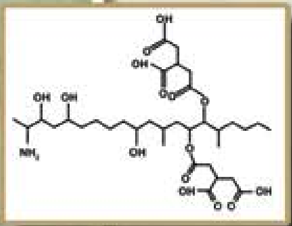
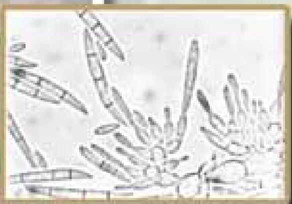
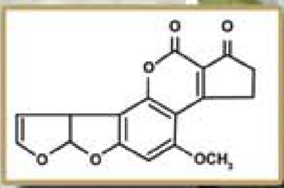
Management of Grain Mold and Mycotoxins in Sorghum







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Abstract

In sorghum, grain mold is an important biotic constraint in relation to grain quality and concerns about mycotoxin contamination. Grain molds and subsequent mycotoxin contamination are severe in the newly developed hybrids and varieties that are grown in warm humid environments and mature before the recession of the rains. A wide range of mold fungi including *Aspergillus*, *Alternaria*, *Cladosporium*, *Diplodia*, *Fusarium*, *Curvularia*, *Phoma* and *Penicillium*, are associated with the grain mold and mycotoxin production in sorghum. Extensive research work has been done on sorghum grain mold biology and epidemiological aspects; however, very little is known on mycotoxin contamination and its management. This bulletin carries brief descriptions about the important mycotoxins in sorghum, their effects on human and livestock health as well as economic impacts. On-farm trial samples from Andhra Pradesh (AP) and Maharashtra states were analyzed for mycotoxins (aflatoxins and fumonisins) and higher levels of aflatoxins (0-362 μg/kg) were found in AP samples. The mycotoxin contamination level in Maharashtra was negligible. Fumonisins contamination levels were much lower than the 5,000 μg/kg permissible limit. Management practices such as planting resistant cultivars, timed planting, harvesting, controlling pest and diseases, harvesting, drying, sorting and storage practices that reduce or remove mycotoxin contamination in sorghum are mentioned briefly. Descriptions/methods of mycotoxin control through a decontamination process and alternative uses of mycotoxin contaminated sorghum grain for breweries and bio-fuel (ethanol) production are also described here.

Acknowledgements

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Global Theme on Crop Improvement

Management of Grain Mold and Mycotoxins in Sorghum

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Foreword

Concerns about food safety are growing among researchers, policy makers, traders and consumers. Among the several issues pertaining to food safety, mycotoxin contamination in food and feed occupies a prominent place. Globally, about 25 percent of food spoilage is due to mycotoxins, with losses ranging from US$ 0.5 to 1.5 billion in the USA alone. The Food and Agriculture Organization (FAO), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Consultative Group on International Agricultural Research (CGIAR) recognize the economic and health implications of mycotoxins as an important constraint to the goal of improving human health and well-being through agriculture, and pursue various strategies to eliminate mycotoxin contamination in food and feed.

Mycotoxin contamination in commodities is gaining global significance due to its deleterious effects on human and livestock health as well as international trade. Given its harmful effects, considerable attention has to be paid to preventing or reducing contamination to ensure safe food and feed supply. In the recent past, a serious outbreak occurred in Kenya, with 317 human aflatoxicosis cases and more than 125 deaths reported due to consumption of aflatoxin-contaminated corn.

Exposure to aflatoxin leads to liver and other cancers, child growth retardation, malnutrition, immunosuppression and synergistic effects with hepatitis viruses B and C in humans. The fungi produce the contaminating toxins during grain development and post-harvest under storage conditions. Mycotoxin contamination has become unavoidable under present production, processing and storage conditions; hence the urgency to study the phenomenon in order to maintain a competitive edge in contemporary agriculture.

Our scientists have been working on integrated management of sorghum grain mold and mycotoxins through host plant resistance and cultural and agronomic practices to mitigate mycotoxin contamination in staples. A number of grain mold-resistant germplasm lines with varying characters and agronomic background have been used extensively in breeding programs to generate advanced breeding lines and hybrid parents with moderate to high levels of resistance to grain molds and mycotoxins.

Since mycotoxin contamination cannot be seen and is difficult to eliminate totally from grains, low-cost detection tools are essential to estimate toxin levels. I am proud to say that ICRISAT has developed a low-cost ELISA-based technology for estimating mycotoxins in commodities. The technology was used successfully in Malawi, due to which the country was able to revive its groundnut export market to Europe and other countries.

This publication is an outcome of the CFC-FAO-ICRISAT project on "Enhanced utilization of sorghum and pearl millet grains in poultry feed industry to improve the livelihoods of small scale farmers in Asia". I would like to take this opportunity to thank the Common Fund for Commodities for its continued support to our research and development program.

I am sure that this publication with its vast storehouse of knowledge on managing grain mold and mycotoxins in sorghum will generate interest in the research community and more importantly, create greater awareness among various sections of society including policy makers.

