh Tiwari, and Shivani B. Mishra (Eds) 'Smart Biomolecules in Medicine' VBRI Press, India 132-177

- Nyathi, C. B., Mutiro, C. P., Hasler, J. A. and Chetsanga, C. J. (1987) A survey of urinary aflatoxin in Zimbabwe *International Journal of Epidemiology* 16, 516-519.
- Nyathi, C. B., Mutiro, C. F., Hasler, J. A. and Chetsang, C. J. (1989) Human exposure to aflatoxins in Zimbabwe *Central African Journal of Medicine* 35, 542-545.
- Nyikal, J., *et al.* (2004) Outbreak of aflatoxin poisoning - Eastern and Central Provinces, Kenya January-July 2004, *Morbidity and Mortality Weekly Control* 53, 790-793.
- Obidoa, O and Gugnani, H.C. (1992). Mycotoxins in Nigerian foods: causes, Consequences and remedial measures. In Z.S.C Okoye (ed) Book of proceedings of the first National Workshop on Mycotoxins held at University Jos, on the 29th November, 1990, 95-114.
- Obilana AB. 2002. 'Overview: importance of millets in Africa', Retrieved on 1st June, 2011 from Website: www.afripro.org.uk/papers/Paper02Obilana.pdf
- Ocama, P., Nambooze, S., Opio, C. K., Shields, M. S., Wabinga, H. R. and Kirk, G. D. (2009) Trends in the incidence of primary liver cancer in central Uganda. 1960-1980 and 1991-2005 *British Journal of Cancer* 100, 799-802.
- Odoemelam, S. A and Osu, C.I (2009). Aflatoxin B1 contamination of some edible grains marketed in Nigeria. *E-Journal of Chemistry* 6 (2):308-314.
- Ogbadu, G. (1979) Effect of low gamma irradiation on the production of aflatoxin B1 by *Aspergillus flavus* growing on *Capsicum annuum* *Microbios letters* 10, 139-142.
- Ogbadu, G. and Bassir, O. (1979) Toxicological study of γ -irradiated aflatoxins using the chicken embryo *Toxicology and Applied Pharmacology* 51, 379-382.
- Ogbadu G (1980a) Influence of gamma irradiation of aflatoxin B1 production by *Aspergillus flavus* growing on some Nigerian foodstuffs. *Microbios.*; 27(107):19-26.
- Ogbadu, G. (1981) Ultra structural changes in gamma-irradiated *Aspergillus flavus* spores *Cytobios* 30, 167-171.
- Ogbadu, G. (1988) Use of gamma irradiation to prevent aflatoxin B1 production in smoked dried fish *International Journal of Applied Instrumentation* 31, 207-207.
- Ogunsanwo, B.M., Faboya, O.O., Idowu, O.R., Lawal, O.S. and Bankole, S.A (2004). Effect of roasting on the aflatoxin contents of Nigerian peanut seeds. *African Journal of Biotechnology* 3 (9): 451-455
- Okoye, Z. S. C. (1987). Carryover of aflatoxin B1 in contaminated substrate corn into Nigerian native beer. *Bulletin of Environmental Contamination and Toxicology* 37 (4) 482-489
- Olson, L.C., Bourgeois, C.H., Cotton, R.B., Harikul, S., Grossman, R.A. and Smith, T.J. (1971) Encephalopathy and fatty degeneration of the viscera in northeastern Thailand. Clinical syndrome and epidemiology *Paediatrics* 47, 707- 716.
- Omer, R. E., Bakker, M. I., van't Veer, P., Hoogenboom, R. L., Polman, T. H., Alink, G. M., Idris, M. O., Kadaru, A. M. and Kok, F. J. (1998) Aflatoxin and liver cancer in Sudan *Nutrition and Cancer* 32, 174-180.
