

Aflatoxins contents determination in some foodstuffs in Burkina Faso and human health risk assessment

Moumouni Bandé^{a,b,*}, Inna Traoré^c, Fulbert Nikiema^a, Naamwin-So-Bawfu Romaric Médà^a, Dissinvel S. Kpoda^{a,d}, Bazoin Sylvain Raoul Bazié^a, Marceline Ouédraogo/Kagambèga^a, Inoussa Ilboudo^a, Ouambila Isidore Sama^a, Abdoul Kiswensida Müller Compaoré^a, Naa-Imwine Stanislas Dimitri Meda^a, Bernadette Pane Ouattara Sourabie^a, Hervé Hien^e, Élie Kabré^{a,b}

^a National Public Health Laboratory, 09 BP 24 Ouagadougou 09, Burkina Faso

^b Joseph KI ZERBO University, 03 BP 7021 Ouagadougou 03, Burkina Faso

^c Research Institute of Health Sciences, 03 BP 7192 Ouagadougou 03, Burkina Faso

^d University Centre of Ziniaré, 03 B.P. 7021 Ouagadougou 03, Burkina Faso

^e National Institute of Public Health, BP 10278 Ouagadougou, Burkina Faso

ARTICLE INFO

Handling Editor: Dr. Ray Norton

Keywords:

Aflatoxins
Cereals
Peanut
Health
Risk
Burkina Faso

ABSTRACT

Aflatoxins are produced by fungi of the genus *Aspergillus* that colonize many foodstuffs during agricultural production, harvesting, transportation, storage, and food processing. In view of these aflatoxins toxicity to humans, their presence in foods such as cereals and oilseeds constitutes a major challenge for global food security, health and nutrition. This study was therefore initiated to assess the level of aflatoxin contamination of various foodstuffs sold in urban and semi-urban markets in Burkina Faso, and to evaluate the carcinogenic risk which the consuming population is exposed to. Two hundred and twelve foodstuff samples were collected in two large cities (Ouagadougou and Bobo Dioulasso) and three semi urban localities (Cinkansé, Dakola and Niangoloko). Aflatoxins contents in foodstuffs were determined by immunoaffinity chromatography and human health risk assessment was performed by using the Monte Carlo algorithm. The aflatoxins contents determination showed that 41.50% of studied samples were contaminated with concentrations up to 182.28 µg/kg for AFB1 in peanuts. Chronic Daily Intake, calculated based on the consumption patterns assumed in this study, was estimated to be higher in large cities (CDI = 33.68 µg/kg bw in Ouagadougou and 10.18 µg/kg bw in Bobo Dioulasso) than in semi urban localities (CDI = 4.29 µg/kg bw in Cinkansé, CDI = 0.39 µg/kg bw in Dakola and CDI = 0.18 µg/kg bw in Niangoloko). The MOE determination showed that the sorghum meal and whole grain maize consumption was associated to the carcinogenic risk for public health in large cities (the percentile 95 of MOE = 3316 for rice, 4511 for peanuts, 3334 for sorghum meal and 4530 for whole grain maize). In semi urban localities, no carcinogenic risk was observed to public health. These results should inspire the country's sanitary and agricultural authorities to undertake actions to fight against the agricultural food products contamination by aflatoxins in order to safeguard the population's health.

1. Introduction

Aflatoxins are classified as carcinogenic group 1 by the International Agency for Research on Cancer (IARC, 2012). They are produced by fungi of the genus *Aspergillus* that colonize many foodstuffs during agricultural production, harvesting, transportation, storage and food processing (Zinedine et al., 2006). The most common producing species

are *Aspergillus flavus*, *Aspergillus flavus* subsp. *Parasiticus* and *Aspergillus nomius* (Zinedine et al., 2006). Approximately 20 aflatoxins have been identified and four of them occur naturally, including aflatoxin B1 (AFB1), B2 (AFB2), G1 (AFG1), and G2 (AFG2) (Deng et al., 2018). These aflatoxins widely contaminate various types of crops all over the world, such as maize, peanuts, wheat, barley, and rice (Deng et al., 2018). Of all the mycotoxins, aflatoxin B1 (AFB1) produced by *Aspergillus flavus* and

* Corresponding author. Joseph KI ZERBO University, Laboratoire de Toxicologie Environnement Santé (LATES) 03 BP 7021, Ouagadougou 03, Burkina Faso.
E-mail address: bande.moumouni@ujkz.bf (M. Bandé).

Aspergillus parasiticus is the most common and most toxic form (hepatotoxic, teratogenic and mutagenic) to mammals (Tabuc, 2007) and causes damage such as toxic hepatitis, hepatocarcinoma, hemorrhage, Alzheimer's disease and Parkinson. In view of these mycotoxins toxicity to humans, their presence in staple foods such as cereals and oilseeds constitutes a major challenge for global food security, health, nutrition, and economic systems (Dieme et al., 2016).

The problem is most glaring in developing countries which are otherwise faced with recurrent food insecurity and for which the populations' diet is largely provided by cereals and oilseeds. For example, in Kenya out of a total of 342 maize samples, 182 (53.2%) had total aflatoxin levels above the United State Department of Agriculture maximum value (20 µg/kg) (CDC, 2004). Aflatoxins with concentrations up to 1020 µg/kg have been reported in maize grain in Malawi (Moss, 2008). The mean values of aflatoxin B1 (AFB1) contamination of cereals in Nigeria are 257.82 µg/kg for maize, 2587.47 ± 78.23 µg/kg for millet and 82.5 ± 16.9 µg/kg for rice with a very high incidence in the case of millet and maize (Hussaini et al., 2009; J. Atehnkeng et al., 2014; Makun et al., 2007). The analysis of the different results above shows that aflatoxin contamination of cereals varies according to the locality and also according to the season. In any case it is generally very high throughout Africa. This presence of aflatoxin at high concentrations in cereals is the main characteristic that tarnishes the quality of cereal production in the continent.

Several countries have established or proposed regulatory limits for mycotoxins in foods. European Union (EU) countries edited regulations to limit their presence in the foods in Europe (Yacine Ware et al., 2017). Concerning the sum of aflatoxins B1, B2, G1 and G2, the harmonized EU maximum limit (ML) of 4 µg/kg is applied by 29 countries again mainly EU and European Free Trade Association (EFTA) countries (EFSA, 2012). Regarding AFB1, a ML of 2 µg/kg was in force in these countries. In Africa, countries such as South Africa, Nigeria or Ghana have set regulatory values on mycotoxins and produce important scientific research, especially on aflatoxins and fumonisins (Ezekiel et al., 2014). However, regulatory limits in sub-Saharan Africa are absent or rarely in place or poorly enforced and regular monitoring is often a major problem (Yacine Ware et al., 2017).