William D Dar
Director General
ICRISAT

About the project

The production of sorghum and pearl millet is declining for the last two decades at an annual rate of 0.7 globally. Within Asia, India, China and Thailand are the major producers of sorghum and pearl millet (Sorghum: 9.3 million ha area with a production of 7.3 million tons; and pearl millet: 9.5 million ha area with a production of 8.5 million tons in India, sorghum: 0.8 million ha area with a production of 3.1 million tons in China and 0.1 million ha area with a production of 0.2 million tons in Thailand). In these countries in Asia, market demand for food uses of sorghum and pearl millet grain has declined with growth in incomes and subsequent changes in consumer preferences. Grain supply in the market has been affected by a relatively slower increase in productivity compared to competing crops as well as policy-induced factors.

The demand for poultry feed is increasing due to the fast growth (by 15-20%) of the poultry sector, while the usual energy source in poultry feed, maize's growth rate is limited to only 2-4 percent annually. Hence some poultry feed manufacturers are using sorghum and pearl millet in poultry feed formulations to some extent whenever there is a shortage of maize supply. Therefore, it was felt that farmers will benefit if information on the recommended package of practices and supply of seeds of improved cultivars and improved input supply, and grain harvesting, processing, storage, bulking and market linkages between the grower/ farmer and poultry feed manufacturer are facilitated.

Project objectives:

- To mobilize groups of small-scale sorghum and pearl millet farmers in order to improve crop productivity and enhance skills in harvesting, bulking, storage and handling practices of grain
- To provide the information on the improved production packages and seeds of improved cultivars by involving private seed companies
- To provide other inputs such as credits, fertilizer, etc, by organizing farmers into groups for effective input delivery mechanisms and
- To link farmer groups with poultry feed manufacturing companies and poultry producers to enable the farmers to sell the bulked grain in the villages to poultry feed manufacturers to benefit both groups

The project will be operational in the following target areas in three countries:

1. Two clusters in Mahbubnagar district of Andhra Pradesh state in India
2. Three clusters in Beed and Parbhani districts of Maharashtra state in India

3. One cluster in three counties Beizen, Heishan and Yi of Liaoning province in China
4. One cluster in Suphen Buri, Kanchana Buri and Nakon Sawan provinces in Thailand

Each of the five clusters in India and the two in China and Thailand consist of 250 farmers coming from 5 to 6 villages.

The project was funded by the Common Fund for Commodities (CFC), the Netherlands, in partnership with the Food and Agriculture Organization of the United Nations. The project in coalition mode brings together partners from the agricultural research institutes, universities, NGOs, poultry feed manufacturers, poultry growers and farmers groups from three countries. The three-year project, which commenced on 1 May 2005 has a total funding of US$ 2.1 million. While US$ 1.5 million is from the CFC, as a grant, the remaining resources will be in kind contributions by the Project Executing Agency (PEA) and other partner institutions.

Introduction

Grain mold and mycotoxin contamination in sorghum are considered as one of the most important constraints globally for grain quality and production (Frederiksen et al. 1982, ICRISAT 1987). Sorghum grains suffer from infection and colonization by several mold fungi during the panicle and grain developmental stages. The infection results in molded grain or grain mold, also referred to as 'blackening'. Many species of fungi cause grain mold in sorghum. Most grain mold fungi are relatively non-specific and can colonize several species of plants (cereals, oilseeds, spices and nuts). *Aspergillus*, *Alternaria*, *Cladosporium*, *Diplodia*, *Fusarium*, *Curvularia*, *Phoma* and *Penicillium* are among the prevalent grain mold pathogens of sorghum (Ahmed and Ravinder Reddy 1993, Bandopadyay et al. 2000, Thakur et al. 2006).

Grain mold occurs every year to varying degrees on rainy season sorghum. Most grain mold pathogens become associated with the panicle seeds in the field and under certain environmental conditions (moderate temperature and high relative humidity) and grain moisture, these molds can grow within the colonized seed and even spread to adjacent seed during drying, threshing, transport and storage (Navi et al. 2005). The degree of growth on the seed and the appearance of the mold vary with the species of fungi and the prevailing environmental conditions. Incidence (the proportion of moldy panicles) and severity (the proportion of infected grains on a panicle) of disease depends on pathogen race, cultivar and environmental conditions.

Most of the grain mold fungi deteriorate/reduce grain quality; cause loss in seed mass, grain density, seed germination, storage quality; affect feed efficiency and grain processing characteristics; and can also affect animal and human health due to associated allergenicity and hypersensitivity with the inhalation of moldy spores (Indira and Rana 1997, Somani and Indira 1999, Maiti et al. 1985). Additionally, some grain mold pathogens produce harmful secondary metabolites, known as mycotoxins that are toxic to animals and humans. Only certain strains of certain fungal species have the potential to produce mycotoxins. Most important mycotoxins produced by grain mold fungi are aflatoxins, fumonisins, ochratoxins, trichothecenes (DON, T2), zearalenone and alternaria toxins (Bhat et al. 1997, Bilgrami and Choudhary 1998).

