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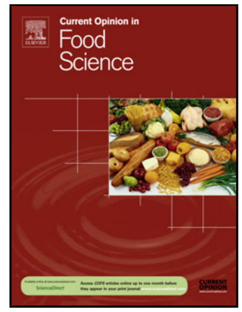

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The global overview of the occurrence of mycotoxins in Cereals: A three-year survey

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Abstract

Mycotoxins are secondary metabolites from molds that can contaminate the food and cause serious health problems in consumers. Aflatoxins, deoxynivalenol, fumonisins, zearalenone, T-2 toxins, ochratoxin A, are mycotoxins with acute carcinogenic, mutagenic, teratogenic, hepatotoxic, estrogenic effects. Cereals are very important and strategic grains that are very susceptible to mycotoxin contamination. In this study, the most recent studies about mycotoxins' occurrence in cereals (wheat, corn, rice, oats, barley, rye, sorghum) from 2018 to 2020 were reviewed. It can be concluded that the majority of the studies in the last three years have been done on corn, wheat, and rice, respectively. According to the results, the hazard of aflatoxin B_1 in wheat, corn, and rice is serious as it was higher than the EU limit in most of the studies. Due to climate change globally, the fungal population and mycotoxin patterns in different regions and crops are changing. Therefore, the development of practical control and management strategies is essential to ensure crop safety.

Keywords: Mycotoxins; cereals; worldwide prevalence; contamination; grains

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Introduction

Mycotoxins are secondary fungal metabolites mainly secreted by some toxigenic species of *Alternaria, Aspergillus, Fusarium, and Penicillium* [1, 2]. To date, 400 types of mycotoxins have been identified, but only a few of them are dangerous to humans and animals, including aflatoxins (AFs), ochratoxin A (OTA), deoxynivalenol (DON), T-2/HT-2 toxins, fumonisins (FUMs), and zearalenone (ZEN) [3, 4]. Depending on the type of mycotoxins and their metabolic conditions in the body, age, nutrition, and duration of exposure, they may cause acute or chronic problems such as carcinogenicity, mutagenicity, teratogenicity, hepatotoxicity [5]. Mycotoxins based on the severity of the effect are classified into five major groups: 1, 2A, 2B, 4, and 5 [6]. Group 1 is considered as carcinogenic for humans such as AFs, and group 2B are defined as likely carcinogenic for humans such as OTA, FUMs. Moreover, group 3, such as DON, ZEA, and T-2 toxin, are not classified as human carcinogenic toxins due to the insufficient evidence [6, 7].

Cereals are commonly consumed as an essential source of energy, minerals, fiber, and vitamins worldwide [8]. However, these products are susceptible to infection from various fungi on the farm or after harvest and storage. The diversity and contamination of mycotoxins in cereal grains depend on poor storage conditions, climate, temperature, insect damage, and drought [9]. Some of the physical and chemical properties of cereals, including pH, chemical composition, and water activity are increasing the occurrence and concentration of mycotoxin[1, 10].

Mycotoxins cause serious health issues in consumers and cause significant economic losses to food resources in different countries due to contamination. Therefore, in this review, the prevalence of mycotoxins' primary group in cereals was investigated to assess the mycotoxin contamination status in these products. This review's results can help the orientation of future studies and assist regulatory organizations in focusing more on the contamination in these products.

Search strategies

Scopus and Web of Science, with more than 40,000 and 24,000 journals, respectively, cover almost a wide range of journals. Therefore, the search strategies (Supplementary 1) were conducted in Scopus and Web of Science to obtain the most interesting papers from the great wealth of original publications considering AFs, FUMs, OTA, DON, ZEN, and T-2/HT-2 in selected cereals (wheat, corn, rice, oats, barley, rye, and sorghum) that met inclusion criteria in 2018, 2019, and 2020 (**Figure 1**).

General results

The results of this literature review showed that the majority of studies conducted in the last three years have been on corn, wheat, and rice, respectively (**Figure** 2). Meanwhile, the least included articles were related to rye and oats. The results of **Figure**

3 showed that the majority of studies have been conducted in Africa. Perhaps the poor planting, harvesting, and storage in this continent have led to many studies in this area.

