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Fungi and mycotoxins in stored foods

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This review focused on the worldwide contamination of foods and feeds with mycotoxins as a significant problem. Mycotoxins are secondary metabolites of molds that have adverse effects on humans, animals, and crops that result in illnesses and economic losses. Aflatoxins, ochratoxins, trichothecenes, zearelenone, fumonisins, tremorgenic toxins, and ergot alkaloids are the mycotoxins of greatest agro-economic importance. Factors influencing the presence of mycotoxins in foods or feeds include environmental conditions related to storage that can be controlled. Other extrinsic factors such as climate or intrinsic factors such as fungal strain specificity, strain variation, and instability of toxigenic properties are more difficult to control. The economic impact of mycotoxins include loss of human and animal life, increased health care and veterinary care costs, reduced livestock production, disposal of contaminated foods and feeds, and investment in research and applications to reduce severity of the mycotoxin problem. Although efforts have continued internationally to set guidelines to control mycotoxins, practical measures have not been adequately implemented.

Key words: Fungi, mycotoxins, aflatoxins, contamination, relative humidity, safe moisture content.

INTRODUCTION

Fungi are a subdivision of the subkingdom Thallophyta. They have a well defined nuclei but lack the chrophyll which is a characteristic of most other plant (Mavor and Harold, 1966). They also lack vascular tissue but made up of an assimilative body which may be amoeboid or unicellular in some species, but typically are made up of multicellular branching filaments called hyphae reproducing asexually by the means of spores (Talbot, 1971). They are heterotrophs feeding on substrates of plants and animals.

The term moulds and yeasts have no taxonomic significance, but are useful in describing the most predominant forms of fungi. The terms moulds and yeasts are not mutually exclusive, since many fungi are moulds in their normal saprobic growth but are yeast like under modified growth conditions or in animal tissues. Moreover,any fungi whose predominant form is yeast or Yeast- like may exhibit mould like structures when grown under appropriate conditions (Moore and Jaciow, 1979).

Many fungi are pathogens of plants grown for food, while a smaller number are agents of diseases in animals, including man. They attack and destroy raw and manufactured products resulting in great economic loss. On the other hand, they are useful to man: food yeast (a source of proteins, vitamins and amino acids), yeast used for baking and minor source of food including mushrooms (Talbot, 1971).

Fungi have a worldwide distribution, and grow in a wide range of habitats, including deserts, hyper saline environments (Sancho et al., 2007), the deep sea (Hawksworth, 2006), on rocks (Mueller and Schmit, 2006), and in extremely low and high temperatures. They have been shown to be able to survive the intense UV and cosmic radiation encountered during space travel (Alexopoulos et al., 1996).

Scientific research has confirmed fungistatic effects of some of the plants used traditionally by farmers in Africa to protect stored grain against mould. An extract of dried fruits of *Xylopia aethiopica* (Annonaceae) and dry seeds of the pepper *Piper guineense was* even able to completely prevent development of *Aspergillus flavus.* For practical fungus control purposes, however, these effects do not seem reliable enough. Damages caused by fungi is often neglected until it has reached an advanced stage.

Fungi do not only cause direct losses but can threaten

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the health of both man and animals by producing poisons, so called mycotoxins, which contaminate food and feed.

Mycotoxins are secondary fungal metabolites that contaminate agricultural commodities and can cause sickness or death in humans and animals. Filamentous fungi, especially those of the Fusarium, Myrotecium, Trichoderma, and Stachybotrys genera, produce trichothecenes mycotoxins. These mycotoxins are extremely heat stable and resist ultraviolet light inactivation (Kiark, 2002).

Diseases caused by mycotoxins are called mycotoxicoses. Mycotoxins can be acutely or chronically toxic or both depending on the kind of toxins and dose. In animals, acute diseases include liver and kidney damage, attack on central nervous system (CNS), skin diseases and hormonal effects. Among the mycotoxins, aflatoxins produced by *A. flavus, Aspergillus parasiticus*, *Aspergillus nomius* are most potent natural carcinogenic compound causing mutation (transversion) of 249th codon of P_{53} gene (Deng and Ma, 1998).

