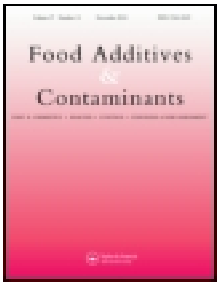

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Aflatoxins in food products consumed in Brazil: a preliminary dietary risk assessment

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Aflatoxins in food products consumed in Brazil: a preliminary dietary risk assessment

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A preliminary dietary exposure assessment for aflatoxins (AFs; AFB1, AFB2, AFG1 and AFG2) was conducted to evaluate the potential carcinogenic risks for the Brazilian population. AF concentration data in food were obtained from analysis reports issued by the Central Public Health Laboratory of the Federal District (LACEN-DF) and from published work. Food consumption and body weight (bw) data were obtained from a national survey conducted in 2008/2009. Cancer risks arising from exposure to aflatoxins were assessed using the carcinogenic potency of AFs estimated by the JECFA, and hepatitis B virus prevalence in the Brazilian population. Additionally, margins of exposure (MOE) were also calculated for the various scenarios investigated. A total of 942 food samples were analysed for AFs in the Federal District between 2002 and 2011 with 4.5% of them being positive for at least one aflatoxin (LOQ = $2\,\mu g\,kg^{-1}$). The highest percentage of contamination was found in peanuts (8.1%) and Brazil nuts (6.0%), with mean levels ranging from $6.7\,\mu g\,kg^{-1}$ in peanut products to $36.9\,\mu g\,kg^{-1}$ in Brazil nuts. Most of the studies conducted elsewhere in Brazil found similar results. Total AF intake for the total Brazilian population and high consumers of food relevant for AF contamination in Brazil (upper bound; samples < LOQ = 0.5 LOQ) were 6.8 and 27.6 $ng\,kg^{-1}\,bw\,day^{-1}$, respectively. Cancer risk reached 0.0753 cancers $year^{-1}$ per 10^5 individuals for the total population and 0.3056 cancers $year^{-1}$ per 10^5 individuals for high consumers. MOE reached 25 and 6 for the total population and high consumers, respectively, indicating a potential risk for consumers. Aflatoxins are genotoxic carcinogens, and government action should be maintained and continuously improved in order to guarantee that human exposure levels are kept as low as possible.

Keywords: aflatoxins; exposure assessment; cancer risk; Brazil

Introduction

Mycotoxins are toxic secondary metabolites produced by a range of fungi and they can be found in a wide variety of agricultural commodities, contaminated either before and/or after harvesting (Frisvad, Andersen, et al. 2007; Magan and Aldred 2007). Mycotoxins can affect human health in several ways, some being acutely toxic, some chronically toxic and others both (Frisvad, Thrane, et al. 2007).

Aflatoxins (AFs) are considered the most important group of mycotoxins in the world food supply. They are produced in nature primarily by the fungi *Aspergillus flavus* and *Aspergillus parasiticus*, and are often found in crops like maize, peanuts and cottonseed (Pitt and Hocking 2009). Aflatoxin B_1 and naturally occurring mixtures of AFs (AFB1, AFB2, AFG1, AFG2) have been classified by the International Agency for Research on Cancer (IARC) (1993) as carcinogenic to humans and they are considered one of the most potent mutagenic and carcinogenic substances known (World Health Organization (WHO) 1999). AFs have also been shown to cause acute liver damage, liver cirrhosis, immunosuppression and interference with protein uptake (Williams et al. 2004; Kuniholm et al. 2008). Data obtained from epidemiological studies have shown a positive correlation between AFB1 exposure and liver cancer, a risk that can be increased by a number of factors, mainly the presence of hepatitis B virus (Liu et al. 2012). Carcinogenic potency of AFs is 30 times higher for populations with hepatitis B virus ($HBsAg^+$; WHO 1999).