- Ominski, K.H., Marquardi, R.R., Sinha, R.N and Abramson, D (1994). Ecological aspects of growth and mycotoxin production by storage fungi. In: Miller, J.D and Trenholm, H.L (1994). Mycotoxins in grains: Compounds other than aflatoxins. Eagan Press, St. Paul Minnesota, USA. 287-314.
- Opadokun, J.S (1992). Occurrence of aflatoxin in Nigerian food crops In Z.S.C Okoye (ed) Book of proceedings of the first National Workshop on Mycotoxins held at University Jos, on the 29th November, 1990, 95-114.
- Orsi, R. B., Oliveira, A. A., Dilkin, P., Xavier, J. G., Direito, G. M. and Correa, B. (2007) Effects of oral administration of aflatoxin B₁ and fumonisin B₁ in rabbits (*Oryctolagus cuniculus*) *Chemical and Biological Interactions* 170, 201-208.

- Otsuki, T., Wilson, J.S. and Sewadeh, M. (2001) What price precaution? European harmonization of aflatoxin regulations and African groundnut exports. *European Review of Agricultural Economics* 28: 263-283.
- Oyelamin, O. A., and Ogunlesi, T. A. (2007) Kwashiorkor - is it a dying disease?, *South African Medical Journal* 97, 65-68.
- Oyelami, O. A., Maxwell, S. M., Aladekomo, T. A. and Adelusola, K. A. (1995) Two unusual cases of kwashiorkor: can protein deficiency explain the mystery? *Annals of Tropical Paediatrics* 15, 217-219.
- Oyelami, O. A., Maxwell, S. M., Adelusola, K. A. and Oyelese, A. O. (1997) Aflatoxins in the lungs of children with kwashiorkor and children with miscellaneous diseases in Nigeria *Journal of Toxicology and Environmental Health* 51, 623-628.
- Oyero, G.O and Oyefolu, A.B (2010) Natural occurrence of aflatoxin residues in fresh and sun-dried meat in Nigeria *Pan African Medical Journal*. 7:14
- Paterson, R.R.M and Lima, N (2010) How will climate change affect mycotoxins in foods? *Food Research International* 43, 1902 - 1914
- Peers, F. G. and Linsell, C. A. (1973) Dietary aflatoxins and human liver cancer. A population based study in Kenya *British Journal of Cancer* 27, 473-484.
- Perz, J. F., Armstrong, G. L., Farrington, L. A., Hutin, Y. J. and Bell, B. P. (2006) The contribution of hepatitis B virus and hepatitis C virus infection to cirrhosis and primary liver cancer world wide *Journal of Hepatology* 45, 529-538.
- Peterson, S.W., Ito, Y., Horn, B.W., Goto, T. (2001) *Aspergillus bombycis*, a new aflatoxigenic species and genetic variation in its sibling species, *A. nomius*. *Mycologia* 93, 689-703
- Pietri, A., Bertuzzi, T., Agosti, B. and Donadini, G. (2010). Transfer of aflatoxin B₁ and fumonisin B₁ from naturally contaminated raw materials to beer during an industrial brewing process. *Food Additives & Contaminants: Part A: Chemistry, Analysis, Control, Exposure & Risk Assessment*. 27 (10): 1431 - 1439
- Pildain, M.B., Frisvad, J.C., Vaamonde, G., Cabral, D., Varga, J. and Samson, R.A. (2008). Two novel aflatoxin-producing *Aspergillus* species from Argentinean peanuts *International Journal of Systematic and Evolutionary Microbiology* 58, 725-735.
- Probst, C., Njapau, H., and Cotty, P. J. (2007) Outbreak of an acute aflatoxicosis in Kenya in 2004: identification of the causal agent, *Applied and Environmental Microbiology* 73, 2762-2764.
- Rehana, F. and Basappa, S.C. (1990). Detoxification of aflatoxin B₁ in maize by different cooking methods. *Journal Food Science Technology*. 27: 379-399.