Scientists estimate that there are 300 to 400 mycotoxins presently identified with more being isolated as new techniques and processes evolves. A list of mycotoxins significantly impacting agricultural commodities would include aflatoxin produced by *A. flavus,* and *A. parasiticus*, zearalenone and trichothecenes (particularly deoxynivalenol) produced by *Fusarium* spp., ochratoxin produced by *A.ochraceus* and fumonisins produced by *Fusarium moniliforme.* Approximately 25 % of world's food crops are affected each year by mycotoxins. Mycotoxins may develop in almost any feedstuff during the growing season, at harvest, or during storage.

Cool, wet weather favours fusarium toxins, while hot, humid weather encourages aflatoxin formation. While grains receive the most attention, by-product feeds, protein concentrates, finished feeds, oilseeds, wet brewer's grains, food wastes, and forages may also contain mycotoxins.

Depending on the definition used, and recognizing that most fungal toxins occur in families of chemically related metabolites, some 300 to 400 compounds are now recognized as mycotoxins, of which approximately a dozen groups regularly receive attention as threats to human and animal health (Cole and Cox, 1981). While all mycotoxins are of fungal origin, not all toxic compounds produced by fungi are called mycotoxins.

Storage fungi

Fungi found in stored food can be divided in two groups, the "field fungi" and the "storage fungi". In some cases, a sharp distinction is not possible as fungi growth may start in the field and during storage. The original source of fungi is in the field. Store fungi include all species of *Aspergillus, Fusarium* and *Penicillium.* The growth of fungi in storage is governed by the following factors:

(1) composition of nutrients in the grain
(2) moisture and temperature conditions
(3) biotic factors like competition or the presence of stored product insects.

Storage fungi are much more frequent in lots infested by stored product insects, because insects generate moisture and distribute fungi spores in the commodity. Storage fungi require a relative humidity of at least 65% (or a water activity of a_w = 0.65*)* which is equivalent to an equilibrium moisture content of 13% in cereal grain. They grow at temperatures of between 10 and 40°C.

Every species of fungus has its own optimum climatic requirements as Table 1 shows the minimum moisture contents required in grains for the growth of some important storage fungi (Multon, 1988) (Table 1).

Factors governing growth of fungi in stored products

Eight factors govern the growth of fungi in foods:

(1) Water activity
(2) Hydrogen ion concentration
(3) Temperature
(4) Gas tensions, specifically of oxygen and carbon dioxide
(5) Consistency that is, liquid or solid state
(6) Nutrient status
(7) Specific solute effects
(8) Preservatives (Pin and Hocking, 1985).
(9) Other factors like damaged grain during harvest, handling, threshing or drying, penetration of water (leakage).

In stored products, several of these factors are either fixed or stable. Stored products are solids, of more or less neutral pH, and of adequate nutrient status for fungal growth.

Compounds such as sodium chloride (NaCl), which produce specific solute effects, are usually absent. The principal factors governing fungal growth are thus water activity. Temperature, gas tension, and preservatives (including fungicides and fumigants). Consideration of each of these follows.

Water activity

Water activity (a_w) is a chemical concept, introduced to microbiologists by Scott in 1957, who showed that effectively quantified the relationship between moisture in foods and the ability of microorganisms to grow on them. Water activity is defined as a ratio: $a_w=p/p_o$

Table 1. **S**afe moisture content against fungus species.

Fungus species	Commodities affected
Alternaria alternate	rice, sorghum, soybeans
A. *longissima*	rice, sorghum
A. padwickii	Rice
Aspergillus flavus	cashews, copra, maize, groundnuts, sorghum, soybeans
Fusarium moniliforme	maize, sorghum, soybeans
F. semitectum	Maize
Penicillium citrinum	Sorghum, soybeans

Source: (Christensen et al., 1986).

