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Occurrence of 30 trace elements in foods from a multi-centre Sub-Saharan Africa Total Diet Study: Focus on Al, As, Cd, Hg, and Pb

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ABSTRACT

This paper reports occurrence data related to 30 trace elements in food composite samples from a multi-regional Sub-Saharan Africa Total Diet Study. Herein, 2700 samples grouped in 225 food composite samples corresponding to 13 food groups: cereals, tubers, legumes, vegetables, fruits, nuts/seeds, meat, eggs, fish, milk/dairy, oil/fats, and beverages from eight locations in four countries, namely Benin (Littoral/Borgou), Cameroon (Duala/North), Mali (Bamako/Sikasso), and Nigeria (Lagos/Kano) were prepared as consumed, pooled, and analysed using a validated method based on inductively coupled plasma-mass spectrometry. The occurrence data for Al, As, Cd, Hg, and Pb as regulated by the *Codex Alimentarius* are discussed herein. Although the levels of As, Cd, Hg, and Pb were above the limit of quantification, they were below the maximum limits set by the Codex in most samples analysed. A distinct feature was observed for cereals and tubers, as they were mostly contaminated with Al and Pb. A pilot study regarding the impact of using artisanal cookware (made from recycled aluminium) on the contamination of food samples was performed. Relevant contamination with Al and Pb when cooking tomato samples from Cameroon and Nigeria using artisanal aluminium cookware was compared to that when cooked using stainless-steel.

1. Introduction

Food contaminants can originate from the environment or from specific practices and processes as the food is taken from field to fork. Thus, safety assessment of food is challenging given the diversity of available foods and the variety of agricultural, processing, and culinary practices worldwide. Among potential food hazards, inorganic chemical contaminants, such as trace elements, are of particular interest due to the chronic exposure of consumers to and potential long-term health effects of metal exposure (Rehman et al., 2018).

Trace As (inorganic), Pb, Cd, and Hg are routinely monitored in Europe and other countries (Council of the European Union, 2015a,b, 2014, 2011, 2008, 2006), but other inorganic contaminants are not regulated and monitoring data are limited. Recommendations can be generated within the framework of total diet studies (TDS) according to previously published protocols (WHO, 2006, EFSA, 2011a,b; Moy and Vannoort, 2013, Ingenbleek et al., 2017; Papadopoulos et al., 2015; Turrini et al., 2017).

TDSs are endorsed by the World Health Organisation (WHO) and the Food and Agriculture Organization of the United Nations (FAO) has been tasked with assessing the chemical contamination of food prepared as consumed (EFSA, 2011b; FAO/WHO, 2009). This allows for

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the estimation of human dietary exposure after matching contamination data (occurrence) with consumption patterns based on representative samples. TDSs provide scientific information to national authorities to address the risks of food-related chemical hazards for public health protection.

TDSs have been performed in several countries such as the USA (U.S. Food and Drug Administration, 2017; Egan et al., 2007), the UK (UK Report on the Total Diet Study, 2014), Germany (BfR, 2015), Canada (Rawn et al., 2004; Dabeka and Cao, 2013), Italy (Carnovale et al., 2000), Spain (Marin et al., 2017), Australia (Abbey et al., 2013; Food Standards Australia New Zealand, 2014), and Cameroon (Gimou et al., 2013, 2014a, 2014b). In France, two TDSs targeting the general population were performed in 2004 and 2011 (Leblanc et al., 2005; Arnich et al., 2012).

Information concerning the exposure of African population to chemical hazards via food consumption is extremely scarce. To date, published TDS data concerning trace elements in Africa are available only for Cameroon (Gimou et al., 2013, 2014a, 2014b).

The data presented herein were generated in the framework of the Sub-Saharan Africa Total Diet Study (SSA-TDS), which involved two study centres (see Section 2.1) in each of the four countries: Benin, Cameron, Mali, and Nigeria under the leadership of the FAO jointly with the WHO and Centre Pasteur of Cameroon (Ingenbleek et al., 2019a,b,c). Herein, the occurrence data related to 30 inorganic contaminants including Al, As, Cd, Hg, and Pb in 225 composite samples of food are reported. The sampling plan included 194 food composite samples (representing 2338 subsamples prepared using stainless-steel cookware). Additionally, eight tap water composite samples (representing 96 subsamples) were collected and 23 migration study composite samples (representing 276 subsamples prepared using traditional cookware) were obtained within the framework of SSA-TDS. The total chemical content was determined using an accredited method based on inductively coupled plasma-mass spectrometry (ICP-MS) followed by acid digestion (Chevallier et al., 2015). Herein, the occurrence data relating to toxic trace elements (Al, As, Cd, Hg, and Pb) for which JECFA has proposed health-based guidance values or endpoints were examined in detail (WHO, 2011). The occurrence data related to 25 additional inorganic elements are provided in the Supplementary Material (Tables S1 and S2).

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.envint.2019.105197.

2. Material and methods

2.1. Food samples, classification, and food consumption data methodology

The food samples analysed herein were obtained within the framework of SSA-TDS whose methodology and implementation design are described elsewhere (Ingenbleek et al., 2017). Briefly, food consumption data were derived from household budget surveys (HBS) in Benin, Cameroon, Mali, and Nigeria, starting from food expenditure data processed with a unit price database, edible fraction conversion factors, and cooking yield factors obtained from the West Africa Food Composition Table (FAO, 2012).

In October 2017, 2700 sub-samples were collected from eight Sub-Saharan regions as follows: Littoral and Borgou in Benin; Duala and North in Cameroon; Bamako and Sikasso in Mali; and Lagos and Kano in Nigeria. The samples were grouped into 225 food composite samples and subsequently into 13 food groups,: *(i)* cereals, *(ii)* tubers, *(iii)* legumes, *(iv)* vegetables, *(v)* fruits, *(vi)* nuts/seeds, *(vii)* meat, *(viii)* eggs, *(ix)* fish, *(x)* milk/dairy, (xi) (oil/fats), *(xii)* beverages, and *(xiii)* miscellaneous. The SSA-TDS sampling plan was performed based on food consumption data and some less consumed but highly contaminated items may have been omitted for sampling cost effectiveness. Eight tap water samples (not listed here as food) were also included.

The sampling plan was designed to obtain a representative coverage of the most consumed food groups by weight. Hence, the coverage of food groups representing ≥1% of total food consumption was set so as to include a variety of food samples that covered at least 90% of the food groups defined above. However, when food groups represented < 1% of the mean total food consumption, the sampling covered a minimum of 50% of the food groups (Ingenbleek et al., 2017). This approach was used to reduce the number of samples and decrease the cost of the sampling and analysis, while focusing on the most commonly consumed foods representative of the typical diet of the population.

Table 1 summarises the core foods and their proportion of the mean national total diet obtained using the sampling plan in Benin, Cameroon, Mali, and Nigeria.

It is difficult to compare TDS occurrence data due to differences in samples chosen to obtain a given food core, account for natural background presence of trace elements, contamination control, and culinary practices used to prepare the consumed food samples.

Table 1
Coverage of the mean national total diet (TD) by the SSA-TDS sampling plan.[a]

Food core	Benin		Cameroon		Mali		Nigeria	
	% mean TD	No. of samples	% mean TD	No. of samples	% mean TD	No. of samples	% mean TD	No. of samples
Cereals	53.5	7	39.5	6	78.6	9	52.7	7
Tubers	16.6	5	19.5	8	1.7	7	23.8	5
Legumes	4.8	2	6.0	4	2.6	4	7.1	4
Vegetables	5.4	6	6.5	7	2.3	9	3.8	6
Fruits	0.2	1	7.7	3	2.3	7	1.3	7
Nuts/Seeds	0.0	1	0.2	1	0.0	1	0.2	1
Meat	0.2	2	0.4	2	0.6	1	0.5	2
Eggs	0.1	1	0.2	1	1.0	1	0.1	1
Fish	0.5	2	1.1	4	0.4	2	0.6	1
Milk/Dairy	0.5	3	0.3	1	1.1	2	0.5	1
Oil/Fats	1.8	2	1.9	3	1.0	2	1.5	4
Beverages	4.4	5	4.5	6	0.3	2	1.4	7
Miscellaneous	7.0	3	7.8	4	4.9	3	2.8	8
Total	**94.9**	**40**	**95.6**	**50**	**96.8**	**50**	**96.3**	**54**

[a] Ingenbleek et al. (2017).

