CODEX ALIMENTARIUS COMMISSION E

Food and Agriculture Organization of the United Nations

World Health Organization

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Agenda Item 9(c) CX/CF 12/6/14

January 2012

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON CONTAMINANTS IN FOODS

Sixth Session

Maastricht, The Netherlands, 26 – 30 March 2012

DISCUSSION PAPER ON FUNGI AND MYCOTOXINS IN SORGHUM

BACKGROUND

1. The Codex Committee on Contaminants in Foods at its 5th Session, considered a Discussion Paper on Mycotoxins in Sorghum prepared by the delegation of Sudan with assistance from Belgium, Brazil, Japan and USA. The discussion paper presented in CX/CF 11/5/9 focussed on the following main areas: mycotoxin producing fungi in Sorghum, the types and levels of mycotoxins found in Sorghum.

2. The Committee noted the recommendations made by the electronic Working Group, which concerned two points: collection of more data and research on the occurrence of mycotoxins in Sorghum and the development of Code of Practice (COP) for the management of aflatoxins in Sorghum as an additional annex to the existing COP (CAC/RCP 51-2003).

3. The Representative of WHO informed the Committee that sufficient funding had been secured through the Codex Trust Fund to enable FAO and WHO to jointly implement a project covering four (4) pilot countries in Africa to collect samples and analyse mycotoxins and mycotoxin- producing fungi in Sorghum.

4. The Committee noted that since data would be collected in the Codex Trust Fund pilot study on mycotoxins in Sorghum, there would be no need for further discussion on maximum limits (MLs) at this point; however further data collection and submission to GEMs Food Programme is encouraged.

5. The Committee thereafter, agreed to re-establish the electronic Working Group (eWG), under the chairmanship of Nigeria open to all Codex members and observers, to:

   - Update the discussion paper;
   - Scrutinize the general part of the existing *COP for the Prevention and Reduction of Mycotoxin Contamination in Cereals* and ascertain whether it was relevant and feasible for the production of Sorghum;
   - Explore the feasibility of including an additional Annex for "Prevention and Reduction of contamination by aflatoxins in grain Sorghum to the COP" for consideration by the next session.[1]

6. This discussion paper was updated to include: records of production up to 2010, other reported mycotoxins such as patulin, sterigmatocystin and T_2; the rising profile of sorghum in international trade and various domestic and industrial uses; in addition to incidences of mycoflora and mycotoxins and dietary intake up to 2011. A section on prevention, control and regulation of mycotoxins in sorghum was introduced including the section on dietary intake. The information garnered from the discussion paper was employed in scrutinising the COP for the Prevention and Reduction of Mycotoxin Contamination in Cereals, which informed recommendations of the eWG to the 6th Session of the Committee.

INTRODUCTION

1. Sorghum is a genus of about twenty eight species of grasses but only one species namely Sorghum *bicolor* is cultivated for food and feeds. Archaeological data and historical records are definite that Sorghum *bicolor* which is mainly grown for its edible grain originated from Africa, around Sudan, Ethiopia, Chad and Cameroon. While the earliest archaeo-botanical records are clear that Sorghum was domesticated in India by 2000 BC (de Wet *et al.*1966), it is obvious that its cultivation for food in Africa is earlier than when it appeared in Asia and is estimated to be between 4000 BC -3000 BC. There are five primary varieties of Sorghum *bicolor* namely *bicolor, caudatum, durra, guinea* and *kafir,* and ten intermediate varieties which are all combinations of the basic varieties. The varieties are distinguished by the grain shape, glumes and panicle.

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1 RE11/CF, paras. 52-59.

2. The cultivated Sorghum species can grow in arid soils of tropical and subtropical areas and so can withstand prolonged droughts. Waliyar *et al.* (2007) enumerated four features that make it one of the most drought-resistant crops of all. It's very large root-to-leaf surface area and ability to roll its leaves to lessen water-loss by transpiration during drought endows the plant with high water management efficiency. During extreme drought conditions it goes into dormancy rather than dying. Another important feature that makes Sorghum drought resistant is the protection of its leaves by a waxy cuticle.

3. The crop is cultivated particularly for its starch. FAO (1994) has given the nutrient composition of Sorghum. The whole kernel contains 73.8% of starch and a substantial amount of protein (12.3%) with rich deposit of B-complex vitamins (niacin, riboflavin and pyridoxin). The appreciable amount of protein enables dependent human population to subsist on it. The grain is poor in ash (1.67%) and oil (3.6%) contents. As with other crops, Sorghum contains some anti-nutritional factors. Phytates, which renders several minerals biologically unavailable to animals and man, occur in the grain ranging from 170 - 380 mg/100 g of grain. Polyphenols (phenolic acids, tannins, flavonoids) that enhances the grain's resistance to pests and microbial infestation are likely carcinogenic compounds and abundant in Sorghum. Inhibitors of amylases and proteases, goitrogens (interferes with iodine utilization), amino acid imbalance, heavy metal and mycotoxins are the other nutritional inhibitors and toxic substance associated with Sorghum.

4. Sorghum and incidence of polyphenols is characterised by the grain types. The crop is unique for having significant amounts of tannins which occur in the pigmented inner layer called testa of brown-grained sorghum. The advantages of its presence (imparting tolerance/resistance to insect and disease pests) and disadvantages (anti-nutritional) have already been mentioned. White grain food sorghums do not have tannins but could contain low amounts of phenolic acids. The white/cream/yellow types are the types used mostly (up to 75%) in Nigeria for human food; while the browns are mostly used for indigenous beverages and drinks after due processing. The red grain types are intermediates with no tannin content (contains no testa) but some phenolic compounds in its red pericarp (Daiber and Taylor, 1995). Processing for utilization in Nigeria; including fermentation, dry and wet milling, malting, steaming, extrusion, baking and popping, could be a major research area for mycotoxins. Malt is an important industrial product in Nigeria and polyphenol research in malts should be a significant consideration. This is especially so as it provides better nourishment than the ordinary grain by increasing in-vitro starch digestibility, increasing contents of vitamins and minerals (Ca, Mg, P and Zn), increasing enzymatic activity (especially alpha-amylase), increasing bio-availability of some proteins, and most importantly decreasing phytate content which is the anti-nutritional factor in sorghum by up to 75% (Rabie and Thiel, 1985).

5. In view of the aforementioned chemical composition, Sorghum is an important crop cultivated traditionally for food energy supply for human beings and animals as well as for production of alcoholic beverages and subsequently biofuels. Sorghum has considerable potential in foods and beverages because the gluten-free content of the cereal makes it suitable for coeliacs while its antioxidant phenolics and cholesterol-lowering waxes avails industries with a potentially important source of nutraceuticals (Taylor *et al.* 2006). Cakes, cookies, pasta, a parboiled rice-like product and snack are produced from Sorghum. Lager and stout beers with Sorghum are brewed commercially. About 12% of US domestic Sorghum production is used for manufacturing of ethanol and its co-products (US Grains Council, 2010).

6. Sorghum is a rich source of various phytochemicals including tannins, phenolic acids, anthocyanins, phytosterols and policosanols; these phytochemicals have the potential to significantly impact human health (Awika and Rooney, 2004). Most phytochemicals are concentrated in bran fractions which can be easily separated from Sorghum grain and then used for dietary supplementation, food quality improvement and/or therapeutic applications.

7. Sorghum (also known as guinea corn) is a cereal that has been neglected for some time; this was because it was replaced by maize as a staple food commodity in many rural settlements (Bandyopadhyay *et al*. 2007). However, its rising industrial profile as a suitable raw material for food and agricultural industries 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). Also 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), has brought more attention to these two African traditional crops.

8. The search for renewable fuel source has also increased the demand for Sorghum. As a drought tolerant crop containing anti-microbial substance, it offers farmers the ability to cut costs on irrigation and other farm expenses. The renewed focus on Sorghum is also because it is one of the most drought tolerable crops and its 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.

9. Sorghum is a staple grain for over 750 million people in Africa, Asia and Latin America (CAC, 2011) that is traditionally grown mainly in the semi-arid tropics for human consumption and production of local alcoholic drinks and animal feeds. Regardless of its inherent resistance to mould infestation due to its high composition of fungicidal principles; phenols and tannin (Audilakshmi *et al*. 1999), 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).

10. In view of the increasing need for this crop and the threat to its production and utilization by fungi and their toxins there is need for more attention to toxic contaminants of the grain but the reality is that there is limited information on mycotoxins in Sorghum 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 an updated discussion paper on 'mycotoxin in Sorghum grain' is timely and significant. This discussion paper therefore intents to review the latest data on world Sorghum production and utilization, and factors that influence the distribution of fungi and mycotoxins in Sorghum around the globe. Additionally an in-depth review of the fungal and mycotoxin contamination of this drought tolerant crop worldwide is provided. The information on the types of fungi and mycotoxins in Sorghum that will be generated will form the basis for review of the current code of practice employed in the prevention of mycotoxin contamination in cereals.

