

Review Paper

Mycotoxin contamination of food and associated health risk in Cameroon: A 25-years review (1993-2018)

ABSTRACT

The Gross Domestic Product of Cameroon is partially based on agricultural products. Crops like maize, peanuts, beans, cassava, cocoa and coffee are the most cultivated ones. A high portion of this production is locally consumed, and the other part is exported to foreign countries in order to balance the economy. Postharvest losses due to fungal contamination and the presence of mycotoxins in food (which is also linked to this contamination), represent some of the most important problems this producing country government and populations are facing. Mycotoxins are secondary metabolites produced by certain mould species, mainly *Aspergillus*, *Penicillium* and *Fusarium* genera, which have a negative effect on human and animal health. Aflatoxins, fumonisins, ochratoxins, zearalenone and deoxynivalenol are the most common mycotoxins in food and feed commodities. This paper reviews effects of mycotoxins on human health and associated regulations, their occurrence in food commodities from Cameroon, as well as the dietary exposure of consuming populations and the results obtained from their bio-monitoring.

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Keywords: Foods; Mycotoxins; Occurrence; Exposure; Bio-monitoring; Cameroon

1. INTRODUCTION

Part of the Cameroonian economy rely on agriculture. The World Bank Group has estimated that the agricultural sector's share in the Gross Domestic Product (GDP) of this country in 2016 was 16.7%. Maize, peanuts, cassava, sorghum, cocoa and coffee represent the main crops contributing to this agricultural GDP [1]. These crops are highly consumed by local populations and are also exported all over the world. Cameroon, like many other countries worldwide, face the serious challenge of post-harvest losses which are partially due to mould contamination [2]. The tropical climate (high temperature and humidity) and the poor crop storage conditions are frequently conducive to the fungal growth [3]. This contamination may occur during cultivation, harvesting or storage and lead to the presence of mycotoxins in the food [4,5]. Mycotoxins are secondary metabolites produced by some fungi and have a potential negative impact on human and animal health. They are produced by certain moulds species, mainly belonging to *Aspergillus*, *Penicillium* and *Fusarium* genera. Aflatoxins (AFs), fumonisins (FBs), ochratoxins, zearalenone (ZEN) and deoxynivalenol (DON) are the ones of major agro-economic and public health importance [6,7]. These toxins are regularly detected worldwide in several crops such as those previously mentioned. Mycotoxins contamination is nowadays considered as an important quality

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29 and safety parameter for foods. The Food and Agricultural Organization [8] has estimated that about
30 25% of the world's food crops are significantly contaminated with mycotoxins annually. In order to limit
31 the associated health risk, strict standards on the maximum tolerable concentration of different
32 mycotoxins in foods have been fixed at both national and international levels. These toxins account
33 for millions of US dollars lost annually worldwide in terms of human and animal health, and destructed
34 agricultural products [9-12]. This paper reviews mycotoxins effect on human health and associated
35 regulations, their occurrence in food commodities from Cameroon over the past 25 years (1993-
36 2018), as well as the dietary exposure of populations and the results obtained from their bio-
37 monitoring.

38 2. EFFECT OF MYCOTOXINS ON HUMAN HEALTH AND ASSOCIATED REGULATIONS

39 Human contamination with mycotoxins can occur directly through the consumption of foods
40 containing mycotoxins or indirectly through consumption of animals in which mycotoxins have been
41 bio-accumulated. Table 1 presents the impact of the most common mycotoxins (Aflatoxins,
42 fumonisins, ochratoxins...) on human health, together with their producing moulds. Mutagenic,
43 hepatotoxic, dermonecrotic, nephrotoxic, haematotoxic, immunosuppressive, neurotoxic, carcinogenic
44 and teratogenic effects have been reported on both humans and animals [24] and vary from one
45 mycotoxin to another.