Corn

Corn seeds are often contaminated with *Fusarium verticillioides and Fusarium proliferatum* that produce the FUMs toxin. However, other mycotoxins have been found in corn along with FUMs [11]. Of the 41 studies survey about corn seeds, the highest contamination rate was related to AFB_1, ZEN, and DON, respectively (**Figure 4**). The European Commission (EC) has defined maximum concentration for mycotoxins in corn. When corn is used for human consumption, these maximum amount are 4000, 1750, 350, 5, 2, 10, 100 μg/kg for FUMs, DON, ZEN, OTA, AFB_1, AFs, and T-2 + HT-2, respectively [12, 13]. In 87.5% of samples detected with AFB1, the AFs level was higher than the allowed level. This value was 80%, 66.6% for AFs and OTA, respectively. For other mycotoxins, the detected values were often lower than the maximum values of the EC. The results demonstrated that the greatest prevalence of AFB_1 was in Haiti [14], Kenya [15], and Serbia [16] with 188, 76.2, and 44 μg/kg, respectively (**Supplementary Table 1**). Also, Kos et al. (2020) [17] reported a high mean prevalence of DON (963 μg/kg), ZEN (163 μg/kg) in Serbia [17]. The high content of OTA (1662 μg/kg) is reported in Vietnam [18], and Skendi et al. (2019) in Greece reported the lowest levels of OTA (0.7 μg/kg) [19]. The highest content of FUMs was 43296 μg/kg, reported by

Bertuzzi et al. (2020) in Italy [20]. Corn is applied as a raw material in many food products, including popcorn, breakfast cereals, flour, and baby food [21]. Therefore, continuous monitoring of mycotoxins levels in corn is essential because some mycotoxins such as AFB_1, DON, ZEN, and OTA in corn are a potential hazard for the entire food and feed chain. Moreover, due to the high consumption level of corn in animal feed, the possibility of AFs in milk from these animals is very high [22].

Wheat

Wheat is contributed to a broad range of bakery products such as bread, breakfast cereals, biscuits, cakes, pasta, and other cereal-based products. Therefore, the level of wheat contamination with mycotoxins is critical in the food and feed chain. Of the 25 studies survey about wheat seeds, the major mycotoxins occurrence were DON, ZEN, AFB_1, OTA, HT-2/T-2, AFs, and FUMs, respectively (**Figure 4**). According to EC regulation, the recommended limit for mycotoxins in wheat are4 μg/kg, 2 μg/kg,1250 μg/kg, 5 μg/kg, and100 μg/kg for AFs, AFB1, DON, OTA, and ZEN, respectively [13]. Among the studies about mycotoxins in wheat grains, only in 16.6% of the samples, DON exceeded the EU recommended. This value was 50%, 40%, 22.2% for AFs, AFB_1, and ZEN, respectively. It can be concluded that the greatest mean prevalence of DON was in China with 17753 μg/kg [23], while Hassan et al. (2019) reported 0.1 μg/kg for DON in wheat samples from Qatar [24] (**Supplementary Table 2**). The highest and lowest ZEN content was reported in India [25] and Qatar [24], respectively. The maximum level of AFs was reported in wheat samples from Qatar (9 μg/kg) [24] that it was above than EU maximum level of 4 μg/kg, and no AFs detected in wheat samples from Greece [19].

Rice

The results of this review displayed that the rank order of rice seeds based on prevalence was AFB_1, ZEN, DON, FUMs, AFs, OTA, and HT-2/T-2 toxins (**Figure 4**). According to the maximum allowed the number of mycotoxins by EC for rice seeds which can be mentioned as 4 μg/kg for AFs, 2 μg/kg for AFB1; 5 μg/kg for OTA, 100 μg/kg for ZEN, and 1250 μg/kg for DON, the following results were attained. Among the analyzed studies, 50% of AFs and AFB_1, 11.1% of ZEN, 16.6% of DON, 25% of FUMs exceeded the EC standard limit. A study in Somalia showed that AFB1 (330 μg/kg) and FUMs (4361 μg/kg) in rice samples were greatly exceeded the recommended value by EU limits [26] (**Supplementary Table 3**). The level of FUMs and HT-2/T-2 toxins in all rice samples was below the EU maximum level. In China, the maximum allowed level for DON in rice samples is reported as 1607 μg/kg.