- Raisuddin, S., Singh, K. P., Zaidi, S. I. A., Paul, B. N. and Ray, P. K. (1993) Immunosuppressive effects of aflatoxin in growing rats *Mycopathologia* 124, 189-194
- Ramjee, G., Berjak, P., Adhikari, M. and Dutton, M. F. (1992) Aflatoxins and kwashiorkor in Durban, South Africa *Annals of Tropical Paediatrics* 12, 241-247.
- Reiter EV, Dutton MF, Mwanza M, Agus A, Prawano D, Häggblom P, Razzazi-Fazeli E, Zentek J, Andersson G, Njobeh PB (2011) Quality control of sampling for aflatoxins in animal feedingstuffs: Application of the Eurachem/CITAC guidelines. *Analyst*. 136 (19): 4059-4069
- Reye, R.D.K., Morgan, G. and Baral, J. (1963) Encephalopathy and fatty degeneration of the viscera: a disease entity in childhood *Lancet* 2: 749-752.
- Riba, A., Bouras, N., Mokrane, S., Mathieu, F., Lebrihi, A. and Sabaou, N (2010). *Aspergillus* section Flavi and aflatoxins in Algerian wheat and derived products. *Food and Chemical Toxicology* 48, 2772-2777

- Robertson, A. (2005). Risk of aflatoxin contamination increases with hot and dry growing conditions. *Integrated Crop Management* 185-186. Retrieved on 11th May, 2011 from <http://www.ipm.iastate.edu/ipm/icm/2005/9-19/aflatoxin.html>.
- Rogan, W. J., Yang, G. C. and Kimborough, R. D. (1985) Aflatoxin and Reye's syndrome: a study of livers from deceased cases *Archives of Environmental Health* 40, 91-95.
- Ryan, N. J., Hogan, G. R., Hayes, A. W., Unger, P. D. and Sirai, M. Y. (1979) Aflatoxin B₁; its role in the etiology of Reye's syndrome *Paediatrics* 64, 71-75.
- Sahar, N., Ahmed, M., Parveen, Z., Ilyas, A. and Bhutto, A. (2009). Screening of mycotoxins in wheat, fruits and vegetables grown in Sindh, Pakistan *Pakistan Journal Botany*, 41(1): 337-341
- Sánchez-Hervás, M., Gil, J.V., Bisbal, F., Ramón, D and Martínez-Culebras, P.V (2008). Mycobiota and mycotoxin producing fungi from cocoa beans. *International Journal of Food Microbiology* 125:336-340.
- Schindler, A.F. (1977) Temperature limits for production of aflatoxin by twenty-five isolates of *Aspergillus flavus* and *Aspergillus parasiticus*. *Journal of Food Protection*. 40:39-40.
- Sharma, R. P. (1993) Immunotoxicity of mycotoxins *Journal of Dairy Science* 76, 892-897.
- Shuaib, F. M., Ehiri, J., Abdullahi, A., Williams, J. H., and Jolly, P. E. (2010a) Reproductive health effects of aflatoxins: a review of the literature, *Reproductive Toxicology* 29, 262-270.
- Shuaib, F. M., Jolly, P. E., Ehiri, J., Jiang, Y., Ellis, W. O., Stiles, J. K., Yatich, N. J., Funkhouser, E., Person, S. D., Wilson, C. and Williams, J. H. (2010b) Association between anemia and aflatoxin B₁ biomarker levels among pregnant women, *American Journal of Tropical Medical Hygiene* 83, 1077-1083.
- Sibanda L, Marovatsanga LT, Pestka JJ (1997) Review of mycotoxin work in sub-Saharan Africa. *Food Control* 8:21-29 647.
- Sinha, R.N (1984). *Journal of Economic Entomology* 77: 1463-1488.
- Smith, T.K., Mehrdad, M. and Ewen, J.M. (2000) Biotechnology in the Feed Industry *.Proceedings of Alltech's 16th Annual Symposium*, Pp 383-390.
- Smith, T. K., McMillan, E. G. and Castillo, J. B. (1997) Effect of feeding blends of *Fusarium* mycotoxin-contaminated grains containing deoxynivalenol and fusaric acid on growth and feed consumption of immature swine *Journal of Animal Science* 75, 2184-2191.