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Table 1: Effects of the most common mycotoxins on human health

Mycotoxins	Producing moulds	Effects	References
Aflatoxin B ₁ , B ₂ , G ₁ , G ₂ and M ₁	<i>Aspergillus flavus</i> , <i>A. parasiticus</i> , <i>A. nomius</i> , <i>A. arachidicola</i> , <i>Emericella astellata</i> , <i>E. venezuelensis</i> , <i>E. olivicola</i>	Hepatocarcinogenic, carcinogenic, immunosuppressive, genotoxic, oncogenic	[13-15]
Ochratoxin A	<i>Penicillium verrucosum</i> , <i>A. ochraceus</i> , <i>A. carbonarius</i> , <i>A. melleus</i> , <i>A. alutaceus</i> , <i>A. alliaceus</i> , <i>A. albertensis</i>	Mutagenic, teratogenic, neurotoxic, hepatotoxic, and immunotoxic	[8,15,16]
Fumonisin	<i>Fusarium verticillioides</i> , <i>F. proliferatum</i> , <i>F. anthophilum</i> , <i>F. dlamini</i> , <i>F. napiforme</i> , <i>F. nygamai</i> , <i>Alternaria alternata</i>	Esophageal and liver carcinogens, neurotoxic, Genotoxic	[17,18]
Zearalenone	<i>Fusarium graminearum</i> , <i>F. culmorum</i> , <i>F. crookwellense</i> , <i>F. equiseti</i>	Decreased fertility, precocious puberty, breast cancer, endometrial carcinoma, hyperplasia of uterus	[19]
Trichothecenes	<i>Fusarium graminearum</i> , <i>F. culmorum</i> , <i>F. crookwellense</i> , <i>F. sporotrichioides</i> , <i>F. poae</i> , <i>F. tricinctum</i> , <i>F. acuminatum</i> , <i>Cephalosporium</i> sp., <i>Myrothecium</i> sp., <i>Trichoderma</i> sp., <i>Trichothecium</i> sp., <i>Phomopsis</i> sp.,	Cytotoxic, genotoxic, immunosuppressive, development of autoimmune diseases, anorexia, rectal bleeding, and diarrhoea	[15,18,20,21]
Patulin	<i>Penicillium expansum</i> , <i>Aspergillus clavatus</i> , <i>Byssosclamyces nivea</i> , <i>A. longivesica</i> , <i>A. terreus</i>	Neurotoxic, genotoxic, teratogenic, immunotoxic, immunosuppressive and carcinogenic effects	[15,22]
Ergot alkaloids	<i>Claviceps purpurea</i> , <i>C. paspali</i> , <i>C. africana</i> , <i>C. fusiformis</i> ,	Abdominal pain, burning sensation of the skin, insomnia, hallucinations and gangrene	[23]

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Besides these mycotoxins commonly found in foods which caused many outbreaks worldwide [25,26], there are also new emerging mycotoxins like fusaroproliferin, gliotoxin, cyclopiazonic acid, penitrem A and verruculogen for which toxicological studies are still ongoing [27-31].

Due to their potential negative impact on health, norms on the level of mycotoxins in marketed and consumed foods have been established worldwide. In fact, based on the toxicological studies, a maximum acceptable content of each specific mycotoxin in different food matrices has been defined at both national and international levels. Table 2 presents the standards associated to some common mycotoxins in foods in different countries. The most updated and used regulations are those of developed countries (European Union and USA). Their standards serve as reference to many other countries from which they import foods. In fact, they are the main importers of many crops and food products, and are strict on the maximum tolerated limits of mycotoxins.

