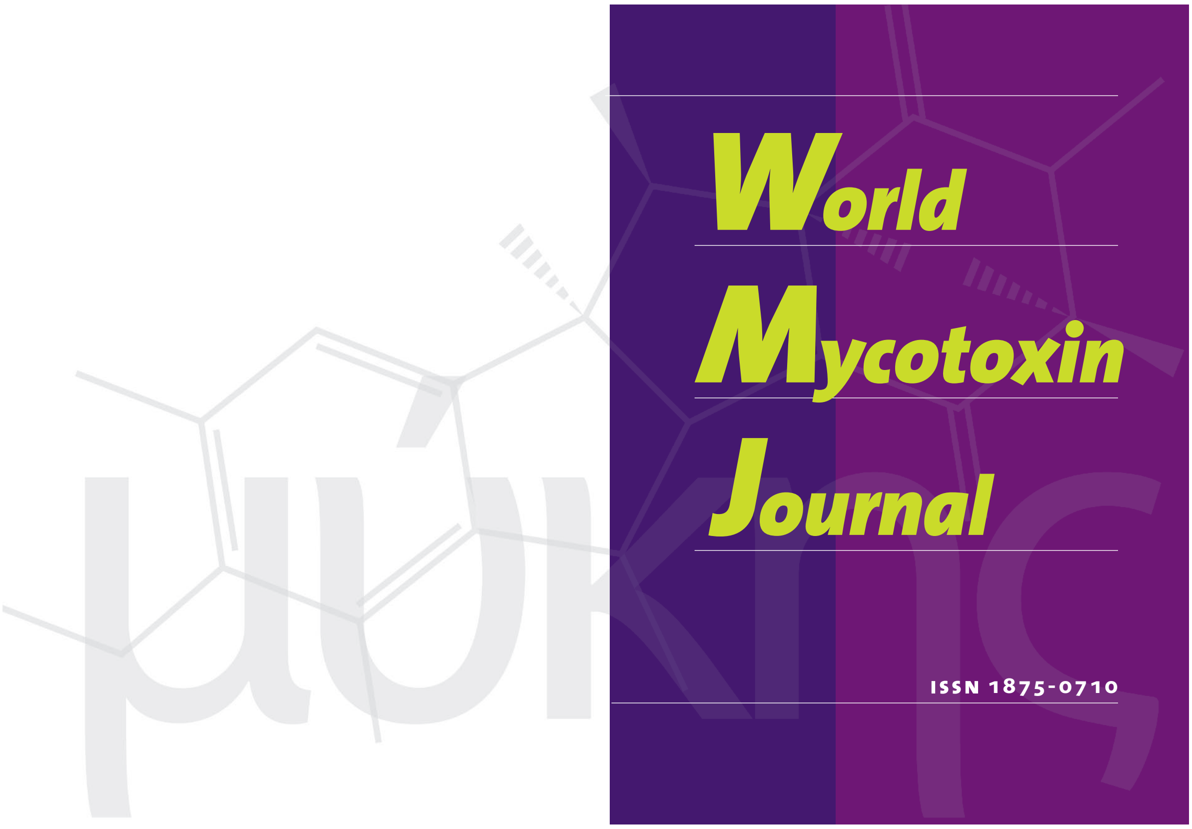
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Aflatoxins in cereals: worldwide occurrence and dietary risk assessment

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RESEARCH ARTICLE

Abstract

The worldwide occurrence of aflatoxins (AFB_1, AFB_2, AFG_1, AFG_2), genotoxic mycotoxins, in raw maize, rice, sorghum and wheat samples collected since the year 2000 was evaluated using published data and occurrence data from the GEMS/Food database (https://extranet.who.int/gemsfood). Dietary risk assessments were conducted using GEMS/Food total aflatoxin occurrence and food consumption data obtained from the 17 Cluster Diets. Risk characterisation arising from aflatoxin exposure was conducted using both cancer risk and margin of exposure (MOE) approaches. A total of 89 publications were retrieved from the literature, reporting data related to 18,097 samples, of which 37.6% were positive for at least one aflatoxin. The total upper bound (UB) mean for all samples analysed was 13.6 μg/kg, and was higher for rice (24.6 μg/kg) and sorghum (25.9 μg/kg). Of data related to the analysis of 4,536 samples reported to GEMS/Food database, 12.7% were positive for at least one aflatoxin. The total UB mean was 1.9 μg/kg, and was higher for rice (2.4 μg/kg) and maize (1.6 μg/kg). Total intakes ranged from 3.0 ng/kg bw/day (Cluster C11) to 17.1 ng/kg bw/day (Cluster C09). On average, the consumption of rice contributed to 41.6% of the total aflatoxin intake in all clusters, followed by wheat (35.4%), maize (21.2%) and sorghum (1.8%). The lowest cancer risk was found in cluster C11 (0.057 cancers/year/10^5 individuals), and the highest in cluster C09 (0.467 cancers/year/10^5 individuals). MOE ranged from 56 (C11) to 10 (C09), indicating a potential risk to consumers. These results highlight the need for continuous action by health authorities to decrease aflatoxin contamination in cereals, as they are staple foods in diets worldwide. These actions include the enforcement of code of practices at the national level and the establishment of maximum contamination levels by the Codex System.

Keywords: aflatoxins, cereal diets, dietary exposure, carcinogenicity, risks

1. Introduction

Cereals are staple foods in diets around the world. Wheat is the main cereal consumed in America and Asia accounting, respectively, for 14.1 and 24.3% of the total calorie intake in these regions. Rice is the main contributor to the total energy intake in Asia (28.5%) and wheat and maize contribute equally (30%) in Africa (FAO, 2014). The contamination of cereals with aflatoxins B_1, B_2, G_1 and G_2 (AFB_1, AFB_2, AFG_1 and AFG_2) has been reported worldwide. Mean concentrations in positive maize samples in Argentina and Uganda were, respectively, 35.8 μg/kg (total aflatoxins; 264/3,192 samples) (Garrido *et al.*, 2012), and 19.5 μg/kg (total aflatoxins; 296/390 samples) (Kaaya and Kyamuhangire, 2006). The mean level of aflatoxins found in rice from Pakistan was 11.2 μg/kg (total aflatoxins; 185/413 samples) (Iqbal *et al.*, 2012), while in South Korea it was only 1.7 μg/kg (total aflatoxins; 6/160 samples) (Ok *et al.*, 2014). In Nigeria, 55% of the 168 sorghum samples were contaminated with AFB_1 with levels up to 1,164 μg/kg (Hussaini *et al.*, 2009), while in Turkey wheat samples reached levels up to 643.5 μg/kg (total aflatoxins; 24/41 samples) (Giray *et al.*, 2007).

Aflatoxins are human liver carcinogens, with AFB_1 shown to be genotoxic (IARC, 1993); as such, exposure should be as low as reasonably achievable (CAC, 1995). The complete elimination of aflatoxins from the food supply, however, is not possible, and worldwide strategies are needed to control and manage contamination (CAC, 2003). *Aspergillus flavus* and *Aspergillus parasiticus* infection and aflatoxin production in cereals are influenced by several environmental factors such as temperature, humidity, insect damage and drought (Miraglia *et al.*, 2009). Furthermore, aflatoxins can also be produced after harvesting the grain (Pitt *et al.*, 2013), mainly during storage.

Several countries have established regulatory limits to control the presence of aflatoxins in cereals, including Brazil (Anvisa, 2011), European Union (EC, 2006), and the United States (USFDA, 2000). Internationally, maximum levels (ML) for aflatoxins in cereals are currently under discussion at the Codex Committee on Contaminants in Foods (FAO/WHO, 2014). Given the difficulty of eliminating aflatoxins from the food chain and considering the worldwide consumption of cereals, dietary risk assessments for aflatoxins are essential to help government authorities and the Codex Alimentarius to take actions aimed at reducing risk while still ensuring the food security.

In the context of food safety, risk assessment is a four-step conceptual framework that aims to estimate the risk of occurrence of adverse health effects after exposure to chemicals present in food. The hazard identification step is designed to identify the nature of the adverse health effects caused by human exposure to the contaminant, and the aim of the hazard characterisation step is to establish a quantitative relationship between exposure and the incidence of adverse effects. In the exposure assessment step the likely intake of contaminants through the diet is estimated, taking into account the concentration of the chemical in food, as well as consumption patterns. The risk characterisation step finalises the process, providing an estimation of the probability of occurrence of health outcomes in a population under defined exposure conditions (IPCS, 2009).

Dietary exposure assessments for aflatoxins have been conducted worldwide. In most studies, cereals accounted for over 90% of the total intake (Andrade *et al.*, 2013; Ding *et al.*, 2012; Li *et al.*, 2014; Park *et al.*, 2004; Yazdanpanah *et al.*, 2013). Risk characterisation for aflatoxins has been conducted using two different approaches. The first, developed by the FAO/WHO Joint Expert Committee on Food Additives (JECFA), estimates the cancer risk for a given population considering the incidence of the hepatitis B virus (HBsAg$^+$ individuals) and the carcinogenic potency of aflatoxins, which was defined for HBV carriers and non-carriers (FAO/WHO, 1998). More recently, the margin of exposure (MOE) approach has been used by the European Food Safety Authority (EFSA) and was recommended by JECFA to evaluate compounds that are both carcinogenic and genotoxic (EFSA, 2005; FAO/WHO, 2006). The MOE is the ratio of a toxicological threshold obtained from animal studies and the estimated human exposure (IPCS, 2009).

This study aimed to evaluate the current scenario on aflatoxin contamination in raw maize, rice, sorghum and wheat commercialised worldwide, and to estimate the dietary exposure to aflatoxins and the potential health risks arising from this exposure. The first draft of this paper was the basis for the preparation of the Discussion Paper on Aflatoxins in Cereals presented at the 8th Session of the Codex Committee on Contaminants in Food (CX/CF 14/8/15; CAC, 2014a).

2. Materials and methods

Aflatoxins occurrence: data obtained from the literature

Occurrence data on aflatoxins in raw maize, rice, sorghum and wheat were obtained from published studies related to samples collected from 2000 to 2014. The search was conducted in the Web of Science database and Google Scholar in September 2012, July 2013, and May 2014, using the following keywords: 'mycotoxin' and 'aflatoxin' alone, or in combination with 'maize', 'rice', 'sorghum' and 'wheat', using the logical operator AND. Papers related to samples that were inoculated with mycotoxin producing fungi in the laboratory were excluded. Only peer review papers were considered in the search, written in English or in other languages.

For each crop, the mean values estimated for all studies were calculated by weighting the reported mean of each study by the number of samples analysed in that study. When only the median value was reported in the study, this value was used to estimate the weighted mean. When only the concentration range was reported, the midrange was used in the calculation. The lower bound of the total mean (LB) was estimated considering samples below the limit of detection (LOD) or below the limit of quantification (LOQ) as zero. The upper bound (UB) was obtained considering samples below LOD or below LOQ as ½LOD or ½LOQ. Whenever the LOD or LOQ of the method used in the study were not reported, limits found in other studies that used a similar analytical method were used in the calculation of the UB mean. When both LOD and LOQ were reported, the latter was used in the estimation.