- Smith, J.E and Moss M.O. (1985). *Mycotoxins: formation, analysis and significance*. John Wiley & sons. Chichester, Britain, 83-103.
- South African Department of Health (2004a) Government Gazette 6th March 2009. Regulations governing tolerance for fungus-produced toxins in foodstuffs. Foodstuff, Cosmetics and Disinfectants Act 1972 (Act 54 of 1972).
- South African Department of Health (2004b). Government Gazette 6th March 2009. Regulations governing tolerance for fungus-produced toxins in foodstuffs. Foodstuff, Cosmetics and Disinfectants Act 1972 (Act 54 of 1972) 1.
- Speijers, G. J. and Speijers, M. H. (2004) Combined toxic effects of mycotoxins *Toxicology Letters* 153, 91-98.
- Stoev, S. D., Goundasheva, D., Mirtcheva, T. and Mantle, P. G. (2000) Susceptibility to secondary bacterial infections in growing pigs as an early response in ochratoxicosis *Experimental Toxicology and Pathology* 52, 287-296.
- Stoloff, L. (1989) Aflatoxin is not a probable human carcinogen: the published evidence is sufficient *Regulatory Toxicology and Pharmacology* 10, 272-283.

- Stora, C., Dvorackova, I. and Ayraud, N. (1983) Aflatoxin and Rey's syndrome *Journal of Medicine* 14, 47-54.
- Stössel, P. (1986). Aflatoxin contamination in soybeans: role of proteinase inhibitors, zinc availability, and seed coat integrity. *Applied and Environmental Microbiology* 52, 68-72.
- Sylla, A., Diallo, M.S., Castegnaro, J., Wild, C.P (1999). Interaction between hepatitis V virus and exposure to aflatoxin in the development of hepatocellular carcinoma: a molecular epidemiological approach. *Mutation Research* 428:187-196
- Tandon, H. D., Tandon, B. N. and Ramalingaswami, V. (1978) Epidemic toxic hepatitis in India of possible mycotoxin origin *Archives of Pathology and Laboratory Medicine* 102, 372-376.
- Taylor, E. R. (1992) Aflatoxin B₁ and DNA adducts. Proposed model for surface noncovalent and covalent complexes with N7 of guanine *Journal of Biomolecular Structure and Dynamics* 10, 533-550.
- Tchana, A. N., Moundipa, P. F. and Tchouanguep, F. M. (2010) Aflatoxin contamination in food and body fluids in relation to malnutrition and cancer status in Cameroon *International Journal of Environmental Research and Public Health* 7, 178-188.
- Trauner, D. A. (1984) Reye's syndrome *The Western Journal of Medicine* 141, 206-209.
- Trenk, H.L., and Hartman, P.A. (1970) Effects of moisture content and temperature on aflatoxin production in corn. *Applied Microbiology*. 19:781-784.
- Trucksess, M. W. and Scott, P. M.(2008) 'Mycotoxins in botanicals and dried fruits: A review', *Food Additives & Contaminants: Part A*, 25: 2, 181 – 192
- Tsega, E. (1977) Current views on liver diseases in Ethiopia *Ethiopian Medical Journal* 15, 75-82.
- Turkez, H., and Geyikoglu, F. (2010) Boric acid: a potential chemoprotective agent against aflatoxin B₁ toxicity in human blood, *Cytotechnology* 62, 157-165.
- Turner, P.C., Moore S.E., Hall, A.J., Prentice A.M. and Wild C.P. (2003) Modification of immune function through exposure to dietary aflatoxin in Gambian children *Environmental Health Perspectives* 111, 217-220.
- Turner, P.C., Collinson, A.C., Cheung, Y.B., Gong, Y., Hall, A.J., Prentice, A.M. and Wild, C.P. (2007) Aflatoxin exposure *in utero* causes growth faltering in Gambian infants *International Journal of Epidemiology* 36, 1119-1125.