2.2. Preparation of the food samples

Herein, 225 food sub-samples (approximately 1 kg) were prepared as consumed. A schematic representation of the sampling methodology is provided in Fig. 1 including those prepared for the migration study with relatively inert cookware composed of stainless-steel.

Although this type of cookware is not representative of common cooking practices in the four countries of interest, the use of stainless-steel allowed for identification of the contamination source.

This study was performed to obtain occurrence data of trace elements from contamination of the food itself and not arising from cooking practices. However, a pilot study related to the impact of the traditional cookware made of recycled aluminium on food contamination during cooking is also addressed herein. Thus, five to six of the most consumed foods in each country including tap water, rice, maize, sorghum, millet, and cassava, as well as an acidic matrix (tomato) were split into two identical portions and each portion was cooked under the same conditions using the two types of cookware mentioned above (Fig. 2).

Distilled water was used for cooking to prevent sample contamination from tap water. Similarly, this type of water is not representative of the culinary practices in the African countries, but prevented food contamination from tap water. Tap water composite samples were also analysed and were collected at 12 sites considered to be representative of the cities of interest, as for the other core foods. Identical amounts of each of the samples were subsequently pooled and analysed as for the other composite samples.

Dry foodstuffs (cereals, tubers, and dried legumes/vegetables) were also prepared as consumed by rehydrating the respective matrices with distilled water according to national standard culinary practices (Gautier and Mallet, 2006; Madubike, 2013; Nya-Njike, 1998; Vinakpon-Gbaguidib, 2003). Generally, the food products were ground before preparation, with the exception of rice, in compliance with food consumption habits.

All samples were shipped frozen by air with dry ice from the kitchen laboratory (Benin, Cameroon, Mali and Nigeria) to the analysis laboratory (France). The transportation timeframe did not exceed 24 h. The samples were kept frozen for periods not exceeding three months (−20 °C) prior to analysis.

2.3. ICP-MS analysis

The samples were analysed using an in-house validated and accredited method (French Accreditation Body-COFRAC) based on ICP-MS using acidic microwave digestion as reported elsewhere (Chevallier et al., 2015). Briefly, 0.2–0.4 g of the sample was precisely weighed into a quartz digestion vessel and subsequently pre-digested with 3 mL of ultrapure nitric acid (HNO_3, 67% v/v, VWR chemicals, Prolabo). Then, 3 mL of ultrapure water (18.2 mΩ·cm, Millipore SA, Saint-Quentin-en-Yvelines, France) was added and the sample mineralised using a closed (high-pressure) microwave system (Multiwave 3000 and Multiwave PRO, Anton-Paar, Courtaboeuf, France). The digests were quantitatively transferred to 50 mL (certified volume) polypropylene tubes and filled with ultrapure water. The concentrations of 30 inorganic contaminants were determined by ICP-MS (Agilent 7700, Agilent Technologies, Les Ulis, France). A solution of mixed internal standards (IS), including scandium (Sc), indium (In), bismuth (Bi), rhenium (Re), yttrium (Y), and gold (Au) was added to all blanks, standards, and food

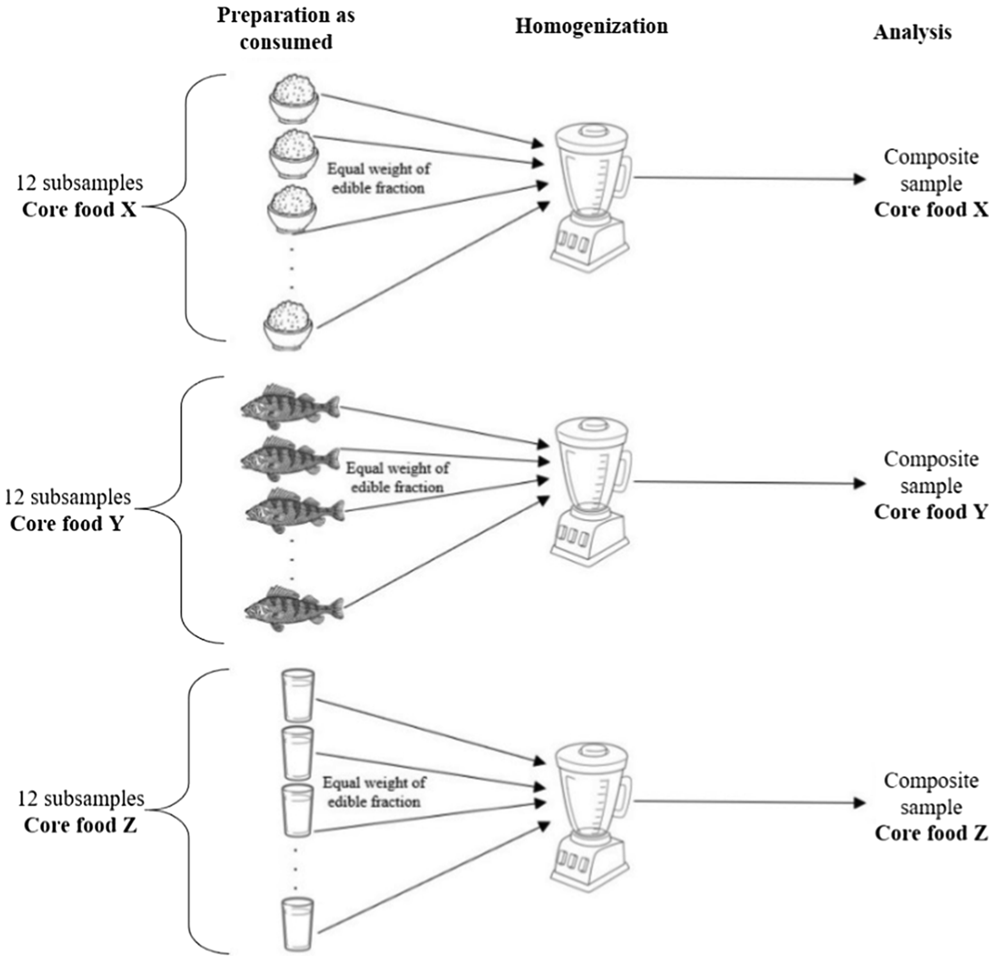

Fig. 1. Schematic representation of the core food composite sample formation from 12 subsamples of equal weight.