Aflatoxins occurrence: data from the GEMS/Food database

The Global Environment Monitoring System/Food Contamination Monitoring and Assessment Programme (GEMS/Food) compile surveillance and monitoring data on food contamination submitted by national government authorities. In July 2013, the JECFA issued a specific public call for data on aflatoxin contamination in cereals, to be submitted to GEMS/Food (https://extranet.who.int/gemsfood). Data on total aflatoxin (AFB_1 + AFB_2 + AFG_1 + AFG_2) in raw maize, rice, sorghum and wheat were extracted from the GEMS/Food database using an ADS WHO partner login, and exported to MS Excel (Microsoft, Redmond, WA, USA) spreadsheets. Data were obtained for all WHO regions and countries, with the sampling period starting in 2000. Data were extracted on October 21, 2013 and on July 02, 2014.

The informed food codes (WHO food identifier, WHO food code and local food identifier) were used to identify processed commodities, which were not included in this study. Rice samples that included inedible portions (husk) or that were submitted to heat treatment (cooked) prior to analysis were also excluded. When the portion analysed was not mentioned, it was assumed that the analysis was performed in the cereal edible portion. Information regarding analytical quality assurance was also obtained from the GEMS/Food database.

For some samples, there were up to six entries in the database (individual aflatoxins, sum of AFB$_1$ and AFB$_2$, and total aflatoxins), but only the total aflatoxins value was considered. When the total aflatoxins value was not included, it was estimated from the individual aflatoxin values. When values reported were below LOQ or LOD, they were considered as 0 or ½LOQ/LOD in the LB or UB estimations of the means, respectively. When both LOD and LOQ were reported, ½LOQ was used. Where LOD or LOQ was not reported, the value informed for other samples from the same laboratory or country was used.

Consumption of cereals: data from the 17 GEMS/Food Consumption Cluster Diets

The Food and Agriculture Organization of the United Nations (FAO) compiles country-level data on the production and trade of food commodities, producing food balance sheets that provide data on the overall per capita supply of commodities within countries (FAO, 2014). GEMS/Food uses the FAO Food Supply Utilisation Account data to determine the food consumption patterns that are used in chronic dietary risk assessments conducted at the international level by FAO/WHO scientific panels, including the JECFA. The 17 GEMS/Food cluster diets were elaborated based on FAO Food Supply Utilisation Account data from 2002 to 2007 for 179 countries. Clusters were formed according to their consumption system profiles (combination of different food products and local factors such as availability, seasonality and socio-cultural habits) using statistical methods (Sy *et al.*, 2013). The average data were weighted by the population size to determine the average kg/person/cluster over a 5 year period. The countries included in each Cluster are shown in Figure 1. Body weight (bw) is 60 kg for all clusters, except cluster 09 (55 kg).

Dietary risk assessment

Total chronic intake of aflatoxins through the consumption of rice, maize, wheat and sorghum for each of the GEMS/Food Cluster Diets was estimated using the International Estimated Daily Intake (IEDI) 17 Cluster diets template, developed by the Dutch National Institute for Public Health and the Environment, in cooperation with the WHO, to conduct dietary intake by the FAO/WHO Joint Meeting on Pesticide Residues (FAO/WHO, 2013).

The IEDI 17 Cluster diets template estimates the dietary intake of aflatoxins, according to FAO/WHO recommendation (FAO/WHO, 2005), as shown in Equation 1:

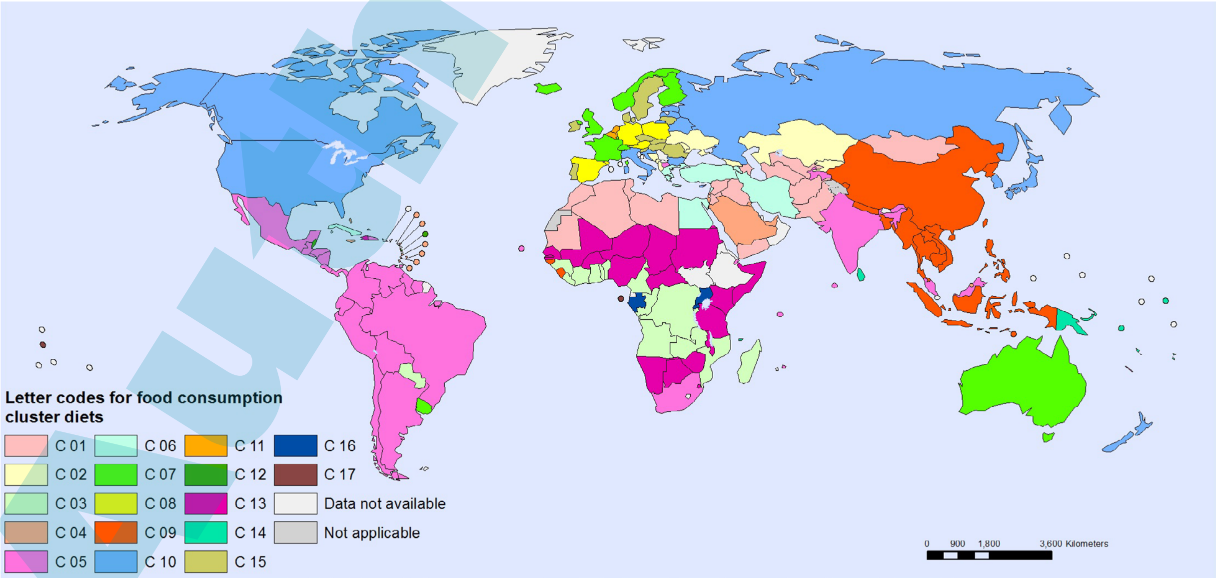

Figure 1. 17 GEMS/Food Consumption Cluster Diets (WHO, 2014).

$$Total\ intake = \sum \frac{(consumption \times concentration)}{body\ weight} \quad (1)$$

The Cluster diet consumption figures used in the intake estimation includes processed food. For maize, it includes flour, oil, beer, germ and starch; for rice, it includes polished and husked rice, flour, oil, beverages and starch; for sorghum, it includes beer and flour; and for wheat, it includes whole meal, flour, beverages, pasta, bread, starch, gluten, and mixed grain. The concentration used in the intake estimations was obtained from samples submitted to the GEMS/Food database (UB mean concentration).

Risk characterisation arising from aflatoxin exposure was conducted using both the cancer risk (FAO/WHO, 1998) and MOE approaches (EFSA, 2005). The cancer risk for each cluster was calculated by multiplying the carcinogenic potency (P_{cancer}) by the total intake of AFs (Equation 2). The P_{cancer} considers both the carcinogenic potency of AFs for individuals with hepatitis B virus ($PHBsAg^+$ = 0.3 cancers/year/100,000 individuals/ng aflatoxin/bw/day) and for non-infected individuals ($PHBsAg^-$ = 0.01 cancers/year/100,000 individuals/ng aflatoxin/bw/day), as well as the percentage of carriers ($HBsAg^+$) and non-carriers ($HBsAg^-$) of hepatitis B virus in the population (Equation 3). The worldwide prevalence of chronic hepatitis B virus infection among adults published by CDC (2014) was used to estimate the prevalence of hepatitis B virus ($HBsAg^+$) for each cluster.

$$Cancer\ risk = P_{cancer} \times total\ intake \quad (2)$$

$$P_{cancer} = (PHBsAg^+ \times \%pop.HBsAg^+) + (PHBsAg^- \times \%pop.HBsAg^-) \quad (3)$$

The MOE was given by the ratio between the benchmark dose level that caused a 10% increase in cancer incidence in rodents (BMDL10 = 170 ng/kg bw/day; 95% lower confidence limit) (EFSA, 2007) and the total intake (Equation 4). MOE values lower than 10,000 may indicate a public health concern (EFSA, 2005).

$$MOE = BMDL10\ /\ total\ intake \quad (4)$$

3. Results

Aflatoxins occurrence: data from the literature

A total of 89 publications reporting data on aflatoxins contamination in raw cereal samples collected since 2000 were retrieved from the literature. The first such study was published in 2003, and the highest numbers of papers were found in 2011 and 2012 (15 and 14 papers, respectively). A summary of the published studies, grouped by continent, is shown in Table 1. Data covers samples collected in a wide range of countries. Most papers concerned maize (n=47) and rice (n=39), and 18 studies analysed two or more cereals of interest to this study. The majority of papers

Table 1. Summary of published data on aflatoxins in cereal samples collected from 2000 onwards.

Country	Cereal[1]	Reference
African continent		
Algeria	W	Riba *et al.*, 2010
Benin and Togo	M	Egal *et al.*, 2005
Burkina Faso	M	Probst *et al.*, 2014; Warth *et al.*, 2012
Cameroon	M	Abia *et al.*, 2013; Probst *et al.*, 2014
Egypt	M	Nogaim *et al.*, 2011
Ethiopia	S	Chala *et al.*, 2014; Probst *et al.*, 2014
Kenya	M, W	Daniel *et al.*, 2011; Muthomi *et al.*, 2008; Mwihia *et al.* 2008; Probst *et al.*, 2014
Ivory Coast	M, R	Probst *et al.*, 2014; Sangare-Tigori *et al.*, 2006
Lesotho	M	Mohale *et al.*, 2013; Probst *et al.*, 2007
Malawi	S	Matumba *et al.*, 2011; Probst *et al.*, 2014
Morocco	W	Zinedine *et al.*, 2006
Mozambique	M	Probst *et al.*, 2014; Warth *et al.*, 2012
Nigeria	M, R, S, W	Adejumo *et al.*, 2013; Ayejuyo *et al.*, 2011; Bandyopadhyay *et al.*, 2007; Bankole and Mabekoje, 2004; Hussaini *et al.*, 2009; Makun *et al.*, 2011
South Africa	M	Chilaka *et al.*, 2012; Shephard *et al.*, 2013
Tanzania	M	Kimanya *et al.*, 2008; Probst *et al.*, 2014
Tunisia	M, R, S, W	Ghali *et al.*, 2008, 2009, 2010; Oueslati *et al.*, 2012
Uganda	M	Kaaya and Kyamuhangire, 2006; Probst *et al.*, 2014
Zambia	M	Mukanga *et al.*, 2010; Probst *et al.*, 2014
D. Republic of Congo, Ghana, Mali, Rwanda, Senegal, Sierra-Leone, Somalia, Zimbabwe	M	Probst *et al.*, 2014

Table 1. Continued.