Complete elimination of mycotoxins from the food supply is quite difficult, and risk management strategies to reduce human exposure include the enforcement of legislation and regulation to guarantee that consumers are getting safe food (Nielen and Marvin 2008). The *Codex Alimentarius* recommends that exposure to AFs should be as low as reasonably achievable, and adoption of good agricultural practices (GAP) and good manufacturing practices (GMP) are important tools to achieve a considerable reduction in AF levels in food (Codex Alimentarius Commission 1995). The establishment of regulatory limits and the

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implementation of monitoring programmes can also help keep mycotoxin contamination under control in the food supply. The first Brazilian legislation on AFs was published in 1976, setting a maximum level (ML) of $30\,\mu g\,kg^{-1}$ for AFB1 + AFG1 for all food and feed commodities (Comissão Nacional de Normas e Padrões para Alimentos (CNNPA) 1977). In 2002, an ML of $20\,\mu g\,kg^{-1}$ for total AFs (AFB1 + AFB2 + AFG1 + AFG2) was established for peanuts, peanut butter, corn and corn meal for human consumption (RDC 274/2002; ANVISA 2012). More recently, an ML of $20\,\mu g\,kg^{-1}$ was established for in-shell Brazil nuts and of $10\,\mu g\,kg^{-1}$ for shelled Brazil nuts and other nuts (RDC 07/2011; ANVISA 2012).

This study aims to evaluate current data on AF contamination in the food supply of the Federal District area and other Brazilian regions, and to estimate the dietary exposure of the Brazilian population to AFs and the cancer risks arriving from the exposure.

Material and methods

Aflatoxin levels in food

Data on AF levels in food commercialised in the Federal District were obtained from analysis reports issued by the Central Public Health Laboratory of the Federal District (LACEN-DF) from 2002 to 2011. Food samples were collected (at least 1 kg/sample) by the Federal District Health Inspection Department at various local retail stores in the region as part of the sanitary surveillance programme. Samples were kept at ambient temperature and analysed by the Mycotoxins Laboratory of the LACEN-DF according to Soares and Rodrigues-Amaya (1989). In this method, samples were extracted with methanol, re-extracted with chloroform, and analysed by TLC with visual detection. The method was validated at a limit of quantification (LOQ) of $2\,\mu g\,kg^{-1}$ for each AF.

AF data from other Brazilian regions were obtained from published studies related to samples collected from 2002 to 2011. Weighted mean AF concentrations for each food product in each study were estimated based on the data provided (number of samples analysed, number of positive samples, LOQ/LOD reported, concentration). At the national level, estimated weighted means were calculated considering the results of the present study. Although available, data on corn grain were not considered in this study as corn requires considerable processing before consumption.

Food consumption data

Food consumption data were obtained from a survey conducted by the Brazilian Institute of Geography and Statistics (IBGE) (2011) from July 2008 to June 2009. The survey obtained information on the amount of food entering in 55,970 Brazilian households over 7 consecutive days (household budget survey; HBS), in addition to body weights and age for all household members. This survey also provided individual consumption data (2 non-consecutive reporting days) obtained from 34,003 individuals aged 10 years or older, which were used to obtain food consumption data at national level. As only three individuals from the Federal District reported any food relevant for this study, food consumption in the region was estimated from the HBS data obtained in 977 households. For the purpose of this study, all food that entered the household was considered to be consumed equally by the household members aged 2 years or older.

The mean consumption per body weight was estimated for each food or food group relevant for this study (peanuts, peanut products, nuts, corn products and rice). The mean consumption of the total population was estimated considering all households that participated in the HBS or all individuals who provided individual consumption data to the survey (all entries considered). To estimate the mean consumption of high consumers, only the households (in the HBS) or the individuals (in the individual consumption data) that reported acquiring or consuming these products, respectively, were considered (blank entries not considered).

Chronic dietary intake of aflatoxins

The total chronic intakes of AFs for the Federal District and Brazil were estimated as the sum of the intakes for each food or food group considered in the study (Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) 2005):

$$\text{Total intake} = \sum [\text{mean consumption} \times \text{concentration}]/\text{body weight} \quad (1)$$

The lower bound (considering samples below the LOQ as zero) and upper bound (considering samples below the LOQ as 0.5LOQ) intakes were calculated in each case.

Carcinogenic risk of aflatoxins

The carcinogenic potency of AFs ($P_{\text{estimated}}$) and the cancer risk from exposure to AFs present in the diet were estimated using equations (2) and (3), according to the procedure of the FAO/WHO Expert Committee on Food Additives (JECFA) (WHO 1999). These estimations consider the carcinogenic potency of AFs for individuals with the hepatitis B virus

Table 1. Aflatoxin levels (AFB1 + AFB2 + AFG1 + AFG2) in food samples analysed in the Federal District between 2002 and 2011.

