



## Ochratoxin a in Maize: Origin, Occurrence, and Health Implications, Albania Case

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**Abstract.** Mycotoxins are toxic secondary metabolites produced by fungi that frequently contaminate cereal grains, compromising food safety. Among the most concerning are aflatoxins and ochratoxin A (OTA), primarily produced by *Aspergillus* and *Penicillium* species. OTA contamination typically occurs under warm, humid conditions, especially during poor post-harvest storage. Albania's maize-growing regions—Lushnja, Fieri, Korça, Shkodra, and Elbasan—are climatically predisposed to such risks. Although OTA is not the most prevalent mycotoxin in Albanian maize, recent findings confirm its presence in samples linked to inadequate storage. OTA is nephrotoxic and has been associated with renal damage and Balkan Endemic Nephropathy. While the OTA incidence on Albanian maize is relatively low, the risk assessment indicate high concentration levels for OTA in positive contaminated samples. Poor storage and limited monitoring elevate the crop vulnerability. These findings underscore the need for systematic testing and improved post-harvest practices to mitigate contamination and protect public health.

**Keywords:** Mycotoxins, Ochratoxin A, Maize, Albania, Food And Feed Safety, Nephrotoxic.

### 1 Introduction

Maize and other cereal grains are vital to the global food supply, serving as staples for billions of people and essential components of animal feed. However, these crops increasingly are contaminated by mycotoxins, toxic secondary metabolites produced by fungi under stress conditions. They are a diverse and ubiquitous group of fungal compounds specifically associated with the precipitation of deleterious effects in humans and animals (D'Mello, 2003; Neme and Mohamed, 2017). Their presence in food and feed chain has raised food safety and security concerns globally. Common foods susceptible to mycotoxins contamination include grains such as maize, sorghum, millet, wheat, and rice as well as peanut/groundnut.

Mycotoxin contamination is associated by huge economic impact globally, manifested as loss of human and animal health and life, increased healthcare costs, reduced livestock production, disposal costs of contaminated foods and feeds, research investment, and regulatory programs aimed at reducing or avoiding mycotoxins from products (Zain, 2011; Tahiri et al., 2025).



Viewed globally, food safety is regularly compromised by the presence of mycotoxins occurring in cereal grains, nuts, fruit and green coffee beans. Animals exposure to mycotoxin contaminated feed will bring their metabolites in foods of animal origin, e.g. milk, eggs, etc (Kabak, Dobson, & Var, 2006).

One of mycotoxins being in focus of human and animal toxicity has been Ochratoxin A. First evidence on Ochratoxin A toxicity in humans was reported in '70s of last century, when OTA exposure has been associated with renal damage and Balkan Endemic Nephropathy (Pavlović, 2013).

### 1.1 Origin, chemistry, and toxicity of main mycotoxins

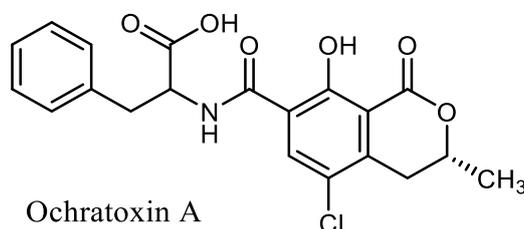
The mycotoxins of major concern in human and animal health are produced by *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria* and *Claviceps*, genera. (D'Mello, 2003).

In foods and feedstocks most important mycotoxins produced by *Aspergillus* genus are aflatoxins, mainly by *Aspergillus flavus* and *A. parasiticus*; Ochratoxin A (OTA) by *Aspergillus ochraceus* and related species. Sterigmatocystin, by *A. versicolor*, and cyclopiazonic acid, by *A. flavus* (Pitt & Hocking, 2022).

Over 80 species from the genus *Penicillium* are producers of most important mycotoxins related to human exposure including: OTA, citrinin, cyclopiazonic acid, patulin (Pitt & Hocking, 2022).