Symptoms

Depending on the fungi involved, the grain maturity stage and severity of infection, the symptoms could be highly variable (Fig. 1). Severely infected grain is fully covered with mold; partially infected grain may look normal and discolored. Fungal growth occurs at the hilar end of the grain, and subsequently extends to the pericarp surface. Severe infection in the field results in multicolored grains due to infection with various colored fungal mycelium and sporulating structures depending on the fungal pathogen involved in colonizing the sorghum grains (Bandopadhyay et al. 2000, Castor 1981, Navi et al. 1999). Discoloration of the grains due to fungal infection is more prominent on white-grain than in brown/red grain sorghums. Other types of damage that arise from grain mold relate to storage quality (Hodges et al. 1999), food and feed processing quality, and market value. Certain grain mold pathogens have consistently been associated with losses in seed mass.

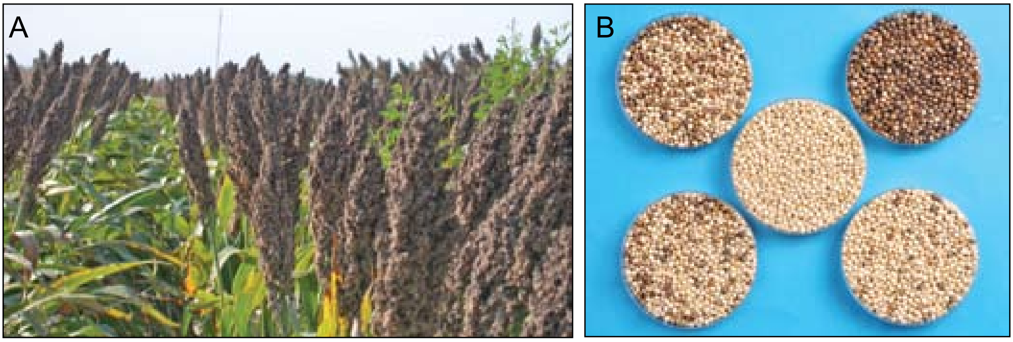


Figure 1. A) Sorghum crop affected by grain mold disease. B) Different levels of grain mold infected sorghum (healthy grain in the center).

Economic significance

Production losses due to sorghum grain mold range from 30 percent to 100% depending on cultivar, time of flowering and prevailing weather conditions during flowering to harvesting (Singh and Bandopadhyay 2000). It is difficult to estimate accurate losses caused by the disease since it involves the assessment of losses from production to marketing and finally utilization of the grain or seed. On a conservative scale, the annual economic loss due to sorghum grain mold in Asia and Africa has been estimated to be US$ 130 million (ICRISAT 1992).

In sorghum, grain molds are important in relation to grain quality and concerns over mycotoxin contamination. This bulletin gives general information about mycotoxin effects on human and livestock health, as well as economic impacts; and some approaches to reduce the effect of toxins on human beings and animals. This bulletin also gives information on sorghum and highlights work done on mycotoxin problems of other cereals such as maize and on oil seeds such as peanuts and cotton seed.

Mycotoxins

Mycotoxins are toxic secondary metabolites produced by various genera of fungi that can contaminate 25 percent of crops and processed food and feed. Mycotoxin producing fungi are ubiquitous, prevalent in soil and air, and widespread at all levels from production to processing and also in the supply chain (Chelkowski 1998, Horn 2005). Health risks associated with the consumption of cereal products contaminated with mycotoxins are recognized worldwide and depend on the extent to which they are consumed in a diversified diet. Outbreaks of human intoxications associated with mycotoxin contaminated food have been reported from India, China and Kenya with symptoms including nausea, abdominal pain, throat irritation, diarrhea, dizziness and headaches (Beardall and Miller 1994, Fung and Clark 2004). In 2004, an outbreak of aflatoxicosis occurred in Kenya and a total of 315 cases with 125 deaths were reported due to consumption of maize contaminated with aflatoxins (Lewis et al. 2005, Probst et al. 2007).

Mycotoxin contamination is regarded as unavoidable and it is not possible to entirely prevent their occurrence during cultivation, harvest, storage and processing operations by currently used agronomic and manufacturing practices. This necessitates risk assessment carried out by regulatory bodies in several countries to help establish regulatory guidelines to protect public health (FAO 2004, Viswanath 2004, van Egmond and Jonker 2005). It has been estimated that annual costs related to mycotoxins for crop loss, research and monitoring range from US$ 0.5-1.5 billion a year in the United States alone (Cardwell et al. 2001, Robens and Cardwell 2005). Under favorable conditions of temperature and humidity, the fungi grow on most foods resulting in production of the toxins. Among the several mycotoxins, aflatoxins produced by Aspergillus (Fig. 2) and fumonisins produced by Fusarium species (Fig. 3), are considered important in sorghum because of their deleterious effects on human and livestock health as well as trade (Bhat et al. 2000, Bilgrami and Choudhary 1998, Vasanthi and Bhat

1998). There is continuous need to protect the health of humans and livestock by limiting their exposure to mycotoxins because of their toxicological manifestations, which include stunted growth in children, immuno-suppression, mutagenicity, estrogenic, gastrointestinal, uro-genital, vascular, kidney and nervous disorders and cancer. Mycotoxins can also be metabolized by animals fed with contaminated grains and passed into milk, eggs, meat and organs, thus entering the food chain once again (Williams et al. 2004, Wild 2007).