Country	Cereal[1]	Reference
American continent		
Argentina	M	Broggi *et al.*, 2007; Garrido *et al.*, 2012
Brazil	M, R	Almeida *et al.*, 2012; Carvalho *et al.*, 2010; Dors *et al.*, 2011, 2013; Moreno *et al.*, 2009; Nunes *et al.*, 2003; Oliveira *et al.*, 2010; Rocha *et al.*, 2009
Canada	M, R, W	Bansal *et al.*, 2011; Martos *et al.*, 2010
United States of America	M, R, W	Abbas *et al.*, 2006; Bruns *et al.*, 2007; Liao *et al.*, 2013
Asian continent		
China	M, R	Fu *et al.*, 2008; Gao *et al.*, 2011; Lai *et al.*, 2014; Liu *et al.*, 2006; Sun *et al.*, 2011; Zhu *et al.*, 2013
India	R, S, W	Ratnavathi *et al.*, 2012; Reddy *et al.*, 2009; Toteja *et al.*, 2006
Iran	M, R	Ghiasian *et al.*, 2011; Karami-Osboo *et al.*, 2012; Mazaheri, 2009; Mohammadi *et al.*, 2012; Sani *et al.*, 2014; Yazdanpanah *et al.*, 2013
Japan	M, R	Sugita-Konishi *et al.*, 2006
Korea	M, R	Kim *et al.*, 2013; Park *et al.*, 2004
Malaysia	R, W	Khayoon *et al.*, 2012; Rahman and Jinap, 2010; Reddy and Baharuddin, 2010; Soleimany *et al.*, 2011; Soleimany *et al.*, 2012
Pakistan	M, R, S, W	Ahsan *et al.*, 2010; Asghar *et al.*, 2014; Hussain *et al.*, 2011; Iqbal *et al.*, 2012; Khatoon *et al.*, 2012; Lutfullah and Hussain, 2012; Shah *et al.*, 2010
Qatar	R, W	Abdulkadar *et al.*, 2004
South Korea	R	Ok *et al.*, 2014
Taiwan	R	Yu *et al.*, 2013
Vietnam	R	Nguyen *et al.*, 2007
European continent		
Austria	R	Reiter *et al.*, 2010
Germany	M, R	EFSA, 2007; Reinhold and Reinhardt, 2011
Italy	M, W	Covarelli *et al.*, 2011; EFSA, 2007; Pace *et al.*, 2012
Serbia	M, W	Jakic-Dimic *et al.*, 2009; Kos *et al.*, 2013
Turkey	M, R, W	Alptekin *et al.*, 2009; Aydin *et al.*, 2011; Giray *et al.*, 2007; Oruc *et al.*, 2006
Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Ireland, Latvia, Luxembourg, Slovakia, Slovenia, Spain, Sweden	M	EFSA, 2007

[1] M = maize; R = rice; S = sorghum; W = wheat.

(56) reported method validation data. One study reported that the laboratory participated in proficiency testing, two in interlaboratory studies, and one reported the use of certified reference material for method validation. Thirty papers did not provide any analytical quality assurance information. Even though quality assurance information was not available in some studies, all data were included in the dataset in order to describe the occurrence scenario.

Table 2 summarises the published data on aflatoxin levels in cereals. A total of 18,097 samples were analysed in the studies, with maize accounting for 54.3% of the samples (9,819 samples), followed by rice (21.1%). About 41% of the samples were collected in Asia, of which 39.2% were rice samples. Maize was the main cereal analysed in American countries, accounting for 85.6% of the samples for the region. Most of the analysed wheat samples were from Asian countries (72.1%). Sorghum was only analysed in samples from African and Asian countries.

Considering all samples analysed in the studies, 37.6% were positive for at least one aflatoxin (Table 2). Sorghum had the highest incidence of positive samples (68.9%), followed by rice (52.3%). Contaminated rice, sorghum and wheat samples were mostly from Asia (about 80%), while 40% of contaminated maize came from Africa. There was no positive wheat sample reported in the American continent and the lowest incidence of aflatoxins for the other commodities was also found in this continent.

Table 2. Worldwide occurrence of total aflatoxin in cereals obtained from published literature (samples collected from 2000 onwards).

	n[1]	Positive/analysed samples (%)	Positive samples (μg/kg)		Total mean[2]
			Mean ± SE[1]	Range	LB[3] - UB[4] (μg/kg)
Maize	47	2,496/9,819 (25.4)	28.2±5.5	0.01-48,000	7.2-8.1
Africa	20	997/2,771 (36.0)	25.9±6.2	0.01-48,000	9.3-9.7
America	9	409/4,056 (10.1)	30.8±4.5	0.1-1,393	3.1-4.9
Asia	12	655/1,134 (57.8)	35.6±19.9	0.02-888.3	20.5-20.8
Europe[5]	6	435/1,858 (23.4)	20.1(6)±5.5	0.01-820	4.8-5.0
Rice[7]	39	1,995/3,811 (52.3)	46.6±3.6	0.002-371.9	24.4-24.6
Africa	6	64/99 (64.6)	28.9±13.3	0.3-371.9	18.7-18.8
America	7	205/625 (32.8)	5.2±7.6	0.002-176.3	1.7-2.3
Asia	23	1,654/2,889 (57.3)	54.0±4.6	0.01-308	30.9-31.0
Europe	3	72/198 (36.4)	8.8±3.1	0.05-21.4	3.2-3.5
Sorghum	11	1,433/2,079 (68.9)	37.3±17.4	0.01-1,164	25.7-25.9
Africa	9	257/463 (55.5)	79.7±21.1	0.34-1,164	44.2-44.3
Asia	2	1,176/1,616 (72.8)	27.8±11.4	0.01-264	20.2-20.4
Wheat	18	874/2,388 (36.6)	18.0±9.1	0.05-643.5	6.6-7.8
Africa	6	66/206 (32.0)	4.9±1.4	0.13-37.4	1.6-2.0
America	2	0/56 (0.0)	–	–	ND-3.7
Asia	7	691/1,721 (40.2)	14.4±1.9	0.1-606	5.8-7.2
Europe	3	117/405 (28.9)	46.9±51.4	0.05-643.5	13.5-13.9
Total	89	6,798/18,097 (37.6)	34.2±3.4	0.002-48,000	12.9-13.6

[1] n = number of studies; SE = standard error.
[2] Mean of all samples.
[3] Lower bound: samples < LOD/LOQ = zero.
[4] Upper bound: samples < LOD/LOQ = ½LOD/½LOQ.
[5] Includes monitoring data collected by EFSA (2007).
[6] Mean of positive samples not available in EFSA (2007).
[7] Mostly rice collected on the market, but some studies may include rice samples with the husk.

The mean aflatoxin level found in positive samples, considering all cereals, was 34.2±3.4 μg/kg, with rice samples having the highest mean among the grains analysed (46.6±3.6 μg/kg). The highest aflatoxin level (48,000 μg/kg) was found in a sample collected in Kenya (Daniel *et al.*, 2011). Samples of maize and rice analysed from Asia had the highest mean of positive samples (35.6 μg/kg and 54.0 μg/kg, respectively), while Africa showed the highest mean level of contamination in sorghum (79.7 μg/kg), and Europe in wheat (46.9 μg/kg). The total UB mean of all samples analysed was 13.6 μg/kg. Sorghum samples had the highest total mean, with similar lower and UB levels (25.7 and 25.9 μg/kg).

Aflatoxins occurrence: data from the GEMS/Food database

Figure 2 shows the countries that submitted data on aflatoxins in raw maize, rice, sorghum and wheat to the GEMS/Food database, related to 4,536 samples collected since the year 2000. Singapore submitted the largest dataset (1,028 samples), followed by Canada (967), the Republic of Korea (392), Germany (387), and Brazil (377). Most maize samples came from the USA (27.9%), rice from Singapore (27.8%), sorghum from Republic of Korea (85.5%) and wheat from Canada (81.5%). On average, 324 samples were collected for analysis each year, most of which in 2005 and 2011 (32% of all samples). The smallest number of samples was obtained in 2000 (0.9%), and 2004 (0.6%).

The GEMS/Food dataset was comprised mainly of samples collected by random sampling (78.5% of the samples), and 20.0% by target sampling. For 1.5% of the samples, the sampling method was not informed. Information on portions analysed was not available for 21 samples, none of which were contaminated with aflatoxins. Regarding analytical quality assurance of the laboratory, the GEMS/Food system allows one of four options to be checked: officially accredited methodology, internal quality assurance, proficiency testing, and unknown. For most of the samples (53.3%) officially accredited methodologies were used; for 19.3% the laboratory had internal quality

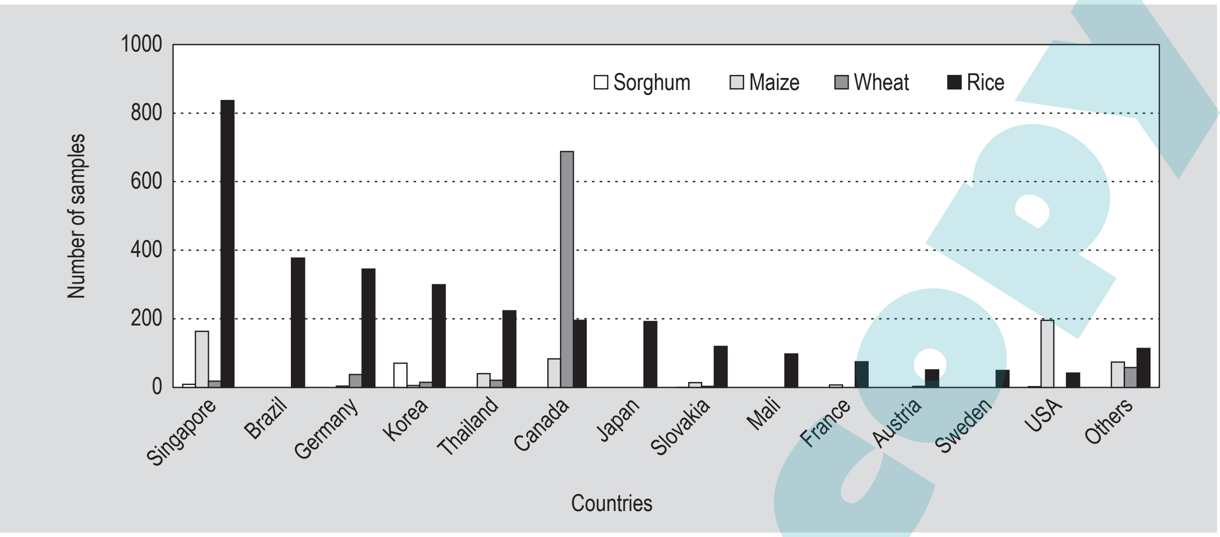

Figure 2. Number of samples submitted to the GEMS/Food database on aflatoxin in maize, rice, sorghum and wheat by country.

assurance, and for 17.9% the laboratory participated in proficiency testing. This information was unknown or was not provided for the remaining samples (9.5%). All samples were kept in the dataset, even those analysed by laboratories that have not provided quality assurance information.

Table 3 summarises the data submitted to GEMS/Food, grouped by continent. Considering all samples analysed, 12.7% were positive for aflatoxins, with a mean of 10.7±35.3 μg/kg. Total LB and UB means were, respectively, 1.4 μg/kg and 1.9 μg/kg. Rice was the commodity with the largest number of records in the database (66.6%), and with the highest incidence of positive samples (17.7%), including the highest aflatoxin level (347 μg/kg in a Mali sample). Rice also had the highest LB and UB values (1.9 and 2.4 μg/kg, respectively). Wheat was the cereal with the lowest incidence and levels of aflatoxins (Table 3).

Consumption of cereals: data from the 17 GEMS/Food Cluster Diets

Consumption data for maize, rice, sorghum and wheat (including processed products) for the 17 clusters are summarised in Figure 3. Wheat is the cereal most consumed worldwide (daily mean of 205.8 g/person), and the most consumed in 11 of the 17 clusters, including C01, C02, and C06 (mainly countries in Northern Africa and Asia; Figure 1). Rice is the second cereal most consumed (91.3 g/person/day), and the main cereal consumed in clusters C05, C09, and C14 (mostly South American and Asian countries; Figure 1). Maize (mean of 48.9 g/person/day) is the main cereal consumed in clusters C03, C13, and C16 (mostly African countries; Figure 1). The mean worldwide consumption of sorghum is 11 g/person/day, with the highest consumption in clusters C13 (89.2 g/person/day), and C16 (35.4 g/person/day).