Barley, sorghum, oats, and rye

As shown in **Figure 4**, DON was the abundant mycotoxin in the barley samples collected from different countries, followed by ZEN and T-2/HT-2 toxins. A study in

Canada revealed that 56% of the cool-season barley submitted to the industry contaminated with the mycotoxins that the DON concentration in some of the samples was above the regulatory level (1250 μg/kg) [27]. DON has been reported as the major *Fusarium* mycotoxins in barley samples from Argentina [28], Czech Republic [29], and Brazil [30]. The level of DON in barley samples from Turkey was below the EU maximum level (138-973 μg/kg), and no ZEN was detected in these grains [31] (**Supplementary Table 4**). DON, FUMs, T-2/HT-2 reported in 50%, 25%, and 50% of barley samples from market feed-in Qatar with the average values of 0.048, 0.553, and 0.067mg/kg, respectively [24].

AFB_1, FUMs, and ZEN are reported as the most common mycotoxins occurring in sorghum [32]. 67% of the sorghum samples from Togo were contaminated by FUMs, followed by AFB1 (25%) [33]. A study in Somalia showed that AFB_1 and FUMs (FB_1 and FB_2) in sorghum samples were greatly exceeded the recommended value by EU limits [26]. AFB_1 was found as the significant mycotoxin (0.03-31.7 μg/kg) from sorghum samples in Tunisia, followed by OTA (1.04-27.8 μg/kg) and ZEN (3.75-64.52 μg/kg) [34]. Another study showed that AFs and FUMs occurred in 100% of sorghum from different parts of north-central Nigeria and the mean value for AFs, FUMs, and OTA from other recorded places was 15.31, 6198, and 2.44 μg/kg, respectively [35].

Schöneberg et al. (2018) reported that the T-2/HT-2 toxins were the major mycotoxins from the oats collected in Switzerland [36], and 84% of oat samples collected from India were found to be positive for ZE (5.31-389 μg/kg) [25]. Jin et al. (2018) observed that the DON levels in 75% of the USA's rye samples were below 1.0 mg/kg, but it showed increment by the malting process [37].

Climate change and predictions of mycotoxin contamination

According to this review, it is clear that mycotoxin contamination is still high in some regions of the world. Although it was expected that with the advancement of technology in agriculture and improvement of planting, harvesting, and storage conditions for cereals, the incidence of mycotoxins would be decreased, the studies show that the risk of some carcinogenic mycotoxins such as AFs is still high. Perhaps one of the possible reasons for this phenomenon is climate change. Climate change may be causing global warming. Earth temperature is expected to rise by 1.5 to 4.5 °C until the end of the 21st century [38]. Global warming is causing severe droughts and extreme rains in different regions of the world. Global warming increases water evaporation from the earth's surface and allows the atmosphere to hold more moisture. Hence, humidity and temperature are critical factors for the growth of fungal species and directly affect mycotoxin production.

Moreover, increasing temperature and drought cause stress in plants and make them more vulnerable to pests, indirectly causes the growth of fungal species [39]. Each fungal species has optimal environmental conditions (especially temperature and relative humidity) for toxin production, colonization, survival, and crop infection. Therefore, Climatic changes will lead to alteration in the fungal population and mycotoxin patterns [40]. In general, climate change can shift the prevalence and type of mycotoxins in cereals in different world regions.

Conclusion

The purpose of this review was to survey the significant types of mycotoxins in cereals that are directly or indirectly consumed by humans. Studies show that the contamination of various mycotoxins is still high in developing countries, and it remains the primary concern in these regions. In the last three years, most contamination reports have been reported in corn, wheat, and rice, respectively. AFB_1 are considered the most hazardous mycotoxins and had a high prevalence in cereals, that in most of the studies it exceeded the EC allowed limit. DON, ZEN, and FUM are the other significant mycotoxins in cereals such as barley, sorghum, and oats. Mycotoxins' high stability during cereals production, distribution, storage, and processing has concerned the contamination of mycotoxins in cereals. Therefore, the development of practical control and management strategies is essential to ensure consumer safety.

Declarations of interest

There is no conflict of interest.