Where p is the partial pressure of water vapour in the test material and p_o is the saturation vapour pressure of pure water under the same conditions. Water activity is numerically equal to equilibrium relative humidity (ERH) expressed as a decimal. If a sample of food is held at constant temperature in a sealed enclosure until the water in the sample reaches equilibrium with the water vapour in the surrounding air, then $1/a_w$ (food) = ERH (air)1100.

In many practical situations, is the dominant environmental factor controlling growth of fungi and hence determining the stability of stored products. Knowledge of fungal water relations will then enable prediction of storage life of commodities, and knowledge of the water relations of mycotoxin production will assist in understanding the potential for mycotoxins to form. Like all other organisms, fungi require water for growth, and the tolerance of low aw by different classes of fungi is often sharply defined. Certain storage fungi which occur in dried foods have the ability to grow at lower aw levelsthan any other organisms. The degree of tolerance to low water activity is most simply expressed in terms of the minimum at which fungal spore germination and hyphal growth can occur.

Fungi are able to grow at low aware termed xerophiles (literally 'dryness loving'): one operational definition of a xerophile is that fungus is able to grow below 0.85 under at least one set of environmental conditions (Pitt, 1973). At the lower end of the scale, only a few xerophilic fungi are able to grow at or below $O.75a_w$ within 6 months (Pitt and Hocking, 1985). Put another way, commodities stored at humidities between 75 and 85% ERH are susceptible to attack by xerophilic fungi within normal storage times, that is, a few months.

Temperature

Although temperature is a very important factor in the growth of fungi, the fact is that commodities are usually stored under conditions suitable for fungal growth. Temperatures below 20°C tend to favour cold-tolerant fungi, such as *Penicillium* and *Cladosporiwn,* while higher storage temperatures favour *Aspergillus* species. Under tropical conditions, stored products are more susceptible to *Aspergillus* species than other fungi, as many Aspergilli are favoured by the combination of low and relatively high storage temperatures.

Gas tension

Both reduction in oxygen tension and increase in carbon dioxide concentrations can have profound effects on the growth of fungi. These factors are important in the storage of commodities, where such conditions are primarily for the control of insects (Hocking, 1991).

Preservatives

Generally, stored products are free of preservatives when destined for human consumption. Insecticides and fumigants may be present under some circumstances, but information about their effect on storage fungi is relatively meagre (Hocking, 1991). Commodities for use as animal feeds may sometimes contain weak acid preservatives such as propionates usually sold as proprietary chemicals. In general, such preparations are barely cost effective. Maintaining low water activity is usually a more certain means of inhibiting fungal growth.

Combinations of factors

The various factors just discussed do not act independently, and indeed often are synergistic. If two or more factors act simultaneously, it may be feasible to store commodities for longer than would otherwise be expected.

For stored products, the combination of low water activity, low temperature, reduced oxygen and/or increased carbon dioxide levels may profoundly influence storage life. Under natural storage conditions, aw is the dominant factor determining the storage life of commodities. Drying a product quickly and keeping it dry' remains the most effective method for ensuring fungi do not invade stored products.

Damages caused by storage fungus

(1) Loss of nutrients
(2) Discoloration of grain
(3) Reduction in germination ability
(4) Caking of grains
(5) Increase in the temperature of the stored goods up to spontaneous combustion
(6) Moldy smell and taste
(7) Production of mycotoxins
(8) Creation of environment for the development of special insect species (= indicator for low grain quality) (Christensen and Meronuck, 1986).

