Mycotoxins: A Threat to Food Security and Health

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Abstract
Multicellular filamentous fungi grown on the surface and inside of moist food secretes toxins in the form of their secondary metabolites which are commonly called mycotoxins. The presence of mycotoxins in food has been a burning issue and a threat to food security and safety. The global population has skyrocketed and continues to be, which has created a challenge of providing quality food to the consumers. Aflatoxins, prevalent in most of the food crops in Nepal as well have posed a risk to national food security. Moreover, the consumption of food products containing mycotoxins is a cause of several health hazards like cancer, gastrointestinal problems, and neuropsychiatric effects. Mycotoxins not only has affected humans but also animals. Prevention, decontamination, and inhibition of absorption of toxins have been done to manage and mitigate the effects of mycotoxins. Recent research on mycotoxins is focused on the development of new methods to detect and analyse masked mycotoxins obtained from various sources. This review shows the contribution of mycotoxin in the global food security issue as well as its deleterious effects on human and animal health.

Keywords: Aflatoxins; Decontamination; Food Security; Mycotoxins; Neuropsychiatric effects

Introduction
Mold is a type of multicellular filamentous fungus grown on the surface and inside of moist food. All grain product and food products which have a water activity less than 0.8 are susceptible to the fungal infection when a specific weather pattern occurs during the growing season. The specified group of fungi is capable of producing toxic substances known as mycotoxins. Mycotoxins are secondary metabolites produced by microfungi (molds) that are capable of causing disease and death in humans and other animals. (Ismaiel and Papenbrock, 2015). The term mycotoxin was first used in 1960 to describe the toxin associated with contaminated peanut in animal feed and loss of turkey in England (Turnkey-X-disease). The functions of mycotoxins are still not fully understood, perhaps they function as an insecticide, they might play a role in fighting against the plant defence to the fungus in some way to complete their ecological niche in nature (Richard, 2007). Unlike the bacterial toxins, the mycotoxins are non-pretentious and hence are not detectable by the immune systems of humans and animals. The mycotoxins are...
usually heat-stable and are not destroyed by canning and similar processes.

The contamination of food with mycotoxins are unavoidable and unpredictable, which makes it a unique challenge for food safety (Lopez-Garcia et al. 1999). Food safety refers to limiting the presence of those hazards, whether chronic or acute, that may make food detrimental to the health of the consumer. As per the United Nations committee on world food security, food security means that all people, at all-time, have physical, social and economic access to sufficient, safe and nutritious food that meets food preferences and dietary needs for an active and healthy life. The presence of mycotoxins in food makes the food products unsafe for consumption, which eventually leads to the post-harvest loss and becomes a threat to food security. The growth of various fungi in agricultural products leads to yield reduction and quality deterioration with significant economic losses (Adeyeye, 2016).

Classification of Mycotoxins

The primary category of fungi which are responsible for the production of mycotoxins is Aspergillus, Penicillium and Fusarium, Trichoderma, Trichotheceum (Richard, 2007). Many species of toxigenic molds have been known till date, but only a few of them, which affects the food crops like cereals and groundnuts are considered to be significant for humans (Adeyeye, 2016). The toxigenic fungi are broadly categorised into two categories, i.e. field fungi (e.g., Closstridium, Fusarium, Alternaria species) which gets access into seed during the development of plant and storage fungi (Aspergillus, Penicillium etc.). Which grows during storage. Mycotoxins are not only hard to define, but they are also challenging to classify (Hendrich, 2017). Some major types of mycotoxins are:

- Aflatoxins (produced by Aspergillus spp) - Aflatoxin B1, B2, G1, G2, M1 and M2
- Ochratoxin - Ochratoxin A, B, and C
- Trichothece (produced by Stachybotrys) - Satratoxin-H, Vomitoxin, and T-2 mycotoxins
- Fumonisins - Fumonisin B1 and B2

Global Food Security and Mycotoxins

The current challenge to feed 7.6 billion people globally with limited and gradually decreasing cultivable land and food produce has ultimately pose a risk to food security. The global population is to be expected to rise to 9 billion by 2040, and with this growth rate, it will hit 11 billion by 2100 (World Population Clock, 2015). Most of this global population feeds on three major crops and their products, i.e. Rice, Wheat and Maize. 60% of global energy intake is contributed by these three crops, which are acknowledged as the staple food. Unfortunately, Maize and Wheat are vulnerable to the risk of mycotoxins. Fungi being cosmopolitan and flourish under the same environmental conditions where maize and wheat can grow effectively has affected the quality of products and causing massive production loss. Annual food loss of 16% is attributed to microbial diseases out of which fungi alone has contributed about 80% (David et al. 2013). Aspergillus, Penicillium and Fusarium, Trichoderma, Trichotheceum are some of the significant fungi groups producing mycotoxins like Aflatoxins, Fumonisins, Ochratoxins, etc. (Richard, 2007). FAO estimates that mycotoxins, produced by different groups of fungi, has affected one-third of global food crops (Krska et al., 2012). The United States, the largest producer of corn, reported that 98% of samples were affected by at least one mycotoxin and 74% of corn contained more than two mycotoxins (Mycotoxin Survey in US corn, 2019). These alarming figures imply the amount of food lost due to contamination by mycotoxins, ultimately leading to a threat to global food security.