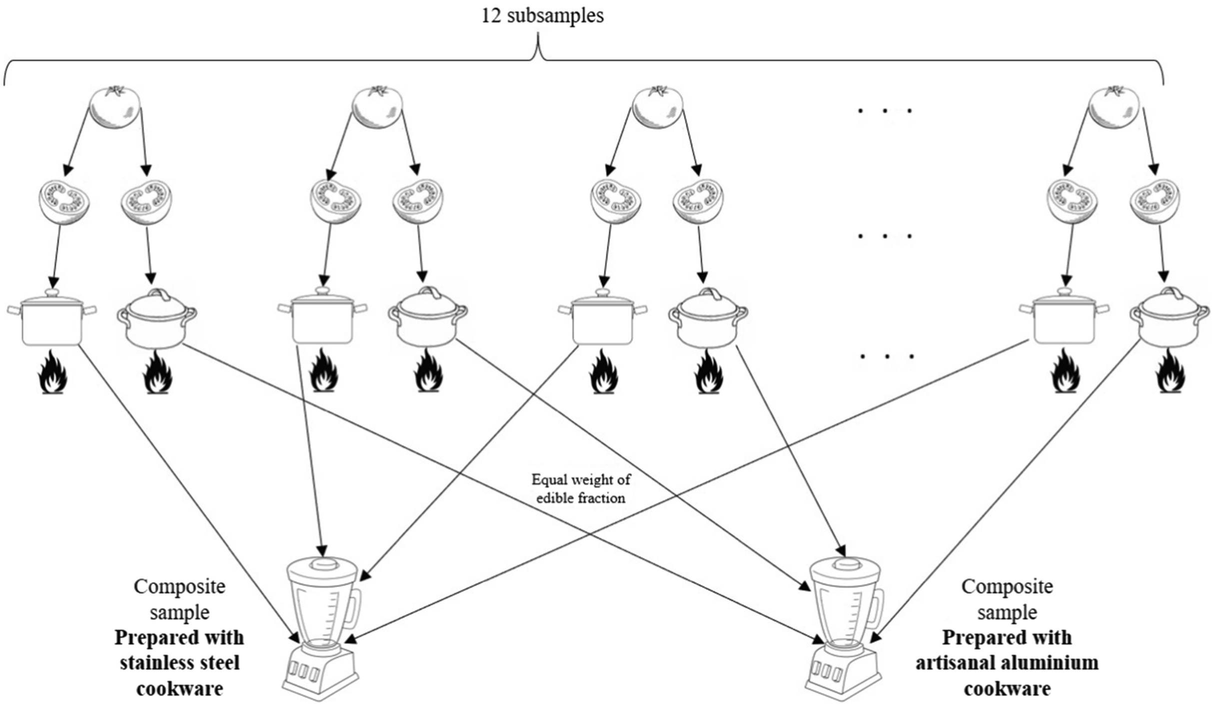

Fig. 2. Schematic representation of the processes of sample duplication prepared using stainless-steel or aluminium cookware.

samples to correct for non-spectral interferences and instrumental drift (each IS was spiked at 2 ng mL^{-1}). The ICP-MS washing solution (6%, v/v) contained gold (Au) at 10 mg L^{-1} to reduce memory effects related to Hg analysis. The limits of quantification (LOQ) and intermediate precision (CV_R, %) for two concentrations (≤ 2 × LOQ and > 2 × LOQ) of the accredited method are reported in Table 2.

2.4. Internal quality control

Internal quality controls were used to ensure data reliability and a measurement was considered valid only when all the acceptance criteria were globally satisfied (Chevallier et al., 2015).

Method accuracy and precision were assessed daily via analysis of three certified reference materials (CRM), namely ERM-278K (European reference material, mussel tissue, European Commission), TORT-2 (lobster hepatopancreas) from the National Institute of Standards and Technology (NIST, USA), and SRM 1548 - typical diet (NIST, USA). The analysis of a real sample batch was considered valid when the analyte concentration in each CRM fell within the confidence interval (CI) calculated based on the certified value ($X_{certified}$) (Eq. (1)).

$$CI = X_{certified} \pm \left[k \times \frac{CV_R \times X_{certified}}{100 \times \sqrt{N}} \right] \tag{1}$$

Table 2
Limits of quantification (LOQ in mg/kg fresh weight) and intermediate precision (CV_R, %) for As, Al, Pb, Cd, and Hg.[a]

Analyte	LOQ[b] (mg/kg)	CV_R (%)	
		Sample level ≤ 2 × LOQ	Sample level > 2 × LOQ
Al	0.033–0.17	20	12
As	0.0008–0.004	20	12
Cd	0.0002–0.001	12	10
Hg	0.003–0.017	15	10
Pb	0.001–0.005	15	8

[a] LOQ and CV_R for the other trace elements measured were provided in Chevallier et al. (2015).

[b] Depending on the amount of analysed sample.

where

CI, confidence interval;
CV_R, intermediate precision;
k = 3 (p = 99%);
N, number of replicates.

For the analytes not present in the CRM or not certified, the method accuracy was assessed by determination of the corresponding recovery factors at two spiking levels depending on the analyte. The method accuracy was considered acceptable when the recovery factors ranged between 80 and 120% for all spiking levels.

A standard solution containing each analyte at a concentration of LOQ + 3 × CV_R was also analysed in parallel with each batch to assess the measurements reliability at concentrations close to the LOQ. This analysis was considered valid if the measured concentration fell within the CI obtained from the method validation using a similar equation as Eq. (1). Most data (> 90%) related to the analysis of CRM and control standard solution (LOQ + 3 × CV_R level) complied with the CI calculated for the inorganic contaminants investigated herein.

2.5. Calculations and statistical methods

The trends were assessed by Student' tests (Microsoft ® Excel® software, 2016) for simplicity due to the relatively low number of samples subjected to statistical analysis.

The data presented herein are the upper bound (UB) concentrations, meaning that the concentration of non-detected analytes was set to LOD for non-detected analytes and to the LOQ for detected but non-quantified analytes. The lower bound concentrations indicated that the concentration of non-detected analytes was zero for non-detected analytes and was assumed to be the LOD for detected but non-quantified analytes, as presented in the Supplementary Data. This indicates that the uncertainty due to censored data was considered, as recommended for TDSs (EFSA, 2011a). All concentrations presented herein are expressed in mg/kg fresh weight.

3. Results and discussion

The occurrence data in terms of Al, As, Cd, Hg, and Pb, which are commonly regulated inorganic contaminants in a large variety of food matrices either by the EC or Codex are reported for the composite samples of the SSA-TDS. In addition to the actual concentrations of these analytes in the various core foods discussed as a function of study centre, the proportions of samples for each of the measured levels of Al, As, Cd, Hg, and Pb exceeding the LOQ are shown in Table 3 (these samples are referred to as quantified samples, which denotes samples with analyte levels exceeding the LOQ).

The concentrations of Al, As, Cd, Hg, and Pb measured in each composite sample of the food groups analysed for the four countries including the eight tap water samples are also reported in Table 4. The low concentrations of Al, As, Cd, Hg, and Pb in the water samples, considering the measurement uncertainty, should conform to the Codex Standard (1981) and are unlikely to contribute significantly to the overall dietary exposure.

The overall mean for a given element as well as the minimum and maximum values were provided for each given analyte in each composite sample.

The concentrations of Al, As, Cd, Hg, and Pb (including the minimum and maximum) for each core food and each study centre are listed in Table 5.

The data obtained for the pilot study assessing contamination with Al, As, Cd, Hg, and Pb when preparing tomato and the other core foods in stainless-steel or traditional artisanal aluminium cookware are provided in Table 6. Contamination is expressed as a concentration factor (CF) that represents the ratio between the sample concentration prepared in aluminium cookware and that measured in the stainless-steel cookware prepared samples.

Supplemental Table S1 lists the mean and minimum/maximum (min-max) concentrations of the 25 inorganic contaminants in various core foods (LB and UB) for the four countries, whereas supplemental Table S2 reports the same type of data in various food groups depending on the study location.

3.1. Total arsenic (As_t)

The highest As_t quantification fractions were observed for the samples collected in Mali, which were mostly found in core foods (except for fruits, milk/dairy, and beverages) and with a 100% proportion in all samples of nuts/seeds, meat, eggs, and fish (Table 3). As_t was quantified in 100% of the meat samples, except in for those obtained from Cameroon, where the quantification fraction was 50%. As_t was quantified in cereals from the four countries, with rates ranging from 57% (Benin) to 83% (Cameroon). The lowest As_t quantification rate was obtained for the fruits, eggs, and milk/dairy food groups.