PRODUCTION AND UTILIZATION OF SORGHUM

Production

11. Sorghum is the fifth most cultivated and consumed grain in the world after maize, rice, wheat and barley (FAOSTAT, 2010). It is one of the crops that provide more than 85% of the world's food calories. The latest FAO statistics on Sorghum area and production which is for the year 2009 is presented on Table 1. According to the figures, Sorghum is cultivated in 105 countries covering a total of 39,969,624 hectares of land in the world. Forty one African countries produce Sorghum while 20 countries cultivate the cereal in North and South America. Twenty five, fourteen and five are Sorghum producers in Asia/Middle East, Europe and Oceania respectively. Over half of the world Sorghum area is in Africa (60.6%) while 22.2% of world Sorghum cultivated area was occupied by Asian and Middle East countries in the year under review. The Americas, Pacific or Oceania and Europe covered 14.9%, 1.92% and 0.39% of the world Sorghum area respectively. The ten countries with the largest area under Sorghum cultivation in decreasing order are India, Sudan, Nigeria, Niger, USA, Mexico, Burkina Faso, Ethiopia, Mali and Tanzania

Productivity

12. Sorghum is a crop with high productivity such that a yield of as much as 20.1 tonnes per hectare has been recorded in the United States (US Grain Council, 2010) but paradoxically most of the countries with large Sorghum area achieve low yields. African countries that account for a major bulk of the area under Sorghum cover have the least yield of 0.904 tonnes per hectare followed by Asia and Middle East with productivity of 1.096 tonnes/hectare.

The developed countries of Europe, Pacific and Americas have remarkable yields of 4.451, 3.860 and 3.561 tonnes per hectare respectively in spite of their temperate climate which is not favourable for Sorghum cultivation. Jordan, Algeria, Israel, Italy, Egypt, France, Turkey, Uruguay, Uzbekistan and Oman, USA, Argentina, Mexico, Australia, China and Brazil (Table 1) have the highest Sorghum yield/ha in the world in decreasing order. The reasons advanced for the low Sorghum yield in undeveloped parts of Africa and Asia in spite of their favourable tropical climates are cultivation of marginal land, low fertilizer use, adverse agro-climatic conditions (floods, failure of rains or drought during crop growing period), unfavourable government policies favouring other cash crops and mineral resources (Waliyar *et al.* 2007). Insects, rodents, birds, and fungi account for substantial losses of grains on the field. Other factors like continued use of open pollinated varieties instead of hybrids, political unrest and reduction of hands on the farms as a result of labour migration to urban settlement for greener pasture also explains the observed low yield in Africa and Asia.

13. With regards to production, as a continent, Africa is the largest producer of Sorghum, producing 21.9 million tonnes annually which is equivalent to 39.044% of world production, and is followed by Americas (37.5%), Asia/Middle East (17.4%), Oceania (4.8%) and Europe (1.2%). According to FAOSTAT, (2010), 56.0 MT of the grain was produced in 2009 in the world and the leading producers during the 2009 fiscal year were USA (9.7 MT), India (7.2 MT), Mexico (6.1 MT), Nigeria (5.2 MT), Sudan (4.1 MT), Ethiopia (2.9 MT) and Australia (2.6 MT). Others include Brazil (1.8 MT), Argentina (1.8 MT) and China (1.6 MT). However, recent data provided by US Grain Council (2010) show that Nigeria was the leading producer of Sorghum during the 2010 fiscal year with a production of 11.5 MT. The other world top ten producers were US (9.7 MT), India (6.9 MT), Mexico (6.2), Argentine (3.6), Sudan (2.6), Ethiopia (2.0), Brazil (1.8 MT), China (1.6 MT) and Australia (1.6 MT). The other 95 producing countries harvested a total of 11.6 MT bringing the total amount of Sorghum produced in the world in 2010 to 59.5 MT.

Table 1: World Leading Countries in Sorghum Production – 2009

Country	Production (Million tonnes)	Area (Hectares)	% World production	Productivity (Tonnes/Hectare)
USA	9728220	2233890	17.341	4.354
India	7250000	7530000	12.923	0.962
Mexico	6108090	1690520	10.888	3.613
Nigeria	5270790	4736730	9.395	1.112
Sudan	4192000	6652500	7.472	0.630
Ethiopia	2971270	1618680	5.290	1.837
Australia	2691790	766986	4.798	3.509
Brazil	1853930	793027	3.304	2.337
Argentina	1805220	456510	3.217	3.954
China	1677319	559542	2.989	2.997
Burkina Faso	1521470	1653120	2.700	0.920
Mali	1465620	1091040	2.612	1.343
Egypt	880000	158000	1.568	5.569
Niger	738661	2544720	1.316	0.290
Tanzania	709000	874219	0.126	0.811
Chad	600963	850000	1.070	0.707
Cameroon	600000	500000	1.060	1.200
Uganda	497000	329000	0.885	1.510
Venezuela	370000	217000	0.659	1.705
Ghana	350550	267200	0.624	1.311
Others including:	4816367	4446940	9.763	1.083
Jordan	1060	77	0.0018	13.766
Israel	37500	6000	0.066	6.250
Algeria	389	43	0.0006	9.046
Italy	243400	39900	0.433	6.100
France	312819	58002	0.0577	5.393
Turkey	390	76	0.00069	5.131
Uruguay	324200	68100	0.577	4.760
Uzbekistan	20000	4500	0.035	4.444
Oman	9700	2200	0.0172	4.0409

Source: FAOSTAT (2010)

Utilisation

14. Sorghum is now grown for food, feeds, alcoholic and non alcoholic beverages, malt foods and biofuels. Its improved agricultural and industrial profile has elicited increase in world production and productivity from 1961 to date and its inclusion in the current list of export crops by many producing countries.

15. The current official information of FAO with regards to world Sorghum utilization and trade is for the 2007 fiscal year (FAOSTAT, 2010). The data reports that more of the cereal is used for animal feeds than for human foods. While fifty eight countries used 26.1 MT (41.7% of the world production for 2007) of Sorghum as human food in the year under review, one hundred and seven countries utilized 27.5 MT (43.9%) for animal feeds manufacture. Studies have shown that some products resulting from the fermentation of mouldy Sorghum have nutritive value and are safe for use as an animal feed (Siruguri *et al*. 2009). Nigeria, India, Sudan, Ethiopia, Burkina Faso, China, Yemen, Mali, Niger and Chad were the leading human consumers of the grain. However, the developed countries including Mexico, USA, Australia, Argentina and Spain top the world chart in utilization of Sorghum for animal feeds. It invariably means that 8.95 MT of Sorghum is employed for industrial purposes and that is 14.4% of world production.

16. The ardent demand for Sorghum is obvious in the fact that while only 59 countries export it (7.6 MT), 110 countries import 7.4 MT for their Sorghum need. Similarly, there is no continent even Africa, the largest producer of Sorghum that does not import the grain (Table 2). The major exporters are those that are leading producers of the grain but do not use it for food and they include USA, Argentina, China, Brazil and Netherlands. The main importers on the other hand are those that use Sorghum for either feeds or industrial purpose and are Mexico, Spain, Japan, Netherlands and Belgium. Recent data from US Grain Council (2010) however, reveals that US (4.0 MT), Argentina (1.5 MT), Australia (0.3), India (0.7) MT and Nigeria (0.5 MT) are the major exporters of Sorghum for the year 2010. Others were Brazil, China and South Africa. From the foregoing it can be deduced that Sorghum production, yield, consumption and industrial utilization are on the increase but the supply is not commensurate to the increased demand by the fast growing world population. This justifies the renewed focus on this cereal.

FACTORS INFLUENCING MOULD DEVELOPMENT AND MYCOTOXIN PRODUCTION.

Predisposing Factors

17. Human and animal food borne diseases are of public health and economic concern. One of the major biotic constraints to food production and therefore food security is fungi. Fungi are the major cause of spoilage in stored grains and seeds, and rank second only to insects as a cause of deterioration and loss. The susceptibility of Sorghum *bicolor* to fungi worldwide is well documented and presented on Table 3. Growing susceptible varieties, over-crowded plant population and, un-seasonal rains during maturing and harvesting of grains are pre-harvest factors that predispose to fungal contamination of agricultural commodities (Bhat *et al*. (2000). According to the same authors, other conditions that enhance mould growth on the field are plants suffering from other diseases and physical damage of seed by predators (insects, birds, rodents etc). The workers also identified harvesting over-matured crop, delayed drying and grain damage during threshing as post-harvest conditions that encourage fungal growth on crops.

18. Storage of harvested grains at >10% moisture content and for prolonged period in poor storage facilities cause proliferation of moulds on grains (Ominski *et al.* 1994, Abdalla 1998, Ahmed *et al* 2009). Similarly unwholesome practice 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 (Wagacha and Muthomi, 2008). Other compelling factors adduced by the authors that worsen the fungi and mycotoxin burden in Africa in particular 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

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Table 2: Regional Sorghum production, consumption, export and Import

Region	Number of Sorghum producing countries in region	Production (Tonnes)	Area (Hectares)	%World Production	Productivity (Tons/Ha)	Domestic Human consumption (Food in Tonnes)	Domestic animal consumption (Feed in tonnes)	Export (Tonnes)	Other Utilizations (Tonnes)	Imports (Tonnes)
Africa	41	21,903,220	24,226,758	39.044	0.904	17,563,058 (67.8%)	2,820,536 (10.8%)	130,408 (0.38%)	4,787,424 (18.2%)	508,090 (1.9%)
Americas	20	21,056,189	5,912,834	37. 534	3.561	506,148 (1.9%)	16,365,269 (60.1%)	7,019,224 (26.3%)	777,025 (2.9%)	2,114,242 (7.8%)
Asia/Middle East	25	9,768,970	8,910,465	17.414	1.096	8,097,633 (66.5%)	2,949,176 (27.5%)	283,070 (2.6%)	831675 (7.7%)	1,422,622 (11.6%)
Europe	14	674,497	151,526	1.202	4.451	589 (0.014%)	3,636,900 (91.2%)	331,962 (8.3%)	16669 (0.4%)	3,338,380 (83.7%)
Oceania	5	269,5384	768,041	4.804	3.860	No data	1,755,497 (96.8%)	20,800 (1.1%)	No data	36,043 (1.9%)

Source: FAOSTAT, 2010 Note: Data for production, area,%world production and productivity are for the year 2009.