Table 1: Various fungi, their substrate and mycotoxins.

<table>
<thead>
<tr>
<th>Fungi</th>
<th>Substrate</th>
<th>Mycotoxins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspergillus flavus</td>
<td>Maize, groundnut, oilseed, cottonseed</td>
<td>Aflatoxin (carcinogenic to humans)</td>
</tr>
<tr>
<td>Aspergillus parasiticus</td>
<td>Maize, groundnut, oilseed, cottonseed</td>
<td>Aflatoxin (carcinogenic to humans)</td>
</tr>
<tr>
<td>Aspergillus nomius</td>
<td>Maize, groundnut, oilseed, cottonseed</td>
<td>Aflatoxin (carcinogenic to humans)</td>
</tr>
<tr>
<td>Aspergillus ochraceus</td>
<td>Bakey Wheat</td>
<td>Ochratoxin (Potentially carcinogenic)</td>
</tr>
<tr>
<td>Aspergillus carbonerius</td>
<td>Grapes, Wine, Coffee</td>
<td>Fumonisins (Hepatotoxic and Nephrotoxic)</td>
</tr>
<tr>
<td>Fusarium oxysporum</td>
<td>Wheat, Barley, Maize</td>
<td>Fumonisins (Hepatotoxic and Nephrotoxic)</td>
</tr>
<tr>
<td>Fusarium sp.</td>
<td>Wheat, Barley, Maize</td>
<td>T-2 Toxin</td>
</tr>
<tr>
<td>Penicillium verrucosum</td>
<td>Wheat, Barley, Maize</td>
<td>Ochratoxin (Potentially carcinogenic)</td>
</tr>
<tr>
<td>Claviceps purpurea</td>
<td>Rye</td>
<td>Ergot Alkaloid</td>
</tr>
<tr>
<td>Stachybotrys</td>
<td>Hay</td>
<td>Satratoxin</td>
</tr>
</tbody>
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Source: (Bennett and Klich, 2003)
Nepalese Prospect

Mycotoxin monitoring in Nepal was first started in 1978 when FAO/ UNEP Regional Monitoring of Food Contaminants Project involved Nepal in which 150/850 food samples collected comprising of mainly Cereals, Pulses, Oilseeds, and Spices. were found contaminated with aflatoxin. Among them, Maize and Peanuts were most susceptible to aflatoxin contamination, during the period from 1980-1987 (Karki and Sinha, 1992). Maize production in Nepal is mostly in the hilly region, i.e. 72.85%. (Timsina et al. 2016). Most of the population of hilly region and Himalayan region have maize as their staple food; also researches show that aflatoxin contamination in Maize and Peanuts, as well as their products, are higher in Nepalese context. Aflatoxins, produced by Aspergillus flavus, was found to me major mycotoxin contributor in Nepalese maize and maize products. More than 19% of maize and 28% of maize products were contaminated with aflatoxin; most of them belonged to the regions having high temperature and humidity (Holcomb and Thompson, 1991). Whereas, in the hills and mountains, the dominance of Fusarium spp. (Fusarium oxysporum and F. gibbsosum) that produces toxins like Fumonisins, was found (Karki and Sinha, 1992). Hence, major maize producing areas of Nepal are at higher risk of mycotoxin contamination.

To sum up, the higher risk of mycotoxin contamination in staple food of most population in Nepal would eventually lead to the food security issue by making the produce un consumable, considering its toxic effects on human as well as animal health.

Recent Studies On Mycotoxins

Mycotoxins have been the centre of interest for many researchers and scientists since 1961. Since mycotoxins are one of the major hazards for food security and health, several studies have been carried out to overcome the effects of mycotoxins. Many structurally related compounds that are either generated by plant metabolism or food processing can coexist together with the native toxins in the mycotoxin contaminated commodities (Galaverna et al. 2009). The mycotoxins either extractable conjugated or non-extractable bound mycotoxins remain present in the plant tissues and can easily escape the routine analysis and hence called as the “Masked mycotoxins” (Berthiller et al. 2013). These masked mycotoxins have the potential to transform from harmless when outside the body to harmful when inside. The most commonly occurring masked mycotoxins in food commodities are deoxynivalenol-3-glucoside (D3G), zearalenone-14-glucoiside (Z14G), and zearalenone-14-sulfate (Z14S). These compounds are either totally or partially hydrolysed to release the parent aglycone after ingestion (Dall’ Ertal et al. 2013).