The highest mean concentration of As_t (Table 4) was measured in fish (0.71 mg/kg) and nuts/seeds (0.030 mg/kg). The most contaminated samples were the smoked and sea fish (≅1.06 mg/kg), whereas, As_t levels in freshwater fish were considerably lower (0.016 mg/kg). For the cereals, As_t levels were considerably higher in rice (0.024 mg/kg) compared to those of the other core foods such as maize, wheat/bread, pasta, sorghum, and millet (< 0.002–0.009 mg/kg; Table 4).

Current European regulations only specify a limit for inorganic As (As_i) of 0.10 mg/kg for rice destined for the production of infants and young children foods to 0.30 mg/kg in rice waffles, rice wafers, rice crackers, and rice cakes (Council of the European Union, 2015a). The mean As_t levels in the four countries showed that the rice was considerably lower (≅8 fold) than the European regulated limits and the Codex maximum (Codex Alimentarius, 1995) for inorganic arsenic in regular rice (0.20 mg/kg).

Concerning the fish samples, the highest As_t level (≅1.0 mg/kg) was observed in sea fish, indicating that sea fishery products are more contaminated with arsenic compared to freshwater fish. However, the dominant As species in marine organisms is arsenobetaine, which is the least toxic of all As species (Hong et al., 2014; EFSA, 2009).

Speciation data to determine the amount of inorganic As, which is the most toxic fraction, are needed (EFSA, 2014) to better characterise the contamination of fishery products with As and assess the impact of fishery product consumption on the general population in the Sub-

Table 3
Fraction (%) of quantified samples of the food groups in each country (Benin, Cameroon, Mali, and Nigeria) participating in the SAA-TD.

Analyte	Country	Cereals	Tubers	Legumes	Vegetables	Fruits	Nuts/Seeds	Meat	Eggs	Fish	Milk/Dairy	Oil	Beverages	Miscellaneous
n[a]	Benin	7	5	2	6	1	1	2	1	2	3	2	5	3
	Cameroon	6	8	4	7	3	1	2	1	4	1	3	6	4
	Mali	9	7	4	9	7	1	1	1	2	2	2	2	3
	Nigeria	7	5	4	6	7	1	2	1	1	1	4	7	8
Al	Benin	100	100	100	100	100	100	100	0	100	100	100	60	100
	Cameroon	100	100	100	100	100	100	100	0	100	100	0	83	100
	Mali	100	100	100	100	100	100	100	100	100	100	100	0	100
	Nigeria	100	100	100	100	100	100	100	100	100	100	75	57	100
As	Benin	57	20	0	33	0	0	100	0	0	33	0	60	67
	Cameroon	83	0	25	29	0	100	50	0	100	0	0	33	50
	Mali	44	29	75	22	0	100	100	100	100	0	50	0	33
	Nigeria	71	0	0	33	14	0	100	0	100	0	50	29	50
Cd	Benin	71	60	100	100	0	100	50	0	100	0	0	40	100
	Cameroon	67	88	100	100	33	0	0	0	75	0	0	17	50
	Mali	o	86	75	89	0	100	100	0	100	0	0	0	0
	Nigeria	71	60	100	100	14	100	100	0	100	0	0	57	75
Hg	Benin	0	20	0	0	100	0	50	0	100	0	0	0	0
	Cameroon	0	0	0	0	0	0	0	0	100	0	0	0	25
	Mali	0	0	0	0	0	0	0	0	100	0	0	0	0
	Nigeria	0	0	0	0	0	0	0	0	100	0	0	0	38
Pb	Benin	57	80	0	83	0	0	100	0	100	67	50	40	67
	Cameroon	67	50	50	100	67	100	100	0	50	0	0	50	50
	Mali	33	57	75	22	0	100	100	100	100	50	0	0	33
	Nigeria	100	100	100	100	86	100	100	100	100	0	50	57	88

[a] Number of samples analysed in each food group.

Table 4
Mean ($\bar{X}$), minimum (min), and maximum (max) upper bound concentrations of Al, As, Cd, Hg, and Pb (mg/kg) in the core foods of the four countries (Benin, Cameroon, Mali and Nigeria).