Ways of minimizing/controlling storage fungus

(1) Drying of the produce as quickly and evenly as possible after harvesting up to the critical moisture/safe moisture level. The critical water content for safe storage corresponds to a water activity of about 0.7.
(2) Prevention of grain damage during harvest, handling, threshing or drying by keeping them in a cool and dry place.
(3) Prevention of condensation (Sealed storage under a modified atmosphere). On a large scale, areas should be equipped with instruments for measuring ambient conditions: keep temperatures in the store as constant as possible and carrying out regular controls.
(4) Prevention of moisture absorption as a result of incorrect ventilation or water entering the store.
(6) Avoid development of high insect population (= "hot spots").
(7) Arrange re -drying of parts of the stack with unacceptable high moisture content (Christensen and Meronuck, 1986).

MYCOTOXINS

Mycotoxins are toxic metabolic substances which are produced by various fungi. They remain in the stored produce as residues. Mycotoxins can be found in the stored produce as soon as 24 h after infestation with fungus. The optimum climatic conditions for the growth of fungi and the formation of mycotoxins are often not identical and dependent on various unidentified factors. Therefore, mycotoxin contamination can only be stated with certainty by means of laboratory examination (Anon, 1989).

All mycotoxins are low-molecular-weight natural products (that is, small molecules) produced as secondary metabolites by filamentous fungi. These metabolites constitute a toxigenically and chemically heterogeneous assemblage that is grouped together only because the members can cause disease and death in human beings and other vertebrates.

Not surprisingly, many mycotoxins display overlapping toxicities to invertebrates, plants, and microorganisms (Bennett, 1987). Mycotoxin losses result from (A) lowered animal production and any human toxicity attributable to the presence of the toxin, (B) the presence of the toxin in the affected commodity which lowers its market value, as well as (C) secondary effects on agriculture production and agricultural communities.

The economic effects of mycotoxins are many fold affecting all sections of production and consumption of grain production viz. grain producers, handlers, processors, consumers and society as a whole. Grain producers are affected by limited yields, restricted end markets due to contamination and price discounts. Grain handlers are affected by restricted storage facilities, costs of testing grain lots and loss of end markets. Grain processors incur higher cost due to higher product losses, monitoring costs and restricted end markets. Consumers end up paying higher end product prices due to increased monitoring at all levels of handling and in extreme cases death problems due to consumption of contaminated products.

On the other hand societies as a whole end up paying higher costs due to increased regulations, needed research, lower export costs and higher import costs. These costs are found at every level of grain production system; however, it is almost impossible to estimate the amount of losses. In North Carolina alone the losses to the animal production industry for one year (1992) were $ 20 million for poultry, $ 10 million for swine, $ 5 million for dairy and $ 1 million for beef and sheep, and $ 1 million for horses (Choudhary and Kumari, 2010). Studies by Nigerian Stored Products Research Institute (NSPRI) over the years have revealed the presence of aflatoxin in Nigerian groundnut and livestock feed maize, sorghum and millet (Oyeniran, 1978; Opadokun and Ikeorah 1979).

In the following table some important mycotoxin producing fungi are listed together with affected commodities (Table 2).

Occurrence

Mycotoxins occur on the field prior to harvesting. Post harvest contamination can occur if drying is delayed and during storage if the water content exceed the critical level for mould growth. Insect / rodent infestation facilitate mould invasion of stored products. Milk, cheese, eggs are often contaminated as a result of consumption of aflatoxin contaminated feeds by livestock as aflatoxins M1 has been found in human milk. They are unstable in processes such as those in making tortillas that employ alkaline conditions or oxidizing steps (Goldblatt, 1969). Various agricultural commodities and industrial products have been contaminated by either aflatoxin producing

Table 2. Major fungi species and the commodities they affected.

Fungus species	Commodities affected
Alternaria alternate	rice, sorghum, soybeans
A. *longissima*	rice, sorghum
A. padwickii	Rice
Aspergillus flavus	cashews, copra, maize, groundnuts, sorghum, soybeans
Fusarium moniliforme	maize, sorghum, soybeans
F. semitectum	Maize
Penicillium citrinum	Sorghum, soybeans

Source:(FAO Handbook, 1979).

fungi or aflatoxins.