Figures for domestic consumption as food and feed, export, other utilizations and imports are for 2007 fiscal year.

The% values in bracket are percentages of the cumulative sum of total amount of Sorghum produced and imported into the continent.

Other utilizations include waste, processed products and industrial uses.

Pre-harvest and Post-harvest Fungi

19. Fungi identified from cereals were previously classified into three groups namely: field, storage and advanced decay fungi. Field fungi invade developing and mature seed before harvesting and include species of *Alternaria, Fusarium, Helminthosporium, Cladosporium, Chaetomium* and *Curvularia* in order of predominance (Javis, 1971). All field fungi require a high seed moisture content of between 20-25% water content to grow and so are referred to as hydrophilic fungi (Lillehoj, 1973). The same worker gave the representative species of field fungi as *Alternaria alternata, Cladosporium herbarum, Fusarium graminearum, Rhizopus nigricans* and *Trichoderma lignorum*.

20. The storage fungi that invade grains after harvesting, and in storage consist of the genera *Aspergillus, Penicillium, Phoma, Sporendonema,* some species of *Fusarium* and a few species of yeast (Javis, 1971 and Elegbede, 1978). They are able to grow on substrates in which the moisture content has been reduced to 13-18%, equivalent to an equilibrium relative humidity of 70-85% (Javis, 1971). This group also known as mesophilic storage fungi have the following as their representative species: *Aspergillus flavus, A.fumigatus, A.terreus, Paecilomyce varioti, Penicillium aurantiogriseum, P.citrinum* and *P.viridicatum*. Others are *Aspergillus ochraceus* and *A versicolor* (Lillehoj, 1973). The major factors influencing the development of this group of fungi are moisture content of stored grain, temperature, storage period, degree of earlier invasion before arrival at the storage site, amount of foreign material and the activities of insects and mites (Ominski *et al*. 1994).

21. Advanced decay fungi require the same general moisture range as field fungi but rarely develop on seed in the field and consist of the genera, *Fusarium and Chaetomium*. These fungi grow after considerable damage from other microorganisms has occurred (Javis, 1971 and Lillehojj, 1973). However, it is important to note that when field fungi were found in stored grain and vice versa (Mycock and Berjak, 1999), the earlier rigid classification was discouraged.

22. Although the grouping of fungi into field and storage fungi is no more in vogue it is noteworthy that data presented in Table 3 indicate *Phoma sorghina, Claviceps sorghi, C. africana, Alternaria spp, Curvularia lunata, Aspergillus flavus* and *Fusarium verticillioides* as typical field fungi of Sorghum worldwide while *Aspergillus species* (*A.flavus, A. Parasiticus, A.niger* and *A.ochraceus*), *Penicillium* and several *Fusarium* species as representative storage fungi of the cereal.

MYCOFLORA AND MYCOTOXINS OF SORGHUM AND SORGHUM PRODUCTS.

23. The major fungi associated with Sorghum in Nigeria, are species of *Aspergillus, Fusarium, Penicillium, Phoma, Alternaria, Curvularia, Chaetomium* and *Helminthosporium* (Mantle and Waight, 1968, Tyagi, 1974, Elegbede, 1978, Dada, 1979, Salifu, 1981, Atanda, 1999 and Makun *et al.* 2009a). Other genera represented are *Colletrotrichum, Pericona, Rhizopus, Mucor, Trichotecium, Trichoderma* and *Cephalosporium.* The predominant field fungi found on Sorghum by same workers in the country include *Aspergilli, Fusarium* spp, *Curvularia* spp, *Phoma sorghina* and *Aspergillus* (Atanda, 1999) while those identified during storage are mainly species of *Fusarium, Penicillium, Phoma* and *Aspergillus,* which also account for most of the fungi that attack sorghum malt.

24. In Sudan, the most prevalent fungi in Sorghum grains are *Aspergillus, Rhizobus, Fusarium, Penicillium, Phoma, Alternaria* and *Curvularia (*Abdel-Rahim *et al*., 1989, Abdalla, 1998, Abu Agla, 2002, Ahmed *etal*., 2005, Ahmed *et al*., 2008, Ahmed *et al*. 2009). The predominent species found in the field by these workers were *Aspergillus niger, A. flavus, A. ochraceous, Fusarium moniliformae, Penicillium sp., Phoma sorghi, Alternaria alternate, Alternaria tenuis* and *Curvularia lunata.* The most frequently isolated fungi from stored grains in same studies were *Aspergillus niger, A. flavus, A. ochraceous, Rhizobus stolonifer, Fusarium moniliformae, Penicillium sp., Phoma sorghi, Alternaria alternata* and *Curvularia lunata.*

25. Fungal growth and mycotoxin production on Sorghum is a worldwide phenomenon and are presented in Table 3. Connole and Hill, 1970 isolated *Aspergillus niger, Penicillium* and *Cladosporium* species from the grain in Canada. The fungi found in Sorghum in United States include species of *Claviceps*, *Fusarium, Alternaria* and *Epicoccum* (Porter *et al*. 1974) while Species of *Alternaria, Fusarium, Chaetomium, Cladosporium, Culvularia, Helminthosporium, Fusarium, Penicillium, Trichoderma verticillium, Scopulariopsis, Trichothecium, Caphalosporium, Mucor, Rhizopus,* and *Thermomyces* are the fungal contaminants of the cereal in Japan (Uraguchi and Yamazaki, 1978).

26. Bandyopadhyay et al. (2000) noted the mycoflora and mycotoxins contaminating sorghum around the world and the authors found that prominent among the fungal genera producing mycotoxins are *Alternaria, Dreschslera, Cladosporium, Olpitrichum, Fusarium, Curvularia and Gibberella.* In a critical review of the threat of ergot on the world sorghum industry, Bandyopadhyay *et al*. (1998) expounded that there are three *Claviceps* species that infect sorghum with recorded losses of between 10% and 100% of hybrid seed yield around the globe and the species are *Claviceps africana*, *C. Sorghi* and Japanese *Claviceps* species. According to the report *C.africana* which is a producer of dihydroergosine is wide spread in North and South America, Africa, Asia and Australia while the non-toxigenic *C.sorghi* is commonly distributed in Asia with the Japanese *Claviceps* species that secretes the alkaloid, paliclavine is seemly confined to Japan.

27. With regards to global distribution of Sorghum fungi, while *Aspergillus, Fusarium, Penicillium* and *Alternaria* species are common natural inhabitants of the desert and tropical climate of Africa, Asia and Middle East, *Fusarium* species are widespread in Europe and Americas with *Alternaria* and *Fusarium* species being frequent in Oceania (Table 3).

28. Based on the toxigenic fungi isolated from the grain around the globe, there are over thirty potential mycotoxins that can contaminate it (Table 3) and they include alternariol, alternariol methyl ether, Altenuene, altertoxin, tenuazonic acid, aflatoxins, cyclopiazonic acid, ochratoxins, viridicatin, citrinin, patulin, roquefortine, luteoskyrin, cycloclotoyin, moniliformin, cytochalasin, fumonisins, rhizonin and rhizoxin. Others include sterigmatocystin, cladosporin, emodin, zearalenone, curvularin, chaetomin, 3-nitropropionic acid, diacetoxyscirpenol, nivalenol, gliotoxins, ergot alkaloids and T-2 toxin. Beauvericin, fusaproliferin, fusarenone X, gibberellins, deoxynivalenol and neosolaniol are also inclusive.

Table 3: Summary of reports of potentially toxic fungi from Sorghum worldwide

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
Worldwide			*Asperigillus flavus*	Aflatoxins	CAST, 2003
			A.versicolor	Cyclopiazonic acid	
			A.ochraceus	Ochratoxins	
			Alternaria	Tenuzonic/AAL	
			Penicillium cyclopium	Cyclopiazonic acid	
			P.viridicatum	viridicatin	
			P.citrinum	citrinin	
			P.expansum	Patulin/roquefortine	
			P.islandicum	Luteoskyrin/cyclochlorotine	
			P.urticae	Patulin, roquefortine	
			Fusarium thapsinum	Moniliformin	Glenn, (2007)
Africa	Burkina Faso	Field Sorghum	*Colletotrichum graminicola*	-----------------	Neye and Le Normand, (1998)
			Phoma sorghina	Cytochalasin/Tenuazonates	
			Fusarium verticillioides	Fumonisins	Somda *et al*. (2007)
	Nigeria	Sorghum grain	*Rhizopus arrhizus*	Tremorgen, rhizonin/rhizoxin	Atanda and Akano, (1999).
			Aspergillus oryzae	Patulin	
			A.niger	Ochratoxins	
			A. flavus	Aflatoxins/sterigmatocystin	
			A.tamarii	Aflatoxins/cyclopiazonic acid	
			Penicillium citrinium	Citrinin	
			Fusarium verticillioides	Fumonisins/cladosporin	
			Cladosporium fulvum	Emodin	
			Syncephalastrum racemosum	----------------------------------	
				AFs, ST, OTA, CA etc	Elegbede, (1978)
			Aspergillus		
			Fusarium	ZEA, FB, MON,	