Burkina Faso, a country located in the heart of West Africa, has enormous culinary potential given the diversity of agricultural products encountered. Among these agricultural products, cereals and oilseeds have social, economic, and nutritional importance for the populations (Yacine Ware et al., 2017). According to statistics from the Ministry of Agriculture and Hydro-Agricultural Development, cereal production in 2019 was estimated at 4,567,065 tons/year with an increasing trend in cereal farmland (Ministère de l'Agriculture et les Aménagement Hydro-agricoles, 2019). Over the period 2009–2019, the quantity of cereals available per capita has evolved above normal (190 kg/person), increasing by 27 kg in ten years thanks to production efforts. However, the mycotoxins presence in these foodstuffs, favored by subtropical type climatic conditions, has an impact on health and affects more particularly rural populations because they often consume cereals and oilseed products as staple foods (Dieme et al., 2016). Moreover, cereal products from Burkina Faso are increasingly being rejected internationally and by some institutions working the food security field, such as the World Food Programme (WFP), because of their high mycotoxin content (Romuli et al., 2020). The country has not yet established regulations on mycotoxins, so the country's control agencies apply the European limit values.

This study was therefore initiated to assess the aflatoxin contamination level of various foodstuffs sold in urban and semi-urban markets in Burkina Faso, and to evaluate the carcinogenic risk which the population is exposed to by using probabilistic modelling that was proposed as an approach to cumulative risk assessment (Rotter et al., 2018). At the end, it will contribute to the availability of data on the aflatoxin problem in cereal and oilseed products in Burkina Faso, all of which will allow the authorities to make appropriate decisions for the preservation of the

populations' health.

2. Materials and methods

2.1. Sampling and samples processing

The samples were collected in 5 localities in the country from January 2021 to March 2021. The choice of these locations was based on population density (Ouagadougou and Bobo Dioulasso) and the intensity of commercial traffic in the border areas (Niangoloko, Dakola and Cinkanse). Fig. 1 shows the geographical location of these localities on the map of Burkina Faso.

In the localities selected for the study, samples were collected in popular markets. For towns with several markets, a random draw was made to select the markets, which the samples should be taken from. Foods have been selected on the basis of the most consumed foods identified in the report of the Ministry of Agriculture. To determine the number of samples to be taken for each type of food, the following formula was used:

$$N = t^2 \times p \times (1-p) / m^2$$
 where n is the minimum sample size to be taken, t: Confidence level (t = 1.96); p: The desired proportion's expected value (p = 0.5); m: Error margin (set to 5%).

The number of samples obtained using the formula was then related to the size of the cities' populations and the frequency with which each food was consumed. So, three (3) cereals (husked and polished rice, whole grain maize and sorghum meal) and an oilseed crop (peanut) were chosen to be part of the study.

Each sample was packed in a sterile plastic bag and transported to the laboratory at room temperature for analysis. The samples collected in the form of grains were finely ground with an IKA type mill (WERKE, Type M20). In order to limit the risk of contamination, the grinder was cleaned beforehand and the cleaning was repeated after each grinding. The powdered samples resulting from this process were packed in plastic bags.

2.2. Aflatoxins determination

All the solutions were prepared with the double de-ionized water provided by the Milli Q water purification system (LAB TOWER AFT, Thermo scientific). Aflatoxin standard (Aflatoxin mix 4 solutions; AFB1&G1 2 µg/mL and AFB2&G2 0.5 µg/mL) was purchased from Biopharm Rhône Ltd, Glasgow, UK with a purity >98%. The stock solution concentration was 50 ng/mL in acetonitrile. Standards at different concentrations were prepared in vials. Solvents (methanol, acetonitrile) were HPLC grade, 99.9% of purity and were purchased from Chroma-Solv, Sigma Aldrich. The reagents including Phosphate buffered saline (Sigma Aldrich), sodium hydroxide (Panreact), sodium chloride (Sigma Aldrich) were also used.

To extract the aflatoxins, 5 g of sample was weighed and poured into an Erlenmeyer flask containing 25 mL of an extraction solution composed of 70% of methanol and 30% of distilled water. The resulting mixture was stirred on a rotary shaker for 2 min to allow the toxins to dissolve. After this step, the mixture is filtered through Wattman paper. Finally, 15 mL of the filtrate is removed and added to 45 mL of PBS buffer. The resulting solution is used for the aflatoxins purification.

The aflatoxins purification was performed using AflaStar immunoaffinity columns obtained from Romer Labs. In brief, this procedure consists in passing the filtrate diluted with PBS through the column at a flow rate of approximately 3 mL/min. The column is then washed with 20 mL of distilled water in small portions of about 10 mL at a maximum flow rate of 5 mL/min and dried by applying a vacuum for 5–10 s. The aflatoxins were eluted with 1.5 mL of methanol and then 1.5 mL of distilled water was added to the collected volume. A volume of 2.8 mL is collected in a 4 mL recovery vial.

For each sample, a volume of 20.0 µL of purified extract was taken from the vial and injected into the DIONEX ultimate 3000 Ultra High