The discovery of toxigenic strains of the fungus *A. ochraceus* Wilh., led to the isolation and structure elucidation of ochratoxin A (Van der Merwe et al, 1965). OTA is produced by *Aspergillus* and *Penicillium* species. The economic impact of this mycotoxin is significant because it is present in a wide range of food products. In particular, *P. verrucosum* is responsible for OTA contamination of cereal-based products, *P. nordicum* is responsible for the contamination of some dried foods, *A. ochraceus*, *A. carbonarius*, *A. westerdijkiae*, and *A. steynii* are responsible for the contamination of coffee beans, cocoa, pepper, and dried fruits. Whereas the contamination of grapes, grape juice, raisins, cider, and wine is mainly attributed to *A. carbonarius* and, to a lesser extent, to *A. niger* species “together”.

Chemically, OTA is a structure built from a dihydroisocoumarin ring linked to an L-phenylalanine unit (Gallo *et al.*, 2012).



## 1.2 Kinetics and biotransformation of ochratoxin A in organism

Main route of OTA exposure is through gastrointestinal tract. The metabolism of OTA is unclear, while biotransformation occurs mostly in the liver and kidneys. OTA molecules accumulate in the blood, liver, and kidneys. Due to its strong binding affinity to blood proteins, OTA has a longer half-life in blood than tissues (Kőszegi & Poór 2016). Urine and feces are essential excretion routes for plasma mycotoxin removal in all species, while milk is a major excretion route in mammals (Yanfei et al., 2018). Following the intestinal absorption, OTA molecules interact with serum proteins. According to protein binding affinity and extent, serum half-life varies greatly among species, mostly albumin, over 99%, allowing passive absorption in its non-ionic state (Ringot, Chango, Schneider, Larondelle, 2006). This largely explains its long biological half-life. OTA has cumulative toxicity and quick absorption and sluggish elimination. Bile acid recirculation helps OTA molecules enter the circulatory system from the intestines and redistribute into other tissues (Kőszegi & Poór 2016).

Animals absorb different amounts of OTA. Thus, 66% in pigs, 56% in rodents, and 40% in birds. The tissue distribution in pigs, rodents, poultry, and goats is kidney > liver > muscle > fat (Huff & Hamilton, 1979).

Grain products include Ochratoxin B (OTB), the dechlorinated derivative of OTA. Because there is no chlorine atom to influence structural dissociation, this toxin is 10 times less lethal than OTA (Harris and Mantle, 2001).

## 1.3 Combination Effect over Mycotoxins toxicity

Natural toxicoses are often caused by exposure to mixtures of mycotoxins present in food products. This combination can lead to additive, synergistic or antagonistic toxicity effects (Smith, Madec, Coton, Hymery, 2016).



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The combination effect of OTA and OTB have been shown to be additive. Combined effects of OTA and citrinin have shown synergistic effects with respect to nephrotoxicity in poultry and pigs. Another combined effect is shown with OTA and penicillic acid, that synergistically increase mortality in poultry and rodents, renal lesions in fish.

Being most important mycotoxins, the combined effects of OTA and AFB1, have been in focus. Co-exposure of animals to OTA and FB1 has shown pathological signs of toxicity, for example pulmonary edema, kidney and liver lesions, a synergism in cytotoxic effects between FB1 and OTA in cytotoxicity has been observed (Singh & Kumari, 2022).

Information regarding the combined effects of OTA and zearalenone (ZEA) indicate for antagonistic interaction effects. OTA and trichothecenes often exhibit additive or synergistic toxicity, especially in kidney, liver, and immune tissues. This is due to overlapping mechanisms such as oxidative stress, inhibition of protein synthesis, and disruption of cellular signaling (Kolawole, Siri-Anusornsak, Petchkongkaew, Elliott, 2024).