- Udoh, J.M., Cardwel, K.F., Ikotun, T. (2000) Storage structures and aflatoxin content of maize in five agro-ecological zones of Nigeria. *Journal of Stored Products Research* 36, 187-201.
- US Grain Council (2000) Manual pp 1-42
- Van Rensburg, S. J., Cook-Mozaffari, P., Van Schalkwyk, J. J., Van der Watt, J. J., Vincent, T. J. and Purchase, I. F. (1985) Hepatocellular carcinoma and dietary aflatoxins in Mozambique and Transkei, *British Journal of Cancer* 51, 713-726.
- Van Vleet, T. R., Klein, P. J. and Coulombe, R. A. (2001) Metabolism of aflatoxin B₁ by normal bronchial epithelial cells *Journal of Toxicology and Environmental Health* 63, 525-540.
- Van Vleet, T. R., Klein, P. J. and Coulombe, R. A. (2002a) Metabolism and cytotoxicity of aflatoxin B₁ in cytochrome P₄₅₀ expressing human lung cells *Journal of Toxicology and Environmental Health A* 65, 853-867.
- Van Vleet, T. R., Mace, K. and Coulombe, R. A. (2002b) Comparative aflatoxin B₁ activation and cytotoxicity in human bronchial cells expressing cytochromes P₄₅₀ 1A2 and 3A4 *Cancer Research* 62, 105-112.
- Wagacha, J.M., Muthomi, J.W. (2008) Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. *International Journal Food Microbiology*. 124, 1-12.

- Wang, J. S. and Groopman, J. D. (1999) DNA damage by mycotoxin *Mutation Research* 424, 167-181.
- Wang, J.-S., Shen, X., He, X. H., Zhu, Y.-R., Zhang, B.-C., Wang, J.-B., Qian, G.-S., Kuang, S.-Y., Zarba, A., Egner, P. A., Jacobson, L. P., Munoz, A., Helzlsouer, Groopman, J. D. and Kensler, T. W. (1999) Protective alterations in Phase 1 and 2 metabolism of aflatoxin B₁ by oltipraz in residents of Qidong, People's republic of China *Journal of the National Cancer Institute* 91, 347-354.
- Waterlow, J.C. (1984) Kwashiorkor revisited: the pathogenesis of oedema in kwashiorkor and its significance. *Transactions of the Royal Society of Tropical Medical Hygiene* 78, 436-441.
- Wheeler, C.W., Park, S.S. and Guenther, T.M. (1990) Immunological analysis of cytochrome P450 1A1 homologue in human lung microsomes *Molecular Pharmacology* 38, 634-643.
- World Health Organization (WHO) (2006) Mycotoxins in African foods: implications to food safety and health. AFRO Food Safety Newsletter. World Health Organization Food safety (FOS), Issue No. July 2006. www.afro.who.int/des.
- Wild, C. P. (1996). Summary of data on aflatoxin exposure in West Africa. In K. F. Cardwell (Ed.), *Proceedings of the workshop on mycotoxins in food in Africa*, November 6-10, 1995 (p. 26). Cotonou, Benin: International Institute of Tropical Agriculture
- Wild, C. P. and Gong, H. Z. (2010) Mycotoxins and human disease: a largely ignored global health, *Carcinogenesis* 31, 71-82.
- Wild, C. P., Jiang, Y. Z., Sabbioni, G., Chapot, B. and Montesano, R. (1990) Evaluation of methods for quantitation of aflatoxin-albumin adducts and their application to human exposure assessment *Cancer Research* 50, 245-251.
- Wild, C. P., Hasegawa, R., Barraud, L., Chutimataewin, S., Chapot, B., Ito, N. and Montesano, R. (1996) Aflatoxin-albumin adducts: a basis for comparative carcinogenesis between animals and humans *Cancer Epidemiology, Biomarkers and Prevention* 5, 179-189.