Aflatoxins have been found in food crops and foods such as peanut butter and other peanut products, breakfast cereals, corn and cornmeal, and a variety of other foods and feeds (Smith and Moss, 1985; Wilson and Payne, 1994). Soybean appears to be less susceptible to aflatoxin contamination than other crops (Pinto et al., 1991). The contamination of aflatoxin in soybean and soybean products is rare in commerce in the USA but detectable levels have been demonstrated in edible beans in Africa and Thailand (Smith and Moss, 1985).

The highest risks of aflatoxin contamination are corn, peanut and cottonseed. Milk and milk products, eggs and meat products are sometimes contaminated because of the animal consumption of aflatoxin-contaminated feed. After consumption by animals, the B aflatoxins are metabolized to the M aflatoxins and secreted in the milk (van Egmond, 1994). Aflatoxin M1 is of special interest because it can be transmitted to a newborn offspring in the human's milk (Moore-Landecker, 1996). Aflatoxin M1 has been reported in mother's milk. 99.5% of breast milk from 445 people in Abudabi were found to contain 2-3 ng/l of M1 (Saito et al., 1991). However, 43 samples of human breast milk collected from three hospitals in Bangkok were not contaminated with aflatoxin M1 (Thanaboripat and Sukchareon, 1997).

Ochratoxins are produced by *Aspergillus* species, notably *A. ochraceus* in the tropics growing on cocoa and coffee and *P. verrucosum* in temperate regions growing on cereal such as barley (Carlile et al., 2001). Ochratoxin A has been shown to be a potent nephrotoxin in all species of animal tested, including fish, bird and mammal (Krogh, 1977). Ochratoxin A contaminates a variety of plant and animal products but is most often found in stored cereal grains (Abarca et al., 1994).

Patulin is produced by species of *Penicillium*, *Aspergillus* and *Byssochlamys*. Patulin may occur in fruits and fruit juices such as apple juice and grapefruit juice (van Egmond, 1989). Citrinin and penicillic acid are toxic antibiotics produced by several species of *Aspergillus* and *Penicillium*. Citrinin has been detected from peanut, tomato, corn, barley and other cereals (Sinha, 1993).

Trichothecene and zearalenone (F-2) are primarily produced by species of *Fusarium* on corn, wheat and other cereals (Moore-Landecker, 1996). Zearalenone, an oestrogenic mycotoxin, causes problems with the reproductive organs of farm animals, especially swine (van Egmond, 1989). Zearalenone is particularly occurred in corn and wheat and often found together with deoxynivalenol (vomitoxin). The other *Fusarium* toxin is Fumonisin, produced by *F. moniliforme* and related fungi, has been found most frequently in corn (Chu and Li, 1994). *F. moniliforme* is one of the most common fungi colonizing corn throughout the world. A number of mycotoxins produced by fusaria are found in the corn collected from China and southern Africa where high incidence of oesophageal cancer in humans are reported (Carlile et al., 2001).

Factors favouring aflatoxins production

Fungal growth and aflatoxins contamination are as a result of interaction among the fungus host and the environment. The combinations of these factors determine the infestation and the colonization of the substrate and the amount of aflatoxins produced. Substrate is required for the growth of the fungi and subsequent toxin production, although the precise factor(s) that initiates toxin formation is not well understood. Water stress increases temperature and insect damage of the host plant are the determining factors in mould and toxin production.

Similarly, specific crop growth stages, poor fertility, increase in crop density and weed competition have been associated with high mould growth and toxin production. Aflatoxin is also affected by associated growth of other moulds or microbes. The pre harvest aflatoxins contamination of corns and peanuts is favoured by high temperature, prolonged drought and increased insect activity while the post harvest production is favoured by warm temperature and high humidity.