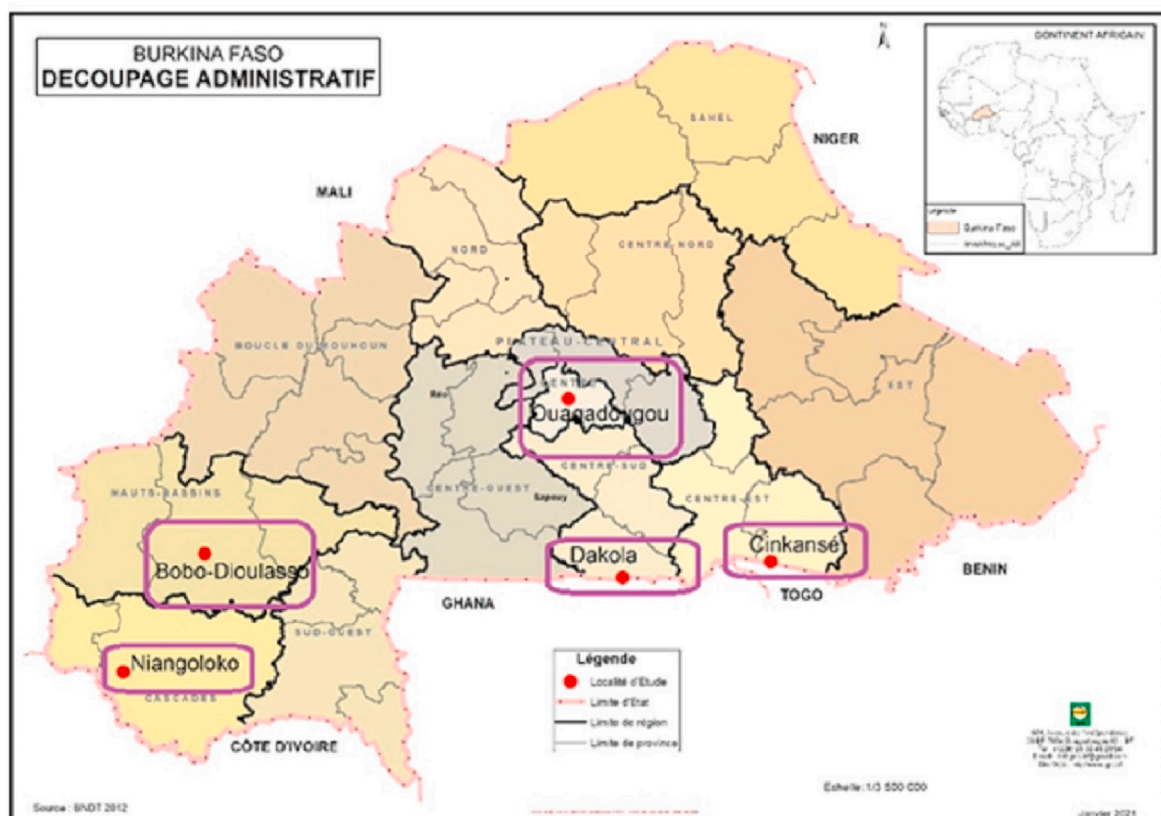


Fig. 1. Geographical location of the study locations on the map of Burkina Faso.

Performance Liquid Chromatograph purchased from TERMO SCIENTIFIC (Waltham, Massachusetts, USA) equipped with a fluorescence detector type RF-10AXL. The operating conditions are summarized in Table 1.

The analytical performance was determined for maize flour and peanuts. As the other foods were also cereals, the analytical performance obtained with maize flour was applied to them. The validation parameters were as follows: Linearity, recovery rate, repeatability, intermediate precision, limit of detection (LOD) and limit of quantification (LOQ). To assess linearity, four-point calibration lines were constructed over a 4 levels concentrations range (4 ng/mL, 10 ng/mL, 20 ng/mL and 80 ng/mL for AFB1 and AFG1 and 1 ng/mL, 2.5 ng/mL, 5 ng/mL and 20 ng/mL for AFB2 and AFG2) using the aflatoxin standard (Aflatoxin mix 4 solution). Linearity was determined for each aflatoxin class using linear regression analysis and expressed as the coefficient of determination (R^2). The limit of detection (LOD) and the limit of quantification (LOQ) were determined from the signal-to noise ratio as more than 3 : 1 and 10 : 1, respectively. Repeatability and intermediate precision were determined using samples of corn and peanut flour spiked with 10 µg/kg AFB1 and AFG2 and 2.5 µg/kg AFB2 and AFG2. Each spiked sample was analyzed 6 times on the same day by the same operator with the same equipment and reagents for the repeatability evaluation and 5 times at a

rate of once a day for 5 days for the intermediate precision evaluation. The recovery rate was determined by analyzing spiked samples with the aflatoxin standard and its value was calculated by the following equation: Recovery rate (%) = (100 X measured concentration for spiked sample)/added concentration.

Performance data of aflatoxins analysis methods are summarized in Table 2.

2.3. AFB1 exposure and probabilistic health risk assessment

The health risk assessment was carried out only for AFB1 in view of its greater toxicity compared to the other classes of aflatoxins. In addition, data from the semi-urban localities (Niangoloko, Dakola and Cinkanse) were aggregated to form a single data set, as were the data from large cities (Bobo Dioulasso and Ouagadougou). The risk assessment was then carried out for the semi-urban areas populations on the one hand

Table 1
Chromatographic operating conditions.

Chromatographic operating conditions	
Column	Shim-pack CLCG-ODS C18, 4 µm, 150 mm x 4,6 mm
Mobile phase	Methanol/acetonitrile (50:50; v/v)
Pump flow rate	1 mL/min
Temperature	40 °C
Injected Volume	20 µl
Detector	Fluorescence: λ excitation: 360 nm; λ émission 440 nm
Analysis time	15 min

Table 2
Validation of aflatoxins analysis performance.

		Validation data of aflatoxins analysis performance			
		AFB1	AFB2	AFG1	AFG2
Repeatability CV (%)	Maize flour	0.61	0.55	0.97	1.01
	Peanut	1.68	1.43	1.87	1.98
Intermediate precision CV (%)	Maize flour	3.72	5.01	5.32	4.68
	Peanut	5.84	6.32	7.48	6.87
Recovery rate (%)	Maize flour	99.8	97.0	93.0	90.1
	Peanut	89.7	90.2	90.7	92.0
LOD	Maize flour	0.3	0.2	0.2	0.1
	Peanut	0.4	0.3	0.3	0.2
LOQ	Maize flour	1.0	0.8	0.8	0.3
	Peanut	1.5	1.0	1.0	0.4
Linearity (R^2)	Maize flour	0.998	0.994	0.999	0.997
	Peanut	0.983	0.989	0.991	0.993

and for the large cities on the other.

The consumers' aflatoxin B1 exposure was assessed by a daily consumption of scenario based on the contamination levels obtained in the current study. The chronic daily intake (CDI) was calculated by using the following formulae (IARC, 2012; US EPA, 2011; Adel et al., 2016; Dadar et al., 2017):

$$CDI = \frac{Ci \times IRI \times EDi \times EFi}{BW \times AT} \quad (1)$$

Ci = Content of AFB1 in studied foodstuffs (ng/g); IRI = daily intake of studied foodstuffs g/day; ED = time-period of detected AFB1 (70 years); EFi = exposure frequency (365 days/year); BW = average body weight (70 kg); and AT = mean time (70 × 365 days).

Since EFi equals 365 days, Edi X EFi = AT, the CDI formula becomes after simplification,

$$CDI = \frac{Ci \times IRI}{BW} \quad (2)$$

Consumption data was taken from the FAO database (2003) due to the lack of country-wide food consumption data. This organization conducted a survey in two regions of Burkina Faso on the consumption of cereal foodstuffs. The results, for the foods concerned by this study, were as follows: maize: 31 g/person/day, rice: 39 g/person/day, sorghum meal: 429 g/person/day, peanuts: 30 g/person/day.

The Margin of Exposure (MOE) was used to determine the carcinogenic risk of AFB1 for human on the basis of studied foodstuffs consumption. The MOE (Margin Of Exposure) was calculated as a ratio between the toxicological reference (Benchmark Dose Level, BMDL₁₀) and the chronic daily intake [17], where BMDL₁₀ (humans) = 400 ng/kg bw/day (EFSA, 2012; Joint FAO/WHO Expert Committee on Food Additives, Meeting (49th: 1997: Joint FAO/WHO Expert Committee on Food Additives, 1998).

$$MOE = \frac{BMDL_{10}}{CDI} \quad (3)$$

Carcinogenic risk (MOE) on studied foodstuffs content of AFB1 was assessed by using Monte Carlo Simulation (MCS). The simulation was executed by introducing in the Crystal Ball software (v11.1.2.4.600 software, Oracle, Decisioneering, Denver, CO, USA) following factors: BMDL₁₀, BW, Ci and IRI. The best fit distributions were applied for consumption data, aflatoxins B1 contents and body weight based on Kalmogorov-Snirnov statistics and the MC model was shown for 10,000 iterations. To assess neither exposed population are at the carcinogenic risk or not, 95th percentiles of MOE distribution were chosen. Exposed population was at an acceptable health risk level when the MOE values > 10,000 (US EPA, 2011).