Dietary risk assessment of aflatoxins using GEMS/Food data

The UB total intakes of aflatoxins through the consumption of maize, rice, sorghum and wheat ranged from 3.0 ng/kg bw/day (Cluster C11) to 17.1 ng/kg bw/day (Cluster C09) (Table 4). LB intakes varied from 0.7 to 12.1 ng/kg bw/day (data not shown). As the concentration for each cereal in the intake calculation was constant (UB mean concentration for each crop; Table 3), only the consumption pattern had an impact on the total aflatoxin intake among the clusters.

On average, the consumption of rice contributed to 41.6% of the total intake in all clusters, followed by wheat (35.4%), maize (21.2%) and sorghum (1.8%). Figure 4 shows the impact of each cereal in total intake for each cluster. The highest impact of rice was mainly due to the highest contamination level (2.4 μg/kg), while for wheat, high consumption was the parameter that most affected intake, as the concentration was low (0.6 μg/kg). The consumption of rice contributed from 46.8 to 89.1% to total intake for eight clusters, including C05, C09, C14 and C17 (mostly Asian countries; Figure 1). Wheat consumption contributed the most to intake in seven clusters (42.9 to 71.3%; including C02, C07 and C11). Maize was the main contributor to total intake for clusters C13 and C16 (42.4-59.4%; mostly African countries; Figure 1). The contribution of sorghum to total intake reached a maximum of 13.4% in C13 (Figure 4).

Risk characterisation from the exposure to aflatoxins was estimated using the cancer risk and MOE approaches, and the results are shown in Table 4. The lowest cancer risk was found in cluster C11 (0.057 cancers/ year/ 10^5 individuals) and the highest in cluster C09 (0.467 cancers/year/10^5 individuals). MOE ranged from 56 (C11) to 10 (C09).

Table 3. GEMS/Food data on aflatoxins in cereals grouped by continent.

	Positive/analysed samples (%)	Positive samples (μg/kg)[1]		Total mean[2]
		Mean ± SD	Range	LB[3] – UB[4] (μg/kg)
Maize[5]	33/588 (5.6)	13.0±18.7	0.2-93.1	0.7-1.6
America	20/279 (7.2)	18.3±22.2	1.7-93.1	1.3-2.3
Asia	9/224 (4.0)	5.9±6.3	0.2-14.8	0.2-0.6
Europe	4/85 (4.7)	2.1±1.4	1.0-3.3	0.1-1.8
Rice	536/3,021 (17.7)	10.6±36.3	0.002-347	1.9-2.4
Africa	84/98 (85.7)	41±71.3	0.2-347	35.1-35.2
America	223/615 (36.3)	8.8±28.7	0.002-272.2	3.2-3.5
Asia	66/1,553 (4.2)	0.4±0.4	0.02-2.5	0.02-0.5
Europe	163/755 (21.6)	1.5±2.5	0.04-17.0	0.3-1.0
Sorghum	4/83 (4.8)	8.6±5.4	0.6-12.0	0.4-0.6
America	2/2 (100.0)	12±0.07	11.9-12.0	12.0
Asia	2/80 (2.5)	5.2±6.4	0.6-9.7	0.1-0.3
Europe	0/1(0.0)	ND	ND	ND-0.08
Wheat	3/844 (0.4)	1.0±0.7	0.1-1.4	0.003-0.6
America	0/688 (0.0)	ND	ND	ND-0.5
Asia	0/54 (0.0)	ND	ND	ND-0.5
Europe	3/102 (2.9)	1.0±0.7	0.1-1.4	0.03-1.4
Total	576/4,536 (12.7)	10.7±35.3	0.002-347	1.4-1.9

[1] ND = not detected; SD = standard deviation.

[2] Total mean = mean of all samples.

[3] Lower bound: samples < LOD/LOQ = zero.

[4] Upper bound: samples < LOD/LOQ = ½LOD/½LOQ

[5] Africa: samples from Mali; America: samples from Brazil, Canada and USA; Asia: samples from Japan, Philippines, Republic of Korea, Singapore, Thailand; Europe: samples from Austria, Belgium, Cyprus, Czech Republic, France, Germany, Greece, Ireland, Italy, Latvia, Portugal, Slovakia, Slovenia, Spain and Sweden.

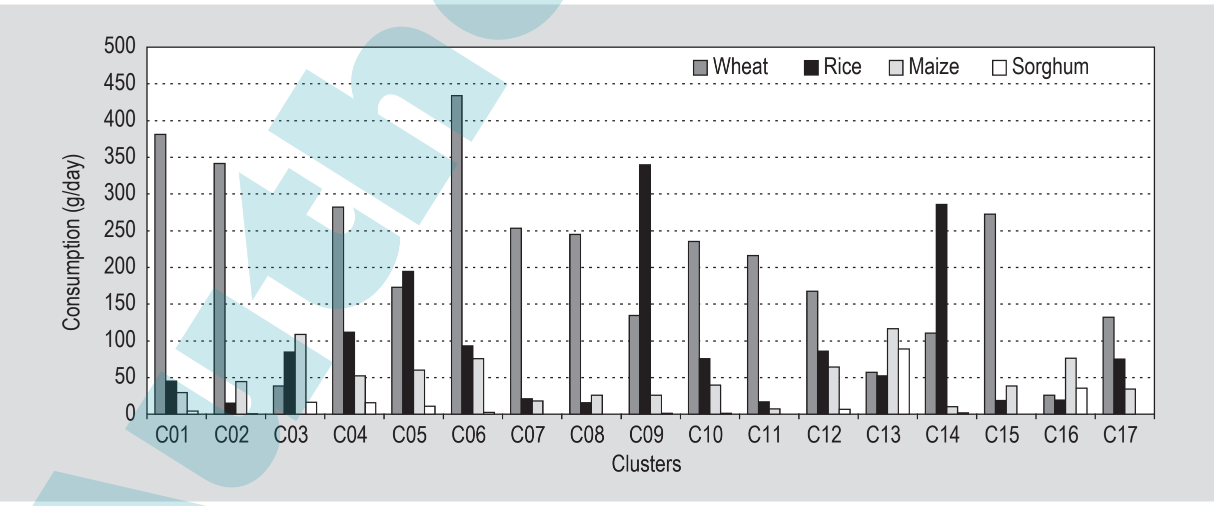

Figure 3. Consumption of maize, rice, sorghum and wheat for the 17 Cluster diets, including consumption of processed cereals (WHO, 2014). For Clusters, see Figure 1.

Table 4. Upper bound of the aflatoxin intake, cancer risk and margin of exposure through the consumption of maize, rice, wheat and sorghum for GEMS/Food Clusters C01 to C17 (ng/kg bw/day).

	Aflatoxins (µg/kg)	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13	C14	C15	C16	C17
HBsAg$^+$		3%	6%	8%	3%	3%	3%	3%	3%	6%	3%	3%	6%	8%	6%	3%	8%	6%
Rice	2.4	1.8	0.6	3.4	4.5	7.8	3.7	0.8	0.6	14.8	3.0	0.7	3.4	2.1	11.4	0.7	0.8	3.0
Maize	1.6	0.8	1.2	2.9	1.4	1.6	2.0	0.5	0.7	0.8	1.1	0.2	1.7	3.1	0.3	1.0	2.0	0.9
Wheat	0.6	3.8	3.4	0.4	2.8	1.7	4.3	2.5	2.4	1.5	2.4	2.2	1.7	0.6	1.1	2.7	0.3	1.3
Sorghum	0.6	0.04	0.001	0.2	0.2	0.1	0.03	0.0	0.0	0.0	0.01	0.0	0.07	0.9	0.02	0.0	0.4	0.0
Total	1.9	6.5	5.2	6.8	8.8	11.2	10.1	3.9	3.8	17.1	6.4	3.0	6.9	6.7	12.8	4.5	3.4	5.2
Cancer risk[1]		0.121	0.143	0.227	0.165	0.21	0.189	0.072	0.071	0.467	0.121	0.057	0.189	0.222	0.352	0.084	0.114	0.144
MOE[2]		26.3	32.6	24.8	19.2	15.1	16.8	44.0	44.9	10.0	26.4	56.0	24.6	25.5	13.2	37.8	49.4	32.4

[1] Cancers/year/10^5 individuals, estimated according to FAO/WHO (1998).

[2] Based on a $BMDL_{10}$ in rodents of 170 ng/kg bw/day (EFSA, 2007).

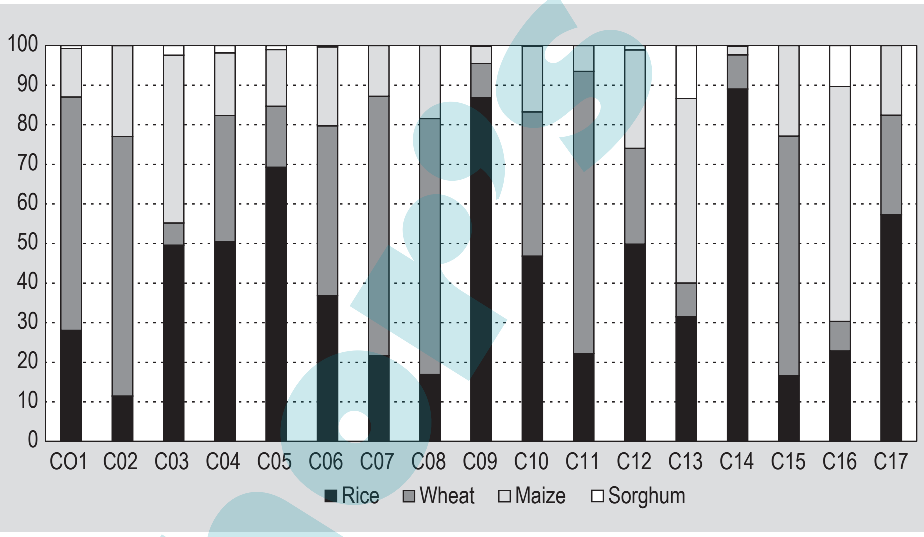

Figure 4. Impact of maize, rice, sorghum and wheat on the total aflatoxin intake for each cluster. For Clusters, see Figure 1.

4. Discussion

In this study, we reported data on aflatoxin contamination in maize, rice, wheat and sorghum grains obtained from the published literature and the GEMS/Food database. Literature data concerned samples collected in 64 countries; data from the GEMS/Food were submitted by 24 countries. No data on samples collected in Oceania countries were available in either dataset. Aflatoxin contamination data were mostly available for maize (54.2% of all samples analysed in the studies), while most of the data submitted to GEMS/Food were related to rice (66.6%). The interest in sorghum was lower in the literature in comparison with the other cereals, and the data provided to GEMS/Food were also very limited (83 samples), and did not include samples collected in African countries, the highest consumers of sorghum worldwide. This dataset will probably increase in the next few years as a FAO/WHO project on mycotoxins in sorghum is being conducted, with samples collected in the four largest producing/exporting countries of this commodity (Burkina Faso, Ethiopia, Mali, and the Sudan) (CAC, 2012). Under this project, up to February 2014, a total of 20,908 of sorghum samples have been analysed, with 3.1% of samples positive for mycotoxins, mainly aflatoxins, fumonisins, and sterigmatocystin (CAC, 2014b). Data reported in the literature may include some monitoring data submitted to the GEMS/Food database, however it was not possible to trace it back. Nevertheless, the dietary risk assessment was conducted using only the GEMS/Food dataset.