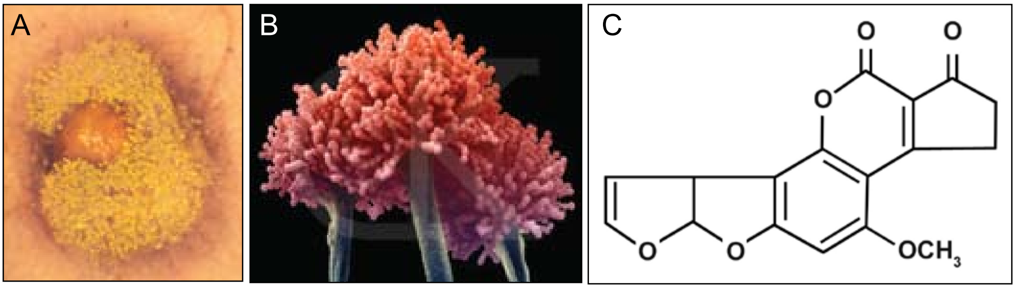


Figure 2. A) Sorghum grain infected with A. flavus. B) A. flavus under scanning electron microscope. C) Aflatoxin B1 structure.

Effects of Mycotoxins

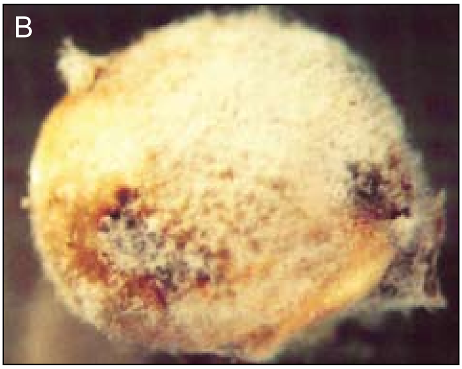
On grain

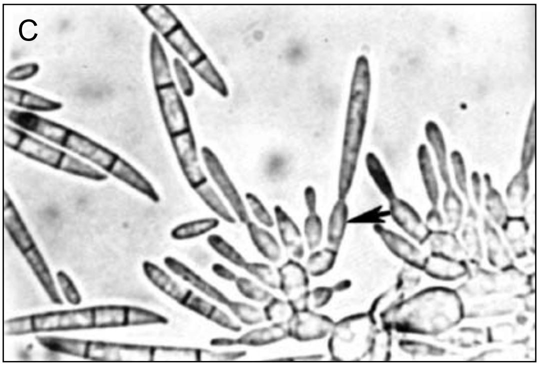
- Marked deterioration in grain quality
- Discoloration of grain
- Reduces nutritional value of grain
- Contaminated grain lots are unfit for the market and consumption
- Seed germination is affected leading to poor plant stand in the fields
- Severely affects the export of the grain and its products.

On health

Aflatoxin

- Carcinogenic and can cause liver and other cancers in humans and livestock
- Synergistic with Hepatitis B and Hepatitis C viruses
- It lowers the body's normal immune response to invasion by foreign substances
- It impairs growth in children notably and causes childhood cirrhosis
- Aflatoxin exposure decreases protein synthesis
- Acute intoxication leads to mortality in humans and livestock





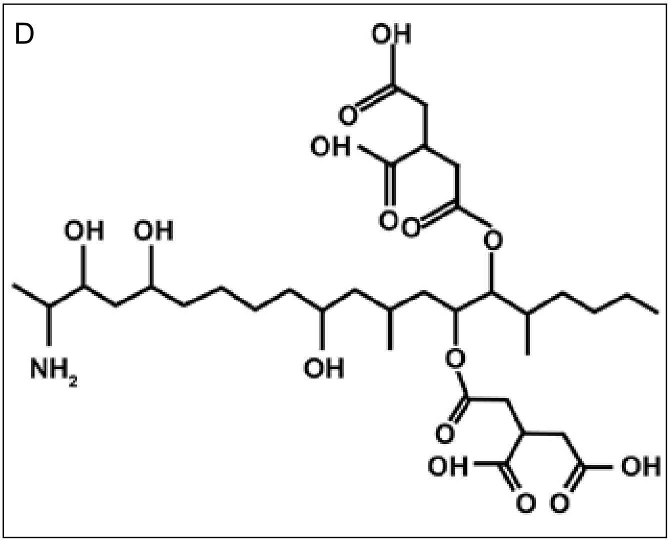


Figure 3. A) Sorghum infected with F. verticelloides (right) and healthy seed (left).
B) F. verticelloides growth on sorghum seed C) Macro and micro conidia and macroconidiophore (arrowed) of F. verticelloides
D) Fumonisin B1 structure.

- Accelerates the progression of HIV-AIDS and significantly reduces the survival span of HIV-AIDS affected persons
- In poultry and livestock, aflatoxins can cause severe and sudden anorexia, convulsive movements, feed refusal, loss of weight (Fig. 4), discolored liver (Fig. 5), reduced egg production, reduced energy conversion rate and milk contamination
- Efficiency of food use is less consistent in livestock and leads to reduced growth rate.