The extraction of mycotoxins from marine fungus also has one of the recent issues in the study of mycotoxins. Nine mycotoxins have been isolated from the fermentation broth of marine gorgonian-derived fungus Aspergillus sp. SC5GAF0093. Out of these nine mycotoxins (1-9), six of them were from aspergillic acid group toxin and the remaining three were from ochratoxins (Xu et al., 2013).

Conventionally the mycotoxins were detected by the expensive high-performance liquid chromatography (HPLC), gas chromatography (GC), Flame ionisation (FID) or MS detectors and enzyme-linked immune sorbent assay (ELISA) techniques. The present day’s interest is in the development of the user-friendly biosensors for the mycotoxin’s detection. The biosensors used for the screening are the biomolecules (antibiotics, DNA and enzymes) and synthetic chemicals (aptamers, MIP, mimotopes, etc.). The biosensors are divided into two categories, i.e. labelled and label-free sensors, which are further categorised into competitive and non-competitive based on the detection strategy (Chauhan et al. 2016).

Mycotoxins and Health

Mycotoxins can cause several serious health issues. The effect can range from acute poisoning to long-lasting and incurable problems like cancer, in humans (WHO, 2018), and in animals (Surai et al. 2008). Some of the serious health hazards caused by mycotoxins are discussed below:

Mycotoxins and Animal Health

Mycotoxins successfully reach into animal’s body through ingestion, skin contact or inhalation of fungal metabolites. These metabolites come from different sources like contaminated feeds, fodders, forages, and silages (Gallo et al. 2015). Ochratoxin, produced by various species of Aspergillus and Penicillium, are nephrogenic and nephrocarcinogenic compounds and found to be occurring in kidney, liver, and blood of animals and transfer from animal feeds. Zearalenone (ZEA), produced by Fusarium sp., is found to be affecting the reproductive health of animals. (Zain, 2011). Aflatoxin B1 produced by various strains of Aspergillus flavus, A. parasiticus, etc. are the most potent carcinogenic aflatoxin for animals (Peterson et al. 2007). Fumonisins (B1 and B2) are cancer-promoting metabolites produced by Fusarium proliferatum and Fusarium verticillioides. Trichothecene, produced by Fusarium sp., Myrothecium sp., Phomopsis sp., Trichoderma sp. etc. inhibit eukaryotic protein synthesis, interfering in the initiation, the elongation and termination steps of protein synthesis in the animal body. Deoxynivalenol (DON), one of the essential trichotheccenes and most commonly found in grains, if ingested by animals in higher doses cause nausea, vomiting, and diarrhoea (Edite et al., 2014). Above shown are just some of the detrimental effects of mycotoxin in animals. Many other toxins are present in feedstuffs, which has contributed to ruining animal health. In the nation like Nepal, where
Mycotoxin monitoring in feed is rarely adopted, along with the degrading health of animals, human health is also posed at risks due to the consumption of contaminated animal products. Meat and milk products produced by the animals who are affected by mycotoxin, transfer these toxins to human beings through their products.

**Mycotoxins and Human Health**

Mycotoxins pose a severe risk to human health. From acute symptoms and illness right after the consumption of contaminated food, to the initiation of long-lasting and sometimes non-curable diseases like cancer and immune deficiency have been reported till date. Also, mycotoxins are globally distributed and have contaminated a substantial share of the world’s staple food and food products. Among hundreds of mycotoxins discovered till date, only a few of them caught the concern of scientists as they were found to be more harmful to humans. Aflatoxin, one of them, is considered to be the most poisonous toxin produced by molds *Aspergillus flavus* and *Aspergillus parasiticus*. Having a wide variety of host range, i.e. maize, wheat, rice— the three leading staple food of globe, pulses, spices, milk and milk products, etc., aflatoxin has affected a considerable sum of population all-round the globe. Ingestion of aflatoxin in large amount would result in liver damage and also genotoxicity, i.e. damaging of DNA following cancer. Ochratoxin A, produced by various species of *Aspergillus* and *Penicillium*, are identified to have a considerable effect in kidney damage. Patulin, also produced by some of the spieces of *Aspergillus*, *Penicillium* and *Byssochlamys*, often detected in apple-related products, have been reported for nausea, gastrointestinal disturbances and vomiting in human beings. Fusarium species that are responsible for the production of different mycotoxins like deoxynivalenol (DON), nivalenol (NIV), T-2 and HT-2 toxins, zearalenone (ZEN), fumonisins, etc. has led to severe health issues: rapid irritation of skin and irritation, intestinal mucosa and lead to diarrhoea. Fumonisins have been associated with oesophageal cancer in humans (WHO, 2018). Moreover, long-term exposure to mycotoxins found to be related to Neuropsychiatric symptoms like including an inability to stand on one’s toes, inability to walk in a straight line with eyes closed, short-term memory loss, altered blink-reflex latency, verbal recall impairments, etc. (Ratnaseelan *et al.* 2018).