With the exception of rice samples from Africa and American continents, the incidence of aflatoxins and the concentration were higher in the published data than in the GEMS/Food database, probably due to sampling differences in the two data sources. Research studies normally do not follow strict sampling plans, and may include samples involved in outbreaks of mycotoxin contamination, not reflecting the general scenario of a specific region or country. This was the case of a survey conducted in Kenya, where some samples were collected in households of patients involved in the aflatoxicosis outbreak (Daniel *et al.*, 2011). On the other hand, the data provided to the GEMS/Food by national authorities were mostly collected under monitoring programs (non-target sampling) and are more representative of mycotoxin contamination in a given country.

In general, higher incidence and concentration calculated from the literature lead to higher aflatoxin mean levels (for positive samples and for all samples) compared to GEMS/Food data. On the other hand, mean levels calculated from published data may be overestimated, as in some studies only the concentration range was reported, and the midrange was used in the estimation (Matumba *et al.*, 2011; Ratnavathi *et al.*, 2012; Reddy *et al.*, 2009; Reiter *et al.*, 2010; Riba *et al.*, 2010). The exclusion of the study that reported the highest value of aflatoxin contamination (maize sample – 48,000 μg/kg) did not have a significant impact on the mean values for this cereal.

UB and LB of total means did not differ greatly in both datasets, which show that LOQs and or LODs of the methods used for analysis were low. The method LOQs for aflatoxins in the published studies ranged from 0.03 μg/kg (high-performance liquid chromatography with fluorescence detection) (Reinhold and Reinhardt, 2011; Yazdanpanah *et al.*, 2013) to 4 μg/kg (thin layer chromatography) (Garrido *et al.*, 2012). Method LOQs provided to GEMS/Food were in the range of 0.05-8.7 μg/kg, although method description was not available in the database. It is important to emphasise that the uncertainties of the UB and LB estimations made using literature or GEMS/Food data could not be assessed due to the limitation of the information provided in both cases.

In this study, we used the UB mean concentration for each crop derived from all the data provided to GEMS/Food to estimate the total exposure. This is justifiable as the crops produced in one region may be in the international trade and consumed elsewhere. With the concentration level for each cereal remaining constant, only the consumption pattern had an effect on the total aflatoxin intake in each cluster. In four of the five clusters that showed the highest intake (8.8 to 17.1 ng/kg bw/day), rice was the cereal that most contributed to the total intake, indicating the importance of controlling fungi infection and aflatoxin levels in this commodity.

Various studies published in the literature have estimated the dietary intake of aflatoxins (Table 5). In Malaysia (C05), the total UB intake of 58.0 ng/kg bw/day (from the consumption 38 foods, both raw and processed) (Chin *et al.*, 2012) was much higher than the intake for cluster C05 estimated in this study (11.2 ng/kg bw/day). On the other hand, the UB intake estimated for the total Brazilian population, also included in cluster C05, was considerably lower (6.8 ng/kg bw/day) (Andrade *et al.*, 2013), with rice contributing to 97.1% of the total intake.

The intakes obtained for C06, C07, C09 and C10 in this study were higher than the intakes found in countries belonging to these clusters. For example, the intake in France (C07), estimated through consumption of 212 foods (including rice and wheat products), was 0.9 ng/kg bw/day (Sirot *et al.*, 2013) while in China (C09) the intake of individual commodities reached 5.8 ng/kg bw/day (rice) (Ding *et al.*, 2012), as shown in Table 5. Most studies considered cereals in the intake estimations, but focused mainly on processed products, unlike the present study in which only contamination data on the raw commodity were considered. A case in point is the assessment performed in Japan, which only considered cooked rice (Sakuma *et al.*, 2013). Intakes found in the present study were also higher than the most recent risk assessment conducted by JECFA (Bendford *et al.*, 2010; FAO/WHO, 2008) (0.4-3.7 ng/kg bw/day), using the previous GEMS/Food Consumption Cluster Diets (13 Clusters). The only cereal considered in the JECFA assessment was maize (including processed products), in addition to peanuts, oilseeds, cocoa products, dried fruits, peanut oil, spices, tree nuts, dried figs, butter of Karité, and other nuts.

Chronic dietary risk characterisation for aflatoxins from the consumption of cereals was conducted in this study using two available approaches. One limitation to the cancer risk approach estimate is related to the prevalence rates of the hepatitis B virus, which were derived from the prevalence map made by the CDC (2014), and agreement with the GEMS/Cluster was not always possible. For example, Brazil (C05), Canada and the United States of America (C10) are considered by CDC as countries with low prevalence of hepatitis B virus (<2% HBsAg$^+$). In this paper, a prevalence rate of 3% HBsAg$^+$ was used for C05 and C10, as they include countries with low-intermediate prevalence of hepatitis B virus (2-4% HBsAg$^+$). Estimation made by the Brazilian Ministry of Health indicates that actual prevalence in the country is 0.37% (Brasil, 2010).

The total exposure to aflatoxins and the risk estimates shown in this paper may be overestimated, as they do not consider the impact of cereal processing on aflatoxin levels,

Table 5. Dietary exposure and risk characterisation for aflatoxins estimated in the present study using GEMS/Food occurrence data and assessments reported in other studies.

Country	Food analysed	Intake[1]	Cancer risk[2]	MOE[3]
Present work[4]	Maize, rice, sorghum and wheat	3.0-17.1	0.057-0.467	56-10
Africa – C03/C13 (Shephard, 2008)[5]	Beer, groundnuts, kenkey, maize, millet, peanut butter, rice, sorghum and yam chips	1.4-850	0.1-70.1	121.4-0.2
Brazil – C05 (Andrade *et al.*, 2013)[6]	Brazil nuts, maize products, other nuts, peanuts, peanut products and rice	6.6-6.8	0.0731-0.0753	25.8-25.0
China – C09 (Ding *et al.*, 2012)[7]	Maize and derived products, peanuts, peanut oil and rice	0.11-5.8	0.003-0.2	24.7-0.5
China – C09 (Li *et al.*, 2014)	Edible oils, maize, oats and other coarse grains, peanuts, rice, soybean and wheat[8]	8.3	-[9]	-
France – C07 (Sirot *et al.*, 2013)[10]	212 foods[11]	0.9	0.011	-
Iran – C06 (Yazdanpanah *et al.*, 2013)	Bread, peanuts, puffed maize snack, rice and wheat flour	3.6	-	-
Japan –C10 (Sakuma *et al.*, 2013)[12]	Cooked rice	1.2	0.0021	209
Japan – C10 (Sugita-Konishi *et al.*, 2010)[13]	24 foods[14]	0.003-0.004	0.00004-0.00005	-
Malaysia – C05 (Chin *et al.*, 2012)[15]	38 foods (raw and processed)[16]	28.8-58.0	0.72-1.45	-
New Zealand – C10 (Cressey and Reeve, 2013)[17]	Dried fruits, maize and derived products, peanut and derived products, snacks, spices, tree nuts and derived products	0.09[18] 0.12[19]	0.0015-0.0019[18] 0.0018-0.0022[19]	-
Republic of Korea – C10 (Park *et al.*, 2004)[20]	Barley and its products, maize and its products, *meju* and rice	1.2-5.8	-	-
Worldwide – 13 Cluster Diets (FAO/WHO, 2008)	Butter of Karité, cocoa products, dried figs, dried fruits, groundnuts, maize, oilseeds, other nuts, peanut oil, spices and tree nuts	0.4-3.7	-	-

[1] ng/kg bw/day.

[2] Cancers/year/10^5 individuals.

[3] Margin of exposure; based on a BMDL$_{10}$ in rodent of 170 ng/kg bw/day, except for China and Japan (140 ng/kg bw/day).

[4] Lower-upper bound, 3-8% HBsAg$^+$.

[5] Range of individual commodities from different African countries, 25% HBsAg$^+$.

[6] Lower-upper bound, 0.37% HBsAg$^+$.

[7] AFB$_1$ only, range of individual commodities.

[8] Including derived products of all foods.

[9] Not estimated.

[10] Upper bound, 1% HBsAg$^+$.

[11] Selected based on pattern of consumption and main known contributors to aflatoxins exposure – includes rice and wheat products.

[12] AFB$_1$ only, 95th percentile.

[13] AFB$_1$ only, 95th percentile, lower-upper bound, 1% HBsAg$^+$.

[14] Selected on the basis of knowledge on the occurrence of AFs – includes rice and wheat.

[15] Lower-upper bound, 5.24% HBsAg$^+$.

[16] Selected based on knowledge on the occurrence of AFs – type of food not informed.

[17] 1.5% HBsAg$^+$.

[18] Female.

[19] Male.

[20] AFB$_1$ only, lower-upper bound.

such as sorting, milling and cooking (Castells *et al.*, 2007; Hussain and Luttfullah, 2009; Hwang and Lee, 2006; Park and Kim, 2006; Pearson *et al.*, 2004; Siwela *et al.*, 2005). On the other hand, no other sources of aflatoxin exposure were considered, such as peanuts and oil seeds, which were shown to contribute significantly to the total exposure estimated by the JECFA for the 13 Cluster Diets (FAO/WHO, 2008; *Benford et al.*, 2010).

This work clearly showed that aflatoxin in rice is a major concern due to its high concentration and consumption patterns in certain regions of the world. Currently, the Codex ML for aflatoxins are only established for almonds, Brazil nuts, hazelnuts, peanuts, pistachios, and dried figs (CAC, 1995), food commodities whose average consumption is much lower than for cereals (maximum of 18.8 g/person/day for peanuts in C13; WHO, 2014). The establishment of a ML for rice would remove the most contaminated samples from the market and would have a significant impact on exposure in various regions of the world. For example, if a hypothetical ML of aflatoxins in rice were set at 40 μg/kg, the cancer risk would decrease by up to 48% in comparison with a no limit situation. At MLs of 20 and 10 μg/kg, the risk would be reduced by up to 63%. Lower limits would not have a significant impact on cancer risk for all clusters, except C09 and C14 (Asian countries), for which a ML of 1 μg/kg would decrease the risk by 76 and 77.8%, respectively. This lower level, however, would have a significant impact on the food supply (about 20% of the samples rejected), when compared with the higher MLs (up to 4% of the samples rejected).

The dietary risk assessment of aflatoxins in cereals conducted in this study used incidence data provided to the GEMS/Food up to July 2014, in response to a public call made by the JECFA and requested by the 7th Session of the CCCF (REP13/CF) to support the discussion on aflatoxins in cereals at the international level. However, only 24 countries responded to this call, yielding a database which is not representative of every region of the world. For example, no rice data were available for China, a country with a high rice consumption rate and that is part of Cluster C09, which had the highest total intake of aflatoxins. In spite of these limitations, the information provided in this paper is of most relevance as it shows rice as a major driver of mycotoxin exposure in most clusters. Furthermore, the study clearly indicates the need for additional data on aflatoxin contamination in cereals, mainly from countries for which these data are lacking, in support of a more sound risk assessment, and the establishment of ML by the Codex Alimentarius.