Fumonisins

- May cause esophageal cancer in humans
- Ingestion of fumonisin-contaminated maize has been associated with spontaneous outbreak of leucoencephalomalacia in horses, a neurological syndrome characterized by focal, often extensive, liquifactive necrosis of the white matter of the cerebrum, and white acute pulmonary edema in pigs.
- Renal injury and liver cancer in rats, immuno-suppression in chickens, toxicity to broiler chicken and chicken embryos, nephro-toxicity and brain hemorrhage in rabbits.

Figure 4. Growth reduction in poultry due to aflatoxin in feed at different levels (left normal birds and right severely affected. Source: MVLN Raju).

Figure 5. Aflatoxin affected chicken liver (Source: MVLN Raju).

Economic impacts of Mycotoxins

Producer costs

Crops

- Yield loss, restricted markets, non-marketable products, price discounts
- Increased product cost, increased post-harvest cost, difficulty obtaining loans on stored grains
- Disposal of useless grains, monitoring and sampling cost

Livestock and dairy

- Higher mortality rates, reproductive failures (abortions), lower egg and meat production
- Reduced feed efficiency, higher feed cost, reduced disease immunity, vaccine failures, increased medicine cost
- Lower milk production, unmarketable milk, monitoring and testing

Handler/distributor cost

- Extra drying cost, excess storage capacity, losses in transit
- Loss of markets, monitoring and testing

Processor cost

- Restricted markets, loss of markets, reduced demand, product loss
- Insurance premium, litigation costs, monitoring and testing

Consumer and social costs

- Less nutritious food, higher product price, possible health problems
- Regulatory costs, research and education, lower foreign exchange earnings, increased cost of imports

Grain molds on poultry feed quality

The severity of mycotoxin contamination is less in sorghum as compared to that of maize owing to its hard seed coat. Occurrence of fumonisins is higher in sorghum than on maize, but the tolerance levels of fumonisins in chicken are at higher levels than aflatoxins.

Factors that favor grain mold infestation and mycotoxin production

Significant levels of grain mold infection can occur in sorghum in the field. Damp conditions from the time of flowering to harvest, insect infestation, delayed harvesting and improper drying and storage are important factors that contribute to this. Some common factors for grain mold contamination are:

Pre-harvest

- Growing susceptible varieties especially with compact panicle
- Cultivating improved, short and medium duration cultivars that mature before the end of the rains
- Over-crowded plant population in the field
- Warm wet conditions between flowering and harvest
- Plants suffering from other diseases
- Insect damage to developing grain in the panicle

Post-harvest

- Harvesting over-matured crop
- Stacking the harvest produce including the panicle for unduly long periods
- Delayed drying and grain damage at the time of threshing
- Stored grain with >10 percent moisture content

- Insect damage to grains in the storage
- Rewetting of the grains in storage due to moist ground or roof leakage

Integrated grain mold and mycotoxin management options

Mycotoxins cannot be considered as a single group of toxicants on the basis of their mechanism of action, and for the same reason, it would be impossible to develop one single control method that would ensure the reduction of all mycotoxins present in agricultural commodities. In addition, mycotoxin contamination distribution is heterogeneous in nature, making for complicated sampling and analysis. Mycotoxin production depends on various environmental factors in the field and/or during storage and remains a unique challenge to food and feed safety.

The control of mycotoxin in food and feeds require a combination of surveillance, regulatory and quality assurance procedures. The proposed control program for processed foods and feeds should be based on the Hazard Analysis and Critical Control Point (HACCP) approach, and should involve strategies for prevention, control, good manufacturing practices and quality control at all stages of production, from the field to the final consumer. The decision-making process for the control of mycotoxins is complicated. The presence of multiple toxins in the same system is a new cause for concern, since toxicological information on the effects of simultaneous exposure is still very limited. However, in a diverse human diet, exposure will be to multiple toxins at low concentrations and intermittent rates over long periods of time. The ultimate effect of such constant exposure is still unknown. Prevention through pre-harvest management is the best method for controlling mycotoxin contamination; however, if contamination occurs, the hazards associated with the toxins must be managed through post-harvest procedures, if the product is to be used for food and feed purposes. In an ideal integrated management system, mycotoxin contamination should be minimized in every phase of production, harvesting, processing and distribution.

Pre-harvest

- Plant sorghum varieties or hybrids that are less susceptible to grain molds in areas with perennial grain mold problems (hybrids tolerant to grain molds: PVK 801, CSH 5 and CSH 6)
- Good crop management practices, such as crop rotation, timed planting and harvesting
- Adjust the planting date to avoid end-of-season rains coinciding with the harvest time. The harvest date should be at least 10-15 days before normal harvest time

- Maintain optimal plant population in the field
- Take necessary precautions to control the pest and diseases of the crop by adopting pest management practices
- Harvest the crop at right maturity (physiological maturity in sorghum) and avoid over maturity of the crop. (Sorghum is considered to be physiologically mature when a black layer forms at the hilar end of the grain)

Post-harvest

- Harvest the panicles, dry them quickly (3-5 days) under natural sunlight to the grain moisture level <10 percent
- Sort the moldy and damaged panicles
- Avoid grain damage during panicle threshing
- Avoid stacking the harvested produce (along with panicle) in the field
- Separate the moldy, colored/discolored, shriveled and small immature grain
- Stack the grain-filled gunny bags on a wooden plank and store them in well aerated, moisture proof storage
- Prevent insect damage to the stored grain through suitable fumigation in the storage
- Monitor sorghum grain at all production, process and storage stages for mycotoxin contamination