Table 2: Regulated maximum level for the most common mycotoxins found in foods

Country /Region	Mycotoxins	Foods	Maximum level (µg/kg)	References
European Union	Ochratoxin A	Cereals, dry fruits, wine, spices, oat, raisins, coffee, cocoa, soybeans, meat	0.5 – 15	[32]
	Ochratoxin A	Wheat, barley and rye	5	[33]
	Aflatoxins	Maize, wheat, rice, spices, almonds, oil seeds, dried fruits, cheese	0.1–8	[34]
	B ₁ , G ₁ , B ₂ , G ₂		4–15	
	Aflatoxin M ₁	Milk, eggs, meat	0.5	[33]
	Patulin	Apples, cherries, cereal grains, grapes, pears, bilberries	10–50	[35]
		Apple juice	50	[33]
	T-2 and HT-2	cereals for direct human consumption	50	[36]
		Oats, Barley (including malting barley) and maize	200	[36]
		Wheat, rye and other cereals	100	[36]
	Deoxynivalenol (DON)	wheat, oats and maize	1250	[35]
		Flour, meal, semolina and flakes derived from wheat, maize or barley	1000	[33]
		Cereal grains (wheat, maize and barley) destined for further processing	2000	[33]
USA	Fumonisin (FB ₁ and FB ₂)	Maize based breakfast cereals and maize based snacks	800	[35]
		Raw maize grain	4000	[33]
		Maize flour and maize meal	2000	[33]
		Maize intended for direct human consumption	1000	[35]
	Zearalenone	Unprocessed cereals other than maize	100	[35]
		Maize intended for direct human consumption, maize based snacks and maize based breakfast cereals	100	[35]
		cereal flour, bran and germ for direct human consumption	75	[35]
	Total Aflatoxins	Food for human consumption	20	[37]
		Corn, peanut products, cottonseed meal	20	[38]
	Aflatoxin M ₁	Milk, milk products	0.5	[37]
	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Maize, wheat, rice, peanut, sorghum, pistachio, almond, ground nuts, tree nuts,	20	[38]

		figs, cottonseed, spices		
	Deoxynivalenol (DON)	Cereals, cereal products for Human food	1000	[39]
	Total Fumonisin (FB ₁ , FB ₂ and FB ₃)	Cereals	2000 - 4000	[40]
		Corn products and cleaned maize used for popcorn	2000 - 3000	[40]
	Patulin	Apples, apple juice, and concentrate	50	[40]
	Ochratoxin A	Cereals, wheat, barley, and rye and derived products.	5	[41]
Russia	Deoxynivalenol	Barley and their derivatives	700 - 1000	
	T-2	Food grain and their derivatives	100	
	Zearalenone	Wheat, barley and maize	1000	[42]
	Fumonisin	Maize flour	200	
Canada	Deoxynivalenol	Uncleaned soft wheat	2000	[43]
China	Aflatoxin B ₁	Maize, peanut	0.02	[44]
	Deoxynivalenol	Wheat, barley, maize and derivatives	1000	[45]
	Zearalenone	Wheat and maize	60	[45]
	Aflatoxins M ₁	Infant food	0	[44]
Brazil	Deoxynivalenol	Whole wheat	1000	[46]
		Wheat derivatives	750	[46]
	Zearalenone	Whole wheat	200	[46]
		Wheat flour and derivatives	100	[46]
		Maize and derivatives	150	[46]
	Fumonisin	Maize meal	1500	[46]
		Maize-based products	1000	[46]
Cuba	Ochratoxin A	Coffee and cereals	5	[47]
Estonia	Ochratoxin A	Cereals, cereal flours, cereal groats and flakes	5	[47]
India	Aflatoxin B ₁	All foods	0.03	[48]
South Korea	Aflatoxin M ₁	Grains and processed grain foods, baby foods	0.02 – 0.05	[49]
	Aflatoxin B ₁	Grains, beans, peanuts and their simple processed foods	10	[50]
Thailand	Zearalenone	All foods	30 - 100	[44]
	Ochratoxin A	Cereals, wheat, barley, and rye and derived products.	5	[41]
	Aflatoxins (AFB ₁ , B ₂ , G ₁ , G ₂)	All food	20	[47]
Malaysia	Aflatoxins B ₁ , M ₁	Raw milks and milks prior to manufacturing processing	0.5	[44]
Morocco	Aflatoxin B ₁	Cereals	5	[47]
	Aflatoxin M ₁	Milk and dairy products	0.03 – 0.05	[47]
	Ochratoxin A	Cereals	30	[47]
	Patulin	Fruits and juices	50	[47]
	Zearalenone	Cereals	200	[47]
Sudan	Ochratoxin A	Wheat	15	[47]
Australia	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Ready to-eat almonds, hazelnuts and pistachios	10	[51,52]
	Total Aflatoxins	Peanuts and pistachios	15	[51,52]
	Ochratoxin A	Maize	5	[32]
	Deoxynivalenol	Cereals	500	[53]
Argentina	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Groundnut, peanut, maize and by-products	5 - 20	[50]
	Aflatoxin M1	Liquid milk, powdered milk, dairy products	0.05 – 0.5	[50]
Ivory Cost	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Ready to eat almonds, hazelnuts and pistachios	10	[51,52]
Egypt	Aflatoxin B ₁	Peanuts, oil seeds, cereals	5	[54]