Generally, tropical conditions such as high temperatures and moisture, monsoons, unseasonal rains during harvest, and flash floods lead to fungal proliferation and production of mycotoxins. Poor harvesting practices, improper storage, and less than

Table 3. Liver cancer etiology: attributable fractions in Europe-US and in Africa-Asia**.**

Risk factor	Europe and US	Africa and Asia
Hepatitis B	<15% (4 to 50%)	60% (40 to 90%)
Hepatitis C	60% (12 to 64%)	<10%
Aflatoxin	Limited or none	Not quantified
Tobacco	<15%	Not estimated
Alcohol	<12%	29% (one study)
Oral contraceptives	(10 to 50%)	Not estimated
Others including hemochromatosis	<5%l	<5%

Source: (Bosch et al., 1999).

optimal conditions during transport and marketing can also contribute to fungal growth and increase the risk of mycotoxin production. (Bhat and Vasanthi, 2003).

Aflatoxin and human health

The consumption of mycotoxin-contaminated commodities is related to several acute and chronic diseases in humans as well as in animals. While the exact cause and effect relationship has been established for only a few of the diseases, speculation about the role of mycotoxins in the aetiology of various illnesses has been based on circumstantial evidence in other cases. The acute diseases for which there is some evidence of an association with mycotoxins include: aflatoxic hepatitis in India and Kenya; enteric ergotism in India; vascular ergotism in Ethiopia; and deoxynivalenol mycotoxicosis in India and China. A common feature in all these outbreaks has been the involvement of staple foods such as corn, wheat or pearl millet, following unseasonable rains or drought during either the growing season or harvest.

Among the mycotoxins, aflatoxins have been implicated in human diseases including liver cancer, Reye's syndrome, Indian childhood cirrhosis, chronic gastritis, kwashiorkor and certain occupational respiratory diseases in various parts of the world, particularly in African and Asian countries.

In China, the Philippines, Thailand, Kenya, Swaziland and Mozambique, higher levels of aflatoxins in the food supply have been correlated with aflatoxins and their derivatives in human fluids which may be associated with liver cancer (Palmgren and Hayes, 1987). *Fusarium* toxins have been suspected to have a role in diseases such as Kashin Beck syndrome in the USSR, China and Viet Nam; Mseleni joint disease in southern Africa; endemic familial arthritis in India; alimentary toxic aleukia in the USSR; and oesophageal cancer in southern Africa.

Ochratoxins have been associated with Balkan endemic nephropathy and urinary tract tumours (Berry, 1988). However, in most of these instances, conclusive evidence for the role of mycotoxins in disease causation has been lacking. Joint-expert-committee-for-food-additives (JECFA) (1998 and 2001) estimated the carcinogenic potency of aflatoxin in a number of animal species and in humans (from epidemiological studies) with and without hepatitis B Virus (HBV) (Table 3).

Aflatoxin and animal health

Aflatoxins are highly poisonous to both humans and animals. If eaten, they lead to a number of diseases known as aflatoxicosis or may cause cancer (potent carcinogens). Aflatoxin contamination of animal feed is not only a hazard to animal health. Although contaminated feed corn containing 100ppb aflatoxin can be fed to nonlactating animals (300ppb for finishing cattle and 150ppb for finishing pigs) without damage to the animals or without harmful toxin or its metabolites appearing in the edible parts of the animals, lactating animals pose a higher risk. Aflatoxin M1 is a metabolite of Aflatoxin B1, and appears in milk at levels which are 3 to 5% of the level of aflatoxin B1 in the feed consumed. Ochratoxin A has been found to appear in edible tissues of animals that received contaminated feed shortly before slaughter.

Furthermore, it has also been detected in sausages, ham and bacon. It is a further danger to human health in that after ingestion it can be passed into the blood sera and milk (Table 4).