Natural occurrence of mycotoxins in sorghum

The biology and epidemiology of sorghum grain mold have been investigated extensively; however, the information on mycotoxin production is very scanty. Keeping this in mind, we have worked exclusively on the natural occurrence of mycotoxins in sorghum. From the on-farm trials, about 60 sorghum grain samples at harvest as well as from farmer storages were collected from 10 villages in Udityal cluster, Mahbubnagar district, Andhra Pradesh, India. Similarly, 149 sorghum samples at harvest were collected from 13 villages representing 3 clusters in Parbhani and Beed districts of Maharashtra state. From each field, sorghum samples at maturity were collected from five spots, and a composite sample was prepared. Similarly, from each farmer storage, grain samples were drawn from at least five bags and all the grain were pooled to get a composite sample. From these composite samples sub-samples were taken for mycotoxin analysis.

A total of 209 sorghum grain samples were collected from 209 farmers from 23 villages in the states of Maharashtra and Andhra Pradesh. Methanol extracts of all sorghum samples were analyzed by indirect competitive ELISA (Fig. 6)

Figure 6. ELISA kit for mycotoxin detection in grain and feeds

for mycotoxin contamination (Waliyar et al. 2005). Results (Table 1) indicate that aflatoxin contamination appears to be the predominant one. Aflatoxin contamination was higher in grain samples from Andhra Pradesh than those from Maharashtra. Fumonisin contamination levels were much lower than the 5,000 μg/kg permissible limit. Moreover, the farmer storage samples from Andhra Pradesh also had higher levels of aflatoxin contamination. About 11 percent of the samples from farmers' fields/storages were unfit for consumption or marketing. Since a very low level of aflatoxin was observed in the samples from Maharashtra, sorghum from these areas can be used for food and feed purposes, whereas sorghum from Andhra Pradesh can be used for production of alcohol and other purposes (Waliyar et al. 2007).

Post-harvest control through decontamination

Although prevention is the best control strategy, mycotoxin contamination will still occur sometimes. For post-harvest control, decontamination is an important tool to avoid consumer exposure to toxins. Several decontamination strategies have been reported for various mycotoxins, and specific information on each method is readily available in the literature. Some traditional processing methods are good either for physically separating toxins or for chemically inactivating them. However, the effectiveness of each processing method should be evaluated for the specific commodity and toxin present in the system. The main aim of the decontamination is to inactivate, destroy or remove the toxin without any change in the nutritive value and food/feed acceptability of the product.

Table 1. Natural occurrence of mycotoxins in farmers' sorghum samples

Village	No. of fields	Aflatoxin μg/kg			Fumonisin μg/kg		
		Range	Village mean	No. fields >30 μg/kg	Range	Village mean	No. fields >100 μg/kg
Farmer field samples, Mahbubnagar district, Andhra Pradesh							
Udityal	6	2-362	67.6	1	12-205	71.9	1
Chouduru	6	8-211	91.6	3	8-117	29.7	1
Surarum	6	0-13	4.5	0	10-139	54.4	1
Bandapalli	6	5-27	15.4	0	1-254	72.4	1
Bheemaram	6	0-17	7.2	0	0-89	37	0
Farmer storage samples, Mahbubnagar district, Andhra Pradesh							
Veerannapalli	6	0-238	40.4	1	0-61	24.4	0
Kakarjala	6	0-3	0.9	0	0-152	42.6	1
Macharam	6	0-157	44.1	2	0-94	36.7	0
Gunded	6	0-16	3.7	0	0-122	45.1	2
Nerellapalli	6	0-317	53.7	1	14-135	56.9	2
Farmer field samples, Parbani and Beed districts, Maharashtra							
Koak	37	0-8	1.2	0	0-441	93.8	16
Maak	28	0-63	4.3	1	0-375	67.7	6
Sheik	15	0-5	0.6	0	0-245	50.3	3
Shrirampur	12	0-6	0.5	0	0-91	35.7	0
Anjanpur	7	0-3	0.8	0	0-71	16.2	0
Rohatwadi	6	0-1	0.2	0	0-17	2.9	0
Thirumalwadi	6	0-2	0	0	0-31	5.1	0
Begarwadi	6	0-2	0.8	0	0-76	28.2	0
Domri	6	0	0.2	0	0-20	3.4	0
Wodzari	6	0-2	0.3	0	0-127	21.2	1
Tofaha	6	0-2	0.8	0	0-24	6.3	0
Bhusarwadi	6	0	0	0	0-15	2.5	0
Naigaam	8	0-3	0.5	0	0-7	1.6	0

Physical methods of mycotoxin removal

Once a contaminated product has reached a processing facility, clean-up and segregation are the first control options. These procedures are usually non-invasive and, except for milling, will not alter the product significantly. In some cases, these are the best methods of reducing mycotoxin presence in final products. For example, when peanuts are processed, a significant amount of aflatoxins can be removed by electronic sorting and hand-picking (Table 2) (Dickens and Whitaker 1975). Separation of mold-damaged maize and/or screening can significantly reduce fumonisin and aflatoxin concentrations (Murphy et al. 1993). In addition, the removal of rot from apples significantly reduces the patulin content in the final product (Lovett et al. 1975). Although some contamination may persist, physical removal represents a good alternative for industry (Lopez-Garcia and Park 1998).