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
			Penicillum	OTA, PAT, CIT, PA, CA etc	
			Curvularia	Curvularin, cytochalasin B	
			Phoma	Cytochalasin/tenuazonates	
			Alternaria	AOH,AME/ALT/ATX/TA	
			Chaetomium	Chaetomin	
			Helminthosporum	Cytochalasin	
			Colletotrichum		
			Periconia	Periconin A and B(inactive)	
			Rhizopus	Rhizonin, Rhizoxin, tremorgen	
			Mucor	3-nitroproionic, tremorgens	
			Trichotecium	Trichothecenes	
			Cephalosporum	Tremorgens	
					Dada, (1979)
			Phoma sorgina	Cytochalasin/tenuazonates	Salifu, (1981)
			Fusarium semitectum	Zearalenone/diacetoscirpenol	
			F.moniliforme	FB, MON, FUS.	
			F.equiseti	ZEA,MON,DAS,NIV	
					Makun *et al* (2009[ab])
			Aspergillus parasiticus	Aflatoxins	
			A.fumigatus	Gliotoxin	
			Alternaria alternate	AOH,AME/ALT/ATX/TA	
	Sudan	Sorghum grains			Abu Agla (2002)
			Aspergillus niger	Ochratoxins	
			Aspergillus flavus	Aflatoxins	
			Aspergillus ochraceous	Ochratoxins	
			Phoma sorghina	Cytochalasin	
			Alternaria tenuis	Alternariol	Abdalla (1998)
			Aspergillus spp.	Aflatoxins, Ochratoxins	
			Penicillium spp	Patulin	
			Alternaria sp.	Alternariol	

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
			Fusarium sp.	Fumonisins	
			Rhizobus sp.	Tremorgens, rhizonin, rhizoxin	
					Ahmed *et al* (2005)
			Aspergillus niger	Ochratoxins	
			Aspergillus flavus	Aflatoxins	
			Aspergillus ochraceous	Ochratoxins	
			Penicillium sp.	Tricothecenes, Fumonisins	
			Fusarium moniliformae		
			Curvularia lunata	Curvularin	
					Ahmed *et al* (2008)
			Aspergillus niger	Ochratoxins	
			Aspergillus flavus	Aflatoxins	
			Aspergillus ochraceous	Ochratoxins	
			Phoma sorghina	Cytochalasin	
					Ahmed *et al* (2009)
			Aspergillus niger	Ochratoxins	
			Aspergillus flavus	Aflatoxins	
			Penicillium sp.	Patulin	
			Fusarium moniliformae	Tricothecenes	
			Curvularia lunata	curvularin	
			Rhizobus stolonifer	Tremorgens, rhizonin, rhizoxin	
	Cameroon				Bandyopadhyay et al (1998)
	South Africa		*Claviceps sorghi africana*	Ergot alkaloids	
	Zimbabwe (many other countries)				
			Asperigillus circinatus		ICRISAT, 2011
	South Africa				
			Alternaria raphani		
			A.tenusinae	AOH,AME/ALT/ATX/TA	Soliman, (2003)

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
	Egypt		*Aspergillus flavus*	AOH,AME/ALT/ATX/TA	
			Cunninghamella elegans	Ochratoxins	
			Drechslera myaki		
			Fusarium graminearum	sterigmatocystin	
			F. verticillioides	ZEA,DON,NIV,FUS	
			F.solani	FB, MON, FUS	
			Rhizopus stolonifer	T-2 toxins	
			Penicillium digitatum	Tremorgens, rhizonin, rhizoxin	
			P. notatum		
				Roquefortine	
			Fusarium chlamydosporum		
			F.verticillioides	Chlamydosporol	Onyike and Nelson, (1992)
			F.equiseti	FB, MON, FUS	
			F.graminearium	ZEA,MON,DAS,NIV	
	Nigeria		*F.nygamai*	ZEA,DON,NIV,FUS	
	Lesotho		*F.semitectum*	FBs, MON, BEA	
	Zimbabwe		*F.compactum*	ZEA, MON	
			F.dimerum	Neosolaniol	
			F.avenaceum		
			F.lateritium	MON, BEA, FUS	
			F.sambucium	DAS, Neosolaniol	
			F.proliferatum	Trichothecenes (DAS)	
			F.sporotrichioides	FBs/MON/FP/BEA	
			F.oxysporum	HT2, T2, DAS, BEA,FUS	
			F.napiforme	ZEA/trichothecenes	
				FBs/MON	
					Mansuetus *et al.* (1997)
			Fusarium fugikuroi		
				FB, GB, MON, BEA	

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
	Tanzania				
			Phoma		Ratnadass *et al*. (2003)
			Fusarium	Cytochalasin/tenuazonates	
			Curvularia	FB, DON,NIV,DAS,T2 etc	
	West and Central Africa			Curvularin	
Americas	USA	Field Sorghum	*Claviceps africana*	Ergot alkaloids	Bandyopadhyay et al
	USA	“	*Asperigillus circinatus*		(1998)
					ICRISAT, 2011
	Brazil	Field and store Sorghum	*A.flavus*	Aflatoxins	
			F.verticillioides	FB, MON, FUS	Pitt and Hocking, (2009)
			F.proliferatum	FBs/MON/FP	
	Brazil	Sorghum grain	*Cladosporium*	Emodin	
			Helminthosporium	sterigmatocystin	Reia *et al.* (2010)
			Fusarium verticillioides	FBs, MON, FUS	
	Argentina		*Fusarium napiforme*	FB, MON, FUS	
					Glenn, (2007)
Asia/Middle East	India	Field Sorghum	*A.flavus*	Aflatoxins	Reddy *et al.* (1985)
			Curvularia lunata	Curvularin	
			F.verticillioides	Fumonisins	
	India	Sorghum	*Aspergillus*	AF, ST, OTA, etc	ICRISAT, 2008
			Alternaria	AOH,AME/ALT/ATX/TA	
			Cladosporium	Emodin	
			Diplodia		
			Fusarium	FB, DON,NIV,DAS,T2 etc	
			Curvularia	Curvularin	
			Phoma	Cytochalasin/tenuazonates	

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
			Penicilium	FB, DON,NIV,DAS,T2 etc	
	South East Asia	Field Sorghum	*A.flavus*	Aflatoxins	Pitt and Hocking, (2009)
			Curvularia lunata	Curvularin	
			C.pallescens	Curvularin	
			Alternaria alternate	AOH,AME/ALT/ATX/TA	
			A.Longissima	AOH,AME/ALT/ATX/TA	
			F.verticillioides	Fumonisins/moniliformin	
			F.semitectum	ZEA, MON	
			Lasiodiplodia theobromae		
			Nigrospora oryzae		
			Phoma species	Cytochalasin/tenuazonates	
	India				
			Fusarium proliferatum	NIV, DON, DAS, Fus-X	Lincy *et al*. (2011)
			F. sacchari		
			F. nelsonii		
			F. equiseti		
			F.asiaticum		
	India				
			Fusarium proliferatum	FB, MON, FUP	Sharma *et al*. (2011)
			F. sacchari		
			F. andiyazi		
			F. thapsinum		
			F.equiseti		
Europe	France		*Asperigillus circinatus*		ICRISAT, 2011
Oceania	Australia		*Asperigillus circinatus*		ICRISAT, 2011
	Australia	Field and stored Sorghum	*Alternaria alternata*	AOH,AME/ALT/ATX/TA	Pitt and Hocking, (2009)
			Alternaria infectoria	AOH,AME/ALT/ATX/TA	
			Phoma sorghina	Cytochalasin/tenuazonates	

Region	Country	Commodity	Toxic Fungi Species	Potential Mycotoxins	References
			Bipolaris sorghicola	Sterigmatocystin	
			Exserohiium rostratum		
			Cladosporium spp.	emodin	
	Australia		*Fusarium nygamai*	FB, MON, BEA	Glenn, (2007)

Note: AOH (Alternariol), AME (Alternariol methyl ether), ALT (Altenuene), ATX (Altertoxin), TA (Tenuazonic acid) aAcDON=mono-acetyldeoxynivalenols (3-AcDON, 15-AcDON); AcNIV=mono-acetylnivalenol (15-AcNIV); BEA=beauvericin; iAcDON=di-acetyldeoxynivalenol (3,15-AcDON); DAcNIV=diacetylnivalenol (4,15-AcNIV); DAS=diacetoxyscirpenol; DON=deoxynivalenol (Vomitoxin); EN=enniatins; FB1 =fumonisin B1; FB2 =fumonisin B2; FB3 =fumonisin B3; FUP=fusaproliferin; FUS=fusarenone-X (=4-Acetyl-NIV); FUC=fusarochromanone; HT2=HT- 2 toxin; MAS=monoacetoxyscirpenol; MON=moniliformin; NEO=neosolaniol; NIV=nivalenol; T2=T-2 toxin; ZEA=zearalenone; ZOH=zearalenols (α and β isomers).

29. The over thirty anticipated Sorghum mycotoxins (see 27 above) notwithstanding, the commonest mycotoxins found in Sorghum and its products worldwide as shown in Table 4 are aflatoxins, zearalenone and ochratoxins A, fumonisins, moniliformin, deoxynivalenol and ergot alkaloids while alternariol, altenuene, tenuazonic acid, nivalenol, patulin, sterigmatocystin and T-2 toxin have also been isolated from the cereal. Ergosine was reported in Australia by Ryle, (2010). The lack of mycotoxin data from Europe notwithstanding, aflatoxins are the most problematic toxins in Sorghum worldwide as they have been found in four of five of the regions of the globe (Table 4) at incriminating levels of up to 1164 µg/kg in mouldy Sorghum from Nigeria (Makun *et al*. 2009a) and should therefore be accorded paramount attention.

30. Next to aflatoxins in terms of prevalence are ochratoxins, zearalenone and fumonisins (Table 4). Data on ochratoxins incidence were mainly from Africa with the highest amount reported in Ethiopian grain at disturbing concentrations of 2106 µg/kg (Ayalew *et al*. 2006). Zearalenone was also isolated from African and Asia grain with the highest concentration of 7260 µg/kg occurring in cereal imported into Japan (Aoyama *et al*. 2001). Fumonisins were reported in the cereal from Ethiopia (Ayalew *et al*. 2006), India (Waliyar *et al*. 2007) and USA (Truckness *et al*. 2000) at low to moderate concentrations of 0 – 2117 µg/kg.