Products	Positive[a]/analysed samples	All samples: Mean[b] ± SD ($\mu g\,kg^{-1}$)	All samples: Range ($\mu g\,kg^{-1}$)	Positive samples[a]: Mean ± SD ($\mu g\,kg^{-1}$)	Positive samples[a]: Range ($\mu g\,kg^{-1}$)
Peanuts[c]	29/359	14.2 ± 85.1	<4–1496	129.0 ± 278.5	7.9–1496
Peanut products[d]	8/295	6.7 ± 24.1	<4–340	101.5 ± 117.1	15.0–340.0
Brazil nuts, shelled	4/67	36.9 ± 241.3	<4–1972	553.6 ± 949.8	16.5–1972
Other nuts[e]	1/82	8.3 ± 38.7	<4–354[f]	352.0	–

Notes: [a]At least for AFB1, $\geq 2\,\mu g\,kg^{-1}$.
[b]Samples < LOQ were considered at 0.5LOQ.
[c]Toasted, salted and shelled peanuts.
[d]Peanut butter and peanut candies.
[e]Includes almonds, cashew nuts, hazelnuts, nuts and pistachios, all shelled.
[f]One positive sample containing AFB1 and AFB2.

($PHBsAg^{+} = 0.3$ cancers year^{-1} per 100 000 individuals) and for non-infected individuals ($PHBsAg^{-} = 0.01$ cancers year^{-1} per 100 000 individuals), the percentage of carriers ($HBsAg^{+}$) and non-carriers ($HBsAg^{-}$) of the hepatitis B virus, and the total intake calculated previously. According to the Brazilian Ministry of Health (2010), the prevalences of $HBsAg^{+}$ in the Federal District and Brazil are 0.26% and 0.37%, respectively:

$$P_{\mathrm{estimated}} = \left[\mathrm{PHBsAg}^{+} \times \ \% \text{ population HBsAg}^{+}\right] + \left[\mathrm{PHBsAg}^{-} \times \ \% \text{population HBsAg}^{-}\right] \quad (2)$$

$$\text{Cancer risk} = P_{\mathrm{estimated}} \times \text{total intake} \quad (3)$$

Margin of exposure (MOE)

The risk from the exposure to AFs was also characterised by calculating the margin of exposure (MOE), which is defined as the ratio between the total intake and a toxicological reference, usually the lower bound of a benchmark dose level that caused 10% cancer incidence in rodents (BMDL10) (European Food Safety Authority (EFSA) 2005). A BMDL10 of $0.17\,\mu g\,kg^{-1}$ bw day^{-1} estimated by EFSA (2005) based on carcinogenicity data in rats exposed to AFB1 was used to determine the MOEs. The larger the MOE, the smaller the risk, and a value lower than 10 000 may indicate a human health concern (EFSA 2005).

Results

Aflatoxin levels in food

A total of 942 food samples were analysed for AFs by the LACEN-DF between 2002 and 2011, with about 100 samples analysed each year. A total of 42 samples (4.5%) were contaminated with at least one AF at level ≥ LOQ and 28 samples had total AF levels (AFB1 + AFB2 + AFG1 + AFG2) > $20\,\mu g\,kg^{-1}$, the current ML for all commodities, except shelled Brazil nut ($10\,\mu g\,kg^{-1}$). Only two positive samples did not contain AFB1. None of the 129 samples analysed in 2003 contained AFs and the highest incidences of contamination were found in 2007 and 2008 (9.2% and 11.0%, respectively).