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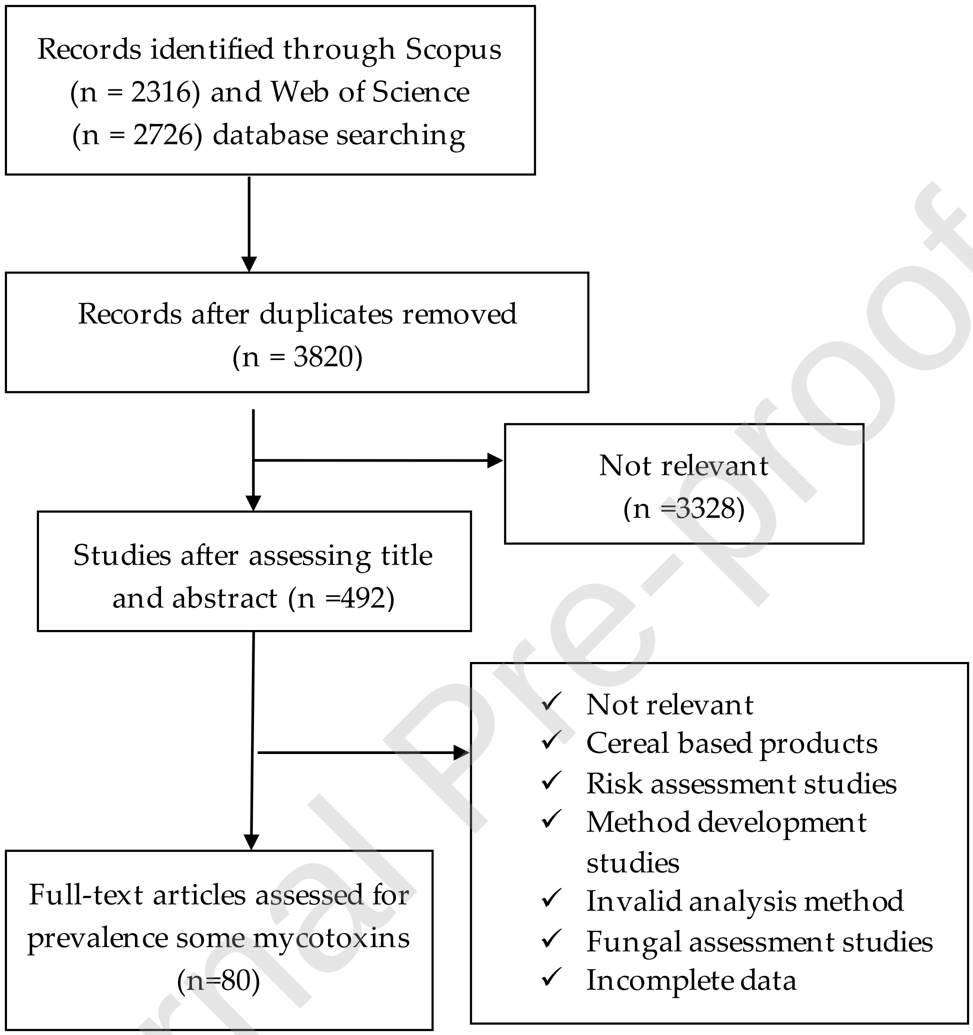


Figure 1. Flow chart of the extensive literature search performed.

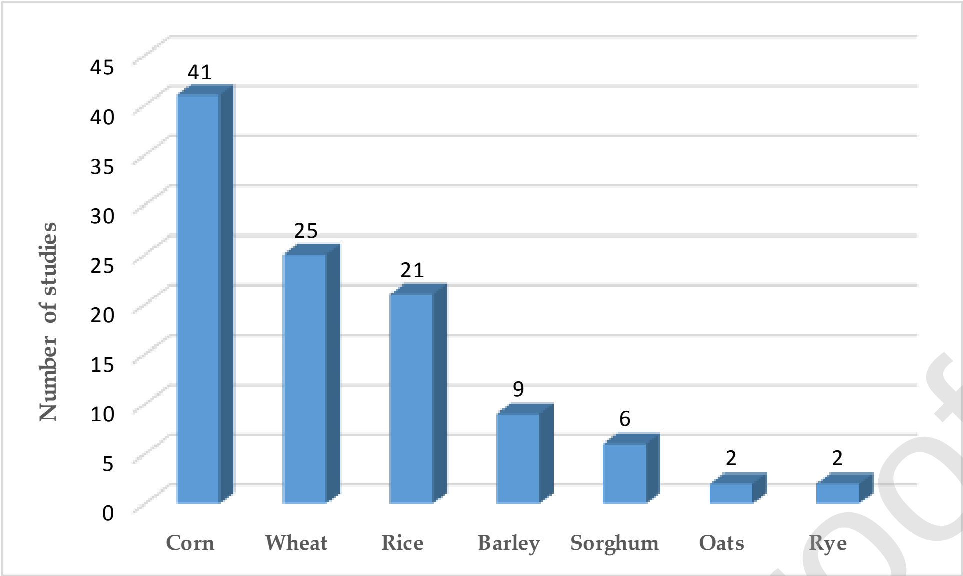


Figure 2. The number of articles published in 2018 to 2020.