5. Conclusions

Occurrence data summarised in the present study showed that raw cereals are frequently contaminated with aflatoxins, a genotoxic mycotoxin. Rice was one of the most contaminated cereals, and presented the highest concentration in both literature and GEMS/Food datasets. The dietary risk assessment conducted in this paper indicated a health concern for all 17 GEMS/Food Clusters (MOE<50), with the consumption of rice, wheat and/or maize as the main contributors to aflatoxin intake. Even if the impact of cereal processing on contamination levels had been considered, the MOE would still be much lower than that considered of low health concern for genotoxic compounds such as aflatoxins (>10,000).

Since cereals are staple foods worldwide, and the elimination of aflatoxins from the food supply is not possible, they should be constantly monitored and actions taken to maintain concentration as low as possible. Actions aimed at lowering the risk of aflatoxin exposure, while still ensuring the food supply, include the enforcement of codes of practices and the establishment of ML. Therefore, considering the results of this study, priority should be given to actions focusing on rice, wheat and maize.

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References

Abbas, H.K., Cartwright, R.D., Xie, W.P. and Shier, W.T., 2006. Aflatoxin and fumonisin contamination of corn (maize, *Zea mays*) hybrids in Arkansas. Crop Protection 25: 1-9.

Abdulkadar, A.H.W., Al-Ali, A.A., Al-Kildi, A.M. and Al-Jedah, J.H., 2004. Mycotoxins in food products available in Qatar. Food Control 15: 543-548.

Abia, W.A., Warth, B., Sulyok, M., Krska, R., Tchana, A.N., Njobeh, P.B., Dutton, M.F. and Moundipa, P.F., 2013. Determination of multi-mycotoxin occurrence in cereals, nuts and their products in Cameroon by liquid chromatography tandem mass spectrometry (LC-MS/MS). Food Control 31: 438-453.

Adejumo, O., Atanda, O., Raiola, A., Somorin, Y., Bandyopadhyay, R. and Ritieni, A., 2013. Correlation between aflatoxin M-1 content of breast milk, dietary exposure to aflatoxin B-1 and socioeconomic status of lactating mothers in Ogun State, Nigeria. Food and Chemical Toxicology 56: 171-177.

Ahsan, S., Bhatti, I.A., Asi, M.R., Bhatti, H.N. and Sheikh, M.A., 2010. Occurrence of aflatoxins in maize grains from central areas of Punjab, Pakistan. International Journal of Agriculture and Biology 12: 571-575.

Almeida, M.I., Almeida, N.G., Carvalho, K.L., Gonçalves, G.A.A., Silva, C.N., Santos, E.A., Garcia, J.C. and Vargas, E.A., 2012. Co-occurrence of aflatoxins B_1, B_2, G_1 and G_2, ochratoxin A, zearalenone, deoxynivalenol, and citreoviridin in rice in Brazil. Food Additives and Contaminants Part A 29: 694-703.

Alptekin, Y., Duman, A.D. and Akkaya, M.R., 2009. identification of fungal genus and detection of aflatoxin level in second crop corn grain. Journal of Animal and Veterinary Advances 8: 1777-1779.

Andrade, P.D., Homen de Mello, M., Franca, J. and Caldas, E.D., 2013. Aflatoxins in food products consumed in Brazil: a preliminary dietary risk assessment. Food Additives and Contaminants:Part A 30: 127-136.

Asghar, M.A., Iqbal, J., Ahmed, A. and Khan, M.A., 2014. Occurrence of aflatoxins contamination in brown rice from Pakistan. Iranian Journal of Public Health 43: 291-299.

Aydin, A., Aksu, H. and Gunsen, U., 2011. Mycotoxin levels and incidence of mould in Turkish rice. Environmental Monitoring and Assessment 178: 271-280.

Ayejuyo, O.O., Olowu, R.A., Agbaje, T.O., Atamenwan, M. and Osundiya, M.O., 2011. Enzyme-linked immunosorbent assay (Elisa) of aflatoxin B$_1$ in groundnut and cereal grains in Lagos, Nigeria. Research Journal of Chemical Sciences 1(8): 1-5.

Bandyopadhyay, R., Kumar, M. and Leslie., J.F., 2007. Relative severity of aflatoxin contamination of cereal crops in West Africa. Food Additives and Contaminants 24: 1109-1114.

Bankole, S.A. and Mabekoje, O.O., 2004. Occurrence of aflatoxins and fumonisins in preharvest maize from south-western Nigeria. Food Additives and Contaminants 21: 251-255.

Bansal, J., Pantazopoulos, P., Tam, J., Cavlovic, P., Kwong, K., Turcotte, A.M., Lau, B.P.Y. and Scott, P.M., 2011. Surveys of rice sold in Canada for aflatoxins, ochratoxin A and fumonisins. Food Additives and Contaminants Part A 28: 767-774.

Benford, D., Leblanc, J.C. and Setzer, R.W., 2010. Application of the margin of exposure (MoE) approach to substances in food that are genotoxic and carcinogenic: example: aflatoxin B$_1$ (AFB$_1$). Food and Chemical Toxicology 48: S34-S41.

Brasil, 2010. Estudo de prevalência de base populacional das infecções pelos vírus das hepatites A, B E C nas capitais do Brasil. Universidade de Pernambuco, Recife, Brazil. Available at: http://tinyurl.com/ne7892n.

Brazilian Health Surveillance Agency (Anvisa), 2011. Resolução no. 7, de 18 de fevereiro de 2011. Anvisa, Brasília, Brazil.

Broggi, L.E., Pacin, A.M., Gasparovic, A., Sacchi, C., Rothermel, A., Gallay, A. and Resnik, S., 2007. Natural occurrence of aflatoxins, deoxynivalenol, fumonisins and zearalelone in maize from Entre Ríos Province, Argentina. Mycotoxin Research 23: 59-64.

Bruns, H.A., Abbas, H.K., Mascagni, H.J., Cartwright, R.D. and Allen, F., 2007. Evaluation of short-season corn hybrids in the mid-south USA. Crop Management 6. DOI: http://dx.doi.org/10.1094/CM-2007-1005-01-RS.

Carvalho, R.A., Batista, L.R., Prado, G., Oliveira, B.R. and Silva, D.M., 2010. Incidence of toxigenic fungi and aflatoxins in rice. Ciência e Agrotecnologia 34: 946-952.

Castells, M., Ramos, A.J., Sanchis, V. and Marin, S., 2007. Distribution of total aflatoxins in milled fractions of hulled rice. Journal of Agricultural and Food Chemistry 55: 2760-2764.

Centers for Disease Control and Prevention (CDC), 2014. Yellow book – prevalence of chronic hepatitis b virus infection among adults 2014. Available at: http://tinyurl.com/nso32kz.

Chala, A., Taye, W., Ayalew, A., Krska, R., Sulyok, M. and Logrieco, A., 2014. Multimycotoxin analysis of sorghum (*Sorghum bicolor* L. Moench) and finger millet (*Eleusine coracana* L. Garten) from Ethiopia. Food Control 45: 29-35.

Chilaka, C.A., Kock, S., Phoku, J.Z., Mwanza, M., Egbuta, M.A. and Dutton, M.F., 2012. Fungal and mycotoxin contamination of South African commercial maize. Journal of Food Agriculture and Environment 10: 296-303.

Chin, C.K., Abdullah, A. and Sugita-Konishi, Y., 2012. Dietary intake of aflatoxins in the adult Malaysian population – an assessment of risk. Food Additives and Contaminants Part B 5: 286-294.

Codex Alimentarius Commission (CAC), 1995. Codex general standard for contaminants and toxins in food and feed – Codex Standard 193-1995. Available at: http://tinyurl.com/mpkehpr.

Codex Alimentarius Commission (CAC), 2003. Code of practice for the prevention and reduction of mycotoxin contamination in cereals, including annexes on ochratoxin a, zearalenone, fumonisins and tricothecenes – CAC/RCP 51-2003. Available at: http://www.codexalimentarius.org/download/standards/406/CXP_051e.pdf.

Codex Alimentarius Commission (CAC), 2012. Sixth session of the joint FAO/WHO food standards programme – Codex committee on contaminants in foods – matters of interest arising from FAO and WHO – Capacity building activities relevant to the work of the Codex Committee on Contaminants in Foods – CX/CF 12/6/5-Add.1. Available at: http://tinyurl.com/prdl5sv.

Codex Alimentarius Commission (CAC), 2014a. Eighth session of the joint FAO/WHO food standards programme - Codex committee on contaminants in foods – discussion paper on aflatoxins in cereals – CX/CF 14/8/15. Available at: http://tinyurl.com/nnejcha.

Codex Alimentarius Commission (CAC), 2014b. Eighth session of the joint FAO/WHO food standards programme - codex committee on contaminants in foods – matters of interest arising from FAO and WHO (including JECFA) – CX/CF 14/8/3. Available at: http://tinyurl.com/p46g9k6.

Covarelli, L., Beccari, G. and Salvi, S., 2011. Infection by mycotoxigenic fungal species and mycotoxin contamination of maize grain in Umbria, Central Italy. Food and Chemical Toxicology 49: 2365-2369.

Cressey, P.J. and Reeve, J., 2013. Dietary exposure and risk assessment for aflatoxins in New Zealand. World Mycotoxin Journal 6: 427-437.

Daniel, J.H., Lewis, L.W., Redwood, Y.A., Kieszak, S., Breiman, R.F., Flanders, W.D., Bell, C., Mwihia, J., Ogana, G., Likimani, S., Straetemans, M. and McGeehin, M.A., 2011. Comprehensive assessment of maize aflatoxin levels in Eastern Kenya, 2005-2007. Environmental Health Perspectives 119: 1794-1799.

Ding, X., Li, P., Bai, Y. and Zhou, H., 2012. Aflatoxin B$_1$ in post-harvest peanuts and dietary risk in China. Food Control 23: 143-148.

Dors, G.C., Bierhals, V.S. and Badiale-Furlong, E., 2011. Parboiled rice: chemical composition and the occurrence of mycotoxins. Ciência e Tecnologia de Alimentos 31: 172-177.

Dors, G.C., Caldas, S.S., Hackbart, H.C.S., Primel, E.G., Fagundes, C.A.A. and Badiale-Furlong, E., 2013. Fungicides and the effects of mycotoxins on milling fractions of irrigated rice. Journal of Agricultural and Food Chemistry 61: 1985-1990.

Egal, S., Hounsa, A., Gong, Y.Y., Turner, P.C., Wild, C.P., Hall, A.J., Hell, K. and Cardwell, K.F., 2005. Dietary exposure to aflatoxin from maize and groundnut in young children from Benin and Togo, West Africa. International Journal of Food Microbiology 104: 215-224.

European Commission (EC), 2006. Commission regulation (EC) no 1881/2006 of 19 December 2006 – setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Union L364: 5-24.

European Food Safety Authority (EFSA), 2005. Opinion of the scientific committee on a request from EFSA related to a harmonized approach for risk assessment of substances which are both genotoxic and carcinogenic. EFSA Journal 282: 1-31.

European Food Safety Authority (EFSA), 2007. Opinion of the scientific panel on contaminants in the food chain on a request from the commission related to the potential increase of consumer health risk by a possible increase of the existing maximum levels for aflatoxins in almonds, hazelnuts and pistachios and derived products. EFSA Journal 446: 1-127.