The main food groups analysed by the LACEN-DF were peanuts (38.1% of all samples) and peanut products (31.3%). Peanuts and Brazil nuts were the products with the highest percentage of positive samples (8.1% and 6.0%, respectively) and with the greatest number of samples containing AFs higher than $20\,\mu g\,kg^{-1}$ (68.9% and 50% of positive samples, respectively). Corn products ($n = 136$) and bean samples ($n = 3$) did not have detectable levels of AFs ($<2\,\mu g\,kg^{-1}$ for each AF). Among other nuts, AFs were found in only one pistachio sample ($352\,\mu g\,kg^{-1}$). The mean and the range levels of AFs in food products in the Federal District are shown in Table 1. Mean levels of AFs in all samples ranged from $6.7\,\mu g\,kg^{-1}$ in peanut products to $36.9\,\mu g\,kg^{-1}$ in Brazil nuts. The mean of positive samples was higher for shelled Brazil nuts ($553.6\,\mu g\,kg^{-1}$). There were two samples with more than $1000\,\mu g\,kg^{-1}$ of AFs, one of raw peanuts ($1496\,\mu g\,kg^{-1}$) and one of shelled Brazil nuts ($1972\,\mu g\,kg^{-1}$).

The incidence of AFs in food commercialised in the Federal District decreased considerably in the last decade, as shown in Figure 1. The percentage of AF positive samples (≥LOQ) dropped from around 30.0% in peanuts and peanut products in 1996–2001 (Caldas et al. 1998, 2002) to 5.7% in 2002–2011. Nuts also showed an important decrease, from 12.5% (1998–2001) to 3.4% (2002–2011). During this period there was also a reduction in AF levels in the products analysed. The percentage of peanuts and peanut

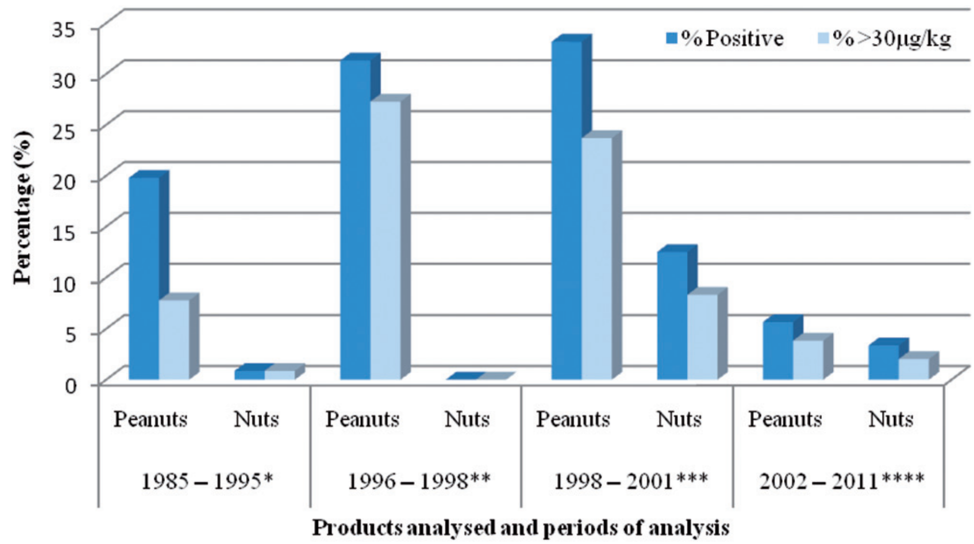

Figure 1. Analysis of aflatoxins in the Federal District between 1985 and 2011. Peanuts include toasted, salted, shelled and peanut products; nuts include shelled Brazil nuts, almonds, cashew nuts, hazelnuts, nuts and pistachios.
Sources: *Silva et al. (1996); **up to June 1998, Caldas et al. (1998); ***from July 1998, Caldas et al. (2002); ****present work.

product samples containing more than 30 µg kg^{-1} of AFB1 + AFG1 (Brazilian ML until 2002) dropped from 27.3% (1996–1998) to 3.8% (2002–2011).

The mean levels of AFs found in food analysed in the Federal District and other Brazilian regions in 2002–2011, which also include data on rice and corn products, are shown in Table 2. The main groups of samples analysed nationally were also peanuts (29.2%) and peanuts products (27.8%), although the highest percentage of positive samples was found in rice collected from various Brazilian states (37.6%).