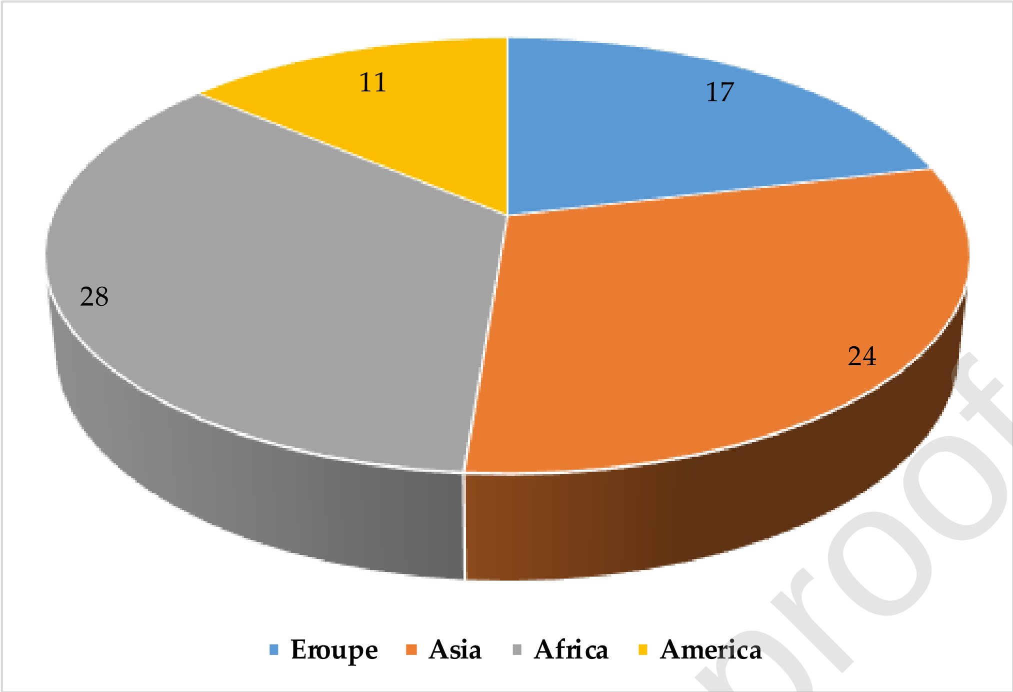
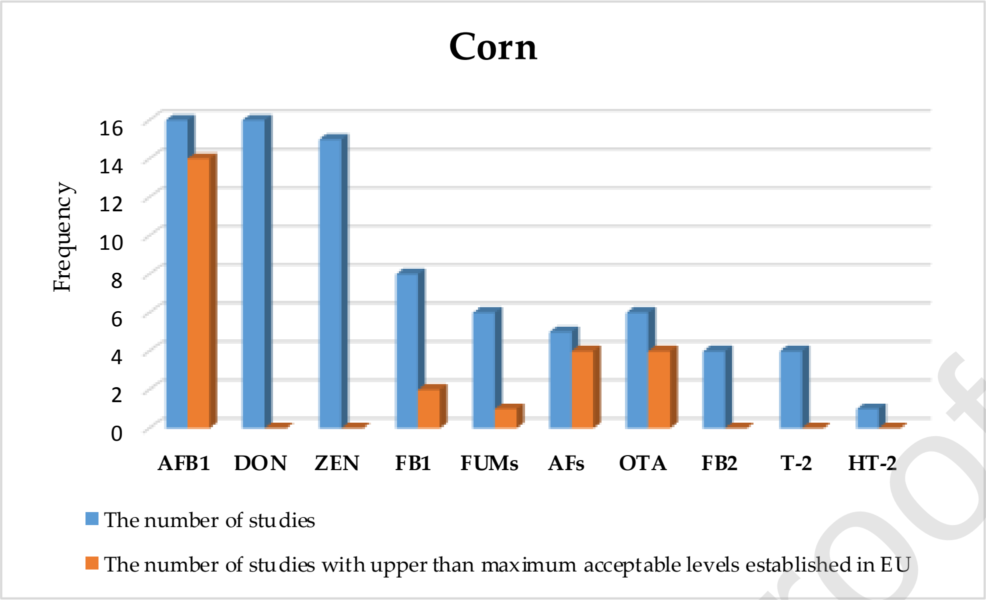
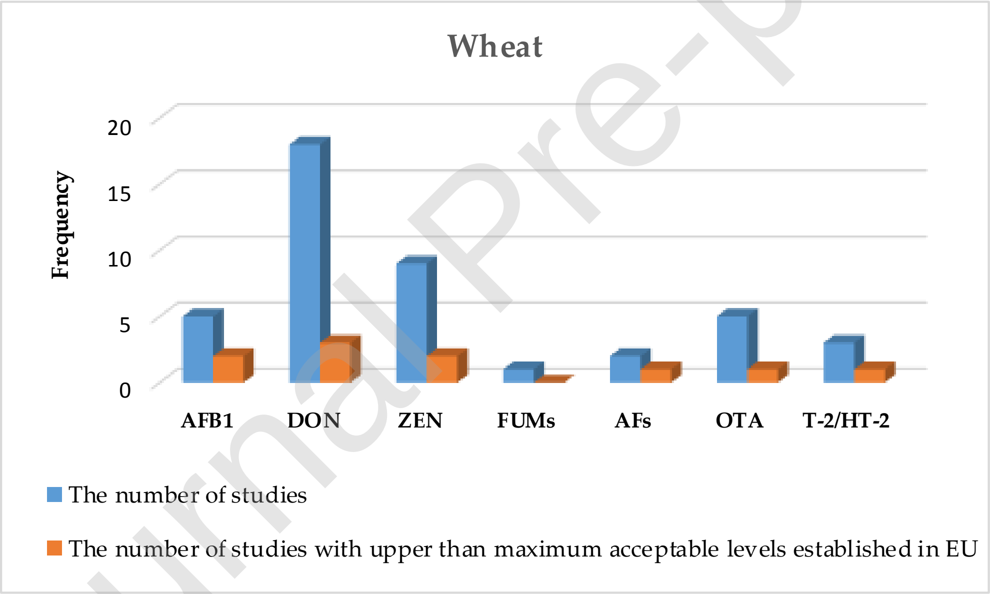