To minimise the risk of mycotoxin in the foods we consume, it is necessary to inspect what we eat. Grains (corn wheat, sorghum, rice), nuts (peanuts, almonds, hazelnuts, walnuts) etc. should be appropriately inspected before consuming and sorting out the infected ones. Any mouldy grains and foodstuffs must be avoided to prevent the contamination from the toxins. As prevention is always better than cure, proper post-harvest handling of food grains: drying of grains before to maintain the optimum moisture level, avoiding any damage and injuries during processing, storage, as injured ones are susceptible to mold attack. Storage units must be maintained properly according to the requirement of the grains to be stored. Too dry or too humid units are prone to mold contamination. Above all, we should include a diverse range of foodstuffs in our diet, which not only helps to reduce mycotoxin exposure but also improve our nutrition intake, enabling us to build immunity.

**Management of Mycotoxins in Food**

Mycotoxins in agricultural products are the primary cause of health hazard to people, food security hazard and economic problems. The consumption of food commodities which are contaminated with mycotoxins can cause chronic mycotoxicosis and may lead to death (Adegoke and Letum, 2013). So, the prevention of fungal growth on agricultural commodities to prevent mycotoxin contamination is of utmost importance (Leibetseder, 2006). Several approaches have been considered for the management and decontamination of mycotoxins in food and agricultural commodities. For avoiding the harmful effects of mycotoxins in food three possibilities can be regarded as i.e.

- Prevention of contamination
- Decontamination of mycotoxin-containing food and feed
- Inhibition or absorption of mycotoxin content of absorbed food into the digestive tract (Juodeikiene *et al*. 2012). By using the techniques such as field management, harvest management, using resistant varieties, use of biological and chemical agents (preharvest methods), improved drying methods, good storage condition, and irradiation (post-harvest methods) the contamination of mycotoxins in food can be prevented Adegoke and Letum, 2013). The mycotoxin contamination in food products can also be prevented by using some selected microorganisms or enzymes which are capable of detoxifying mycotoxins (Jard *et al*. 2011).

The decontamination of mycotoxins can be achieved either by physical, chemical or biological methods. The dry cleaning of the grains and milling operation can result in a reduced level of mycotoxins in the flour (Juodeikiene *et al*. 2012). Since the mycotoxins are heat stable, the heat applied during the processing of the food does not significantly affect the mycotoxin level. The physical absorbents of selective binding nature are also used commercially for the mycotoxin decontamination. The use of chemical agents such as alkali and oxidising agents have also been seen in some countries for this purpose, but this process has got a demerit of reducing the nutritional value of the food products. The biological method, i.e. the use of microorganisms such as yeast (*S. cerevisiae* and *Candida krusei*) and Lactic acid bacteria (LAB) has been best suited for the mycotoxin decontamination as this process tends to improve the palatability and there is no significant loss in the nutritive values of food (ibid). The management of...
mycotoxins in food can also be done by using the principles of Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practices (GMP) (Awad et al. 2010).

**Conclusion**

Mycotoxin exposure has been a significant problem among the global population in the context of health. About one-fourth of the food is contaminated with mycotoxins, and if this issue is not addressed on time, it could be a significant threat to global food security. Several types of research and studies have shown that long term exposure to mycotoxins would result in serious health problems like liver damage, cancer, and even neuropsychiatric symptoms in humans. Not only in humans, but the animal population has also been affected by mycotoxins, which have resulted in degraded animal health and production of contaminated animal products. With proper handling of food products, i.e. pre-harvest and post-harvest handling, we can mitigate the occurrence of mycotoxins in food. Sushant Puri, Shuvam Shingh, Priya Tiwari

**Author’s Contribution**

All authors designed the research plan, performed experimental works & collected the required data. Sushant Puri and Shuvam Shingh prepared the manuscript & critical revised the manuscript. All authors finalized the manuscript.

**Conflict of Interest**

The authors declare that there is no conflict of interest with present publication.

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