Food consumption data

A summary of food consumption data obtained for the foods relevant to this work is shown in Table 3. Information on corn products and rice was not relevant for the Federal District since no corn product sample analysed was positive, and rice was not analysed during the period of the study. Of the 977 households that participated in the HBS in the Federal District, a maximum of five household reported the acquisition of peanuts, peanut products, Brazil nuts and/or other nuts. When all the surveyed households were considered (total population), the highest mean consumption was for peanuts (0.13 g per person day^{-1}). Individual consumption data obtained for the Brazilian population also showed low consumption of these foods (maximum of 1.1% of the total population reported peanut products). Most of the individuals reported rice (95.6%), confirming the Brazilian habit of consuming rice at least once a day.

Dietary risk assessment

The lower–upper bound intakes of AFs through the consumption of peanuts, peanut products, Brazil nuts, other nuts, corn products and rice are shown in Table 4. In the Federal District, total intakes for the total population and high consumers were 0.06–0.08 and 33.3–47.1 ng kg^{-1} bw day^{-1}, respectively, with Brazil nuts contributing the most to the intake for high consumers (54% for the upper bound level). At the national level, the intake of AFs through the consumption of corn products and rice were also considered. For rice, a cooking processing factor of 0.7 (Je-Won et al. 2005) was applied to the mean concentration in the country (Table 2) to determine the final concentration to which the population is exposed to. Total intakes were 6.6–6.8 for the total population (almost 100% from rice consumption) and 16.3–27.6 ng kg^{-1} bw day^{-1} for high consumers (55.1% of the upper bound level from the consumption of rice and corn products).

The risk characterisations from the exposure to AFs (cancer risk and MOE) are shown in Table 5. While in the Federal District the cancer risk for the total population was much lower that what was estimated at the national level (0.0009 and 0.0753 cancers year^{-1} per 10^5 individuals, respectively), for high consumers the risk in the Federal District was twice that for the entire country. The same risk pattern was found when the MOE approach was used. MOEs ranged from 2833 (Federal District, lower risk) to 25 (Brazil) for the total population, and from 10.4 (Brazil, lower risk) to 3.6 (Federal District) for high consumers.

Table 2. Aflatoxins in food products in Brazil.

	Mean, all samples ($\mu g\,kg^{-1}$)[a] (positive/analysed)					
State or region	Peanuts[b]	Peanut products[c]	Shelled Brazil nuts	Other nuts[d]	Corn products[e]	Rice
Minas Gerais	30.6[f] (8/21)	12.1[f] (2/15)				0.2[g] (1/36)
São Paulo[h]	3.4 (34/96)	3.6 (72/144)				
Rio Grande do Sul[i]	17.8 (7/12)	3.2 (6/10)				
Federal District	14.2[j] (29/359)	6.7[j] (8/295)	36.9[j] (4/67)	8.3[j] (1/82)	4.0[k] (0/174)	
North and Northeast[l]			3.0 (n.r./40)			
Amazonas[m]			37.1 (5/30)			
Paraná[n]					4.5 (7/123)	
Various states[o]						4.2 (75/166)
Brazil[a]	12.9 (78/488)	5.8 (88/464)	27.0 (–/137)	8.3 (1/82)	4.2 (7/297)	3.5 (76/202)

Notes: [a]Weighted mean; samples < LOQ were considered at 0.5× the reported LOQ/LOD.
[b]Toasted, salted and shelled peanuts.
[c]Peanut butter and peanut candies.
[d]Almonds, cashew nuts, hazelnuts, nuts and pistachios.
[e]Corn meal, corn flour, corn grits, degermed corn (*canjica*), precooked corn flour, popcorn, corn flakes and snacks.
[f]Rocha et al. (2008); LOD = 5 $\mu g\,kg^{-1}$.
[g]Carvalho et al. (2010); LOQ = 0.05–0.16 $\mu g\,kg^{-1}$.
[h]Oliveira et al. (2009); LOQ = 0.5 $\mu g\,kg^{-1}$.
[i]Oliveira and Koller (2011); LOQ considered as 2 $\mu g\,kg^{-1}$.
[j]See Table 1.
[k]See Table 1 and Caldas and Silva (2007); LOQ = 2 $\mu g\,kg^{-1}$.
[l]Pacheco and Scussel (2007); LOQ = 0.08–0.12 $\mu g\,kg^{-1}$; mean of positive samples.
[m]Pacheco et al. (2010); LOQ = 0.45–0.50 $\mu g\,kg^{-1}$.
[n]Amaral et al. (2006); LOD = 0.5–3.2 $\mu g\,kg^{-1}$.
[o]Almeida et al. (2012); LOD = 0.1–0.3 $\mu g\,kg^{-1}$.
n.r., Not reported.