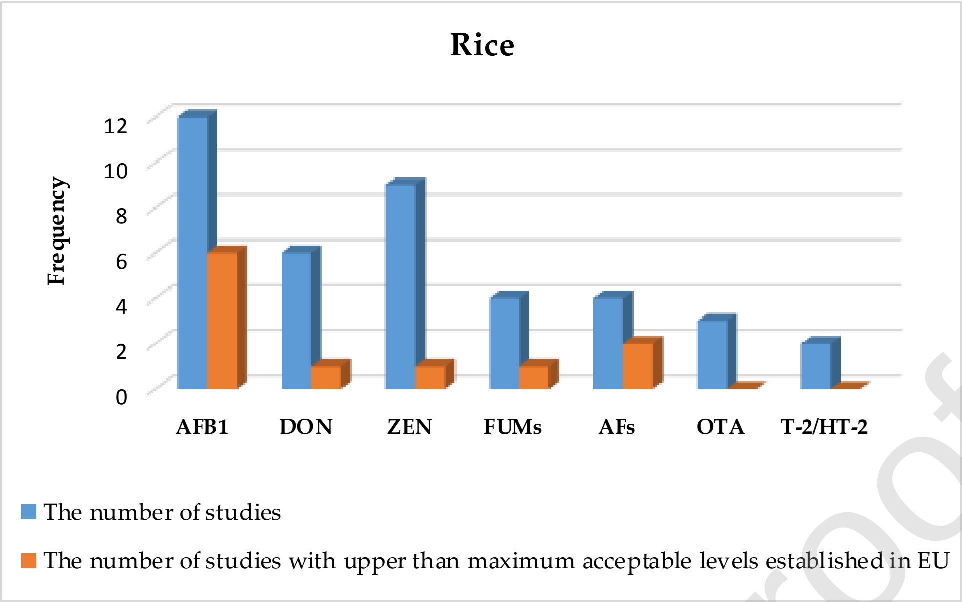
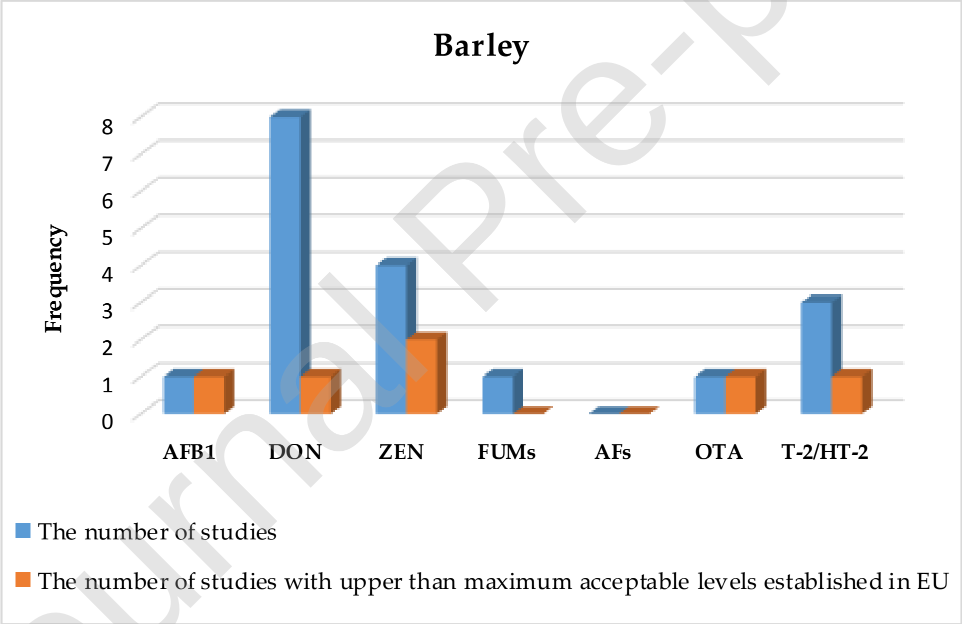