Iran	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Peanuts, oil seeds, cereals	10	[54]
	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂ , M ₁	Milk and dairy products	0	[54]
	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	All foods	30	[50]
	Ochratoxin A	Dates, dried grapes (raisins and sultanas), official figs and all dried fruits	10	[47]
Zimbabwe		Rice and wheat	5	[47]
		Barley and maize	50	[47]
	Total Aflatoxin	All Foods	15	[47]
	Aflatoxins G ₁ , B ₁	Groundnuts, maize, sorghum	4 - 5	[55]
South Africa	Aflatoxins B ₁ , B ₂ , G ₁ , G ₂	Peanut butter, cereals, flour and bread	4 - 20	[55]
	Aflatoxin B ₁	All foods	5	[56]
	Total Aflatoxins	All foods	10	[56]
	Aflatoxin M ₁	Milk and milk products	0.05	[57]
	Patulin	Apple juice and apple juice-based products	50	[58]
	Fumonisin (B ₁ + B ₂)	Raw maize grain	4000	[59]
		Maize flour and maize meal	2000	[59]
	Deoxynivalenol	Wheat, maize and barley	2000	[59]
		Flour, meal, semolina and flakes derived from wheat, maize or barley	1000	[59]

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82 The application of these measures has definitely helped in limiting the mycotoxins risk.
83 Nevertheless, this implies supplementary costs for quality control and an eventual rejection of foods
84 once arrived at the final destination. Unfortunately, many agricultural products originally destined for
85 export are often put aside and destroyed due to their high mycotoxin content thus affecting the
86 economy of producing countries [9-12]. Situations where exporting countries would retain higher risk
87 commodities for their national consumption and therefore expose their own populations also exist [3].
88 Many of the countries exporting their food products are developing or underdeveloped countries,
89 where monitoring of the entire production chain from farms to the final products is a challenge [6,60].

90 3. OCCURRENCE OF MYCOTOXINS IN FOOD COMMODITIES IN CAMEROON

91 The occurrence of many mycotoxins in Cameroonian food commodities such as maize,
92 peanuts, beans and soybeans has been reported by many authors (Table 3). Njobeh et al. [61]
93 observed a high contamination of these foods from different parts of the country by moulds of the
94 *Aspergillus* and *Penicillium* genera, including toxinogenic strains.

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105 **Table 3: An overview of mycotoxins occurrence in some Cameroonian food commodities**