3. Results

3.1. Sum aflatoxin (AFTOT) contamination of analyzed foodstuffs

A total of 212 samples of whole grain maize, husked and polished rice, sorghum meal and peanuts was taken in 5 locations in Burkina Faso, namely Bobo Dioulasso, Cinkansé, Dakola, Niangoloko, and Ouagadougou. The samples for which total aflatoxin levels were found are listed in Table 3.

The results obtained showed that sorghum meal were the most contaminated foodstuffs with 57.44% of samples contaminated followed by whole grain maize samples 42.10% and peanuts samples 30.50%. The least contaminated food was husked and polished rice with 22.50% of the samples contaminated. Out of the 212 samples collected, 88 (41.50%) were contaminated with aflatoxins.

3.2. Foodstuffs aflatoxin content

The levels of aflatoxins B1, B2, G1, G2 and AFTOT, presented in

Table 3

Distribution of aflatoxin contaminated samples by food type and location.

Type of samples	Locality of collect	No. Of samples contaminated by aflatoxins	Harmonized EU maximum limit (µg/kg)
MAIZE (19 samples)	Bobo dioulasso	1	4
	Cinkanse	0	
	Dakola	1	
	Niangoloko	1	
	Ouagadougou	4	
	Total	8 (42.10%)	
RICE (40 samples)	Bobo dioulasso	3	
	Cinkanse	0	
	Dakola	3	
	Niangoloko	0	
	Ouagadougou	3	
	Total	9 (22.50%)	
Sorghum meal (94 samples)	Bobo dioulasso	12	
	Cinkansé	5	
	Dakola	6	
	Niangoloko	7	
	Ouagadougou	24	
	Total	54 (57.44%)	
peanuts (59 samples)	Bobo dioulasso	12	
	Cinkanse	0	
	Dakola	0	
	Niangoloko	5	
	Ouagadougou	1	
	Total	18 (30.50%)	
TOTAL		88 (41.50%)	

terms of percentiles, are summarized in Tables 4–8 respectively.

The highest levels of AFB1 and AFB2 were found in the whole grain maize and peanuts samples with maximum levels of 166.81 µg/kg and 182.28 µg/kg for AFB1 and 18.91 µg/kg and 24.49 µg/kg for AFB2 respectively. These samples came from the cities of Ouagadougou for the whole grain maize samples and Bobo Dioulasso (AFB1) and Niangoloko (AFB2) for the peanut ones. For AFG1 and AFG2, the highest levels were found in the whole grain maize with levels of 64.06 µg/kg and 3.52 µg/kg respectively, taken from the city of Ouagadougou.

3.3. Samples compliance with the maximum tolerated values of AFTOT and AFB1

Fig. 2 shows the median levels of AFTOT (A) and AFB1 (B) respectively, depending on the type of foodstuff and the location where the samples were collected. These levels were compared to the maximum tolerated values of the EU standard which is also in force in Burkina Faso (4 µg/kg for AFTOT and 2 µg/kg for AFB1).

The analysis of Fig. 2A shows that the foodstuffs with median levels of AFTOT above 4 µg/kg were represented by whole grain maize and peanuts. These non-compliant samples were collected in the cities of Ouagadougou for whole grain maize (88.52 µg/kg), and Bobo Dioulasso for peanuts (14.19 µg/kg). The analysis of Fig. 2B shows that the samples for which the median aflatoxin B1 levels exceeded 2 µg/kg, were composed of whole grain maize, sorghum meal and peanuts. These non-compliant samples were found in the cities of Bobo Dioulasso for whole grain maize (5.6 µg/kg) and peanuts (12.27 µg/kg), Cinkansé for sorghum meal (2.12 µg/kg), and Ouagadougou for whole grain maize (76.06 µg/kg).

3.4. AFB1 exposure and probabilistic health risk assessment

The daily exposure of the populations consuming the foodstuffs studied is presented in Table 9.

The analysis of Table 8 shows that the highest daily doses of exposure to AFB1 were found in the cities of Bobo Dioulasso and Ouagadougou with values of 5.25 ng/kg bw/Day (for peanuts) and 33.68 ng/kg bw/Day (for whole grain maize) respectively. The lowest exposure doses

Table 4

AFB1 contents in relation to sample types and localities.

Aflatoxins	Localities	Maize		Rice		Sorghum meal		Peanuts	
AFB1 (µg/kg)	Bobo dioulasso	P25th	<1.0	P25th	<1.0	P25th	<1.0	P25th	11.36
		P50th	5.6	P50th	<1.0	P50th	<1.0	P50th	12.27
		P75th	69.34	P75th	1.04	P75th	<1.0	P75th	130.52
		P100th	122.16	P100th	4.83	P100th	172.74	P100th	182.28
	Cinkanse	<1.0		<1.0		P25th	<1.0	<1.5	
						P50th	2.12		
						P75th	5.32		
						P100th	11.22		
	Dakola	P25th	<1.0	P25th	<1.0	<1.0		<1.5	
		P50th	<1.0	P50th					
		P75th	1.65	P75th					
		P100th	3.31	P100th					
	Niangoloko	<1.0		<1.0		<1.0		P25th	<1.5
								P50th	<1.5
								P75th	<1.5
								P100th	23.89
	Ouagadougou	P25th	4.91	<1.0		P25th	<0.3	P25th	<1.5
		P50th	76.06			P50th	<0.3	P50th	<1.5
		P75th	151.3			P75th	<0.3	P75th	<1.5
		P100th	166.81			P100th	10.21	P100th	1.99

Table 5

AFB2 contents in relation to sample types and localities.

Aflatoxins	Localities	Maize		Rice		Sorghum meal		Peanut	
AFB2 (µg/kg)	Bobo Dioulasso	<0.8		<0.8		P25th	<0.8	P25th	<1.0
						P50th	<0.8	P50th	1.82
						P75th	<0.8	P75th	2.90
						P100th	3.37	P100th	3.37
	Cinkanse	<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
	Dakola	<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
	Niangoloko	<0.8		<0.8		<0.8		P25th	<1.0
								P50th	<1.0
								P75th	<1.0
								P100th	24.49
	Ouagadougou	P25th	<0.8	<0.8		P25th	<0.8	<1.0	
		P50th	3.73			P50th	<0.8		
		P75th	10.03			P75th	<0.8		
		P100th	18.91			P100th	1.06		

Table 6

AFG1 contents in relation to sample types and localities.