FOOD			Concentration (C, mg/kg)									
	Composite sample	n	Al		As		Cd		Hg		Pb	
			$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max
CEREALS	Rice	8	0.85	0.28–1.47	0.024	0.009–0.045	0.004	0.001–0.008	0.0040	[a]	0.004	0.001–0.009
	Maize	8	3.36	0.77–8.63	0.002	0.001–0.002	0.0004	0.0003–0.001	0.0040	[a]	0.007	0.001–0.022
	Wheat/bread	3	5.49	1.80–8.60	0.009	0.004–0.017	0.011	0.004–0.017	0.0080	[a]	0.017	0.005–0.036
	Pasta	1	1.26	[a]	0.004	[a]	0.004	[a]	0.0080	[a]	0.003	[a]
	Sorghum	5	25.0	4.42–61.5	0.009	0.001–0.017	0.0006	0.0003–0.001	0.0040	[a]	0.037	0.003–0.095
	Millet	4	20.7	1.84–60.1	0.006	0.001–0.019	0.002	0.001–0.004	0.0040	[a]	0.026	0.001–0.062
	Mean		**9.44**		**0.009**		**0.004**		**0.0053**		**0.016**	
TUBERS	Cassava fresh	4	6.81	0.64–19.0	0.002	0.001–0.002	0.001	0.0005–0.003	0.005	0.004–0.008	0.057	0.033–0.12
	Cassava dry	6	24.7	4.2–93.5	0.011	0.001–0.050	0.002	0.0003–0.004	0.006	0.004–0.008	0.22	0.035–0.53
	Yam fresh	5	1.63	0.21–6.11	0.001	0.001–0.002	0.002	0.001–0.004	0.012	0.004–0.041	0.006	0.001–0.019
	Yam dry	1	12.5	[a]	0.002	[a]	0.001	[a]	0.004	[a]	0.13	0.13
	Potato fresh	2	1.27	1.20–1.30	0.001	[a]	0.012	0.001–0.022	0.004	[a]	0.002	0.001–0.002
	Sweet potato	4	0.78	0.54–1.15	0.001	[a]	0.001	0.0003–0.002	0.004	[a]	0.003	0.003–0.004
	Cocoyam/taro	2	0.96	0.39–1.5	0.002	0.001–0.002	0.003	0.0003–0.005	0.004	[a]	0.004	0.003–0.005
	Macabo	1	0.55	[a]	0.001	[a]	0.001	[a]	0.004	[a]	0.003	[a]
	Mean		**6.16**		**0.003**		**0.003**		**0.0054**		**0.052**	
LEGUMES	Beans	8	2.40	1.7–3.7	0.0020	0.001–0.002	0.001	0.0003–0.002	0.004	0.004	0.009	0.001–0.030
	Peanuts	5	16.7	1.3–39.4	0.0060	0.004–0.10	0.010	0.002–0.014	0.008	0.008	0.019	0.005–0.031
	Peas	1	2.95	2.95	0.0010	[a]	0.001	[a]	0.004	0.004	0.018	[a]
	Mean		**7.34**		**0.0030**		**0.004**		**0.005**		**0.015**	
VEGETABLES	Tomato	8	1.92	0.33–4.63	0.002	0.001–0.005	0.004	0.001–0.008	0.004	[a]	0.007	0.001–0.013
	Green leaves	4	32.3	9.9–77.1	0.006	0.002–0.013	0.007	0.0005–0.020	0.005	0.004–0.010	0.037	0.011–0.10
	Cabbage	1	0.28	[a]	0.001	[a]	0.004	[a]	0.004	[a]	0.001	[a]
	Onion/garlic	8	1.31	0.18–2.74	0.001	0.001–0.003	0.008	0.002–0.018	0.004	[a]	0.010	0.001–0.045
	Okro/gombo	5	1.89	0.91–4.43	0.001	0.001	0.003	0.001–0.010	0.004	0.0040	0.011	0.001–0.021
	Other vegetables	1	24.2	[a]	0.005	[a]	0.008	[a]	0.004	0.0040	0.12	[a]
	vegetables	1	0.24	[a]	0.001	[a]	0.001	[a]	0.004	0.0040	0.001	[a]
	Mean		**8.87**		**0.003**		**0.005**		**0.004**		**0.027**	
FRUITS	Banana	4	0.26	0.19–0.45	0.001	[a]	0.0005	0.0003–0.001	0.004	[a]	0.005	0.001–0.012
	Plantain	3	1.45	0.13–3.92	0.001	[a]	0.0003	[a]	0.004	[a]	0.003	0.001–0.005
	Mango	1	0.22	[a]	0.001	[a]	0.0003	[a]	0.004	[a]	0.003	[a]
	Citrus	5	1.04	0.15–1.97	0.001	0.001–0.003	0.0003	[a]	0.010	0.004–0.035	0.014	0.001–0.047
	Pawpaw	2	0.17	0.12–0.22	0.001	[a]	0.0003	[a]	0.004	0.004	0.004	0.001–0.006
	Watermelon/melon	3	0.87	0.15–2.20	0.001	0.001–0.002	0.0009	0.0003–0.002	0.004	0.004	0.008	0.001–0.022
	Mean		**0.67**		**0.001**		**0.0004**		**0.005**		**0.006**	
NUTS/SEEDS	Palm nut	2	1.47	0.92–2.01	0.006	0.004–0.008	0.0008	0.0005–0.001	0.008	[a]	0.008	0.003–0.014
	Other nuts/seeds	2	333	0.92–662	0.054	0.004–0.103	0.011	0.008–0.014	0.008	[a]	0.18	0.023–0.33
	Mean		**167**		**0.030**		**0.006**		**0.008**		**0.092**	
MEAT	Beef	7	6.73	0.72–21.5	0.004	0.001–0.008	0.010	0.0003–0.64	0.010	0.004–0.045	0.069	0.007–0.26
	Mean		**6.73**		**0.004**		**0.010**		**0.010**		**0.069**	
EGGS	Poultry eggs	4	0.42	0.42–0.98	0.002	0.001–0.002	0.0003	0.0003	0.004	0.004	0.003	0.001–0.008
	Mean		**0.42**		**0.002**		**0.0003**		**0.004**		**0.003**	
FISH	Sea fish	2	0.31	0.23–0.39	1.05	1.00–1.10	0.015	[a]	0.043	0.040–0.046	0.008	0.003–0.013
	Fresh water fish	1	0.52	[a]	0.016	[a]	0.0003	[a]	0.011	0.011	0.003	0.003
	Smoked fish	6	101	0.60–373	1.06	0.02–3.08	0.040	0.002–0.18	0.058	0.034–0.101	0.11	0.007–0.25
	Mean				**0.71**		**0.018**		**0.024**		**0.040**	
MILK / DAIRY	Fresh/fermented milk	3	0.24	0.087–0.35	0.0007	0.0004–0.0008	0.0001	[a]	0.002	[a]	0.002	0.001–0.003
	Dehydrated milk	4	0.48	0.28–0.79	0.005	0.004–0.006	0.0006	0.0005–0.001	0.008	[a]	0.003	0.003–0.005
	Mean		**0.36**		**0.003**		**0.0004**		**0.005**		**0.003**	
OIL / FATS	Palm oil	4	3.24	0.08–6.71	0.005	0.004–0.005	0.0006	0.0005–0.001	0.008	[a]	0.022	0.003–0.053
	Groundnut oil	2	0.26	0.21–0.31	0.002	[a]	0.0005	[a]	0.008	[a]	0.005	0.005
	Other vegetables oil	4	0.38	0.083–1.26	0.005	0.002–0.008	0.0005	[a]	0.008	[a]	0.004	0.003–0.005
	Other fat/oil	1	0.17	[a]	0.004	[a]	0.0005	[a]	0.008	[a]	0.003	0.0030
	Mean		**1.01**		**0.004**		**0.0005**		**0.008**		**0.009**	
BEVERAGES	Water	7	0.022	0.017–0.055	0.0005	0.0002–0.0008	0.0001	[a]	0.002	[a]	0.001	[a]
	Traditional soft drink	3	19.0	0.57–50.2	0.0011	0.0004–0.002	0.002	0.001–0.002	0.002	[a]	0.010	0.002–0.023
	Traditional fermented drink	4	2.08	0.17–4.77	0.001	0.0004–0.002	0.002	0.0001–0.004	0.0020	[a]	0.006	0.001–0.011
	Industrial soft drink	3	0.04	0.017–0.087	0.0005	0.0004–0.0008	0.0001	[a]	0.002	[a]	0.001	[a]
	Industrial fermented drink	3	0.075	0.041–0.097	0.002	0.001–0.003	0.0002	0.0001–0.0003	0.002	[a]	0.003	0.001–0.008
	Mean		**4.24**		**0.001**		**0.0008**		**0.002**		**0.004**	

(*continued on next page*)

Table 4 (*continued*)

FOOD			Concentration (C, mg/kg)									
	Composite sample	n	Al		As		Cd		Hg		Pb	
			$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max
MISC.[b]	Sugar	6	0.38	0.20–0.79	0.002	[a]	0.001	0.0005–0.001	0.008	[a]	0.003	0.003–0.005
	Salt	7	11.3	1.07–38.9	0.017	0.007–0.029	0.001	0.001–0.002	0.048	0.008–0.16	0.054	0.024–0.079
	Broth	2	5.09	4.34–5.84	0.038	0.007–0.069	0.004	0.002–0.005	0.022	0.017–0.028	0.023	[a]
	Chili/pepper	3	6.66	3.59–7.43	0.002	0.001–0.002	0.004	0.002–0.005	0.004	[a]	0.009	0.003–0.013
	Mean		**4.69**		**0.012**		**0.002**		**0.016**		**0.018**	
WATER	Tap water	8	0.089	0.017–0.31	0.0005	0.0004–0.001	0.0001	0.0001–0.0003	0.002	[a]	0.001	0.001–0.002
	Mean		**0.089**		**0.0005**		0.0001	[a]	0.002	[a]	0.001	[a]

[a] Upper bound value (no min/max available).

[b] Miscellaneous.

Saharan region, but this task was beyond the scope of the TDS. Additionally, the ratio of organic and inorganic arsenic in fishery products varied greatly, complicating the assessment of risks related to As_i exposure from consumption of this food type.

Table 5 shows the occurrence data related to As_t in various food groups as a function of study locations. The highest As_t level (3.08 mg/kg) was observed in a smoked fish sample from Borgou, Benin (not shown here). This is twice the level measured in the freshwater fish sampled at the other Benin location. Nevertheless, the origin of As_t could not explain unambiguously attributed to the environment or due to the water loss during drying.

A similar trend was observed for the two Cameroon location, where different levels of As_t in fish were obtained (approximately 43-fold higher in Duala compared to in North Cameroon). Again, the two samples corresponded to different fish species and origins (sea and freshwater).

Apart from fish, levels of As_t exceeding the LOQ were measured in samples from the miscellaneous food group collected in Lagos, Nigeria, with a sample of broth/bouillon cube being the most contaminated (0.069 mg/kg, not shown here) along with rice composite samples from Duala, Cameroon (0.023 mg/kg).