Food commodity	Method of analysis	Number of samples	Mycotoxin detected	Frequency of mycotoxin-positive samples (%)	Mean (Range) concentration (µg/kg)	References
Green coffee beans	HPLC	7	Ochratoxin A	57	1.7 (1-2.5)	[76]
Maize	ELISA	18	Fumonisin B ₁	NS	(300–26000)	[62]
			Deoxynivalenol	NS	(<100–1300)	
			Zearalenone	NS	(<50–110)	
Maize	TLC	1800	Aflatoxins	NS	NS	[63]
	ELISA	18	Fumonisin	89	(50-26000)	
	ELISA	18	Deoxynivalenol	NS	(100-1300)	
	ELISA	18	Zearalenone	NS	(50-180)	
Stored Cassava chips	ELISA	72	Aflatoxins	33	(5.2 - 15)	[79]
Maize		40	Fumonisin B ₁	65	3684 (37–24225)	[64]
			Zearalenone	78	69 (28–273)	
			Deoxynivalenol	73	59 (18–273)	
			Aflatoxins	55	1.5 (0.1–15)	
peanuts		16	Fumonisin B ₁	19	517 (25–1498)	
			Zearalenone	63	70 (31–186)	
			Deoxynivalenol	75	123 (17–270)	
			Aflatoxins	75	6.5 (0.1–13)	
Beans	TLC+ HPLC	15	Fumonisin B ₁	20	727 (28–1351)	
			Zearalenone	33	48 (27–157)	
			Deoxynivalenol	47	25 (13–35)	
			Aflatoxins	33	2.4 (0.2–6.2)	
Soybeans		5	Fumonisin B ₁	40	195 (25–365)	
			Zearalenone	0	-	
			Deoxynivalenol	40	110 (13–207)	
			Aflatoxins	40	2.1 (0.2–3.9)	

Miscellaneous (Rice, pumpkin seeds "egusi", fermented cassava flakes "gari", fermented cassava flour "nkum nkum")		6	Fumonisin B ₁	0	-	
			Zearalenone	17	67	
			Deoxynivalenol	50	25 (13-35)	
			Aflatoxins	17	0.3	
Eggs	HPLC	62	Aflatoxins	45	0.82 ± 1.7	[81]
Cow milk	ELISA	63	Aflatoxin M ₁	16	0.006-0.53	
Sorghum beer (<i>Bil-bil</i>)	ELISA	70	Deoxynivalenol	100	450 (140-730)	[78]
			Fumonisin B ₁	79	150 (0-230)	
Sorghum beer (<i>Kpata</i>)		50	Deoxynivalenol	74	520 (0-680)	
			Fumonisin B ₁	100	210 (0.5-340)	
Cocoa beans	Immunoaffinity column+HPLC	36	Ochratoxin A	NS	11.52 (5.3-21)	[73]
Groundnuts	LC-MS/MS	35	Aflatoxin B ₁	97	47(<LOQ-210)	[65]
Maize		37	Fumonisin B ₁	100	508 (2-2313)	
Maize	Aflatest	77		9	1 (≤2-42)	[66]
Peanuts meal	immunoaffinity column+HPLC	41	Aflatoxins	100	161 (39-950)	
Sorghum (Variety Damugari)	ELISA	NS		75	(0-230)	[77]
			Aflatoxin B ₁			
Sorghum (Variety Djigari)		NS		45	(0-145)	
Robusta coffee	Immunoaffinity column+HPLC	48		75	0.6-18	[75]
Arabica coffee		51	Ochratoxin A	65	0.3-4.9	
Maize kernels	LC-MS/MS	165	Fumonisin	74	(10-5412)	[80]
			Aflatoxin B ₁	22	(6-645)	
			Zearalenone	14	(27-334)	
			Deoxynivalenol	12	(27-3842)	
Peanut		90	Aflatoxin B ₁	29	(0.3-12)	
			Ochratoxin A	13	(6-125)	
Cassava products (flakes+chips)		165	Aflatoxin B ₁	25	(6-194)	
			Penicillic acid	6	(25-184)	
Arabica coffee	Immunoaffinity	104	Ochratoxin A	NS	(0.12-124)	[74]