Aflatoxins	Localities	Maize		Rice		Sorghum meal		Peanuts	
AFG1 (µg/kg)	Bobo Dioulasso	<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
	Cinkanse	<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
		<0.8		<0.8		<0.8		<1.0	
	Dakola	P25th	<0.8	<0.8		<0.8		P25th	<1.0
		P50th	<0.8	<0.8		<0.8		P50th	<1.0
	Niangoloko	P75th	16.05					P75th	<1.0
		P100th	64.06					P100th	1.78

Table 7

AFG2 contents in relation to sample types and localities.

Aflatoxins	Localities	Maize	Rice	Sorghum meal	Peanuts
AFG2 (µg/kg)	Bobo dioulasso	<0.3	<0.3	<0.3	<0.4
	Cinkasse	<0.3	<0.3	<0.3	<0.4
	Dakola	<0.3	<0.3	<0.3	<0.4
	Niangoloko	<0.3	<0.3	<0.3	<0.4
	Ouagadougou	P25th	1.25	<0.3	<0.4
		P50th	1.89		
		P75th	2.47		
		P100th	3.52		

were found in the semi-urban localities of Niangoloko (0.17 ng/kg bw/Day for pranut), Dakola (0.39 ng/kg bw/Day for husked and polished rice) and Cinkanse (4.29 ng/kg bw/Day for sorghum meal). For the health risk analysis, it was therefore decided to group together the two cities (Ouagadougou and Bobo Dioulasso) and the semi-urban localities (Cinkanse, Dakola and Niangoloko).

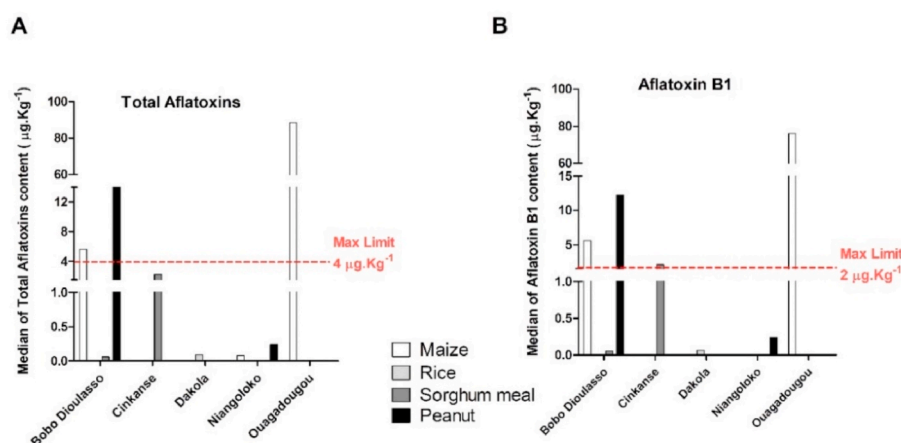
Figs. 3 and 4 show the probabilistic MOE values for peanut and husked and polished rice, sorghum meal and whole grain maize in semi-urban and large cities respectively.

The analysis in Fig. 3 shows that for peanuts and husked and polished rice, the MOE values were below 10,000 for semi-urban while in large cities, they were above 10,000. Fig. 4 shows that for sorghum meal and whole grain maize, on the other hand, the MOE values were below

Table 8

AFTOT contents in relation to sample types and localities.

Aflatoxins	Localities	Maize		Rice		Sorghum meal		Peanuts	
AFTOT ($\mu\text{g/kg}$)	Bobo dioulasso	P25th	<0.3	P25th	<0.3	P25th	<0.3	P25th	11.36
		P50th	5.6	P50th	<0.3	P50th	<0.3	P50th	14.09
		P75th	69.34	P75th	1.04	P75th	<0.3	P75th	133.42
		P100th	122.16	P100th	4.83	P100th	176.11	P100th	185.65
	Cinkanse	<0.3		<0.3		P25th	<0.3	P25th	<1.5
						P50th	2.12	P50th	
						P75th	5.32	P75th	
						P100th	11.22	P100th	
	Dakola	P25th	<0.3	<0.3	<0.3	<0.3	<0.3	<1.5	<1.5
		P50th	<0.3						
		P75th	1.65						
		P100th	3.31						
	Niangoloko	<0.3		<0.3	<0.3	<0.3	<0.3	P25th	<1.5
								P50th	<1.5
								P75th	<1.5
								P100th	24.49
	Ouagadougou	P25th	6.16	<0.3	<0.3	P25th	<0.3	P25th	<1.5
		P50th	81.68			P50th	<0.3	P50th	<1.5
		P75th	179.85			P75th	<0.3	P75th	<1.5
		P100th	252.44			P100th	11.27	P100th	3.77

**Fig. 2.** Comparison of medians of total aflatoxin (AFTOT) (A) and Aflatoxin B1 (AFB1) (B) levels with maximum tolerated values in foodstuffs.**Table 9**

Estimation of daily doses of populations exposed to AFB1.

Localities	Chronic Daily Intake (CDI) (ng/kg bw/Day)				Total CDI (ng/kg bw/Day)
	Maize	Rice	Sorghum meal	Peanut	
Cinkanse	–	–	4.29	–	4.29
Dakola	–	0.39	–	–	0.39
Niangoloko	–	–	–	0.17	0.17
Bobo	2.48	–	2.45	5.25	10.18
Dioulasso					
Ouagadougou	33.68	–	–	–	33.68

^a bw = body weight.

10,000 for large cities and remain above 10,000 in semi-urban localities, which implies that the consumption of these foodstuffs contaminated with AFB1 entails a carcinogenic risk to public health in large cities.

4. Discussion

Aflatoxin contamination of cereal and oilseed foods is an important issue for international agricultural trade, food safety and human nutrition organizations. In many African countries, this contamination reaches levels that can compromise the consuming population's health.

The results obtained in this study showed that 41.50% of all samples analyzed were contaminated by aflatoxins. This high proportion of contaminated samples could be associated with factors related to cultivation conditions including late harvesting of cereals, storage of insufficiently dried cereal seeds and damage to seeds during dehulling (Dieme et al., 2016). In addition, Burkina Faso has a tropical climate characterized by periodic droughts, high humidity and high pre-harvest temperatures in the high-growth regions of the west, south and east. These conditions are ideal for the growth of *Aspergillus* fungi and the production of aflatoxins in cereals (Ibrahim et al., 2018). An analysis of the results by food matrix shows that sorghum meal was the most contaminated with 57.44% of the samples. The process of obtaining meal from sorghum seeds could explain this high percentage of contamination of meal samples. Indeed, before milling, sorghum seeds are soaked in water for at least 12 h, which increases the moisture content, an ideal condition for the proliferation of aflatoxin-producing moulds (Nguyen, 2007).