3.2. Lead

From Table 3, Pb levels were above the LOQ in all meat samples in the four countries and in all fish samples collected in Benin, Mali, and Nigeria. Pb was also quantified in all vegetables and nuts from Cameroon, in all nuts and eggs from Mali, and in all cereals, tubers, legumes, vegetable, nuts/seeds, and eggs from Nigeria. The mean Pb levels amongst the core foods ranged from 0.001 mg/kg (LOQ; oil/fats group) to 0.052 mg/kg in tubers (Table 4).

Pb levels in samples from various locations ranged between 0.001 (LOQ) and 0.33 mg/kg for a nuts/seed sample from Sikasso, Mali and 0.23–0.25 mg/kg in fish from Mali (Sikasso) and Benin (Borgou; Table 5). The highest Pb levels observed in fish slightly exceeded the Codex maximum limit (0.30 mg/kg), likely due to the predominant use of leaded gasoline in these countries. This type of fuel may result in environmental Pb contamination via organolead species, which are more bioavailable compared to inorganic lead (Tiwari et al., 2013). Other sources of Pb contaminants in the aquatic environment and ultimately the fish include leaded paint, the materials in contact with the foods (including grinders), and specific food processing practices such as smoking. However, these sources are impossible to discriminate, and it cannot be determined whether environmental or a post capture process contaminated the fish. Speciation analysis of organolead compounds is necessary to discriminate the different origins of Pb, but this exceeds the scope of the study.

Pb concentrations measured in tubers from Mali and vegetables from Cameroon were relatively higher than the levels observed in the other samples. It would be interesting to analyse soil samples to examine soil contamination correlation with Pb concentrations in tubers and vegetables since cassava tubers can readily accumulate metal contaminants from polluted soils (Nworu et al., 2018).

3.3. Cadmium

Cadmium (Cd) was quantified in most food samples with a maximum quantification rate being observed in legumes and vegetable from Benin, Cameroon, and Nigeria; from fish in Benin, Mali, and Nigeria; and from nuts/seeds in Benin, Mali, and Nigeria (Table 3). The mean Cd concentration in various food cores ranged from 0.0003 mg/kg (LOQ) in eggs to 0.018 mg/kg in fish (Table 4). Cd was quantified in meat from Nigeria (Lagos, 0.064 mg/kg), fish from Borgou, Benin (0.18 mg/kg), nuts/seeds from Kano, Nigeria (0.014 mg/kg), and vegetables from Duala, Cameroon (0.011 mg/kg), whereas the lowest mean Cd level was observed for the fruit and milk/dairy food groups (Table 5). Regarding Cd distribution amongst the study centres, the concentrations ranged from 0.0002 mg/kg (LOQ) to 0.18 mg/kg in a fish sample from Benin (Borgou; Table 5).

The highest Cd concentration (0.036 mg/kg) in the fish group was lower than the maximum limit currently set by the EU (0.05 mg/kg; Council of the European Union, 2014). Only one sample exceeded the prescribed maximum Cd level (fish sample from Benin at 0.18 mg/kg), whereas the Codex Alimentarius does not specify a maximum Cd content for fish.

3.4. Mercury

Mercury (Hg) showed the smallest quantification rate in the samples analysed herein ranging from 0.002 mg/kg (LOQ) to 0.16 mg/kg in a salt sample collected in Duala, Cameroon (not shown here as mean values only are shown in Table 5). As expected, Hg was quantified in all seafood samples with means ranging from 0.008 mg/kg (crustacean/molluscs) to 0.10 mg/kg (smoked fish, Bamako, Mali). The maximum Hg concentration was considerably lower than the Codex maximum limits (0.5 and 1.0 mg/kg for non-predatory and predatory fish species, respectively). No Hg was detected in any sample from Mali except in the fish samples. Previous studies highlighted that the most prevalent Hg form in fish is methylmercury (MeHg), the most toxic form. MeHg frequently exceeds 70% of the total Hg in fish (Lescord et al., 2018). Nevertheless, determination of the actual amount of MeHg species requires speciation analysis, which is beyond the scope of this study.

Apart from the fish, wherein Hg was quantified in all samples from the four countries, Hg was more frequently quantified in Benin with a 20% quantification rate in tubers (n = 5), 100% in fruits (n = 1), and 50% in meat (n = 2; Table 3). Hg was quantified in the beef composite sample collected in Benin (Borgou, 0.045 mg/kg), fresh yam composite sample from Borgou (0.041 mg/kg), one tomato composite sample

Table 5

Mean ($\bar{X}$), minimum (min), and maximum (max) upper bound concentrations of Al, As, Cd, Hg, and Pb (mg/kg) in various food groups of the SAA-TDS reported by study location.