column + HPLC						
<i>Kutukutu</i> (a fermented maize-based dough)	ELISA	29	Aflatoxin B ₁	100	(≤2.8)	[68]
Maize- <i>fufu</i>	LC-MS/MS	50	Aflatoxin B ₁	24	0.9 (n.d-1.8)	[70]
			Deoxynivalenol	100	23 (14-55)	
			Fumonisin B ₁	100	151 (48-709)	
			Nivalenol	100	268 (116-372)	
			Patulin	30	105 (12-890)	
			Zearalenone	100	49 (5-150)	
Maize-based dishes	ELISA + LC-MS/MS	22	Aflatoxins	100	(0.8-20)	[69]
			Fumonisin	100	(10-5990)	
Black pepper	ELISA	20	Ochratoxin A	10	1.5 (1.2-1.9)	[82]
White pepper		20		40	3.3 (1.8-4.9)	
Breast milk	ELISA	42	Aflatoxin M ₁	38	7.4 (0.9-37)	[84]

106 *NS, Not specified; ELISA, Enzyme Linked Immuno-Sorbent Assay; TLC, Thin Layer
107 Chromatography; HPLC, High-Performance Liquid Chromatography; LC-MS/MS, Liquid
108 Chromatography coupled with Magnetic Sector Mass Spectrometers

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110 Maize is one of the most vulnerable foods to moulds contamination. Ngoko et al. [62,63]
111 reported *Aspergillus* sp., *Fusarium* sp. and *Penicillium* sp. as the main fungal contaminants of this
112 crop in Cameroon. These authors detected the presence of fumonisin B₁ (FB₁), DON and ZEN at
113 levels which were going up to 26000, 1300 and 1100 µg/kg, respectively. FB₁ was showing the
114 highest prevalence with a concentration increasing with the storage time. The presence of these three
115 mycotoxins in other maize samples from Cameroon was also reported in concentrations which were
116 within the previously mentioned range [64,65]. AFs were also detected by Njobeh et al. [64] in 55% of
117 their samples at concentrations between 0.1-15 µg/kg. This was not the case for Kana et al. [66] who
118 rather observed a prevalence of 9%, the maximal concentration obtained being 42 µg/kg. This toxin
119 content appeared to depend on the agro-ecological zones. The average total aflatoxins level of
120 positive maize samples from the Sahelian Zone was 2.4 µg/kg while positive samples from the
121 Western High Plateau (characterized by its hot climate and high relative humidity) contained 11.9
122 µg/kg. The studies performed by Njumbe et al. [67] with a more accurate and reliable method (LC-
123 MS/MS) showed levels of contamination of maize which could go up to 5412 µg/kg for FBs, 645 µg/kg
124 for AFB₁ and 3842 µg/kg for DON. Several other studies have also been carried out to assess the
125 presence of mycotoxins in maize derived products which are directly consumed by populations. In
126 2015, the analysis of *kutukutu*, a fermented maize-based dough largely consumed in the Northern
127 part of the country revealed an AFB₁ content which in some cases exceeded the 2 µg/kg European
128 Commission standard limit fixed for such products [68]. Nguégwouo et al. [69] noticed that AFs and
129 FBs contents of maize-based dishes (beer, porridge, fufu...) were dependent on the production
130 process. Processes including a sieving step led to lower mycotoxin concentrations. Similar results
131 were obtained by Abia et al. (2017) [70] who also detected low levels of mycotoxins (AFB₁, the
132 bacterial toxin cereulide, DON, FB₁, nivalenol, patulin, ZEN...) in maize-*fufu* (also known as fufu-
133 corn), a boiled maize-doughdish that is consumed especially in the western highland of Cameroon.
134 However, this study revealed for the first time in a Cameroonian food the mixture of cereulide, patulin
135 and ZEN derivatives.