Table 2. Effectiveness of post-harvest aflatoxin management strategies at the processing level[1]

Technology	Aflatoxin level (µg/kg)	Reduction (%)	Cumulative reduction
Farmer stock	217.0	-	-
Belt separator	140.0	35	35.0
Shelling plant[2]	100.0	29	54.0
Color shorting[2]	30.0	70	86.0
Gravity table[2]	25.0	16	88.0
Blanching/color sorting	2.2	91	99.0
Color resorting	1.6	27	99.3

1 Results from processing of a 40,000 kg segregation I lot of contaminated peanuts
2 Data based on medium-category peanuts only
Source: Park and Liang 1993.

Mechanical sorting devices have also been suggested for the kernels of larger sizes such as almonds, Brazil nuts and pistachio nuts. Separation of damaged almonds can be done on the basis of energy reflected from the particles illuminated by UV Light (Schade et al. 1975). Aflatoxin contaminated Brazil nut kernels were found to exhibit yellow fluorescence while pistachio nuts showed brown spots when illuminated under UV light at 360 nm (Steiner 1992). An effective method for reducing levels of aflatoxin has also been reported through flotation and density segregation of toxic kernels in corn (Huff and Hagler 1985) and peanuts (Cole 1989).

Milling is traditionally used for grain processing. This method will separate the grain into different fractions (Bennett and Anderson 1978). It is therefore important to identify the fractions that remain toxic so that they can be diverted to lower-risk uses or subjected to decontamination procedures (Scott 1984).

Some phases of industrial processes can reduce specific mycotoxins to a certain degree through thermal inactivation, but some mycotoxins are chemically stable and will not be completely destroyed at processing temperatures. Thus, thermal inactivation for a particular toxin should be evaluated for the temperatures of a specific process. Roasting is a good method for such commodities as peanuts and coffee. As mentioned before, if a traditional processing method is an effective decontamination procedure, it should be the first choice for management of a particular product (Lopez-Garcia and Park 1998).

Irradiation may also be an option for mycotoxin control. A completely satisfactory way of destroying mycotoxins that have already been formed has not been identified. However, irradiation may be considered as a method to control mycotoxin-producing molds in certain products (Lopez-Garcia and Park 1998).

Decontamination through enterosorption

Clay minerals can selectively adsorb aflatoxins tightly enough to prevent their adsorption from the gastrointestinal tract. Several claims have been made for different adsorption agents, but their efficiency in preventing aflatoxicosis varies with the adsorbent (Phillips et al. 1993). With enterosorption, there is also risk that non-specific adsorbing agents may prevent the uptake of micronutrients from the food (Mayura et al. 1998). In vitro tests of hydrated sodium calcium aluminosilicates (HSCAS) suggest that there is little other adsorption of micronutrients. The use of HSCAS additives in contaminated feeds has proven effective in preventing aflatoxicosis in turkeys, chickens, lambs, cattle, pigs, goats, rats and mice (Harvey et al. 1989, Phillips et al. 1990, Phillips et al. 1993). The use of radio-labeled aflatoxin shows that the addition of clay in a proportion of 0.5% of the volume to a contaminated feed reduced exposure in chicks by 95% (Phillips et al. 1993). Selected calcium montorillonites have proven to be the most highly selective and effective of these enterosorbents. This approach is now widely used in animal production industries worldwide and HSCAS is estimated by one manufacturer to be added to 10% of all animal feeds (Grant 1998, Grant and Phillip 1998).

Biological decontamination

Biological methods have been explored as options for mycotoxin decontamination. In the fermenting industry it has been found that aflatoxins are not degraded during fermentation, although the toxins are absent from the alcohol fraction after distillation. Aflatoxins are usually concentrated in the spent grains. When contaminated products are used for fermentation, it is therefore important to determine the end use of the contaminated by-products. It should be emphasized that biological methods demonstrating effective decontaminating properties usually depend on specific compounds produced by selected microorganisms. When a specific compound is found to be a good decontaminating agent, it is usually more efficient and economical to add the active agent directly. Studies suggest that certain fungi, including *A. parasiticus*, degrade aflatoxins, possibly through fungal peroxidases. Fermentation with yeasts has also been effective in destroying patulin and rubratoxin B (Lopez-Garcia and Park 1998).