Discussion

This study has shown that peanuts and peanut products remain the major food of concern regarding AF contamination in the Federal District and in other parts of Brazil, confirming other studies conducted in the country (Rodríguez-Amaya and Sabino 2002; Rocha et al. 2008; Oliveira et al. 2009). Considering peanuts and peanut products as a single group, the incidence of AF found in the Federal District was lower (5.7%) than that reported in São Paulo (44.2%) using the HPLC/fluorescence detection method, which is five times more sensitive than the TLC method used in the Federal District. The mean level of positive samples was higher in the Federal District (123.0 $\mu g\,kg^{-1}$) than in the states of São Paulo (6.05 $\mu g\,kg^{-1}$; Oliveira et al. 2009), Minas Gerais (56.4 $\mu g\,kg^{-1}$; Rocha et al. 2008) and Rio Grande do Sul (16.2 $\mu g\,kg^{-1}$; Oliveira and Koller 2011). Peanuts and peanut products, in addition to nuts, are not often consumed by the Brazilian population, a pattern that is also found in the WHO Cluster Diet data (Brazil is included in diet K; WHO 2006). Peanuts and peanut products are usually more consumed during June–July in certain folkloric festivities. Brazil nuts and other nuts are mostly consumed during Christmas and the New Year celebrations, and are considered an expensive food by most of the population.

Data on corn products were found only in samples from the Federal District and the state of Paraná (southern Brazil), which is the highest corn producer in the country (IBGE 2010). Most corn product industries are located in the Southeastern and Southern regions of Brazil, and it is most likely that the products analysed in both studies are also consumed elsewhere in the country.

The incidence of AFs in food products found in the current study was similar to that found in a study conducted with imported products in Italy (5.0%; Imperato et al. 2011) but considerably lower than those

Table 3. Data obtained from the Brazilian Household Budget Survey 2008/2009 for both high consumers and the total population of Brazil.

	Total	Peanuts[a]	Peanut products[b]	Brazil nuts[c]	Other nuts[d]	Corn products[e]	Rice
Federal District[f]							
Households (n)	977	4	5	1	4		
Consumers (n)	2703	14	17	3	13		
Mean bw (kg)	59.3	54.8	61.4	69.4	58.9		
Total population[g] (g day^{-1})		0.13	0.1	0.05	0.09		
High consumers[h] (g day^{-1})		63.18	22.09	47.62	21.47		
Brazil[i]							
Consumers (n)	34,003	129	380	38	57	1086	32,502
Mean bw (kg)	63.5	66.6	64.5	61.0	60.8	62.4	64.3
Total population[j] (g day^{-1})		0.04	0.12	0.005	0.01	1.82	170.16
High consumers[k] (g day^{-1})		21.35	19.65	10.57	13.39	114.03	194.28

Notes: [a]Toasted, salted and shelled peanuts.
[b]Peanut butter and peanut candies.
[c]Shelled.
[d]Almonds, cashew nuts, hazelnuts, nuts and pistachios.
[e]Corn meal, corn flour, corn grits and degermed corn (*canjica*).
[f]HBS data.
[g]All households in the survey.
[h]Only households that reported consumption of at least one food item considered in this study.
[i]Individual consumption data for individuals aged 10 years or older.
[j]All individuals in the survey.
[k]Only individuals who reported at least one food item considered in this study.

Table 4. Aflatoxins intake (lower–upper bound) in the Federal District and Brazil through the consumption of peanuts, peanut products, Brazil nuts, other nuts, corn products and rice (ng kg^{-1} bw day^{-1}).