Aflatoxins of type B1 and B2 were the most common in the samples. For AFB1, high levels were found in whole grain maize samples collected in the city of Ouagadougou (166.81 $\mu\text{g/kg}$) and in peanut samples collected in the cities of Bobo Dioulasso (182.28 $\mu\text{g/kg}$) and Niangoloko (23.89 $\mu\text{g/kg}$). These levels were respectively 83.40 times, 91.14 times and 11.94 times higher than the maximum tolerated limit of AFB1 in foodstuffs which is 2 $\mu\text{g/kg}$. The problem of AFB1 contamination in

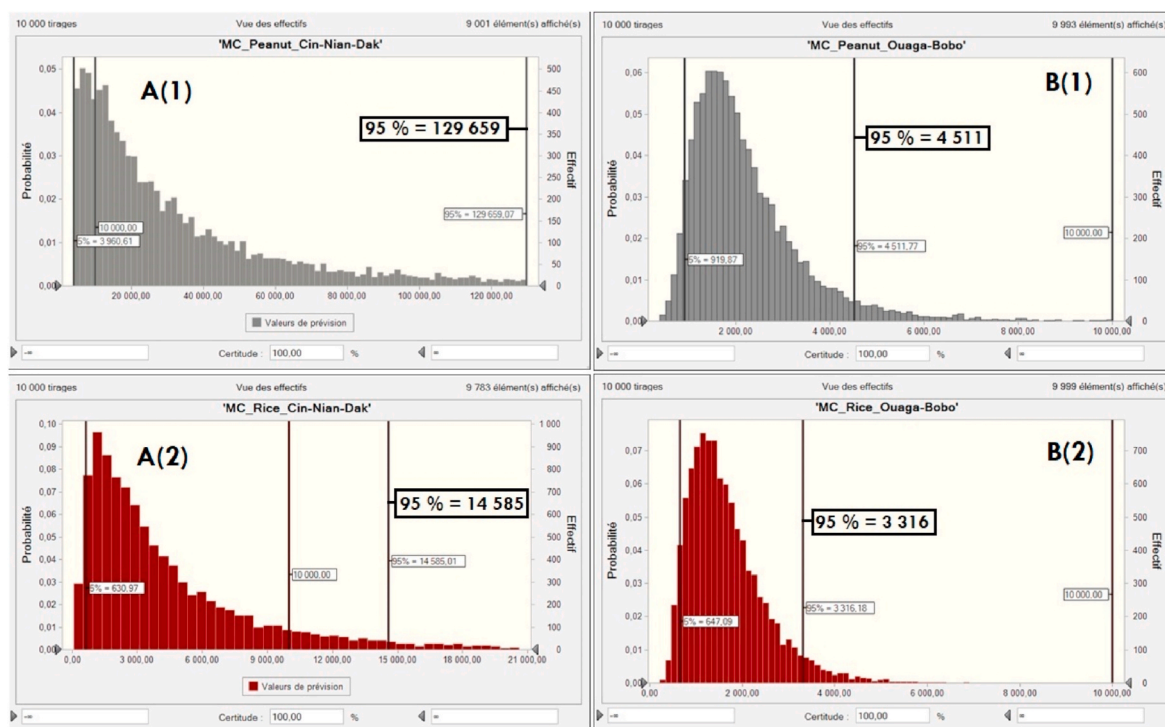


Fig. 3. Margine Of Exposure (MOE) values for Peanut and rice from semi-urban localities A(1) and A(2) respectively and from large cities B(1) and B(2) respectively.

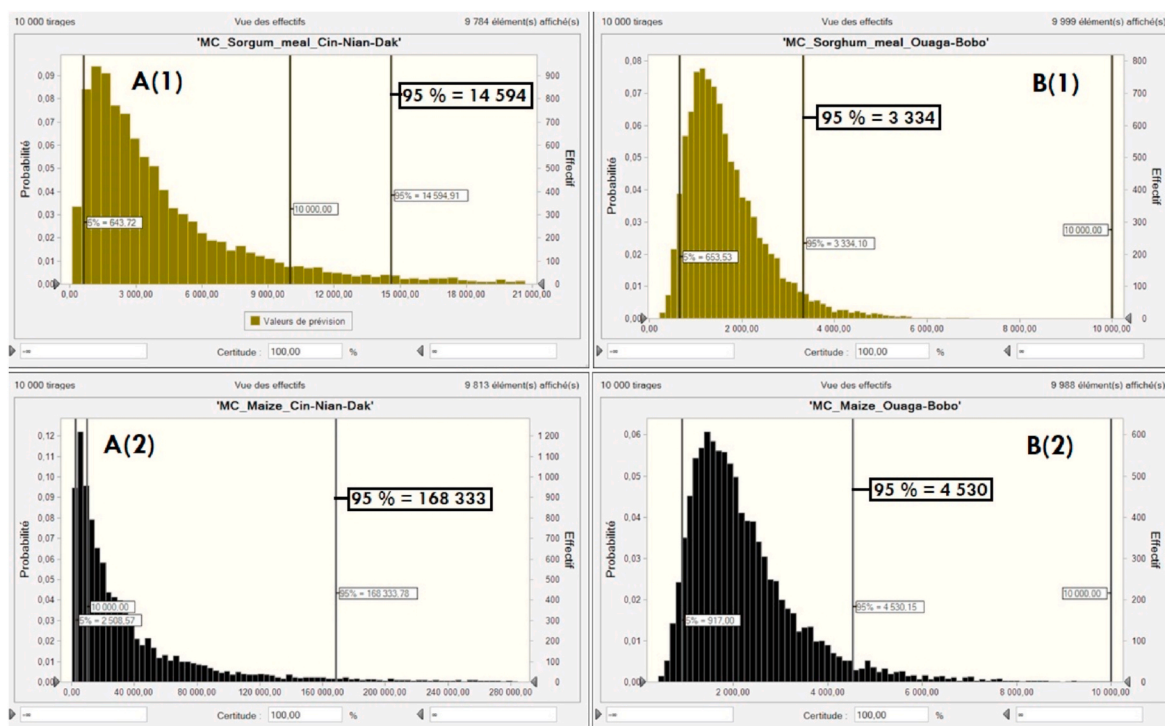


Fig. 4. Margine Of Exposure (MOE) values for Floor and Maize from semi-urban localities A(1) and A(2) respectively and from large cities B(1) and B(2) respectively.

cereals and oilseeds is common to several African countries. In Senegal, for example, levels of AFB1 up to 852.2 $\mu\text{g/kg}$ were detected in whole grain maize samples, while in Tanzania, these levels reached 1081 $\mu\text{g/kg}$ in the same matrix (AfricaAIMS, 2016). According to the same source, in Uganda the amount of aflatoxin in maize ranges from 86 $\mu\text{g/kg}$ to 3300 $\mu\text{g/kg}$ with 20%–65% of samples exceeding the maximum limit. The

aflatoxin found in sorghum ranged from 25 $\mu\text{g/kg}$ to 514 $\mu\text{g/kg}$ with 65%–100% of samples exceeding the maximum limit. The contamination of cereals by aflatoxin is therefore widespread in Africa and has been studied in several countries. In most of these countries, almost half of the cereal production has an aflatoxin content above international standards.