31. The occurrence of *Alternaria* toxins at significant concentrations in Sorghum based food and feeds from South Africa (Sydenham *et al*. 1988), India (Ansari and Shrivastava, 1990) and USA (Hagler *et al*. 1987) and the high predominance of *Alternaria* spp as Sorghum field fungi worldwide (Table 3) should draw more attention to these fungi. Similarly, the incidence of the very toxic haemorrhagic mycotoxin, T-2 toxin at toxicologically significant amount of between 1670 to 15000 µg/kg in Indian Sorghum (Bhavanishankar and Shantha, 1987) is of great concern with regards to public health. Apart from T-2 toxin, enniatins are other minor *Fusarium* mycotoxins that were found at alarming concentrations of up to 683,900 µg/kg in Tunisian Sorghum and Sorghum based products (Souhelb *et al*. 2011).

32. Even though Sorghum, a raw material for feeds have been shown above to be contaminated by quite a few toxins, it is appropriate to consider the occurrence of mycotoxins in animals feeds as processing might alter the toxin concentration of feeds from that of the raw materials. More so, commercial livestock farming is now a major industry in the world and thus feeds have become a main source of exposure of humans to food borne toxins. In view of the anticipated disparity in toxin content between the raw commodities and feeds which will result in different exposure risks of the materials, the few reports of AME (≥ 2250 µg/kg) in Sorghum based swine feed (Sydenham *et al*. 1988) and OTA (≥ 38 µg/kg) in Sorghum poultry feed (Zafar *et al*. 2001) at significant toxicological levels calls for the use of rapid and sensitive mycotoxin test kits by farmers, manufacturers and consumers to monitor the quality of products on the farm.

33. Other foods processed from Sorghum containing different mycotoxins at varying concentrations include Sorghum syrup and meal. In the USA, Trucksess *et al*. (2000), isolated fumonisin B1 in one out 35 samples of Sorghum syrup collected from 15 states at concentration of 0.12 µg/g (LOQ of 0.1 µg/g). While in Brazil, Campos *et al*. (2008) isolated, from Sorghum meal, *Aspergillus* spp. (75.3%) *Alternaria* spp. (22.3%) and *Fusarium.* spp. (2.4%). Seventy seven per cent of the stains of *A. flavus* were aflatoxin producers. All samples examined were contaminated with aflatoxins, at levels of 0.1 to 23.8 µg/kg.

34. Mycotoxins, mainly aflatoxins, ochratoxin A and alternaria toxins, were detected in Sorghum grains in Sudan. Aflatoxins B1, B2 and ochratoxin A are common contaminants whereas aflatoxin G1 was only detected in Sorghum grains used as animal feed (Abdalla, 1998, Ahmed *et al*., 2009, Elzubir *et al* 2009 a and b). Alternariol was detected in Sorghum grains stored in traditional pits (Abdalla, 1998).

35. Although fermentation process reduces mycotoxins in contaminated products (Hell and Mutegi, 2011), evidence presented in Table 4 show a significant carryover of mycotoxins into Sorghum based traditional African beer. Odhay and Naicker, (2002) detected AFB1 (200-400 µg/kg and OTA (0.34-54.5 µg/kg) at unsafe concentrations with moderate amount of ZEA (2.6-426 µg/L) in South African beer. Sorghum based traditional opaque beer from Malawi contained aflatoxins at levels above the CODEX permissible limit of 10 µg/kg (Matumba *et al*.2011). Levels of up to 50 µg/kg were found in Sorghum based local beer from Lesotho (Sibanda *et al*. 1997). In Botswana, Nkwe *et al*. (2005), isolated from 46 samples of traditional Sorghum malt, wort, and beer, *F. verticillioides* and *A. flavus* in 72 and 37% of the samples respectively. No aflatoxins were detected. Fumonisin B1 was detected in malt at intensity of 6.5% and level of 47-1316 µg/kg. Zearalenone was detected in: malt, at 56% intensity and level of 102-2213 µg/kg, wort at 48% intensity and level of 26-285 µg/L and in beer at 48% intensity and level of 20 -201 µg/L. With these unsafe amounts of toxins 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, the contribution of a moderate daily consumption of beer to mycotoxin intake will not contribute significantly to the exposure of the consumer. According to EU standard, the contents of DON and FB_1 found in Cameroonian Sorghum based beer (Roger, 2011) were safe; however, the concern here is the likely synergism of the toxins (Placinta *et al*. 1999).

HEALTH AND ECONOMIC IMPLICATIONS OF FUNGI AND MYCOTOXINS IN SORGHUM

36. From the toxic fungal isolates, *Aspergillus spp, Penicillium, Fusarium* and *Trichoderma* were the most prevalent (Table 3) and so the mycotoxins they are likely to produce would be of major health concern. A host of mycotoxins (Uraguchi and Yamazaki, 1978 and Scott, 1994), some of which are of public health significance are elaborated by species of *Aspergillus* (Gbodi and Nwude, 1988, Prelusky and Rotter, 1994, Peraica *et al*. 1999) but of major concern are the aflatoxins and sterigmatocystin which are naturally occurring carcinogens and have been linked to high incidence of liver cancer in some parts of the world where foods are frequently contaminated with aflatoxins (Bankole and Adebanjo, 2004). Aflatoxins are primarily known hepatotoxins and hepatocarcinogens that were the cause of death of eighty people in Kenya who ate highly aflatoxin contaminated maize meals in 2004 (ProMed, 2004).

37. Hepatocellular carcinoma (HCC) is a chronic disease that has become a major global health problem, causing over 600,000 cases per annum (Ferenci *et al.* 2010) and accounts for over 70% of the liver carcinoma (Lata 2010). In Africa and Asia most likely cause or promoter of such 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 aflatoxin are found.

38. The potency of aflatoxin B_1 as a poison is so vivid in the fact that it was the substance for suicide attempt by a laboratory worker (Peraica *et al*. 1999) and a bio-weapon in the arsenals of terrorists (Lane, 2005). Researchers have also shown that aflatoxin raises level of AIDS virus by 400% in the blood (Lane, 2005) and that is because it suppresses the production of non-specific humoral resistive substances (especially of C4 and Interferon), and prevents phagocytosis, thymus growth and cell-mediated immunity (Pier and Mcloughlin, 1985).

39. Apart from the acute form of aflatoxin poisoning, many diseases and disorders are associated with chronic intake of this toxin. The one of greatest concern in West Africa is the study which showed a significant correlation between aflatoxin exposure from foods and stunted growth in children who are exposed to the toxin right from neonatal stages (Gong *et al*. 2002). High level of aflatoxin exposure upon weaning impaired growth of children in Republic of Benin and Togo (Gong *et al.* 2003 and Gong *et al.* 2004). A strong negative relationship has been shown between aflatoxin levels and birth weight in infants of United Arab Emirate (Abdulrazzaq *et al*. 2004). The fact that aflatoxins are genotoxic can cross placental barrier, they can cause genetic defects at foetal stages (Maxwell *et al*. 1989).

40. Protein energy malnourished (kwashiorkor) children that have aflatoxins in their body have significantly lower haemoglobin level, a longer duration of oedema, increased number of infections and longer duration of hospital stay than those malnourished without aflatoxins in their blood and urine (Adhikari *et al*. 1994). This implies that aflatoxins aggravate kwashiorkor. Aflatoxins have also been associated to neonatal susceptibility to infection and jaundice (IARC, 1976), childhood infections, malignant disease and compromised response to prohylatic immunizations in children (Hendrickse *et al.*. 1983).

41. The major *Penicillium* toxins are ochratoxin A, citrinin, patulin, penicillic acid, roquefortine, cyclopianonic acid, verrucosidin, rubratoxin, cyclochlorotine and luteoskyrin (Scott, 1994). The toxicological significances of these mycotoxins to human health, livestock production and trade have been reviewed by many scientists (Gbodi and Nwude, 1988, Beardall and Miller, 1994, Prelusky and Rotter, 1994, Peraica *et al*. 1999,). Apart from aflatoxins, the three main *Aspergillus* and *Penicillium* mycotoxins that pose the greatest public health are ochratoxin A, patulin and citrinin. Ochratoxin A causes kidney and liver impairment in animals and man especially pigs (Stoev *et al*. 2011). This mycotoxin has been proposed as the causative agent of endemic nephropathy that occurs among rural populations in Croatia, Bosnia and Herzegovina, Yugoslavia, Bulgaria, and Romania, where it has been estimated that about 20,000 people are either suffering from or are suspected to have the disease (Peraica *et al*. 1999). The toxin is also associated with urothelial tumours of pelvis and ureter in Egypt, Croatia, Bulgaria and Yugoslavia and chronic interstitial nephropathy in Tunisia (Wafa *et al.* 1998 and Peraica *et al*. 1999). Patulin and citrinin are neurotoxic and nephrotoxic respectively (Peraica *et al*. 1999). *Penicillium* species especially *P. citreonigrum*, *P. islandicum* and *P. citrinum* alongside their toxins; luteoskyrin, cyclochlorotine and citreoviridin which are found in Sorghum are also linked with yellow rice disease (Uraguchi and Yamazaki, 1978).

42. Zearalenone, an oestrogenic toxin causes infertility in animals and is associated with outbreaks of precocious pubertal changes in children in Puerto Rico and has been suggested to have a possible involvement in human cervical cancer (JECFA, 2000). The other mycotoxins elaborated by *Fusarium spp* are classified into the following major groups; trichothecenes, culmorins, enniatins, fusarins and fumonisins. Others compounds produced by this family of fungi and that do not belong to the aforementioned groups are moniliformin, butenolide and chlamydosporol. All these fusariotoxins especially the trichothecenes and fumonisins are of major health concern and have caused mycotoxicoses in animals (Gbodi and Nwuda, 1988) and humans (Prelusky and Rotter, 1994).