	Federal District[a]		Brazil[b]	
Food	Total population[c]	High consumers[d]	Total population[e]	High consumers[f]
Peanuts[g]	0.02–0.03	8.1–16.4	0.004–0.01	2.3–4.1
Peanuts products[h]	0.005–0.01	1.0–2.4	0.005–0.01	0.9–1.8
Brazil nuts, shelled	0.028–0.03	22.6–25.3	0.002–0.0021	4.3–4.7
Other nuts[i]	0.007–0.01	1.6–3.0	0.0007–0.001	0.9–1.8
Corn products[j]			0.01–0.12	0.5–7.7
Rice			6.5–6.6	7.4–7.5
Total intake	0.06–0.08	33.3–47.1	6.6–6.8	16.3–27.6

Notes: [a]HBS data.
[b]Individual consumption data for individuals aged 10 years or older.
[c]All households in the survey.
[d]Only households that reported consumption of at least one food item considered in this study.
[e]All individuals in the survey.
[f]Only individuals who reported at least one food item considered in this study.
[g]Toasted, salted and shelled peanuts.
[h]Peanut butter and peanut candies.
[i]Almonds, cashew nuts, hazelnuts, nuts and pistachios, shelled.
[j]Corn meal, corn flour, corn grits, degermed corn (*canjica*), precooked corn flour, popcorn, corn flakes and snacks.

reported in Pakistan (29.4%; Luttfullah and Hussain 2011), Malaysia (16.3%; Leong et al. 2010), and South Korea (10.5%; Chun et al. 2007).

The decrease in AF contamination observed in food products in recent years in the Federal District is probably a consequence of the enforcement of a Brazilian government norm regarding the compulsory adoption of GMP by peanut industries as of 2003 (RDC 172/2003; ANVISA 2012). AFs in corn products (corn meal and popcorn) do not seem to be a problem in the Federal District, since no contamination was found in this study or previously in the region (Caldas and Silva 2007). A low incidence of AFs in corn products was found in Parana state, and in other studies conducted in the country before 2002 (Bittencourt et al. 2005; Kawashima and Soares 2006).

Table 5. Risk characterisation for aflatoxins based on cancer risk and margin of exposure (MOE).

	Cancer risk[a]	MOE[b]
Federal District		
Total population[c]	0.0006–0.0009[d]	2833–2125
High consumers[c]	0.3581–0.5065[d]	5.1–3.6
Brazil		
Total population[c]	0.0731–0.0753[e]	25.8–25.0
High consumers[c]	0.1794–0.3056[e]	10.4–6.2
Europe (WHO 1999)		
Total population[f]	0.0041	–
Europe (EFSA 2007)		
Total population[g]	0.0037–0.0205[h]	483–88
High consumers[i]	0.01–0.024[h]	173–76
Africa (Shephard 2008)		
Total population[j]	0.1–70.1[k]	121.4–0.2
Japan (Sugita-Konishi et al. 2010)		
95th[l]	0.00004–0.00005	–
China (Ding et al. 2012)		
Mean[m]	0.003–0.2[n]	24.7–0.5
97.5th[m]	0.17–9.13[n]	1273–24.1

Notes: [a]Cancers year^{-1} per 10^5 individuals, estimated according to WHO (1999).
[b]Based on a $BMDL_{10}$ in rodent of 170 ng kg^{-1} bw day^{-1} (EFSA 2007), with the exception of China (140 ng kg^{-1} bw^{-1}; Benford et al. 2010).
[c]Lower–upper bound.
[d]0.26% $HBsAg^+$.
[e]0.37% $HBsAg^+$.
[f]For an ML of 20 µg kg^{-1} in raw corn, peanut and peanut products, 1% $HBsAg^+$.
[g]For an ML of 4 µg kg^{-1} in almonds, hazelnuts and pistachios, lower bound of Cluster Diet F – upper bound of Cluster Diet B.
[h]0.2% $HBsAg^+$.
[i]High consumers of pistachios and mean consumption of other nuts.
[j]Range of individual commodities from different African countries.
[k]25% $HBsAg^+$.
[l]Lower–upper bound, 1% $HBsAg^+$.
[m]Range of individual commodities (rice, corn and corn product, peanut and peanut oil).
[n]Simulations of prevalence rates (% $HBsAg^+$) of different age groups.