Food and Agriculture Organization of the United Nations (FAO), 2014. FAOSTAT – Statistics division of the Food and Agriculture Organization of the United Nations 2014. Available at: http://faostat.fao.org/site/291/default.aspx.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 1998. Joint FAO/WHO expert committee on food additives – evaluation of certain food additives and contaminants: forty-ninth report of the joint FAO/WHO expert committee on food additives. Available at: http://tinyurl.com/pgrz8uq.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 2005. Dietary exposure assessment of chemicals in food: report of a joint FAO/WHO consultation. May 2-6, 2005. Annapolis, MA, USA. Available at: http://tinyurl.com/q6hxjjv.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 2006. Evaluation of certain food contaminants - sixty-fourth report of the joint FAO/WHO expert committee on food. Available at: http://tinyurl.com/3ab7mc.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 2008. Safety evaluation of certain food additives and contaminants – prepared by the sixty-eighth meeting of the joint FAO/WHO expert committee on food additives (JECFA). Available at: http://tinyurl.com/lgxhdsn.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 2013. Joint FAO/WHO meeting on pesticide residues – acceptable daily intakes, acute reference doses, short–term and long–term dietary intakes, recommended maximum residue limits and supervised trials median residue values recorded by the 2013 meeting. Available at: http://tinyurl.com/p6dynuk.

Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO), 2014. Report of the eighth session of the Codex Committee on Contaminants in foods. Available at: http://tinyurl.com/lzqn82k.

Fu, Z., Huang, X. and Min. S., 2008. Rapid determination of aflatoxins in corn and peanuts. Journal of Chromatography A 1209: 271-274.

Gao, X., Yin, S., Zhang, H., Han, C., Zhao, X. and Ji, R., 2011. Aflatoxin contamination of corn samples collected from six regions of China. Wei Sheng Yan Jiu 40: 46-49.

Garrido, C.E., Pezzani, C.H. and Pacin, A., 2012. Mycotoxins occurrence in Argentina's maize (*Zea mays* L.), from 1999 to 2010. Food Control 25: 660-665.

Ghali, R., Belouaer, I., Hdiri, S., Ghorbel, H., Maaroufi, K. and Hedilli, A., 2009. Simultaneous HPLC determination of aflatoxins B_1, B_2, G_1 and G_2 in Tunisian sorghum and pistachios. Journal of Food Composition and Analysis 22: 751-755.

Ghali, R., Hmaissia-Khlifa, K., Ghorbel, H., Maaroufi, K. and Hedili, A., 2008. Incidence of aflatoxins, ochratoxin A and zearalenone in Tunisian foods. Food Control 19: 921-924.

Ghali, R., Khlifa, K.H., Ghorbel, H., Maaroufi, K. and Hedilli, A., 2010. Aflatoxin determination in commonly consumed foods in Tunisia. Journal of the Science of Food and Agriculture 90: 2347-2351.

Ghiasian, S.A., Shephard, G.S. and Yazdanpanah, H., 2011. Natural occurrence of aflatoxins from maize in Iran. Mycopathologia 172: 153-160.

Giray, B., Girgin, G., Engin, A., Aydin, B.S. and Sahin, G., 2007. Aflatoxin levels in wheat samples consumed in some regions of Turkey. Food Control 18: 23-29.

Hussain, A. and Luttfullah, G., 2009. Reduction of aflatoxin B_1 and ochratoxin A levels in polished Basmati rice (*Oryza sativa* Linn.) by different cooking methods. Journal of the Chemical Society of Pakistan 31: 911-915.

Hussain, A., Ali, J. and Ullah, S., 2011. Studies on contamination level of aflatoxins in Pakistani tice. Journal of the Chemical Society of Pakistan 33: 481-484.

Hussaini, A.M., Timothy, A.G., Olufunmilayo, H.A., Ezekiel, A.S. and Godwin, H.O., 2009. Fungi and some mycotoxins found in mouldy sorghum in Niger State, Nigeria. World Journal of Agricultural Sciences 5: 5-17.

Hwang, J.H. and Lee, K.G., 2006. Reduction of aflatoxin B_1 contamination in wheat by various cooking treatments. Food Chemistry 98: 71-75.

International Agency for Research on Cancer (IARC), 1993. Some naturally occurring substances: food items and constituents, heterocyclic aromatic amines and mycotoxins. IARC Monographs on the evaluation of carcinogenic risks to humans. Vol. 56. IARC, Lyon, France.

International Programme on Chemical Safety (IPCS), 2009. Environmental health criteria 240 – principles and methods for the risk assessment on chemicals in food. Available at: http://tinyurl.com/pscgglx.

Iqbal, S.Z., Asi, M.R., Ariño, A., Akram, N. and Zuber, M., 2012. Aflatoxin contamination in different fractions of rice from Pakistan and estimation of dietary intakes. Mycotoxin Research 28: 175-180.

Jakic-Dimic, D., Nesic, K. and Petrovic, M., 2009. Contamination of cereals with aflatoxins, metabolites of fungi *Aspergillus flavus*. Biotechnology in Animal Husbandry 25: 1203-1208.

Kaaya, A.N. and Kyamuhangire, W., 2006. The effect of storage time and agroecological zone on mould incidence and aflatoxin contamination of maize from traders in Uganda. International Journal of Food Microbiology 110: 217-223.

Karami-Osboo, R., Mirabolfathy, M,. Kamran, R., Shetab-Boushehri, M. and Sarkari, S., 2012. Aflatoxin B_1 in maize harvested over 3 years in Iran. Food Control 23: 271-274.

Khatoon, S., Hanif, N.Q., Tahira, I., Sultana, N., Sultana, K. and Ayub, N., 2012. Natural occurrence of aflatoxins, zearalenone and trichothecenes in maize grown in Pakistan. Pakistan Journal of Botany 44: 231-236.

Khayoon, W.S., Saad, B., Lee, T.P. and Salleh, B., 2012. High performance liquid chromatographic determination of aflatoxins in chilli, peanut and rice using silica based monolithic column. Food Chemistry 133: 489-496.

Kim, D.M., Lee, N., Kim, S.M., Chung, S.H., Kim, M., Han, S.B. and Chun, H.S., 2013. Occurrence of aflatoxin and aflatoxigenic *Aspergillus* species in Corn Harvested in Korea. Journal of the Korean Society for Applied Biological Chemistry 56: 221-225.

Kimanya, M.E., Meulenaer, B., Tiisekwa, B., Ndomondo-Sigonda, M., Devlieghere, F., Van Camp, J. and Kolsteren, P., 2008. Co-occurrence of fumonisins with aflatoxins in home-stored maize for human consumption in rural villages of Tanzania. Food Additives and Contaminants Part A 25: 1353-1364.

Kos, J., Mastilovic, J., Hajnal, E.J. and Saric, B., 2013. Natural occurrence of aflatoxins in maize harvested in Serbia during 2009-2012. Food Control 34: 31-34.

Lai, X.W., Sun, D.L., Ruan, C.Q., Zhang, H. and Liu, C.L., 2014. Rapid analysis of aflatoxins B$_1$, B$_2$, and ochratoxin A in rice samples using dispersive liquid-liquid microextraction combined with HPLC. Journal of Separation Science 37: 92-98.

Li, R., Wang, X., Zhou, T., Yang, D., Wang, Q. and Zhou, Y., 2014. Occurrence of four mycotoxins in cereal and oil products in Yangtze Delta region of China and their food safety risks. Food Control 35: 117-122.

Liao, C.D., Wong, J.W., Zhang, K., Hayward, D.G., Lee, N.S. and Trucksess, M.W., 2013. Multi-mycotoxin analysis of finished grain and nut products using high-performance liquid chromatography-triple-quadrupole mass spectrometry. Journal of Agricultural and Food Chemistry 61: 4771-4782.

Liu, Z., Gao, J. and Yu, J., 2006. Aflatoxins in stored maize and rice grains in Liaoning Province, China. Journal of Stored Products Research 42: 468-479.

Lutfullah, G. and Hussain, A., 2012. Studies on contamination level of aflatoxins in some cereals and beans of Pakistan. Food Control 23: 32-36.

Makun, H.A., Dutton, M.F., Njobeh, P.B., Mwanza, M. and Kabiru A.Y., 2011. Natural multi-occurrence of mycotoxins in rice from Niger State, Nigeria. Mycotoxin Research 27: 97-104.

Martos, P.A., Thompson, W. and Diaz., G.J., 2010. Multiresidue mycotoxin analysis in wheat, barley, oats, rye and maize grain by high-performance liquid chromatography-tandem mass spectrometry. World Mycotoxin Journal 3: 205-223.

Matumba, L., Monjerezi, M., Khonga, E.B. and Lakudzala, D.D., 2011. Aflatoxins in sorghum, sorghum malt and traditional opaque beer in southern Malawi. Food Control 22: 266-268.

Mazaheri, M., 2009. Determination of aflatoxins in imported rice to Iran. Food and Chemical Toxicology 47: 2064-2066.

Miraglia, M., Marvin, H.J.P., Kleter, G.A., Battilani, P., Brera, C., Coni, E., Cubadda, F., Croci, L., Santis, B., Dekkers, S., Filippi, L.R., Hutjes, W.A., Noordam, M.Y., Pisante, M., Piva, G., Prandini, A., Toti, L., Van den Born, G.J. and Vespermann, A., 2009. Climate change and food safety: an emerging issue with special focus on Europe. Food and Chemical Toxicology 47: 1009-1021.

Mohale, S., Medina, A., Rodríguez, A., Sulyok, M. and Magan, N., 2013. Mycotoxigenic fungi and mycotoxins associated with stored maize from different regions of Lesotho. Mycotoxin Research 29: 209-219.

Mohammadi, M., Mohebbi, G.H., Hajeb, P., Akbarzadeh, S. and Shojaee, I., 2012. Aflatoxins in rice imported to Bushehr, a southern port of Iran. American-Eurasian Journal of Toxicological Sciences 4: 31-35.

Moreno, E.C., Garcia, G.T., Ono, M.A., Vizoni, E., Kawamura, O., Hirooka, E.Y. and Ono, E.Y.S., 2009. Co-occurrence of mycotoxins in corn samples from the Northern region of Parana State, Brazil. Food Chemistry 116: 220-226.

Mukanga, M., Derera, J., Tongoona, P. and Laing, M.D., 2010. A survey of pre-harvest ear rot diseases of maize and associated mycotoxins in South and Central Zambia. International Journal of Food Microbiology 141: 213-221

Muthomi, J.W., Ndung'u, J.K., Gathumbi, J.K., Mutitu, E.W. and Wagacha. J.M., 2008. The occurrence of Fusarium species and mycotoxins in Kenyan wheat. Crop Protection 27: 1215-1219.

Mwihia, J.T., Straetmans, M., Ibrahim, A., Njau, J., Muhenje, O., Guracha, A., Gikundi, S., Mutonga, D., Tetteh, C., Likimani, S., Breiman, R.F., Njenga, K. and Lewis, L., 2008. Aflatoxin levels in locally grown maize from Makueni District, Kenya. East African Medical Journal 85: 311-317.

Nguyen, M.T., Tozovanu, M., Tran, T.L. and Pfohl-Leszkowicz, A., 2007. Occurrence of aflatoxin B$_1$, citrinin and ochratoxin A in rice in five provinces of the central region of Vietnam. Food Chemistry 105: 42-47.

Nogaim, Q.A., Amra, H.A. and Bakr, A.A., 2011. Natural occurrence of mycotoxins in corn grains and some corn products. Pakistan Journal of Life and Social Sciences 9: 1-6.