#### **1.4 Mold growth and mycotoxin production influencing factors in grains**

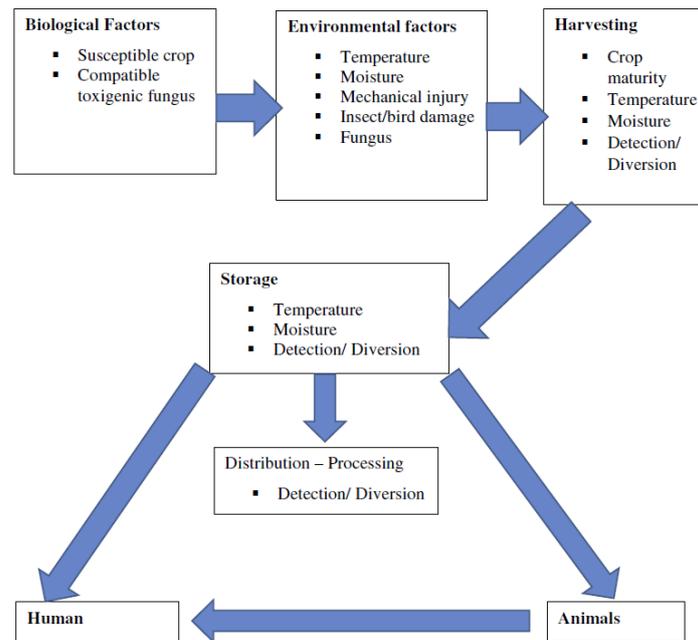
The crops of both cool temperate and hot tropical regions can be affected by ochratoxin because they are produced by different *Aspergillus* and *Penicillium* species (Altomare, Logrieco, & Gallo, 2021).

Fungi are the primary cause of spoilage in stored maize and can cause detrimental changes in appearance, quantity, and quality of stored grain, thereby reducing the end-use value of maize for food, feed, and biofuels (Channaiah & Maier, 2014). The fungi can produce mycotoxins while maize is in the field, during processing, transportation, and storage (FAO, 2011). *Aspergillus* and *Fusarium* species can infect maize pre-harvest, and mycotoxin contamination can increase if storage conditions are poorly managed (Chulze, 2010). The *Penicillium* toxins in maize occur mainly during storage and when the harvest is delayed producing penicillic acid and OTA (Pitt, Taniwaki, & Cole, 2013).

The factors affecting grain contamination include biological factors (susceptible crop), environmental factors (temperature, moisture availability, humidity, mechanical injury, and insect/bird damage), harvesting (crop maturity, temperature, moisture, and handling), storage (structure, conditions, moisture, and temperature), handling and processing (Figure 2) (Milani, 2013).



Their occurrence may start in different stages of crop production, starting from the field, harvesting, handling, storage, and processing. In overall, is established scientifically, that DON, ZEN, and fumonisins contaminate the grains at the field/or pre-harvest stage, while aflatoxins and OTA are mostly occurring during storage due to improper postharvest handling (Neme & Mohammed, 2017).



**Fig.1.** Factors affecting mycotoxin occurrence in human food and animal feed chains. (Adapted from Neme and Mohammed, 2017).

The temperature and moisture content of the grain or commodity are the most critical factors favoring fungal growth and mycotoxin production. Relative humidity is another factor influencing the moisture content of stored grain resulting in water available for mold growth and subsequent mycotoxin production. The optimum temperature and water activity for mycotoxin production in grains are presented in Table 1.

**Table1.** Optimum temperatures and water activity for mycotoxin production.

Mycotoxins	Temperature (°C)	Water activity
Aflatoxin	33	0.99
Ochratoxin	25-30	0.98
Fumonisin	15-30	0.9-0.995
Zearalenone	25	0.96
Deoxynivalenol	26-30	0.995
Citrinin	20-30	0.75-0.85



Adapted from Milani (2013).

Insect infestation is another factor that promotes fungal inoculation and subsequent mycotoxin contamination in several ways of grain (Abbas *et al.*, 2013). Control of storage insects through sorting out damaged grain will reduce the risks to invasion by storage molds, including *A. flavus* (Medina, Rodriguez, Magan, 2014).