43. Trichothecenes are protein inhibitors with consequent immunosuppressive effects causing severe damage to digestive tract and death due to intestinal haemorrhage (Beardall and Miller, 1994). The most common trichothecenes are deoxynivalenol (DON) and T-2 toxin. DON was the causatic agent of a large-scale incident of human toxicosis in the Kashmir Valley, India in 1988, and acute toxicosis of DON has been reported in China, Japan, and Korea among other countries (Beardall and Miller, 1994).

44. Fumonisins especially FB_1 cause liver and kidney cancer, and neural tube defects in rodents, leukoencephalomalacia in equine and pulmonary oedema in pigs (Marasas, 2001). The association of FB_1 with elevated incidence of human oesphageal cancer in parts of South Africa, North Eastern Iran and China, upper gastrointestinal tract cancer in Northern Italy and neural tube defects in human babes (Marasas, 2001) is a major public health concern. The International Agency for Research on Cancer classifies fumonisins as possible human carcinogens (category II-B) (IARC, 1993).

45. *Trichoderma spp* have been found as fungal contaminants of Sorghum, (Uraguch and Yamazaki, 1978 and Gbodi, 1986). The mycotoxins produced by *Trichoderma spp* are numerous and they include alamethicins, chrysophanol, emodin, ergokonin, gliotoxin, gliovirin, G-protein, harzianum A, heptelidic acid, isocyanocyclopentenes, koninginins A,B,C,G, aracelsin, saturnisporin, suzukacillin, trichodermin, trichorzianines A&B, Trichothecenes, Trichotoxin, Trichoviridin and Viridin (Uraguch and Yamazaki, 1978, Scott, 1994). However, satratoxin H, trichodermol, trichodermin and T-2 are the most elaborated and toxic. Satratoxin H is an immunosuppressant that causes abortogenicity in animals while the other three are inhibitors of protein synthesis and cause damage to the gastrointestinal tract and haemoglobin of animals and man (Prelusky and Rotter, 1994 and JECFA, 2000).

46. Although the toxicity of paliclavine elaborated by Japanese *Clavicep sp* has not been investigated, the alkaloids synthesized by *C.africana* are associated with feed refusal and reduction in weight gain in pigs with consequent loss of litters due to failure in milk production by sows. (Bandyopadhyay *et al*. 1998). The pathlogy of the syndrome show significant decrease in blood prolactin levels, proving the possibility of agalactia in the female animals. The review further reported that when chickens were fed with feed contaminated by sclerotia containing the fungus, difficulty in respiration, diarrhoea and death were elicited in the experimental animals.

47. The high incidence of *Mucor* and *Alternaria* spp in mouldy Sorghum, and their proven toxicity in experimental mice (Makun *et al.* 2009b) suggest the likely presence of toxic metabolites of these fungi in the grain. For instance, Rhizonin A secreted by *Mucor* spp that has deleterious effects on the kidney and liver of mice and rats (Wilson, 1984) is to be expected as mycotoxin contaminant of Sorghum. Moulds of the genus, *Alternaria* elaborate many toxins but mainly cytochalasins and tenuazonic acid (Visconti and Sibilia, 1994) which have been implicated in human haemorrhage disease, 'Onyalia' in South Africa (Beardall and Miller, 1994).

48. It is worth mentioning that there is very high co-occurrence of different mycotoxigenic fungi within the same grain sample (Table 3) particularly those that produce AF, OTA and FB, which is likely to result in natural simultaneous contamination of related and unrelated mycotoxins in same food matrix as observed in Table 4. Such co-contamination of Sorghum grain by different toxins has been demonstrated by Makun *et al*. (2009), in this case the concurrent presence of AF, OTA and ZEA. Mycotoxin contaminants could occur in combinations of twos, threes and as much as in fives (Elegbede, 1978, Ayalew *et al*. 2006, Ghali *et al*. 2008).

49. The implications of such toxin "cocktails" on human health are presently unknown. However, the interactive effects of mycotoxins in these natural combinations could be synergistic, additive or antagonistic in host organisms (Miller 1995). Interaction between AFB1 and FB1, which is one of the combinations observed, had an additive effect in mice, causing increased injuries to liver and kidneys of the experimental animals (Gelderblom *et al*. (2002). Other combinations which were observed have been reported to exhibit synergistic interactions include AFB1 and the trichothecenes (Placinta *et al*. 1999), FB1 and OTA (Creppy *et al*. 2004), and FB1 and ZEA (Luongo *et al*. 2008). The simultaneous exposure of OTA and AFB1 to rabbits demonstrated an antagonistic interaction between the toxins with regards to teratogenic effects (Wangikar *et al*. 2005). The complex and varied nature of the effects of mixed mycotoxins is obvious in the synergistic and additive growth depression effects of DON and FB1 in pigs and broiler chicks respectively (Placinta *et al*. 1999). DON is antagonistic to T-2 in the inhibition of human lymphocytes proliferation (Speijer and Speijer 2004). The interaction data between four or more mycotoxin species, a recurring feature in Sorghum samples, are virtually unavailable; however, Speijer and Speijer (2004) postulated that combined exposure to several classes of mycotoxins generally results in an additive effect with a few minor exceptions, indicating synergistic interaction.

50. Economic losses caused by fungi and mycotoxins contamination can be considered at three stages namely, crop production, livestock production and human health levels. At the crop production level, millions of tonnes of crops are destroyed by fungi each year. Food and Agriculture Organisation estimated that 25% of the world's food crops are lost due to mycotoxins each year (Charmley *et al*, 1994). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 2002) gave the following volume of food grains wasted by mycotoxins each year worldwide: maize 16 million tons, rice 12 million t, groundnut 1.8 million tons, Sorghum and millet 378,000 t, copra 3.7 million t, soybean 2.3 million tons. A substantial part of this wastage is in developing Asian and African countries.

51. In the United States only, the mean economic annual costs of crop losses from the mycotoxins, aflatoxins, fumonisins, and deoxynivalenol, are estimated at $932 million (CAST, 2003) and additional losses averaging $466 million stem from efforts to prevent or reduce contamination through regulatory enforcement, testing, and other quality control efforts (Dohlman, 2003). African countries that export agricultural produce loss $670 million annually in order to meet European Union regulation on aflatoxins (Otsuki *et al*. 2001). Such economic impact of AFs is enormous on the continent particularly on the many agricultural African countries, where cereals, dried fruit and nut export accounts for 50% of the national income (Sibanda *et al*.1997). Also in Nigeria the National Agency for Food and Drug Administration Control destroyed aflatoxin-contaminated food worth more than US$200,000 (SFI, 2005).

Table 4: Natural incidence of mycotoxins in Sorghum worldwide

Mycotoxin	Country	Type of sample	incidence	Range of concentration (µg/kg)	Mean ± SD of concentration (µg/kg)	Reference
Aflatoxin	Australia					Ryle, 2010
Aflatoxin	Ethiopia		8.8%	0 - 26		Ayalew et al. 2006
Aflatoxin B_1	Nigeria	Field	8/8	30.32 - 211.20	81.3	Uraih and Ogbadu, (1980)
G_1			8/8	2.40 - 208.00	59.97	
Aflatoxin B_1	Nigeria		22/318	0 – 40		Opadokun, (1992)
Aflatoxin B_1	Nigeria	Store		27.22 – 36.13	30.53± 3.37	Odoemelam & Osu, (2009)
Aflatoxin B_1	Nigeria	Mouldy Field	5/16	0 – 54	9.88 + 17.73	Makun *et al.* (2009a)
		Mouldy store	88/152	0 - 1164	≥266.82	-ditto-
Aflatoxins	Sudan	Traditional Pit	30	0-500	91.7	Abdalla (1998)
Aflatoxin B1	Sudan	store	6/28	0-7	3.0	Ahmed *et al* (2009)
Aflatoxin B2			1/28	0-5	1.5	
Aflatoxin B1	Sudan	store	2/11	37 -375	206+ 0.70	Elzubir *et al* (2009a)
Aflatoxin B2	Sudan		1/11	0-5.46	5.46+0.52	
Aflatoxin G1	Sudan		2/11	0- 24	136.9 +0.75	
Aflatoxin B1	Sudan	store			21.8 +0.05	Elzubir *et al* (2009b)
Aflatoxin B2	Sudan	store			0.08 +0.06	
Alternariol	Sudan	traditional pit		0-350		Abdalla (1998)
OchratoxinA	Sudan	store	84/113	0.33- 1.58	2.5	Ahmed *et al* (2009)
Ochratoxin A	Sudan	Store			0.96	Elzubir *et al* (2009b)
Aflatoxins	USA		3/223	5 -50		JECFA, (1998)
Aflatoxin B_1	Brazil		20/59		3	JECFA, (1998)
Aflatoxin B_1	Brazil		18/140	7 - 33		Da Silva et al. (2000)
Aflatoxin B_1	China			>1	11	JECFA, (1998)
Aflatoxin B_1	Columbia	Field		1.4 – 43		JECFA, (1998)
Aflatoxin B_1	India			600-800		Tripathi, 1973
Aflatoxin B_1	India	Normal and rain affected	2.5 – 100%	0-830		Bhat *et al*. 2000
Aflatoxin B_1	India		/209	7 – 75	≥91.6	Rustom, (1997)
Aflatoxin B_1	India	Field	56/94	0 - 362		Waliyar et al. (2007)
						Shetty & Bhat (1997);