Nunes, I.L., Magagnin, G., Bertolin, T.E. and Badiale-Furlong, E., 2003. Rice comercialized in southern Brazil: micotoxicological and microscopic aspects. Ciência e Tecnologia de Alimentos 23: 190-194.

Ok, H.E., Kim, D.M., Kim, D., Chung, S.H., Chung, M.S., Park, K.H. and Chun, H.S., 2014. Mycobiota and natural occurrence of aflatoxin, deoxynivalenol, nivalenol and zearalenone in rice freshly harvested in South Korea. Food Control 37: 284-291.

Oliveira, T.R., Barana, A.C., Jaccound-Filho, D.S. and Neto, F.F., 2010. Contamination evaluation for total aflatoxins and zearalenone in varieties of Landraces Maize (*Zea mays* L.) through ELISA immunoenzymatic method. Revista Brasileira de Tecnologia Agroindustrial 4: 179-185.

Oruc, H.H., Cengiz, M. and Kalkanli, O., 2006. Comparison of aflatoxin and fumonisin levels in maize grown in Turkey and imported from the USA. Animal Feed Science and Technology 128: 337-341.

Oueslati, S., Romero-González R., Lasram, S., Frenich, A.G. and Vidal. J.L., 2012. Multi-mycotoxin determination in cereals and derived products marketed in Tunisia using ultra-high performance liquid chromatography coupled to triple quadrupole mass spectrometry. Food and Chemical Toxicology 50: 2376-2381.

Pace, R., Menga, V., Vita, V., Franchino, C., Dattoli, M.A. and Fares, C., 2012. Durum and common wheat imports into Puglia during 2010: mycotoxins and grain-quality monitoring. Italian Journal of Food Science 24: 388-395.

Park, J.W. and Kim, Y.B., 2006. Effect of pressure cooking on aflatoxin B_1 in rice. Journal of Agricultural and Food Chemistry 54: 2431-2435.

Park, J.W., Kim, E.K. and Kim, Y.B., 2004. Estimation of the daily exposure of Koreans to aflatoxin B_1 through food consumption. Food Additives and Contaminants 21: 70-75.

Pearson, T.C., Wicklow, D.T. and Pasikatan. M.C., 2004. Reduction of aflatoxin and fumonisin contamination in yellow corn by high-speed dual-wavelength sorting. Cereal Chemistry 81: 490-498.

Pitt, J.I., Taniwaki M.H. and Cole, M.B., 2013. Mycotoxin production in major crops as influenced by growing, harvesting, storage and processing, with emphasis on the achievement of food safety objectives. Food Control 32: 205-215.

Probst, C., Bandyopadhyay, R. and Cotty, P.J., 2014. Diversity of aflatoxin-producing fungi and their impact on food safety in sub-Saharan Africa. International Journal of Food Microbiology 174: 113-122.

Probst, C., Njapau, H. and Cotty, P.J., 2007. Outbreak of an acute aflatoxicosis in Kenya in 2004: Identification of the causal agent. Applied and Environmental Microbiology 73: 2762-2764.

Rahman, A. and Jinap, S., 2010. Validation of the procedure for the simultaneous determination of aflatoxins ochratoxin A and zearalenone in cereals using HPLC-FLD. Food Additives and Contaminants Part A 27: 1683-1693.

Ratnavathi, C.V., Komala, V.V., Kumar, B.S.V., Das, I.K. and Patil, J.V., 2012. Natural occurrence of aflatoxin B_1 in sorghum grown in different geographical regions of India. Journal of the Science of Food and Agriculture 92: 2416-2420.

Reddy, K.R.N. and Baharuddin, S., 2010. A preliminary study on the occurrence of *Aspergillus* ssp. and aflatoxin B_1 in imported wheat and barley in Penang, Malaysia. Mycotoxin Research 26: 267-271.

Reddy, K.R.N., Reddy, C.S. and Muralidharan, K., 2009. Detection of *Aspergillus* spp. and aflatoxin B_1 in rice in India. Food Microbiology 26: 27-31.

Reinhold, L. and Reinhardt, K., 2011. Mycotoxins in foods in Lower Saxony (Germany): results of official control analyses performed in 2009. Mycotoxin Research 27: 137-143.

Reiter, E.V., Vouk, F., Boehm, J. and Razzazi-Fazeli, E., 2010. Aflatoxins in rice – a limited survey of products marketed in Austria. Food Control 21: 988-991.

Riba, A., Bouras, N., Mokrane, S., Mathieu, F., Lebrihi, A. and Sabaou, N., 2010. *Aspergillus* section Flavi and aflatoxins in Algerian wheat and derived products. Food and Chemical Toxicology 48: 2772-2777.

Rocha, L.O., Nakai, V.K., Braghini, R., Reis, T.A., Kobashigawa, E. and Corrêa, B., 2009. Mycoflora and co-occurrence of fumonisins and aflatoxins in freshly harvested corn in different regions of Brazil. International Journal of Molecular Sciences10: 5090-5103.

Sakuma, H., Watanabe, Y., Furusawa, H., Yoshinari, T., Akashi, H., Kawakami, H., Saito, S. and Sugita-Konishi, Y., 2013. Estimated dietary exposure to mycotoxins after taking into account the cooking of staple foods in Japan. Toxins 5: 1032-1042.

Sangare-Tigori, B., Moukha, S., Kouadio, H.J., Betbeder, A.M., Dano, D.S. and Creppy, E.E., 2006. Co-occurrence of aflatoxin B_1, fumonisin B_1, ochratoxin A and zearalenone in cereals and peanuts from Côte d'Ivoire. Food Additives and Contaminants 23: 1000-1007.

Sani, A.M., Azizi, E.G., Salehi, E.A. and Rahimi, K., 2014. Reduction of aflatoxin in rice by different cooking methods. Toxicology and Industrial Health 30: 546-550.

Shah, H.U., Simpson, T.J., Alam, S., Khattak, K.F. and Perveen, S., 2010. Mould incidence and mycotoxin contamination in maize kernels from Swat Valley, North West Frontier Province of Pakistan. Food and Chemical Toxicology 48: 1111-1116.

Shephard, G.S., 2008. Risk assessment of aflatoxins in food in Africa. Food Additives and Contaminants: Part A 25: 1246-1256.

Shephard, G.S., Burger, H.M., Gambacorta, L., Krska, R., Powers, S.P., Rheeder, J.P., Solfrizzo, M., Sulyok, M., Visconti, A., Warth, B. and Van der Westhuizen, L., 2013. Mycological analysis and multimycotoxins in maize from rural subsistence farmers in the former Transkei, South Africa. Journal of Agricultural and Food Chemistry 61: 8232-8240.

Sirot, V., Fremy, J.M. and Leblanc, J.C., 2013. Dietary exposure to mycotoxins and health risk assessment in the second French total diet study. Food and Chemical Toxicology 52: 1-11.

Siwela, A.H., Siwela, M., Matindi, G., Dube, S. and Nziramasanga, N., 2005. Decontamination of aflatoxin-contaminated maize by dehulling. Journal of the Science of Food and Agriculture 85: 2535-2538.

Soleimany, F., Jinap, S., Faridah, A. and Khatib, A., 2012. A UPLC-MS/MS for simultaneous determination of aflatoxins, ochratoxin A, zearalenone, DON, fumonisins, T-2 toxin and HT-2 toxin, in cereals. Food Control 25: 647-653.

Soleimany, F., Jinap, S., Rahmani, A. and Khatib A., 2011. Simultaneous detection of 12 mycotoxins in cereals using RP-HPLC-PDA-FLD with PHRED and a post-column derivatization system. Food Additives and Contaminants Part A 28: 494-501.

Sugita-Konishi, Y., Nakajima, M., Tabata, S., Ishikuro, E., Tanaka, T., Norizuki, H., Itoh, Y., Aoyama, K., Fujita, K., Kai, S. and Kumagai, S., 2006. Occurrence of aflatoxins, ochratoxin A, and fumonisins in retail foods in Japan. Journal of Food Protection 69: 1365-1370.

Sugita-Konishi, Y., Sato, T., Saito, S., Nakajima, M., Tabata, S., Tanaka, T., Norizuki, H., Itoh, Y., Kai, S., Sugiyama, K., Kamata, Y., Yoshiike, N. and Kumagai, S., 2010. Exposure to aflatoxins in Japan: risk assessment for aflatoxin B_1. Food Additives and Contaminants: Part A 27: 365-372.

Sun, G., Wang, S., Hu, X., Su, J., Zhang, Y., Xie, Y., Zhang, H., Tang, L. and Wang, J. S., 2011. Co-contamination of aflatoxin B_1 and fumonisin B_1 in food and human dietary exposure in three areas of China. Food Additives and Contaminants Part A 28: 461-470.

Sy, M.M., Feinberg, M., Verger, P., Barre, T., Clemencon, S. and Crepet, A., 2013. New approach for the assessment of cluster diets. Food and Chemical Toxicology 52: 180-187.

Toteja, G.S., Mukherjee, A., Diwakar, S., Singh, P., Saxena, B.N., Sinha, K.K., Sinha, A.K., Kumar, N., Nagaraja, K.V., Bai, G., Prasad, C.A.K., Vanchinathan, S., Roy, R. and Parkar, S., 2006. Aflatoxin B_1 contamination in wheat grain samples collected from different geographical regions of India: a multicenter study. Journal of Food Protection 69: 1463-1467.

US Food and Drug Administration (USFDA), 2000. Guidance for industry: action levels for poisonous or deleterious substances in human food and animal feed. Available at: http://tinyurl.com/m6dgula.

Warth, B., Parich, A., Atehnkeng, J., Bandyopadhyay, R., Schuhmacher, R., Sulyok, M. and Krska, R., 2012. Quantitation of mycotoxins in food and feed from Burkina Faso and Mozambique using a modern LC-MS/MS multitoxin method. Journal of Agricultural and Food Chemistry 60: 9352-9366.

World Health Organization (WHO), 2014. GEMS/Food Consumption Cluster Diets 2014 Available at: http://www.who.int/nutrition/landscape_analysis/nlis_gem_food/en.

Yazdanpanah, H., Zarghi, A., Shafaati, A.R., Foroutan, S.M., Aboul-Fathi, F., Khoddam, A., Nazari, F. and Shaki, F., 2013. Analysis of aflatoxin B_1 in Iranian foods using HPLC and a monolithic column and estimation of its dietary intake. Iranian Journal of Pharmaceutical Research 12: 83-89.

Yu, F.Y., Gribas, A.V., Vdovenko, M.M. and Sakharov, I.Y., 2013. Development of ultrasensitive direct chemiluminescent enzyme immunoassay for determination of aflatoxin B_1 in food products. Talanta 107: 25-29.

Zhu, Z., Liu, G., Chen, Y. and Cheng, J., 2013. Assessment of aflatoxins in pigmented rice using a validated immunoaffinity column method with fluorescence HPLC. Journal of Food Composition and Analysis 31: 252-258.

Zinedine, A., Brera, C., Elakhdari, S., Catano, C., Debegnach, F., Angelini, S., Santis, B., Faid, M., Benlemlih, M., Minardi, V. and Miraglia, M., 2006. Natural occurrence of mycotoxins in cereals and spices commercialized in Morocco. Food Control 17: 868-874.