Chemical inactivation

Numerous studies have evaluated the use of chemicals for the inactivation and hazard reduction of selected mycotoxins. Most studies have, however, focused on aflatoxins and application to animal feeds. Ammoniation is the chemical method that has received the most research attention. Extensive evaluation of this procedure has demonstrated that it is an efficacious and safe way of decontaminating aflatoxin-contaminated feeds. More than 99 percent effective, this process has been used selectively with success in the United States, France, Senegal, Sudan, Brazil, Mexico and South Africa, in some cases for almost 20 years. The two ammoniation processes primarily used for aflatoxin contamination in maize, peanuts, cottonseed meals are: high pressure/high temperature (HP/HT); and atmospheric pressure/ambient temperature (AP/AT) where the HP/HT process is used for feed mill operations and AP/AT is primarily for on-farm use. The AP/AT process is limited to dealing with aflatoxins in whole-kernel seeds/nuts. Ammoniation has been shown to be less effective against fumonisin contamination. For aflatoxin control, however, practical applications together with research results strongly support the use of ammonia treatment. Other chemical-based procedures utilizing, for instance, monomethylamine, lime or urea/urease have been reported. In-depth reviews and articles have been published and these can be used as a basis for policy-making decisions (Lopez-Garcia and Park 1998).

Nixtamalization, the traditional alkaline treatment of maize used to manufacture tortillas in Latin America, partially degrades aflatoxins and fumonisin, but the residual molecules can either be regenerated by digestive processes or become more toxic (Price and Jorgensen 1985). The addition of oxidizing agents, such as hydrogen peroxide, has been shown to be an effective aid in nixtamalization. These chemicals degrade aflatoxins and fumonisin, thereby reducing toxicity (Lopez-Garcia 1998). Some recent studies have shown that hydrogen peroxide and sodium bicarbonate are effective for simultaneous degradation/detoxification of aflatoxins and fumonisin.

Other chemical processes that have shown promise in controlling aflatoxins are the use of sodium chloride during thermal processing, sodium bisulphite at various temperatures and ozonation. Wet and dry milling processes, which are widely used for maize and cereal grains, have been shown to result in reduced mycotoxin levels (zearalenone, fumonisins, aflatoxins, trichothecenes and ochratoxin A) in several fractions such as milling solubles, gluten, fiber, starch and germ (Lopez-Garcia and Park 1998).

Use of moldy and mycotoxin contaminated sorghum grain

Starch derived from sorghum has wide applications in breweries, pharmaceutical, textile and paper industries. Grains and grain starch are used for various fermentations to produce ethanol, citric acid, lactic acid, erithrotol and sorbitol. Grain starch is hydrolyzed by combination of enzymes and the free sugar in the starch is fermented to produce ethanol. The grain alcohol is much cleaner because of low sulfates and aldehydes and is used for potable purposes. Moldy and mycotoxin contaminated sorghum grains, which are not fit for food and feed purposes can be used for industrial purposes. Taking the price advantage of moldy grains, they are being used in some breweries in India to produce table alcohol (Sheorian et al. 2000). However, when moldy grains are used in breweries, care should be taken when using the alcohol in the food chain because there are good chances that alcohol may contain mycotoxins. The reason is that most of the mycotoxins are stable during the fermentation. Aflatoxin is not completely removed during the beer brewing process and 18-27 percent of toxin remains unaffected. Also, 96 percent of ochratoxins remained during the beer brewing process and none was destroyed during pasteurization and boiling of the beer (Chu et al. 1975). Aflatoxin from contaminated corn does not go into the alcoholic distillate, but accumulation of aflatoxin in spent grains is a potential problem when using this material as animal feed. Further decontamination procedures must be used if these by-products are to be used as animal feed (Dam et al. 1977, Lindroth 1980).

Recently, government and industrial policies in many countries to blend 5-20 percent ethanol with conventional petrol stimulate a lot of demand for ethanol as bio-fuel (Reddy et al. 2005). Mycotoxin contaminated sorghum grain can be used for this purpose. Also, it has a three dimensional effect – it helps the farmers to market the moldy grains; reduces entry of toxin contaminated grain directly into the diets of poor people in the semi-arid tropics and also protects the health of the people.

Conclusion

Mycotoxins are a chemically diverse group of fungal metabolites that have a wide variety of toxic effects. In a normal varied human diet, constant exposure to low levels of several toxins is possible. Information on the potential interactions among all these compounds is still very limited. Furthermore, mycotoxins are known to affect animal and human health. The development of practical control and management strategies is, therefore, essential to ensure consumer safety. Because of the unpredictable, heterogeneous nature of mycotoxin contamination, 100 percent destruction of all mycotoxins in all food systems is not considered a practical option. There is no single solution to help minimize or eliminate the mycotoxins from food and feed because of the involvement of several factors for fungal invasion and subsequent toxin production. However, a practical approach would be the use of a HACCP-based system, in which contamination is controlled throughout production and post-production operations (Table 2). The procedures referred to are used by the peanut industry in the United States while processing peanut butter for human consumption.

Integrated mycotoxin management systems should consider control points from the field to the consumer. With this approach, every phase of production would help reduce the risk, so that by the time the final food or feed reaches the consumer the hazards associated with mycotoxin contamination have been minimized. Simple low-cost ELISA based detection and estimation technologies for monitoring the commodities, foods and feeds will greatly help to remove or reduce mycotoxin contamination. Continued research is required in these areas to provide more effective management of the risks posed by mycotoxin contamination. In the meantime, procedures that have proved effective for specific mycotoxins and/or commodities should be evaluated for other applications. Alternatively, mycotoxin contaminated sorghum should be exploited to produce ethanol and other products, which can be used for other than food and feed purpose, especially as bio-fuels.

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