Mycotoxin	Country	Type of sample	incidence	Range of concentration (µg/kg)	Mean ± SD of concentration (µg/kg)	Reference
Aflatoxin B_1	India/Thailand			0.10 – 30.3		Suprasert & Chulamorakot (1999)
						Rustom, (1997)
Aflatoxin B_1	South Africa		2/6	0 – 25		
		Traditional Beer				Odhav and Naicker, (2002)
Aflatoxin B_1	South Africa		2/13	200 - 400		
		Store				Matumba et al. (2011)
Total Aflatoxin	Malawi	Sorghum malt[1]	6/6	1.7 – 3.0	2.35	
		Sorghum malt[2]	21/21	6.1 – 54.6	17,57	
		Thobwa	3/7	4.3 – 1138.8	408.45	
		Beer	5/5	2.1 – 7.1	4.5	
		Sorghum				Ghali et al. (2009)
Total Aflatoxin	Tunisia		58/93	8.8 – 34.5	22.32	
		Traditional Beer				Odhav and Naicker, (2002)
Ochratoxin	South Africa		8/18	0.34 – 54.5		
		Field				
Ochratoxin A	Nigeria		13/18	3 - 2340		Elegbede (1978)
Ochratoxin B			1/18	0 - 50		
Ochratoxin C				0 -60		
				Qualitative test		
		Field				
Ochratoxin A	Nigeria	Store	2/16	0 – 412	28.05 + 102.85	Makun et al. (2009)
			21/96	0 - 712	≥88.33	
						Ayalew et al. (2006)
						Ghali et al. (2008)
Ochratoxin A	Ethiopia		17/78	0 - 2106	174.8	Zaied et al. (2000)
		Sorghum grain				
Ochratoxin A	Tunisia		9/17	2.5 – 36.4	14.4	Zafar et al. (2001)
Ochratoxin A	Tunisia		43/113	8 - 950	117	CODEX, (2011)
Ochratoxin A	India	Sorghum Poultry feed	2/12	0-38	34	Ayalew et al. 2006
Ochratoxin A	Sudan			6-9		Ayalew et al. 2006
Deoxynivalenol	Ethiopia		48.8%	40-2340		Waliyar et al. (2007)
Fumonisin	Ethiopia			2117		Truckness et al. (2000)
		Sorghum syrup				
Fumonisin	India			0 – 441	≥93.8	
						Ayalew et al. 2006
Fumonisin B_1	USA		1/15	0.12	0.12	
Fumonisin B_2						Ayalew et al. 2006

Mycotoxin	Country	Type of sample	incidence	Range of concentration (µg/kg)	Mean ± SD of concentration (µg/kg)	Reference
Nivalenol	Ethiopia			50 - 380		Makun et al. (2009a)
Zearalenone	Ethiopia			32		
		Field				Elegbede (1978)
Zearalenone	Nigeria	Store	9/16	0- 1454	211.50 +394.46	
			53/152	0 – 1454	184.76 + 328.31	Odhav and Naicker, (2002)
		Field				
Zearalenone	Nigeria		3/18	0-143.5		Ghali et al. (2008)
		Traditional beer				
Zearalenone	South Africa		13/29	2.6 – 426	10.9	Aoyama *et al. (*2009)
		Sorghum grain				
Zearalenone	Tunisia		4/17	7.3-14.0	50	
		Imported Sorghum				Sydenham *et al.*,1988
Zearalenone	Japan		84/169	60 - 7260	705	
						Salifu (1981)
		Sorghum grain				
Zearalenone	South Africa			0.8-1.25		Elegbede (1978)
		Sorghum grain				
Patulin	Nigeria		1	50		
		Field Sorghum				Ansari and Shrivastava,
Sterigmatocystin	Nigeria		3/18	Qualitative analysis		1990
		Sorghum grain				
AME	India		7/20	600-1800		Sydenham *et al.*,1988
		Sorghum based swine feed				Hagler *et al.*,1987
AME	South Africa		4/4	1250-2250		
						Ansari and Shrivastava, 1990
AME	USA			445		Ansari and Shrivastava, 1990
		Sorghum grain				
ALT	India		5/20	20-700		CX/CF09/12. 2010
		Sorghum grain				
TA	India		5/20	1300-5600		
		Sorghum grain				Bhavanishankar and Shantha, 1987
Aflatoxin B_1	Sudan		17.8%	1-7		
Aflatoxin B_2			3.5%	1-5		
						Roger, (2011)
		Sorghum grain				
T-2 Toxin	India		4/84	1670-15000		“
		Sorghum opaque				

Mycotoxin	Country	Type of sample	incidence	Range of concentration (µg/kg)	Mean ± SD of concentration (µg/kg)	Reference
DON	Cameroon	beer	107/120	140-730		
		"				
FB1	Cameroon		105/120	0.5-340		

Note: Sorghum malt1 refers to malt prepared for making thobwa and Sorghum malt2 refers to that prepared for beer.

AME=Alternariol monomethyl ether and ALT=Altenuene

52. The estimated annual losses in the USA and Canada arising from the impact of mycotoxins on food and livestock industries are about U$S 5 billion (Rodriguez *et al*, 2003). While with regards to economic impact of mycotoxins on human health, the loss of 40% labour productivity in Africa due to diseases and deaths exacerbated by AFs (Miller, 1995) is quite worrisome. But how does one assess the economic losses following increased pre-five mortality rates, and the death of several hundreds of people in an Indian village and two districts in Kenya after eating moulded food contaminated with aflatoxin? Neither can one assess the losses following the deaths of several thousand people due to alimentary toxic aleukia, ergotism, oesophageal and liver cancer that ravaged different parts of the world in the past.

DIETARY INTAKE OF MYCOTOXINS IN SORGHUM

53. Four pieces of information are required to estimate the potential intakes due to mycotoxins in crops (1) the levels of toxin in crop in this case Sorghum; (2) the amount of Sorghum consumed; (3) the impact of any subsequent processing on toxin levels; and (4) methods for combining the first 3 to estimate intake. Comprehensive data of mean values of each of the mycotoxin in Sorghum, quantity of the grain consumed by the populace and amount of toxin removed by the cooking are very scarce except for a few which calls for intense researches in this area particularly in Africa and Asia where it is predominantly used for human nutrition.

54. It has been reported that on average, a typical diet of Nigerians includes 138 kg of cereal grains (mainly maize and Sorghum) per person per year (FAO 2005). Given this information, it was calculated that aflatoxin exposure from Sorghum consumption alone would be about 1.2 mg per person per year, and the average daily aflatoxin exposure per person from Sorghum would be 3.3 µg per day (Bandyopadhyay *et al*. 2007).

55. In a study designed to determine aflatoxin levels in samples of Sorghum, Sorghum malt and home-brewed maize-based beers from southern Malawi, it was found that the incidence of aflatoxin contamination in Sorghum samples was very low, however the incidence of aflatoxin contamination was high in Sorghum malt samples (Matumba *et al*. 2011). All of the beers had detectable aflatoxins, however, at a lower level of contamination than Sorghum malt samples that were used in their production. The investigators indicated that in order to gain information on aflatoxin exposure due to drinking of traditional beer in Africa, it is necessary to know the level of beer consumption in various African communities. In a study of locally brewed traditional alcoholic beverages in Tanzania, it was found that local inhabitants may consume up to 5-6 liters per day (Nikander *et al*., 1991). Consumption of 5 liters of the traditional beer from that study translates into a daily intake of 111.6 µg aflatoxins, which gives mean daily aflatoxin exposure of 1.86 µg aflatoxin/kg bw per day for a 60 kg adult (Matumba *et al*. 2011).

56. The production and consumption of artisanal home-brewed Sorghum beer is a widespread traditional practice in the northern Sudan-Sahelian zone of Cameroon (Roger, 2011). On the basis of published data for the consumption of artisan home-brewed Sorghum beer in Cameroon, the fumonisin and deoxynivalenol exposure in these regions among the consumers was found to be well above the provisional maximum tolerable daily intake. High levels of DON and FB_1 were recorded in two Cameroonian artisanal opaque beers and the investigator concluded that if one considers the fact that, there is no direct evidence on their intake levels that have adverse health effects in humans, some concern however can be raised regarding the potential toxicity implication, when beer is contaminated by mixtures of these mycotoxins.

PREVENTION, CONTROL AND REGULATION OF MYCOTOXIN IN SORGHUM

57. The predominance of aflatoxins producing fungi and *Alternaria* species in Sorghum as deduced during this review demands that the intervention strategies to eliminate these fungi and their toxins which were not captured by the COP will be the focus of this section. In 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). A study designed to explore the use of certain biocontrol agents for the reduction of growth of *Aspergillus flavus* and subsequent aflatoxin B_1 in Sorghum grains was recently reported (Reddy *et al*.2010). The microbiologicals tested showed a considerable inhibition of *A. flavus* growth and aflatoxin B_1 reduction, therefore, the use of biocontrol agents should be further explored.

58. Another intervention method is the introduction of genetically modified strains of crops, e.g., genetically modified (GM) Bt maize which inhibits insect damage and hence fungal infection (Wu 2006), and breeding efforts to develop Sorghum lines with grain mould resistant traits (Ambekar *et al*. (2010). Another preventive measure is feeding of animals with proteins and vitamins particularly 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.

59. Risk of aflatoxin contamination of food and feed in Africa is increased due to environmental, agronomic and socio-economic factors (Hell and Mutegi, 2011). Field management practices that increase crop yields can reduce the risk of aflatoxin development. These practices include use of resistant varieties, crop rotation, well-timed planting, weed control, pest control, and avoiding drought and nutritional stress through irrigation and fertilization. The authors further indicated that post- harvest interventions that can reduce aflatoxin contamination include rapid and proper drying, proper transportation and packaging, sorting, cleaning, drying, smoking, insect control, and the use of botanicals or synthetic pesticides as storage protectants. Although the practices suggested here refer to aflatoxins, these practices are believed to be applicable for the control of contamination by all mycotoxins in susceptible grain crops.