The estimated total intake for high consumers of peanuts, peanut products and nuts (high consumers) in the Brazilian population was much higher than for the total population, but it is unlikely that this pattern of consumption is repeated daily on a long-term basis and that the food consumed is always contaminated. The AF intakes in the Federal District (total population) were much lower than those found at the national level, mainly because exposure from the consumption of rice was not considered in the regional estimation. The presence of AFs in rice has been reported worldwide. In most studies, the incidence of positive samples is high (49.7–100%), although the mean levels found in positive sample were lower than 5 µg kg^{-1} (Mazaheri 2009; Bansal et al. 2011; Reddy et al. 2011; Sun et al. 2011). Samples analysed in Turkey and Nigeria showed both high incidence (56.0% and 100%) and contamination levels (0.05–371.9 µg kg^{-1}; Aydin et al. 2011; Makun et al. 2011), though there were no positive samples analysed in Tunisia (Ghali et al. 2010).

The calculated total AF intake for the total Brazilian population was higher than the intake calculated for the European population (0.32 ng kg^{-1} bw day^{-1}) using consumption data from the GEMS/Food Cluster Diets and mean AF levels in corn (unprocessed), peanuts and peanut products up to 20 µg kg^{-1} (WHO 1999) and for the Swedish population (0.8 ng kg^{-1} bw day^{-1}; Thuvander et al. 2001). Clearly, the higher intake comes mainly from the consumption of rice, a staple food in the country. The exposure was also much higher than in the Japanese population (0.003–0.004 ng kg^{-1} bw day^{-1} for high consumers, only AFB1; Sugita-Konishi et al. 2010), but lower than most intakes calculated for African countries for individual commodities (0.1–850 ng kg^{-1} bw day^{-1}; Shephard 2008).

The cancer risk estimated for the total Brazilian population was higher than that estimated for Europe due to the higher intake, as the $HBsAg^+$ prevalences are similar (0.37% and 0.2–1.0%, respectively). The Brazilian $HBsAg^+$ prevalence used in the estimation was much lower than that reported by WHO, which considered Brazil an area of intermediate and high endemic levels (range of 2 to >8% $HBsAg^{+}$; WHO 2002). However, this pattern has changed since 1989 when the Brazilian health system began providing vaccines against the hepatitis B virus, and currently this vaccine is administered to those aged 0–29 years and to vulnerable groups (pregnant women, homosexuals, police officers and healthcare providers) (Ministry of Health – Immunization Programme 2012).

Although the MOEs calculated for Brazil are lower than those reported for the European population, in both cases the values obtained indicate a health concern (lower than 10,000; EFSA 2005). The cancer risks and the MOEs estimated in China (Ding et al. 2012) and Africa (Shephard 2008) are also presented in Table 5. However, a direct comparison with the Brazilian results was not possible as the authors estimated the risks for individual commodities and they were not based on the total intake.

The HBS data used to estimate the consumption of peanuts, peanut products and nuts in the Federal District have certain limitations, the main one being that they reflect the food that is available in the household, which does not imply equal consumption among the household residents, which was assumed in this study. This approach may have overestimated consumption for some groups of the population, such as children. It is also important to point out that the IBGE individual consumption data used to estimate the food consumption nationally only cover individuals aged 10 years or older, and therefore the estimations for the Brazilian population obtained in this study exclude individuals under this age.

One limitation when using published work to estimate concentration levels of contaminants in food is the heterogeneity of published data. Mean concentrations for all samples were not available (weighted mean was estimated) and not all of the studies had reported the method LOQ (sometimes 0.5LOD was used to estimate the upper-bound intake level). Additionally, many studies conducted in Brazil, including in the Federal District, still use the low sensitive thin-layer chromatography method to analyse AFs in food, which leads to an overestimation of the upper bound mean (samples $< LOQ = 0.5LOQ$), mainly for food with low contamination incidence, such as corn products.

Conclusions

The incidence of AFs in food commercialised in the Federal District has decreased considerably in the last decade, although the level of contamination found in some samples is still higher than what is found in other Brazilian states. Rice should be considered in future AF monitoring programmes in the Federal District and other regions as it is a staple food in the Brazilian diet and any level of contamination would have an impact on the total exposure. Although preliminary due to the limitations raised above, the results of this study have shown that the dietary risks of the Brazilian population to AFs are higher than those found in some other regions in the world, and may represent a health concern. AFs are genotoxic carcinogens and government actions should be maintained and continuously improved in order to guarantee that human exposure levels are kept as low as possible.

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