To determine the health condition of the exposed population, a comparison of the concentration of contaminants with the standard limits is not enough, hence health risk assessment should be performed (Zafarzadeh et al., 2018). In the current study, the probabilistic Monte Carlo method was used to assess the carcinogenic risk of the analyzed foodstuffs. The results showed that in semi-urban localities, there was no carcinogenic risk for the populations consuming the analyzed foodstuffs. In contrast, for large cities, the consumption of studied foodstuffs was associated with a carcinogenic risk for the populations. Thus, it appears that populations in large cities were more exposed to hepatocarcinogenic risk than those in semi-urban localities. This impression could be due to the higher contamination of foodstuffs in cities. Indeed, the highest daily exposure of consumers to AFB1 were found in the cities of Bobo Dioulasso and Ouagadougou with values of 5.25 ng/kg bw/Day (for peanuts) and 33.68 ng/kg bw/Day (for whole grain maize) respectively. While this situation is understandable for the city of Bobo Dioulasso, which is located in the west of the country and is characterized by rainfall of up to 1200 mm/year and high relative humidity and temperatures, it seems more paradoxical for the city of Ouagadougou, which is located in the center of the country and has a hot and dry climate (Ibrahim et al., 2018). However, as large cities are places of food consumption and not production, foodstuffs are transported from agricultural areas to be stored in large quantities for a long period by traders. This storage takes place in large, poorly ventilated and closely packed warehouses, all of which promotes the proliferation of mycotoxin-producing fungi, including aflatoxins. In addition, foodstuffs arriving in large cities may be contaminated at source in the regions where they were grown.

The MOE values found in this study are very high compared to those reported in other studies. For example, Blanco-Lizarazo (Blanco-Lizarazo et al., 2019) found MOE values below 8500 in the carcinogenic risk assessment for the Colombian population consuming corn arepas. Similarly, Shepherd (Shepherd, 2008) showed in his study that for whole grain maize, peanuts, sorghum, and beer, the MOE values were 6.5 in Kenya, 37.8 in Botswana, 621.7 in Gambia and 202 in Tanzania respectively. In other continents, a study carried on the exposure assessment and risk characterization of aflatoxins intake through consumption of maize products in the adult populations of Serbia, Croatia and Greece revealed that the estimated average exposure of adults to aflatoxins, from maize consumption, in each of the three countries was between 0.44 ng/kg bw/day and 5.59 ng/kg bw/day (Bozidar et al., 2021). Margin of exposure values for the mean exposure levels, in all three countries, were between 30 and 389 (Bozidar et al., 2021). The very high MOE values in this study could be explained by the food consumption data used. Indeed, these data appear to be very outdated as they date back to 2003 on the one hand, and on the other hand, they were established on the basis of a study carried out in only two communes, which are, moreover, rural communes of Burkina Faso. Thus, their extrapolation to the whole country presents a problem of representativeness with regard to the disparity of food habits in rural, semi-urban and urban localities. It is therefore imperative that studies be conducted to make available the most important food consumption data in Burkina Faso, all of which will enable reliable risk assessment of contaminants in food to guide policy-making for food safety. In addition, aflatoxin determinations should be carried out on ready-to-eat food products to avoid bias due to atypical changes in the aflatoxin content of the raw products by the culinary processing (Bozidar et al., 2021). Research should also be extended to younger age groups, including toddlers and children.

5. Conclusion

The aim of this study was to investigate aflatoxins contents in common foodstuffs sold in markets from 5 localities of Burkina Faso and to evaluate the carcinogenic risk the consuming population was exposed

to.

The results showed that the problem of agricultural food products contamination was a reality in Burkina Faso, exposing the consuming population to a significant hepatocarcinogenic risk. The MOE values obtained showed that this risk was greater in large cities than in semi-urban ones. However, the consumption data used for the calculation of MOE dates back to 2003. Using more recent data could lead to even more alarming results. It is therefore imperative that the health and agricultural authorities, in a joint effort, take strong action against the agricultural food products contamination in order to protect the consuming population's health.

Data availability

The authors do not have permission to share data.

Acknowledgement

This work was carried out within the framework of the PAASME-UE project ("Production et Analyses des données pour Améliorer la Santé de la Mère et de l'Enfant"). This research project is jointly implemented by the National Institute of Public Health and the National Public Health Laboratory. It was fully funded by the European Union (EU) under the number FED/2019/407–596, which should be thanked at the end of this work. It is also important to thank:

- The National Institute of Public Health (INSP) for the scientific collaboration;
- The Regional Health Directorates of the Centre, Hauts-Bassins, Cascades and Centre-East regions for authorizing the conduct of this study;
- The populations of the Centre, Hauts-Bassins, Cascades, Centre-East and Centre-South regions for their collaboration.