FOOD	Country	Centre	Concentration (mg/kg)									
			Al		As		Cd		Hg		Pb	
			$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max
CEREALS	Benin	Littoral	1.50	0.30–2.93	0.008	0.002–0.019	0.003	0.0003–0.004	0.006	0.004–0.008	0.003	0.002–0.003
		Borgou	31.6	0.34–61.5	0.012	0.002–0.019	0.002	0.0003–0.002	0.004	[a]	0.024	0.001–0.052
	Cameroon	Duala	3.3	0.29–6.04	0.017	0.002–0.045	0.006	0.0003–0.011	0.006	0.004–0.008	0.006	0.003–0.011
		Garoua	15.6	1.47–36.6	0.008	0.002–0.014	0.002	0.0005–0.003	0.004	[a]	0.012	0.003–0.027
	Mali	Bamako	6.97	0.89–16.7	0.010	0.001–0.037	0.002	0.0003–0.004	0.005	0.004–0.008	0.004	0.001–0.006
		Sikasso	2.08	0.77–4.42	0.007	0.001–0.025	0.0007	0.0003–0.001	0.004	[a]	0.002	0.001–0.003
	Nigeria	Lagos	3.68	0.83–8.60	0.012	0.001–0.017	0.007	0.004–0.017	0.006	0.004–0.008	0.017	0.004–0.036
		Kano	4.40	1.36–7.61	0.010	0.002–0.029	0.002	0.0003–0.006	0.004	[a]	0.047	0.009–0.095
TUBERS	Benin	Littoral	2.28	0.38–4.17	0.0010	[a]	0.0007	0.0003–0.001	0.004	[a]	0.037	0.003–0.071
		Borgou	8.62	4.02–15.7	0.003	0.001–0.005	0.002	0.0005–0.004	0.018	0.004–0.041	0.056	0.019–0.116
	Cameroon	Duala	2.40	0.39–8.91	0.001	0.001–0.002	0.002	0.001–0.005	0.004	[a]	0.024	0.003–0.123
		Garoua	1.15	[a]	0.001	[a]	0.0003	[a]	0.004	[a]	0.003	[a]
	Mali	Bamako	23.9	0.73–93.5	0.013	0.001–0.05	0.007	0.001–0.022	0.005	0.004–0.008	0.14	0.003–0.533
		Sikasso	6.96	0.65–19.5	0.003	0.001–0.007	0.002	0.0005–0.004	0.006	0.004–0.008	0.18	0.003–0.488
	Nigeria	Lagos	7.94	0.39–19.0	0.001	0.001–0.002	0.0007	0.0003–0.001	0.004	[a]	0.045	0.003–0.125
		Kano	na		na		Na		na		na	
LEGUMES	Benin	Littoral	1.66	[a]	0.001	[a]	0.001	[a]	0.004	[a]	0.003	[a]
		Borgou	1.72	[a]	0.001	[a]	0.001	[a]	0.004	[a]	0.003	[a]
	Cameroon	Duala	1.58	1.27–1.89	0.003	0.002–0.004	0.005	0.001–0.008	0.006	0.004–0.008	0.004	0.003–0.005
		Garoua	11.9	2.42–21.3	0.004	0.001–0.006	0.007	0.001–0.013	0.006	0.004–0.008	0.018	0.005–0.031
	Mali	Bamako	9.89	3.33–16.5	0.004	0.002–0.005	0.007	0.002–0.011	0.006	0.004–0.008	0.006	0.004–0.008
		Sikasso	20.7	2.05–39.4	0.006	0.001–0.010	0.007	0.0003–0.014	0.006	0.004–0.008	0.013	0.001–0.025
	Nigeria	Lagos	2.70	2.39–2.95	0.002	0.001–0.002	0.001	[a]	0.004	[a]	0.022	0.018–0.026
		Kano	4.29	3.66–4.92	0.003	0.002–0.004	0.002	0.001–0.002	0.006	0.004–0.008	0.029	0.028–0.030
VEGETABLES	Benin	Littoral	2.21	0.94–4.22	0.002	0.001–0.004	0.005	0.003–0.008	0.004	[a]	0.004	0.003–0.005
		Borgou	2.80	1.31–4.63	0.002	0.001–0.005	0.006	0.003–0.010	0.004	[a]	0.006	0.005–0.008
	Cameroon	Duala	26.3	0.52–77.1	0.006	0.002–0.013	0.013	0.001–0.02	0.006	0.004–0.008	0.053	0.013–0.102
		Garoua	5.80	0.18–19.8	0.002	0.001–0.002	0.004	0.002–0.006	0.004	[a]	0.015	0.005–0.023
	Mali	Bamako	2.48	0.24–9.87	0.002	0.001–0.005	0.005	0.001–0.015	0.004	[a]	0.004	0.001–0.012
		Sikasso	6.40	0.65–22.2	0.001	0.001–0.002	0.004	0.0005–0.011	0.004	[a]	0.004	0.001–0.011
	Nigeria	Lagos	9.14	0.47–24.2	0.002	0.001–0.005	0.006	0.004–0.008	0.004	[a]	0.049	0.006–0.123
		Kano	2.13	0.53–4.43	0.002	0.001–0.003	0.004	0.001–0.006	0.004	[a]	0.012	0.005–0.020
FRUITS	Benin	Littoral	0.15	[a]	0.001	[a]	0.0003	[a]	0.035	[a]	0.001	[a]
		Borgou	na		na		Na		na		na	
	Cameroon	Duala	2	0.48–3.92	0.001	[a]	0.0005	0.0003–0.001	0.004	[a]	0.005	0.003–0.009
		Garoua	na		na		Na		na		na	
	Mali	Bamako	0.31	0.12–1.03	0.001	[a]	0.0003	[a]	0.004	[a]	0.002	0.001–0.003
		Sikasso	0.26	[a]	0.001	[a]	0.0005	[a]	0.004	[a]	0.001	[a]
	Nigeria	Lagos	0.97	0.15–2.20	0.002	0.001–0.003	0.0006	0.0003–0.002	0.004	[a]	0.018	0.005–0.047
		Kano	0.91	0.24–1.58	0.001	[a]	0.0003	[a]	0.004	[a]	0.005	0.003–0.008
NUTS/SEEDS	Benin	Littoral	0.92	1	0.004	0.004	0.0010	[a]	0.008	[a]	0.003	[a]
		Borgou	na		na		Na		na		na	
	Cameroon	Duala	2.01	[a]	0.008	[a]	0.0005	[a]	0.008	[a]	0.014	[a]
		Garoua	na		na		Na		na		na	
	Mali	Bamako	na		na		Na		na		na	
		Sikasso	662	[a]	0.10	[a]	0.008	[a]			0.33	[a]
	Nigeria	Lagos	na		na		Na		na		na	
		Kano	3.53	[a]	0.04	[a]	0.014	[a]	0.008	[a]	0.023	[a]
MEAT	Benin	Littoral	1.40	[a]	0.002	[a]	0.0010	[a]	0.004	[a]	0.036	[a]
		Borgou	1.06	[a]	0.001	[a]	0.0003	[a]	0.045	[a]	0.019	[a]
	Cameroon	Duala	0.72	[a]	0.002	[a]	0.0005	[a]	0.004	[a]	0.007	[a]
		Garoua	1.30	[a]	0.003	[a]	0.0005	[a]	0.004	[a]	0.011	[a]
	Mali	Bamako	4.00	[a]	0.005	[a]	0.001	[a]	0.004	[a]	0.074	[a]
		Sikasso	na		na		Na				na	
	Nigeria	Lagos	17.2	[a]	0.008	[a]	0.064	[a]	0.004	[a]	0.082	[a]
		Kano	21.5	[a]	0.006	[a]	0.005	[a]	0.004	[a]	0.26	[a]
EGGS	Benin	Littoral	0.083	0.083	0.001	[a]	0.0003	[a]	0.004	[a]	0.001	[a]
		Borgou	na		na		Na		na		na	
	Cameroon	Duala	0.040	[a]	0.002	[a]	0.0003	[a]	0.004	[a]	0.001	[a]
		Garoua	na		na		Na		na		na	
	Mali	Bamako	0.59	[a]	0.0020	[a]	0.0003	[a]	0.0040	[a]	0.0030	[a]
		Sikasso	na		na		Na		na		na	
	Nigeria	Lagos	0.98	[a]	0.002	[a]	0.0003	[a]	0.004	[a]	0.008	[a]
		Kano	na		na		Na		na		na	

(*continued on next page*)

Table 5 (*continued*)

FOOD	Country	Centre	Concentration (mg/kg)									
			Al		As		Cd		Hg		Pb	
			$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max	$\bar{X}$	min–max
FISH	Benin	Littoral	0.60	[a]	1.44	[a]	0.027	[a]	0.101	[a]	0.070	[a]
		Borgou	71	[a]	3.08	[a]	0.18	[a]	0.045	[a]	0.25	[a]
	Cameroon	Duala	1.84	0.23–3.44	1.41	1.11–1.72	0.012	0.009–0.015	0.039	0.038–0.040	0.013	0.003–0.023
		Garoua	7.71	0.52–14.9	0.033	0.016–0.049	0.001	0.0003–0.002	0.023	0.011–0.034	0.013	0.003–0.0023
	Mali	Bamako	144	[a]	0.024	[a]	0.008	[a]	0.072	[a]	0.118	[a]
		Sikasso	373	[a]	0.046	[a]	0.011	[a]	0.058	[a]	0.23	[a]
	Nigeria	Lagos	0.39	[a]	1.00	[a]	0.015	[a]	0.046	[a]	0.013	[a]
		Kano	na		na		Na		na		na	
MILK/DAIRY	Benin	Littoral	0.37	0.27–0.47	0.003	0.0008–0.006	0.0006	[a]	0.005	0.002–0.008	0.002	0.001–0.003
		Borgou	0.09	[a]	0.0004	[a]	0.0001	[a]	0.002	[a]	0.002	[a]
	Cameroon	Duala	0.28	[a]	0.004	[a]	0.0005	[a]	0.008	[a]	0.003	[a]
		Garoua	na		na		Na		na			
	Mali	Bamako	0.36	0.35–0.37	0.002	0.001–0.004	0.0003	0.0001–0.0005	0.005	0.002–0.008	0.0025	[a]
		Sikasso	na		na		Na					
	Nigeria	Lagos	0.79	[a]	0.004	[a]	0.0005	[a]	0.008	[a]	0.0050	[a]
		Kano	na		na		Na		na		na	

Mean ($\bar{X}$) and minimum/maximum (min-max).
na: data not available due to lack of analysed samples.
[a] Upper bound value (no min/max available).