60. With regards to storage facilities a critical water content for storage of 0.70 water activity (Magan and Aldred, 2007) is recommended. 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 aflatoxins 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. The commercialization of the ammoniation procedure in Africa by governments and private companies as has been successfully done in the USA could help livestock farmers in developing countries with relatively safer feeds in the face of highly contaminated feedstuffs and shortage of feeds.

61. 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 researches, *Lippia multiflora* leaf extract has been shown to have fungal static effect on *Aspergillus flavus* and *Fusarium verticillioides* (Anjorin *et al*. 2008). Essential oils, ozone, diatomaceous earth and food grade antioxidants such as butylated hydroxyanisole (BHA),butylated hydroxytoluene (BHT) and propyl paraben (PP) are promising non toxic cost effective alternatives to toxic chemical preservatives against a variety of fungi including but not limit to *Aspergillus, Fusarium* and *Penicillium* (Chulze, 2010). 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 aflatoxin contaminated foods lowers both the toxicity (Ogbadu and Bassir, 1979) and production (Ogbadu, 1979, Ogbadu, 1980a, Ogbadu, 1981 and 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 with the suitable infrastructures 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 which was first intended to ensure safety of foods for astronauts during voyage has become a priceless tool for controlling microbial contamination in foods and pharmaceutical products (FDA, 2011) is also applicable to mycotoxin control (FAO, 2003). Developing a probiotic feed ingredient from a combination of mouldy Sorghum, *cassia tora* and spontaneous fermentation was shown to significantly reduce aflatoxin, fumonisin and ergosterol contents with marginal improvement in nutritive value of feed (Siruguri *et al*. 2009). Only one product of biological origin that is claimed to inactivate trichothecenes in feeds by enzymatic decomposition is available as a feed additive in several countries (Negedu et al. 2011).

62. Clinical treatments for conditions, such as HCC, have been tried with varying degrees of success. These range from preventative measure such as the use of Novasil clay being added to the diet to bind aflatoxin (Afriyie-Gyawu *et al.* 2008); and HVB immunisation (Kew 2005). Emerging technology of formulation of probiotics is another effective mycotoxin control method. The use of drugs can be considered in two parts, the use of compounds that block the cytochrome P_{450}s responsible for the activation of AFB1 to the carcinogenic 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, e.g., 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).

63. Although the intervention strategies discussed in previous paragraphs were focussed on aflatoxins, they are also applicable to *Alternaria* species. However, the peculiarity of conditions of growth and development of these fungi require specific control methods. The favourable conditions for growth of the fungi are warm weather (20-30^{o}c) and abundant dews, and ultraviolet is essential for spore formation (Manjunath *et al*. 2010). Therefore, under greenhouse growing conditions, the use of UV light absorbing film can greatly reduce the incidence of *Alternaria* species (Laemmlen, 2001). Similarly, the other primary intervention strategies are preventing long period of wetness on leaf surface and applying fungicide. Apart from good agricultural practices of farm sanitation, planting resistant crops, crop rotation and planting far apart or trimming leaves to avoid damp conditions, spraying crops with fungicides like azoxystrobin, pyraclostrobin, Bacillus subtilis, chlorothalonil, copper products, hydrogen dioxide, mancozeb, potassium bicarbonate, and ziram curtail *Alternaria* diseases.

64. Ergot alkaloids producing *Claviceps* species are also of great concerns to the sorghum industry. This is because of their worldwide prevalence and adverse health effects on pigs and poultry animals with obvious economic consequences. Therefore additional intervention strategies that are peculiar to them will be required to manage ergots alkaloids.. While the prevention and control methods earlier explained will also offset ergots to a great deal; two points are still worthy of notice. When pollination, flowering and/or fertilization ocur during cool (≥19^{o}C), wet and cloudy weather conditions, ergot synthesis on grain can be severe (Bandyopadyay et al. 1998). The authors therefore recommended adjustment of sowing dates and locations to avoid such ergot susceptible period. Moreover, breeding of seed with traits like fast rate of flower opening, effective self-pollination, rapid fertilization and other characteristics that contribute to shorter ergot-susceptible period, will greatly reduce ergot burden in sorghum.

Legislation

65. In order to safeguard consumers from the hazards of mycotoxins, many countries including 15 African countries (Sibanda *et al*. 1997, Fellinger, 2006, and Njobeh *et al*. 2010) have instituted legislation against some mycotoxins notably aflatoxins. According to these authors the maximum tolerable limits for aflatoxins 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 – 10 ppb). The lowest maximum allowable concentrations by countries that legislate against mycotoxin as recorded by (CAST, 2003) are 5 µg/kg for sterigmatocystin, 5 µg/kg for OTA, 100 µg/kg for ZEA, 1000 µg/kg for FB, 100 for T-2, 500 µg/kg for DON, 50 µg/kg for patulin and 500,000 µg/kg for ergot alkaloids. There seems to be no legislation against *Alternaria* toxins. Hence the need for in-depth toxicity studies of the fungi and subsequent enactment of regulatory limits.

66. While these maximum allowable limits would protect citizens from the dangers of mycotoxins, the biggest challenge of mycotoxin regulation in the developing countries is the lack of enforcement of legislation because of the informal food market system operated in these countries. In this market structure, raw agricultural produces from farms and storage barns are sold directly to consumers without being screened for mycotoxins neither are they subjected to inspection for spoilage. Further more government agencies charged with the responsibility of regulating mycotoxins are nonexistent in many countries and even where they are present; they are dysfunctional due to deplorable infrastructures and logistics. An effective mycotoxin surveillance and food quality control unit which ensures that all foods and feeds deem for human and animal consumption respectively are devoid of mycotoxins at harmful levels must be in place to implement mycotoxin legislation in Africa, the largest producer of Sorghum.

Prevention by Surveillance and Awareness Campaign

67. 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 foods and feed inspection for implementation of legislation for food safety, governments must build or strengthen already existing regional laboratories to monitor on regular basis, the mycotoxin contamination of foods, foodstuffs and feedstuffs making sure they are in compliance with set standards. Invariably, Africa and Asia in particular must reinforce her food quality control agencies and this can only be achievable if professionals working in such establishments possess the academic and 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.

68. Awareness of the adverse impact of mycotoxins should not be limited to the professionals in the food and feed and related industries but to the entire consumers. Public awareness campaign on impact and prevention of mycotoxins especially the notorious aflatoxins 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 therefore imperative for national and international bodies to partner with one another to effectively manage mycotoxins via sharing knowledge and expertise, and establishing research collaborations towards strengthening the capacity of the mycotoxicologists and laboratories in developing countries. It is only pertinent now to encourage scientists and institutions involved in mycotoxin research in the world to collaboratively seek accessible research grants from African Union, European Union and other foreign funding agencies for more effective investigation and control of mycotoxins.

CONCLUSION AND RECOMMENDATIONS

69. The increasing global importance of Sorghum as grains for food, feed and other industrial uses has been highlighted in this paper. This is in addition to its growing significance in export trade. In carrying out the assignment given by the 5th Session of CCF, this discussion paper filled the information gaps in the occurrence and types of mycotoxins in Sorghum and conditions favouring its development. This is in order to screen the general part of the exiting *Code of Practice (COP) for the Prevention and Reduction of Mycotoxin Contamination in Cereals* (CAC/RCP 51-2003) and determine its suitability in application to Sorghum. These efforts lead to recommendations proffered in the following section.

Recommendations

70. We wish to make the following recommendations:

i. The code of practice for management of mycotoxins in cereals focussed on ochratoxins, zearalenone, fumonisins and trichothecenes and since there are many other toxins in Sorghum as shown in this paper, it is only proper to amend the COP to take care of these toxins; if not all, at least the aflatoxins and *Alternaria* toxins. The amendment should be in line with the intervention strategies examined above. The reasons are as follows:

   a. The COP is silent on aflatoxins which are the commonest contaminant of Sorghum worldwide-table 4. The almost 100% presence of *A.flavus* worldwide-table 3 supports a more intensive attention to these toxins.

b. Alternaria species and their toxins as shown in tables 3 and 4 are very prevalent pre-harvest pollutants which need to be eliminated from the grain.

c. Phoma sorghina has been isolated from Sorghum since the inception of research on the grain and its toxins cytochalasin and tenuazonte are associated with the haemorrhage syndrome 'onyali' and so requires more attention

d. Similar to ‘c’ is Claviceps spp and ergot disease which are field fungi and mycotoxins in Sorghum that caused famine in Northern Cameroon in the early 1903 – 1906, and have been isolated from same grain in Zimbabwe and South Africa and in many parts of world. These should definitely be of concern.

e. The natural co-occurrence of moniliformin and fumonisins, and aflatoxins and sterigmatocystin should draw more attention to moniliformin and sterigmatocystin.

ii. While the general aspect of the COP is still relevant to Sorghum, the desirability of having publications on management of mycotoxins in cereals in a single document and the need to deal specifically with the field and storage fungi in Sorghum informs our recommendation for an annex to take care of at least aflatoxins and *Alternaria* sp in Sorghum.

iii. The proposed study on mycotoxins in Sorghum by FAO.WHO sponsored by Codex Trust Fund is commendable. However in view of rising profile of Sorghum worldwide, as shown in this discussion paper, this study should be diversified and extended to capture representative picture by including:

a. As many of the potential toxins as associated with the toxigenic fungi found in the grain.

b. Researchers on mycotoxins from significant Sorghum producing and exporting countries of the world identified in this paper, which include United States, Argentina, India, Australia, Sudan and Nigeria, and others.

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