Table 5 gives an overview over mycotoxins, the fungi producing them, commodities affected and health hazards to man and animals (Wyllie and Morchause, 1978). Commodities with a particular high risk of aflatoxin production are maize, rice, cashew nuts, copra, groundnuts and most other commodities with a high fat content.

Health hazards for domestic animals are well documented in many instances since the famous aflatoxin-caused Turkey X disease which killed some 100 000 turkey poults in Great Britain in 1960 caused by consuming feed made from Brazilian peanuts Moreover, its effect on chicken include liver damage, impaired productivity, decreased egg production, inferior egg shell

Table 4. Recommended maximum levels of fumonisins in human food products and animals feeds.

Product	Recommended maximum level (ppm FB1 + FB2 + FB3)
Human Food Products	
Degermed dry milled corn products	2
Whole or partially degermed dry milled corn products	4
Dry milled corn bran	4
Cleaned corn intended for masa	3
Cleaned corn intended for popcorn	3

Animal feeds	Corn	Total diet
Equids (horses) and rabbits	5	1
Catfish	20	10
Swine	20	10
Ruminants	60	30
Poultry	100	50
Ruminant, mink, and poultry breeding stock	30	15
All other livestock species and pets	10	5

Source: (US food and drug administration, June 6, 2000).

quality and inferior carcass quality (Finley et al., 1992).

It also causes a fatal disease in horses called equine leucoencephalomalacia (ELEM). Clear evidence for association of mycotoxins and human diseases, however, have only been` recorded for aflatoxin, *Fusarium* toxins, o*chratoxin* A and other rare cases.

This fact is due to methodological difficulties and does by no means reflect a minor risk for humans as compared to animals: it increases susceptibility to disease (Eaton and Groopman, 1994).

In consequence of the high toxicity and carcinogenic action of aflatoxins about 60 countries have issued regulations concerning aflatoxin contamination of food and feed. In industrialized countries aflatoxin limits (maximum residue limits = MRL) (Table 6).

The toxicity of mycotoxins is reflected in the extremely low maximum residue limits. As an example, the MRL's of Malathion and Aflatoxin B1 for human food ate given in mg per kg of grain;

(a) Malathion 5 - 30 mg/kg
(b) Aflatoxin B1 0.005 mg/kg

This means that the maximum residue limit of Aflatoxin B1 is 1.000 to 6.000 times less than that of Malathion. Mycotoxins are highly stable and cannot be destroyed by boiling, pressing or processing.

This means that infested produce has to be destroyed. The problem cannot be dealt with by mixing contaminated produce with healthy grain or by feeding it to animals, as the toxins will be accumulated in their body and later consumed by people in form of milk or meat (Finley et al., 1992).

CONCLUSION AND RECOMMENDATIONS

The presence of mycotoxins in food products has serious implications for human and animal health. Many countries have enacted regulations stipulating maximum amounts of mycotoxins permissible in food and feedstuffs. Most developed countries will not permit the importation of commodities containing amounts of mycotoxins above specified limits. Mycotoxins therefore have implications for trade between nations.

Prevention of fungal invasion of commodities is far the most effective method of avoiding mycotoxins problems. Mycotoxins consideration should be an integral commodity management program focusing on the maintenance of commodity quality from the field to the consumer. Several effective ways for prevention and control of hazardous fungi and their dangerous mycotoxins have been presented. The methods include biological control, physical and chemical treatments.

Selection of fungal resistant hybrids of crops are recommended and further experimented. Pre-harvesting preparation of the field and environments in which the crops are grown should be monitored properly. Drying of commodities during post harvest is the most economical and effective means for farmers but this method however, is not suitable during rainy season or wet condition. Thermal treatment or gamma irradiation is not effective or practically used by villagers. Chemical treatments such as alkalinization and ammoniation are well-recognized and industrially used. Some modifications of the application of effective chemicals to detoxification of mycotoxins should be developed. International cooperations through authorized organizations should be

Table 5. Summary of mycotoxins type, products affected and their effects after consumption.