References

- Adel, M., Dadar, M., Fakhri, Y., Conti, G.O., Ferrante, M., 2016. Heavy metal concentration in muscle of pike (*Esox lucius* Linnaeus, 1758) from Anzali international wetland, southwest of the Caspian Sea and their consumption risk assessment. *Toxin Rev.* 35, 217–223. <https://doi.org/10.1080/15569543.2016.1223694>.
- AfricaAIMS, 2016. Africa Aflatoxin Information Management System, C-SAAP (Soutien du Plan D'action et d'Analyse des Aflatoxine) [WWW Document]. <https://archives.au.int/handle/123456789/5472>. URL: <https://archives.au.int/handle/123456789/5472>. accessed 2.5.22.
- Atehnkeng, J., Ojiambo, P.S., Cotty, P.J., Bandyopadhyay, R., 2014. Field efficacy of a mixture of atoxigenic *Aspergillus flavus* Link:Fr vegetative compatibility groups in preventing aflatoxin contamination in maize (*Zea mays* L.). *Biol. Control* 72, 62–70. <https://doi.org/10.1016/j.biocontrol.2014.02.009>.
- Blanco-Lizarazo, C.M., Gamboa-Marín, A., Vega, S., Jiménez-Rodríguez, L.P., Sánchez B, I.C., 2019. Assessment of dietary exposure to aflatoxin B 1 from corn arepas in Colombia. *Food Addit. Contam.* 36, 1109–1117. <https://doi.org/10.1080/19440049.2019.1615643>.
- Bozidar, U., Elena, B., Ilija Djekic, D., Tarcea, Monica, Irena, C.B., Maša, Č.-B., Viktória, S., Alessandra, S., Ayman, E.-K., Vanessa, F., Dace, K., Małgorzata, K., Elena, V., Marcela, L., Dieuwierke, B., Maria, P., Raquel, P.F.G., 2021. Exposure assessment and risk characterization of aflatoxins intake through consumption of maize products in the adult populations of Serbia, Croatia and Greece. *Food Addit. Contam.* 36, No 6 [WWW Document]. URL: <https://www.tandfonline.com/doi/abs/10.1080/19440049.2019.1600748?journalCode=tfac20>. accessed 7.13.21.
- CDC, 2004. Outbreak of Aflatoxin Poisoning — Eastern and Central Provinces. Kenya, January–July 2004 [WWW Document]. URL: <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5334a4.htm>. accessed 3.5.22.
- Dadar, M., Adel, M., Saravi, H.N., Fakhri, Y., 2017. Trace element concentration and its risk assessment in common kilka (*Clupeonella cultriventris caspia* Bordin, 1904) from southern basin of Caspian Sea. *Toxin Rev.* 36, 222–227. <https://doi.org/10.1080/15569543.2016.1274762>.
- Deng, J., Zhao, L., Zhang, N.-Y., Karrow, N.A., Krumm, C.S., Qi, D.-S., Sun, L.-H., 2018. Aflatoxin B1 metabolism: regulation by phase I and II metabolizing enzymes and chemoprotective agents. *Mutat. Res. Rev. Mutat. Res.* 778, 79–89. <https://doi.org/10.1016/j.mrrev.2018.10.002>.
- Dieme, E., Fall, R., Sarr, I., Sarr, F., Traore, D., Seydi, M., 2016. Contamination des céréales par l'aflatoxine en Afrique : revue des méthodes de lutte existantes. *Int. J. Brain Cognit.* Sci. 10, 2285–2299. <https://doi.org/10.4314/ijbcs.v10i5.27>.
- EFSA, 2012. Opinion of the scientific panel on contaminants in the food chain [CONTAM] 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 J. 5, 446. <https://doi.org/10.2903/j.efsa.2007.446>.
- Ezekiel, C.N., Udom, I.E., Frisvad, J.C., Adetunji, M.C., Houbaken, J., Fapohunda, S.O., Samson, R.A., Atanda, O.O., Agi-Otto, M.C., Onashile, O.A., 2014. Assessment of aflatoxigenic *Aspergillus* and other fungi in millet and sesame from Plateau State, Nigeria. *Mycology* 5, 16–22. <https://doi.org/10.1080/21501203.2014.889769>.
- Hussaini, A.M., Timothy, A.G., Olufunmilayo, H.A., Ezekiel, A.S., Godwin, H.O., 2009. Fungi and some mycotoxins found in mouldy sorghum in Niger state. *Nigeria* 13.
- IARC, 2012. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Human Immunodeficiency Viruses and Human T-Cell Lymphotropic Viruses. International Agency for Research on Cancer.
- Ibrahim, B., Karambiri, H., Polcher, J., 2018. Evolution des principales caractéristiques de la saison des pluies au Burkina Faso à partir des données pluviométriques de cinq modèles climatiques régionaux (MCR) 5.
- Joint FAO/WHO Expert Committee on Food Additives, 1998. In: Safety Evaluation of Certain Food Additives and Contaminants. World Health Organization. Meeting (49th : 1997: Rome, I., Organization, W.H., Nations, F. and A.O. of the U., Safety, I.P. on C.
- Makun, H.A., Gbodi, T.A., Akanya, O.H., Salako, E.A., Ogbadu, G.H., 2007. Fungi and some mycotoxins contaminating rice (*Oryza Sativa*) in Niger State, Nigeria. *Afr. J. Biotechnol.* 6 <https://doi.org/10.4314/ajb.v6i2.56106>.
- Ministère de l'Agriculture et les Aménagement Hydro-agricoles, 2019. Accueil - ministère de l'Agriculture et des Aménagements Hydro-agricoles [WWW Document]. URL. <https://www.agriculture.gov.bf/accueil>. accessed 7.13.21.
- Moss, M.O., 2008. Fungi, quality and safety issues in fresh fruits and vegetables. *J. Appl. Microbiol.* 104, 1239–1243. <https://doi.org/10.1111/j.1365-2672.2007.03705.x>.
- Nguyen, M.T., 2007. Identification des espèces de moisissures, potentiellement productrices de mycotoxines dans le riz commercialisé dans cinq provinces de la région centrale du vietnam : étude des conditions pouvant réduire la production des mycotoxines (phd).
- Romuli, S., Schock, S., Somda, M.K., Müller, J., 2020. Drying performance and aflatoxin content of paddy rice applying an inflatable solar dryer in Burkina Faso. *Appl. Sci.* 10, 3533. <https://doi.org/10.3390/app10103533>.
- Rotter, S., Beronius, A., Boobis, A.R., Hanberg, A., van Klaveren, J., Luijten, M., Machera, K., Nikolopoulou, D., van der Voet, H., Zilliacus, J., Solecki, R., 2018. Overview on legislation and scientific approaches for risk assessment of combined exposure to multiple chemicals: the potential EuroMix contribution. *Crit. Rev. Toxicol.* 48, 796–814. <https://doi.org/10.1080/10408444.2018.1541964>.
- Shephard, G.S., 2008. Risk assessment of aflatoxins in food in Africa. *Food Addit. Contam.* 25, 1246–1256. <https://doi.org/10.1080/02652030802036222>.
- Tabuc, C., 2007. Flore fongique de différents substrats et conditions optimales de production des mycotoxines (phd).
- US EPA, 2011. Exposure Factors Handbook 2011 Edition (Final Report).
- Yacine Ware, L., Durand, N., Nikiema, P.A., Alter, P., Fontana, A., Montet, D., Barro, N., 2017. Occurrence of mycotoxins in commercial infant formulas locally produced in Ouagadougou (Burkina Faso). *Food Control* 73, 518–523. <https://doi.org/10.1016/j.foodcont.2016.08.047>.
- Zafarzadeh, Bay A., Fakhri, Y., Keramati, H., Hosseini, Pouya R., 2018. Heavy metal (Pb, Cu, Zn, and Cd) concentrations in the water and muscle of common carp (*Cyprinus carpio*) fish and associated non-carcinogenic risk assessment: alagol wetland in the Golestan. *Iran* 154–160.
- Zinedine, A., Brera, C., Elakhdari, S., Catano, C., Debegnach, F., Angelini, S., Santis, B.D., Faid, M., Benlemlih, M., Minardi, V., Miraglia, M., 2006. Natural occurrence of mycotoxins in cereals and spices commercialized in Morocco. *Food Control* 11, 868–874. <https://doi.org/10.1016/j.foodcont.2005.06.001>.