(Littoral, 0.010 mg/kg), and a citrus sample (Littoral 0.035 mg/kg; not shown here).

In Nigeria and Cameroon, Hg was quantified in salt samples (miscellaneous food group) at 0.098 mg/kg in a sample from Kano/Nigeria and 0.166 mg/kg from Duala, Cameroon (not shown here).

3.5. *Aluminium (Al)*

Al levels were above LOQ in all samples collected from the four countries except in the case of eggs collected from Benin and Cameroon, one edible oil sample collected from Cameroon, and one beverage sample from Mali (Table 3). The most extensive variability of Al concentrations was observed for cereals and tubers (Table 4), with a maximum of 662 mg/kg measured in sesame seeds from Sikasso, Mali (Table 5).

Relatively high Al levels were quantified in fish collected from Mali (144 and 373 mg/kg in Bamako and Sikasso, respectively), in a traditional soft drink (beverages group) from Borgou, Benin (50.2 mg/kg), and two salt samples (miscellaneous group) from Littoral (39.0 mg/kg) and Borgou (11.4 mg/kg). Unfortunately, the Al contamination sources of these food items was not clearly assessed and requires further investigation.

3.6. *Impact of artisanal cookware on food contamination during cooking*

The relatively large variety of artisanal cooking utensils made in Africa from recycled aluminium and the impact of this traditional cookware on food contamination with trace amounts of the five inorganic contaminants studied herein (As, Al, Cd, Hg, and Pb) during cooking were assessed.

The tomato core food, with a relatively acidic matrix, was considered individually as it was previously shown that acidity increases leaching of trace elements from metallic food contact materials (Weidenhamer et al., 2017, Street et al, 2019). The comparative contamination data of the traditional cookware for each country are shown in Table 6 for tomatoes and other mixed core foods. The ratios between the Al, As, Cd, Hg, and Pb concentration obtained using stainless-steel or artisanal cookware (referred to as contamination factors, CF) are reported. It should be noted that the pots were not identical in the four countries studied herein, which may affect the statistical significance of the obtained data.

Among the five trace toxic elements studied herein, relevant contamination of Al and Pb due to the artisanal cookware was observed for the tomatoes (Table 6).

Pb leaching indicates the presence of this contaminant in the alloy of the artisanal cookware considering that such artisanal cookware are generally manufactured from low quality metal waste. For Al, the maximum impact of artisanal cookware was observed in Cameroon and Nigeria with CF values of 17 and 21, respectively. Similar behaviour was observed for Pb, with the highest contamination observed in Cameroon (CF = 26) and Nigeria (CF = 13). The tomato contamination with Al and Pb was lower in Benin and Mali (CF < 6 for both Al and Pb). These data are consistent with the data reported by Weidenhamer et al. (2017) that showed artisanal cookware composed of recycled aluminium may be a significant source of Al and Pb contamination. Therefore, exposure to toxic trace elements leached from inexpensive, artisanal aluminium cookware produced from recycled metallic waste may pose a public health concern in the developing world, including African countries. Apart from Al and Pb, the concentration factors were relatively low (CF $\cong 3$) for As and Cd in tomatoes in Cameroon, while for the other core foods, contamination was negligible, with the exception of Pb in Mali (CF = 5).

Statistical tests (p value) were used to compare the artisanal cookware contamination with Al, As, Cd, Hg, and Pb of tomato composite samples and other core foods from all four countries. Significantly higher contamination ($p < 0.05$, not shown here) of tomatoes was observed compared to those of the other core foods only for Al. This confirms that meals prepared with cooked tomatoes may be prone to contamination with toxic trace metals from the traditional cookware due to their acidity, promoting leaching of Al particularly from artisanal cooking utensils composed of recycled Al.

4. Conclusions

Herein, the concentrations of 30 inorganic (elemental) contaminants in foods collected within the first multi-centre regional Sub-Saharan African TDS (Benin, Mali, Cameroon, and Nigeria) are presented. The discussion focuses on the occurrence data of Al, As, Cd, Hg, and Pb.

Heterogeneous levels of these contaminants were observed in different core foods, countries, and between two locations within the same country. In most of the samples, the levels of the four highly regulated

Table 6

Concentrations and concentration factors (CF) of Al, As, Cd, Hg, and Pb (mg/kg) in core foods prepared with stainless-steel and traditional aluminium cookware.

CORE FOOD	Country	n	Concentration (mg/kg)						
			Al			As			Cd
			Stainless steel	Aluminium	CF[a]	Stainless steel	Aluminium	CF[a]	Stainless steel
TOMATO	Benin	1	4.22	8.70	2.1	0.004	0.005	1.3	0.008
	Cameroun	1	1.33	22.8	17	0.002	0.008	4.0	0.001
	Mali	1	0.33	1.14	3.5	0.001	0.001	1.0	0.004
	Nigeria	1	0.47	9.70	21	0.001	0.002	2.0	0.004
	Mean ± SD[b]		1.59 ± 1.81	16 ± 9.0	**6.7**	0.002 ± 0.001	0.004 ± 0.003	**2.0**	0.004 ± 0.003
OTHER FOODS	Benin	5	1.51	1.74	1.1	0.004	0.0045	1.0	0.001
	Cameroun	5	9.19	8.15	0.9	0.012	0.0102	0.8	0.002
	Mali	4	1.79	3.73	2.1	0.010	0.010	1.0	0.001
	Nigeria	5	3.10	4.11	1.3	0.002	0.003	1.1	0.0004
	Mean ± SD[b]		3.90 ± 3.60	4.43 ± 2.69	**1.1**	0.007 ± 0.0048	0.0079 ± 0.004	**1.0**	0.001 ± 0.001

CORE FOOD	Concentration (mg/kg)							
	Cd		Hg			Pb		
	Aluminium	CF[a]	Stainless steel	Aluminium	CF[a]	Stainless steel	Aluminium	CF[a]
TOMATO	0.010	1.2	0.004	0.010	2.4	0.005	0.007	1.4
	0.003	3.0	0.004	0.004	1.0	0.013	0.34	26
	0.004	1.0	0.004	0.004	1.0	0.001	0.008	6.2
	0.004	1.0	0.004	0.004	1.0	0.006	0.078	13
	0.005 ± 0.003	**1.3**	0.004	0.00 ± 0.003	**1.5**	0.006 ± 0.005	0.11 ± 0.16	**18**
OTHER FOODS	0.002	2.2	0.003	0.003	1.0	0.016	0.016	1.0
	0.002	1.1	0.003	0.003	1.0	0.008	0.018	2.2
	0.002	1.5	0.004	0.004	1.0	0.002	0.011	5.2
	0.0005	1.2	0.003	0.003	1.0	0.036	0.025	0.7
	0.002 ± 0.001	**2.0**	0.003 ± 0.0002	0.003 ± 0.0002	**1.0**	0.015 ± 0.015	0.018 ± 0.006	**1.2**

In bold: mean concentration calculated per trace elements for all countries per core food.

[a] Concentration factor (ratio between the level measured in the same sample prepared with aluminium and stainless-steel cookware).

[b] Standard deviation.

inorganic contaminants (As, Cd, Hg, and Pb) were consistently lower compared to the maxima set by the current Codex or European regulations. It should be noted that the staple foods, cereals and tubers, were frequently contaminated with Al and Pb.

The magnitude of the migration of Al and Pb from artisanal aluminium cookware to the prepared food was particularly noticeable during the preparation of tomato samples. This may represent a significant contribution to the dietary exposure towards these toxic elements, which can be reduced by using stainless-steel kitchen utensils.

The next phase in this research project will be to use the occurrence data to characterise dietary exposure of the studied populations.

5. Disclaimer

The views expressed in this information product are those of the authors and do not necessarily reflect the views or policies of FAO and WHO.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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