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Peanuts, beans and soybeans are also often prone to fungal contamination. Non-mycotoxigenic as well as mycotoxigenic moulds of *Aspergillus* and *Penicillium* genera have been isolated from samples coming from different parts of the country [61]. An evaluation of the mycotoxin content in peanuts by Njobeh et al. [64] showed average values of 517, 70, 123 and 6.5 µg/kg for FB₁, ZEN, DON and AFs, respectively. A concentration of AFs between 39-950 µg/kg was even reported in peanuts meal destined for poultry feeds [66]. Njumbe et al. [67] also detected OTA contamination in 13 of the 90 peanuts tested samples (6-125 µg/kg). With beans and soybeans, Njobeh et al. [64] also reported an average concentration of 727 and 195 µg/kg for FB₁, 25 and 110 µg/kg for DON, 2.4 and 2.1 µg/kg for AFs, respectively. No presence of ZEN was detected in soybeans by these authors while in beans they noticed an average content of 46.7 µg/kg. Abia et al. [65] detected FB₁ in 18 of the 35 peanuts samples they collected and in all 10 soybeans samples, at a mean amount of 5 and 49 µg/kg, respectively.

Cocoa and coffee are food commodities with a high impact on the economy of many producing countries like Cameroon. Unfortunately, these latter are also often contaminated by ochratoxin A (OTA). Due to their high level of consumption, strict standards have been defined for these foods, and they are highly controlled on the international markets. The presence of ochratoxigenic fungi like *Aspergillus niger* and *Aspergillus carbonarius* has already been reported in cocoa samples from Cameroon [71]. Studying the effect of post-harvest treatment on the final OTA content in cocoa beans or their derived products (roasted cocoa, nibs, butter, cocoa powder, chocolate spread), Mounjouenpou et al. [71,72,73] clearly observed that pod damage and late pod opening were aggravating factors for OTA contamination. Fermented dried cocoa from intact pods presented an OTA content below those from poor quality pods (intentionally or naturally damaged) which showed contents of up to 76 µg/kg [72]. *A. carbonarius* and *A. niger* have also been reported by Nganou et al. [74] as the main fungal contaminant of coffee beans from Cameroon, followed by *A. ochraceus*. Among the 104 samples they tested, just few presented an average OTA content above the 5 µg/kg international limit for roasted coffee. Similar observations were made by Mounjouenpou et al. [75]. In fact, their local Arabica coffee brand samples were all below the limit, and only few from the Robusta coffee were above. Studies conducted by Romani et al. [76] had already shown an OTA contamination of green coffee beans from Cameroon between 1 and 2.5 µg/kg.

The occurrence of mycotoxins in sorghum and its derived products has also been studied during the last decade. This cereal is a crop mainly produced and consumed in the Northern part of the country. No presence of OTA, DON and FB₁ was detected in the grains collected in this region by Djoulde [77]. Only AFB₁ was detected in sorghum cultivated in the rainy season (0-230 µg/kg). In some locally produced artisanal sorghum by-products (beer, flour, babies beverage, and cake), mycotoxins were detected at levels ranging between 0-250 mg/kg for AFB₁, 0-45 mg/kg for OTA, and 0-538 µg/kg for DON. In a previous work performed by this author [78], he observed that the local sorghum beers *bil-bil* and *kpata*, were contaminated by both DON (0-730 µg/L) and FB₁ (0-340 µg/L).

Apart from maize, peanuts, beans, soybeans, cocoa, coffee and sorghum, the mycotoxin content of other foods from Cameroon have also been studied. Essono et al. [79] assessed the total aflatoxin content in cassava chips, a cassava derived product (obtained after fermentation and drying) which is widely consumed locally. They reported a contamination of 33% of their samples at levels ranging between 5.2-15 µg/kg. A higher range of aflatoxin content (6-194 µg/kg) in these cassava products (flakes and chips) was noticed by Njumbe et al. (2014) [80] who also reported the presence of penicillic acid inside (25-184 µg/kg). Tchana et al. [81] observed AFs contamination in eggs samples (45.2%) at a mean concentration of 0.82 µg/kg, a contamination which was varying from one climatic region to another. Indeed, the frequency of contamination ranged from 25 to 53%, forest and mountain climatic areas showing a higher contamination level compared to littoral, and savannah and steppe. These authors also noticed aflatoxin M₁ (AFM₁) contamination in 16% of their cow milk samples at levels varying from 0.006 to 0.525 µg/L. More recently, the presence of OTA was detected by Nguégwouo et al. [82] in 10% of black pepper samples (1.2-1.9 µg/kg) and 40% of their white pepper samples (1.8-4.9 µg/kg) collected from Yaoundé markets.