- Williams, J. H., Phillips, T. D., Jolly, P. E., Stiles, J. K., Jolly, C. M. and Aggarwal, D. (2004) Human aflatoxicosis in developing countries a review of toxicology, exposure potential health consequences and intervention *American Journal of Clinical Nutrition* 80, 1106-1122.
- Wogan, G. (1973) Aflatoxin carcinogenesis *Methods in Cancer Research* 7, 309-344.
- Wolzack, A., Pearson, A. M., Coleman, T. H., Pestka, J. J. and Gray, J. I. (1985). Aflatoxin deposition and clearance in the eggs of laying hens *Food and Chemical Toxicology*, 23 (12): 1057-1061
- Wolzack, A., Pearson, A. M., Coleman, T. H., Pestka, J. J., Gray, J. I. and Chen, C. (1986) Aflatoxin carryover and clearance from tissues of laying hens *Food and Chemical Toxicology* 24, 37-41
- Wood, R.D. (1999) DNA damage recognition during nucleotide excision repair in mammalian cells, *Biochemie* 81, 39-44.
- Wu, F. (2004) Mycotoxin risk assessment for the purpose of setting international regulatory standards *Environmental Science and Technology* 38, 4049-4055.
- Wu, F. (2006) Mycotoxin reduction in Bt corn: potential economic, health and regulatory impacts *Transgenic Research* 15, 277-289.
- Wu, F. and Khlangwiset, P. (2010a) Health economic impacts and cost-effectiveness of aflatoxin reduction strategies in Africa: case studies in biocontrol and post harvest interventions *Food Additives and Contaminants* 27, 496-509.

- Wu, F. and Khlangwiset, P. (2010b) Evaluating the technical feasibility of aflatoxin risk reduction strategies in Africa *Food Additives and Contaminants* 27, 658-676.
- Yadgiri, B., Reddy, V., Tulpule, P. G., Srikantia, S. G. and Goplan, C. (1970) Aflatoxin and Indian childhood cirrhosis *The American Journal of Clinical Nutrition* 23, 94-98.
- Yousef, A.E. and Marth, E.H. (1985) Degradation of aflatoxin M₁ in milk by ultraviolet energy. *Journal of Food Protection*, 48, 697-698.
- Zain, M.E (2010). Impact of mycotoxins on humans and animals. *Journal of Saudi Chemical Society*. Retrived on 16th
- Zarba A., Wild C.P., Hall A.J., Montesano R, Hudson G.J. and Groopman JD. (1992) Aflatoxin M1 in human breast milk from The Gambia, west Africa, quantified by combined monoclonal antibody immunoaffinity chromatography and HPLC *Carcinogenesis* 13, 891-894.
- Zhu, L. R., Thomas, P. E., Lu, G., Reuhl, K. R., Yang, G. Y., Wang, L. D., Wang, S. L., Yang, C. S., He, X. Y. and Yan, H. J. (2006) CYP2A13 in human respiratory tissues and lung cancers: an immunohistochemical study with a new peptide specific antibody *Drug Metabolism and Deposition* 34, 1672-1676.
- Zinedine, A., Juan, C., Soriano, J.M., Moltó, J.C., Idrissi, L. and Mañes, J. (2007a). Limited survey for the occurrence of aflatoxins in cereals and poultry feeds from Rabat, Morocco *International Journal of Food Microbiology* 115, 124-127
- Zinedine, A., González-Osnaya, L., Soriano, J.M., Moltó, J.C., Idrissi, L., Mañes, J. (2007b). Presence of aflatoxin M1 in pasteurized milk from Morocco *International Journal of Food Microbiology* 114, 25-29
- Zinedine, A., Brera, C., Elakhdari, S., Catano, C., Debegnach, F., Angelini, S., De Santis, B., Faid, M., Benlemlih, M., Minardi, V., Miraglia, M. (2006) Natural occurrence of mycotoxins in cereals and spices commercialized in Morocco. *Food Control* 17, 868-874.

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