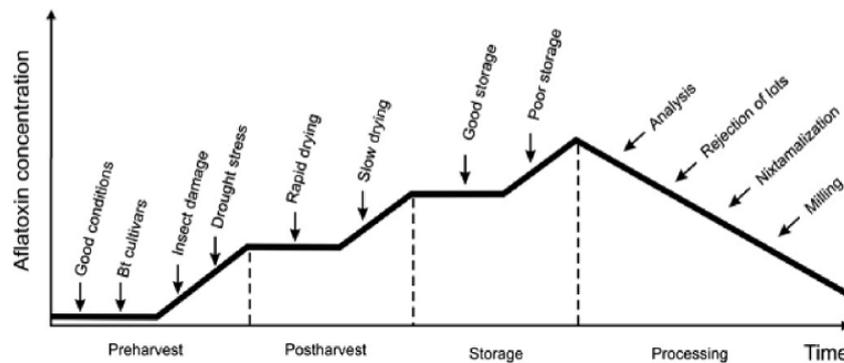


Fig. 2. Aflatoxin formation and reduction in maize. (Adapted from Pitt et al. 2013)

#### 1.4 Postharvest mitigation strategies on mycotoxin contamination

The main postharvest factors for grain mycotoxin contamination are mechanical injury, insect infestation, time of harvesting, drying method, types of storage structure and conditions, handling and processing.

An integrated system management approach is important to mitigate the problem (Fumagalli et al., 2021). Several pre- and postharvest mitigation strategies have been developed to prevent the growth of fungi as well as to decontaminate and detoxify food, contaminated by mycotoxin (Kabak, Dobson, Var, 2006). Pre-harvest methods include using resistant varieties, field management, crop rotation, use of biological and chemical agents, harvest management (Adegoke & Letuma, 2013).

Postharvest interventions include rapid and proper drying, proper transportation and packaging, sorting, cleaning, drying, smoking, postharvest insect control, and the use of pesticides as storage protectants (Hell & Mutegi, 2011; Wild et al., 2015). Good storage conditions, use preserving agents and irradiation prevent mycotoxin contamination after harvesting (Adegoke & Letuma, 2013). Effective postharvest management of stored commodities requires clear monitoring criteria and effective implementation in



relation to abiotic and biotic factors, hygiene to ensure that mycotoxin contamination is minimized (Magan & Aldred, 2007).

A control program for mycotoxins from field to table must incorporate HACCP principles, necessitating a comprehensive understanding of the interactions between toxigenic fungi and agricultural crops, on-farm cultivation and harvesting methods, and the processing of foods for human consumption. Furthermore, it is essential to consider commercial and trade channels, including the preservation and distribution of food to consumers (Richard, 2007).

### 1.5 Harvesting

Postharvest strategies for preventing mycotoxin contamination in stored grains begin at harvest. The timing of harvest greatly affects the extent of mycotoxin contamination. Delayed harvest significantly increased the level aflatoxin in maize, result in poor quality seed due to mold infections and subsequent aflatoxin contamination of the seeds/pods. Mycotoxin content increases with delayed harvest coupled with rain precipitation (Channaiah, 2011).

Freshly harvested cereals should be cleaned to remove damaged kernels and other foreign matter. Strategies such, when 10% or more of the ears have 10-20% mold damage, the field should be scheduled for the earliest possible harvest (Munkvold *et al.*, 2019). Avoiding mechanical damage and grain contact with soil at harvesting stage also minimize contamination of fungal infection.

### 1.6 Storage conditions

Grains are subjected to quality loss during storage. In developing countries, inadequate storage practices account for 20-50% of crop losses (Kumar & Kalita, 2017). The quality deterioration in stored grains is caused mainly by a natural process which breaks down organic matter through either physical/chemical processes or biological processes which contained nutrients and energy are used by other life forms. Store fungi include all species of *Aspergillus*, *Fusarium*, and *Penicillium* (Atanda *et al.*, 2011). Cereal grains are particularly susceptible to grow by Aspergilli in storage environments where the main toxigenic species are *A. flavus* and *A. parasiticus* for aflatoxins, and *Penicillium verrucosum* is the main producer in cereals for OTA (Kabak *et al.*, 2006).