Mycotoxin and toxin-producing fungi	Commodities	Health hazards / toxicities
Aflatoxin *(Aspergillus flavus,* and *Aspergillus parasiticus)*	Maize, groundnuts, oilseeds	Carcinogenic, liver damage and other adverse effects in humans, poultry, pigs and cattle acute human toxicosis, internal
Deoxynivalenol (*Fusarium graminearum*) and related species)	Wheat, maize and barley	Disorders and decreased growth in pigs and other effects
Citrinin (*Penicillium vindicatum* and *Penicillium citrinum)*	Cereals	Kidney diseases in humans and pigs *and* nephrotoxin
Fumonisin (*Fusarium moniliforme* and related species)	Maize	Suspected to cause human oesophageal cancer diseases of equines, pigs and chicks
Ochratoxin *(Penicillium verrucosum*)	Barley and Wheat	Carcinogenic, kidney damage and other adverse effects in pigs and poultry
Aspergillus ochraceous	Barley, wheat and many other commodities	Carcinogenic, kidney damage and other adverse effects in pigs and poultry
Zearalenone (*Fusarium graminearum*)	Maize,	Possible human carcinogen, Hyper-estrogenic effect
	Wheat	Influence on pig production
Citreoviridin (*Penicillium viridicatum*)	Wheat	Cardiac beri beri
Rubratoxin (*Penicillium rubrum*)	Maize and Groundnut	Liver hemmorrhage and fatty infiltration
Patulin (*Penicillium expansum*)	Apricots, grapes, peaches, pears, apples, olives, cereals, and low-acid fruit juice	Brain and lung hemorrhage

Source: FAO Handbook (1979).

promoted and supported aiming at the benefits for the economics and health of people of all the nations.

The United Nations Food and Agriculture Organization (UNFAO) has assisted most countries in sub-Saharan Africa to enter CODEX alimentarius standards into law, but monitoring of food quality for foods destined to local consumption is rare.

Toxin testing laboratories are in place, generally government operated, but targeting only consignments for commodity export. Thus, for example in the case of peanut export to Europe, the best quality nuts are exported and what is left behind is not monitored for quality.

A system for cost sharing to make monitoring possible and sustainable, and sampling protocols appropriate for developing countries are needed. Continuous surveillance of high-risk agricultural commodities for contamination by selected mycotoxins and the monitoring of human population groups for diseases attributable to mycotoxins have to be carried out throughout the world to ensure a supply of safe food which is free from naturally occurring contaminants. The financial and human investments in this endeavour would be returned in terms of better human and animal health as well as reduced economic losses.

There is little doubt that high levels of exposure of people to food-borne mycotoxins is a serious threat to public health. It is a developmental issue, which embraces childhood survival, demographics, immune system function, the economic and human resource drain due to cancers, as well as food security where livestock feeds are contaminated.

Research is needed on inexpensive and appropriate sampling and testing protocols. Research on identification and application of appropriate technologies for obtaining low grain moisture at harvest and maintaining low grain moisture during storage are needed.

Research is needed on traditional food preparation technologies, such as fermentations and nixtimalization, or chelating additives such as clays or yeasts that may lower mycotoxins in prepared foods.

Table 6. Aflatoxin limits (maximum residue limit) in food and feeds.

Commodity	Aflatoxin limits (μg/kg)
Human food	5 to 30
Baby food	5 to 20
Feeds for dairy and young cattle	5 to 20
Feedstuffs for pigs and poultry	10 to 30
Feedstuffs for beef cattle, sheep and goats	20 to 300

Source: FAO Handbook (1979). μg/kg: means one part in one billion.

Research must continue to develop crop plant cultivars that are resistant (or at least not susceptible) in the field to infection by mycotoxin-producing fungi. Breeding for high yield alone is not enough. Research to reduce mycotoxins vulnerability of crops is as important today as ever.

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