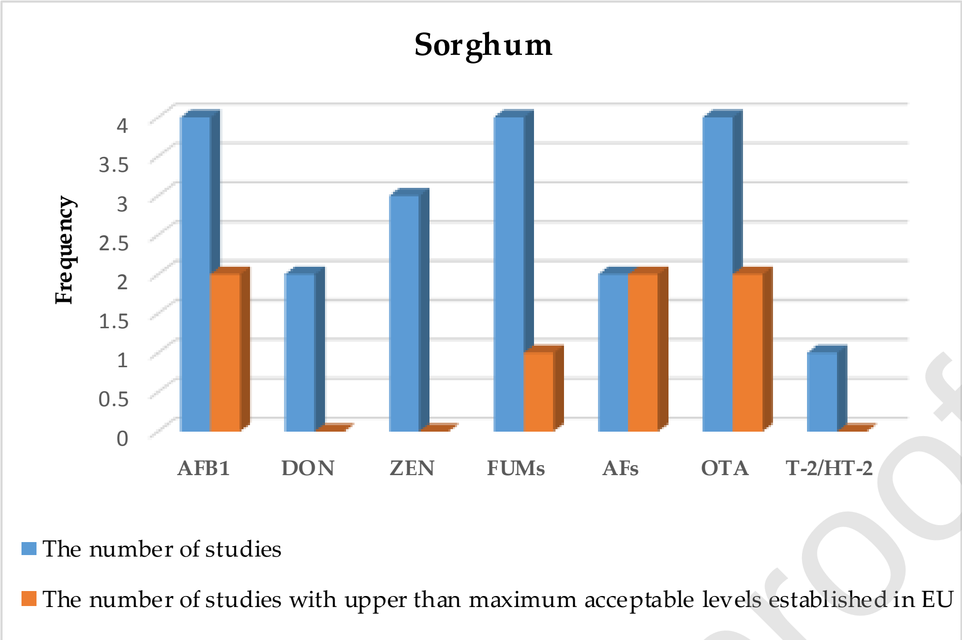
Figure 3. The number of researches carried out based on different continents from 2018 to 2020.