4. DIETARY EXPOSURE AND BIO-MONITORING

Health risks associated to mycotoxins mainly depend on the consumption frequency of contaminated foods, the level of contamination and on the weight of consumers. On the basis of published data on the consumption of artisanal home-brewed sorghum beer (*bil-bil* and *kpata*) in Cameroon, Djoulde [78] estimated that there are no DON or FB₁ health risks for adults of 60 kg even at the maximum detected concentrations of these toxins (730 and 230 µg/kg, respectively). Taking

into consideration the average OTA contamination of coffee in Cameroon, Mounjouenpou et al. [75] estimated the daily intake of an adult of 70 kg at 0.065 ng/kg bw/day. Using the same deterministic approach, the maximum OTA daily intake that could be associated to black pepper (0.182 ng/kg bw/day) and white pepper (0.699 ng/kg bw/day) by adults of 60 kg was also found insignificant in comparison to the EFSA provisional tolerable daily intake value of 17 ng/kg bw/day [82]. Especially for maize, an exposure to FB₁ several-fold higher than the health-based guidance values (2 µg/kg bw/day) has been reported by Njumbe et al. [80]. A high risk was also noticed by these authors with the genotoxic carcinogen AFB₁ for which no tolerable daily intake (TDI) has been set and the principle of “as low as reasonably achievable” (ALARA) applied. However, studying the maize dish called “maize-fufu”, Abia et al. [70] noticed that the average daily exposures to AFB₁, FBs, DON and ZEN that could be associated were lower than 50% of maximum tolerable limit (MTL) for each respective mycotoxin [83].

Some studies have been carried out in Cameroon to assess the presence of mycotoxins in the human body. A recent study carried out by Chuisseu et al. [84] shows the presence of AFM₁ in 16 of the 42 breast milk samples they have collected, at a level ranging between 0.9 and 37 µg/kg feeding. A concentration of this toxin varying from 0.005 to 0.625 µg/L had already been reported by Tchana et al. [81] in 3 of the 62 breastfeeding milk samples they tested. These authors had also noticed that malnourished children suffering from kwashiorkor or marasmic kwashiorkor were showing a significantly higher AFB₁ content in their urines compared to healthy children. The maximum values observed in these 3 groups were 2.84, 0.864 and 0.155 µg/L, respectively. Abia et al. [85] reported a higher occurrence of mycotoxins in urines from HIV positive people and estimated that their TDI should be reduced. In 2013, Njumbe et al. [67] noticed that the mean concentration of AFM₁ detected in the urine of the partially breastfed children (1.43 ng/mL) was significantly higher than those of the fully weaned children (0.282 ng/mL). They also observed that the DON and FB₁ content in these urine samples was significantly lower for females (0.71 and 0.01 µg/L, respectively) compared to males (3 and 0.59 µg/L, respectively).

5. CONCLUSION

The presence of mycotoxins in food may lead to severe health consequences for consumers. Even if the limited studies on the assessment of human exposure in Cameroon tend to show a limited health risk, it is important to note that some of the food samples analyzed presented mycotoxins contamination levels which were above the regulatory standards. This may have a negative agro-economic impact on international trade for this country. Efforts should therefore be made by government to educate producers on mitigation strategies (from farms to the final product), and populations on the risk associated to such contaminated products. More studies on exposure need to be done and should also focus on young children and the elder people which may be the most sensitive groups of the populations.

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Comment [UdMO8]: this mycotoxin contamination is in the agricultural year or in storage commodities ?

Comment [UdMO9]: It is not concluded yet ?

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