During storage, the temperature and relative humidity of the grains are the main mitigation strategies to minimize the growth of fungi. Moisture control is the main critical one for prevention of mycotoxins in grains.

The following moisture contents are considered safe during storage: 14% for maize (Channaiah, 2011). During storage, once the grain  $a_w$  drops below a certain value the mycotoxin production will stop. Sweeney and Dobson (1998) found aflatoxins can be produced at  $a_w$  values ranging from 0.95 to 0.99 with a minimum  $a_w$  value of 0.82 for *A. flavus*, while the minimum  $a_w$  for OTA production is 0.80.

Generally, provided grain is stored at a moisture content equivalent to  $a_w = 0.70$  no spoilage will occur (Medina, Rodriguez, Magan, 2014).

Another important parameters to prevent the growth of molds is temperature. Ideally, grain should be cooled after drying and maintained at 1°C-4°C for the duration of storage, while during the summer months the grain temperature can be maintained between 10 °C and 15 °C (Munkvold et al., 2019). At low or cold temperature, fungal contaminants not killed, but their growth and metabolism are minimal.

Aflatoxins are produced at temperatures ranging from 12 to 40 °C (Sweeney & Dobson, 1998), while OTA production by *P. verrucosum* occurs between 10 - 25 °C (Olsen et al., 2003). *A. flavus* has an unusually high tolerance to heat, compared with other fungi; it thrives in temperatures approaching 37.8 °C and even higher (Medina et al., 2014).

### 1.7 OTA contamination of maize harvested in Albania

In a study presenting the OTA contamination in maize harvested in a two year period 2014-2015, resulted that 71% of samples were contaminated with aflatoxins, of them 36% over the threshold for AFB1 as per EU regulation (EU 2023/915). Maximum values: 3550 µg/kg (AFB1), 4822 µg/kg for total Aflatoxins. The OTA was detected in maize samples surpassed the maximum permissible limit of 5 µg/kg, with overall incidence of 7.0%. The OTA concentration in contaminated samples was minimum (187 µg/kg) to maximum (488 µg/kg), resulting in mean value of 336 µg/kg (Topi et al., 2023).

Risk assessment indicate that all positive samples surpassed the maximum allowable level for OTA in unprocessed cereals (5 µg/kg as per EU Regulation No. 2023/915).



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Comparative analysis at both regional and international levels reveals that the Fier and Lushnja regions exhibited the greatest concentrations of AFB1, attributable to the Mediterranean environment and heavy maize cultivation. In comparison to adjacent nations (Serbia, Croatia, Romania), Albania had elevated contamination levels in maize, particularly in 2014 (Topi et al., 2017; Topi et al., 2019; Topi et al., 2021; Mato et al., 2024; Topi et al., 2024).

Occurrence of OTA in maize (2014–2015) indicate that the detected amounts are exceedingly elevated, posing a substantial risk to public health, particularly if the maize is utilized for human food or animal feed. Comparative analysis by region indicate that western regions present high concern, mainly do to the climate factors, such as high temperatures, and humidity. Maize sample from the Kruja region was found 333 µg/kg of OTA, while maize sample collected from Lushnja, 187 µg/kg (Topi et al., 2023).

OTA mycotoxin was not identified in the other regions (Elbasan and Korça). Study of mycotoxin co-occurrence is of high relevance since the interaction between OTA and aflatoxins (AFs) may produce synergistic effects, particularly on the immune system and liver metabolism.



Fig.3. Main maize producing areas of Albania.

## 2 Conclusion

Despite the low incidence of ochratoxin A (OTA) in Albanian corn samples (7%), all positive cases exceeded EU safety limits, with concentrations reaching up to 488 µg/kg. This highlights a serious food safety concern, especially in regions with warm, humid climates. OTA contamination is often linked to poor post-harvest practices. Preventive measures — such as timely harvesting, proper drying, sanitation, and aeration — are essential. Additionally, grain processing and the use of natural fungistats can help reduce mycotoxin levels. The co-occurrence of OTA with aflatoxins suggests possible synergistic toxicity, warranting further investigation.



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