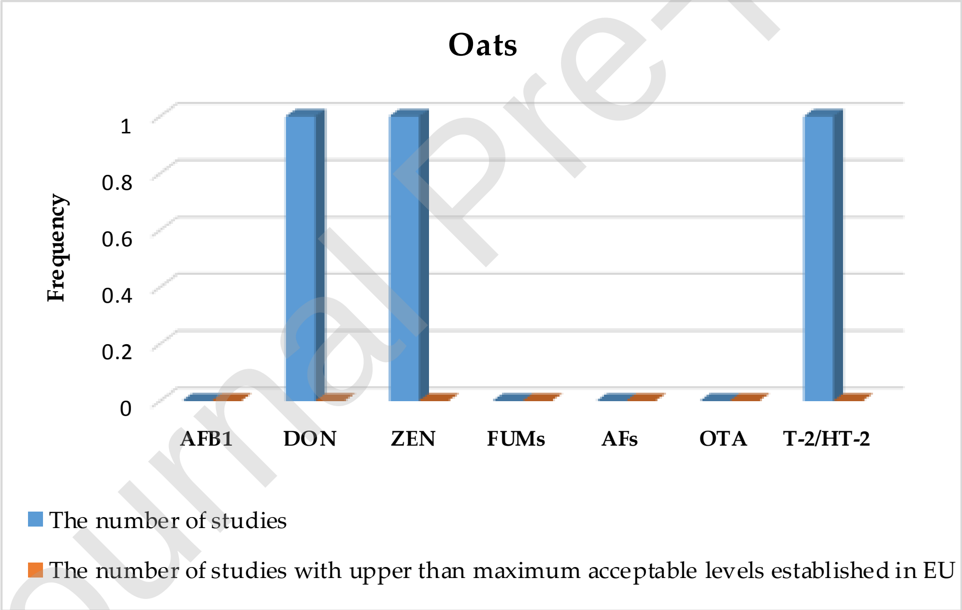

Corn
Frequency
16
14
12
10
8
6
4
2
0
AFB1
DON
ZEN
FB1
FUMs
AFs
OTA
FB2
T-2
HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU


Wheat
Frequency
20
15
10
5
0
AFB1
DON
ZEN
FUMs
AFs
OTA
T-2/HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU


Rice
Frequency
12
10
8
6
4
2
0
AFB1
DON
ZEN
FUMs
AFs
OTA
T-2/HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU


Barley
Frequency
8
7
6
5
4
3
2
1
0
AFB1
DON
ZEN
FUMs
AFs
OTA
T-2/HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU


Sorghum
Frequency
0
0.5
1
1.5
2
2.5
3
3.5
4
AFB1
DON
ZEN
FUMs
AFs
OTA
T-2/HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU


Oats
Frequency
0
0.2
0.4
0.6
0.8
1
AFB1
DON
ZEN
FUMs
AFs
OTA
T-2/HT-2
The number of studies
The number of studies with upper than maximum acceptable levels established in EU

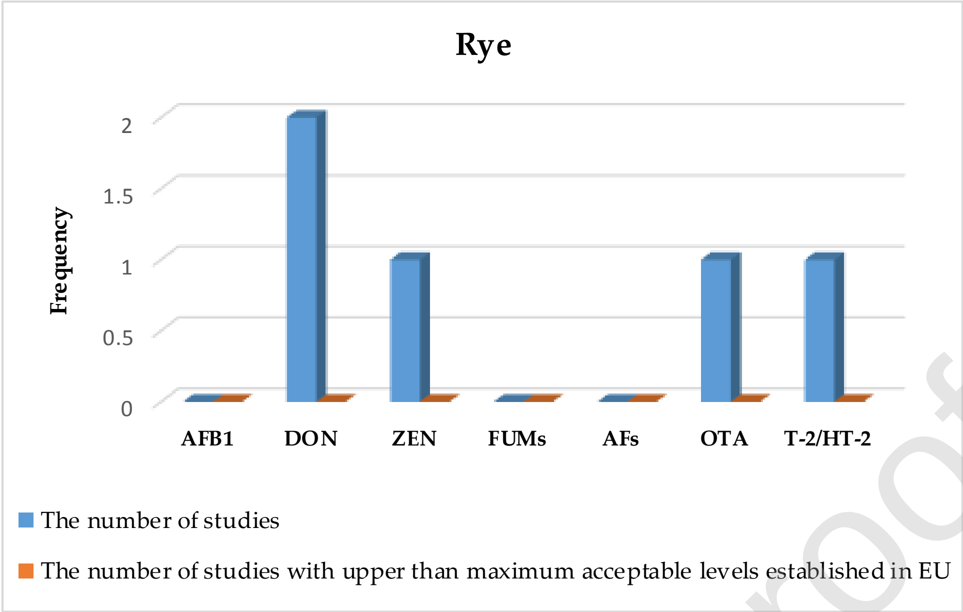


Figure 4. The frequency of some mycotoxins in corn, wheat, rice, barley, sorghum, oats, and rye seeds in 2018 to 2020. AFs: Aflatoxins Total; AFB1: Aflatoxin B1; OTA: Ochratoxin-A; DON: Deoxynivalenol; FUMs: Fumonisins total; ZEN: Zearalenone; FB1: Fumonisins B1; FB2: Fumonisins B2; T2: T-2 toxin; HT2: HT2-Toxin.