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Methodology design of the regional Sub-Saharan Africa Total Diet Study in Benin, Cameroon, Mali and Nigeria

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ABSTRACT

The core food model was described more than three decades ago, and has been used ever since to identify main food contributors to dietary intakes for both nutrients and other food chemicals. The Sub-Saharan Africa Total Diet Study (SSA-TDS) uses this model to describe the food consumption habits of some selected populations of Benin, Cameroon, Mali, and Nigeria, prior to use in the completion of quantitative risk assessments with regard to food chemicals. Food consumption data were derived from food expenditure data contained in national household budget surveys that were provided by the national institutes of statistics in each country. A classification of African foods was established for the purpose of the study and core foods were selected, so as to reflect 96 ± 1% of the average national total diet expressed in weight. Populations from eight study centers were selected by national stakeholders. This approach involves the purchase of 4020 individual foods, prepared as consumed and pooled into 335 food composite samples, for analysis of mycotoxins, PAHs, PCBs and dioxins, pesticides, metals and trace elements, PFAs, and BFRs. This sampling plan aims to provide a representative, cost effective, and replicable approach for deterministic dietary exposure assessments in developing countries.

1. Introduction

Evaluating the human exposure to potentially harmful substances is a key step in public health risk assessments. A better understanding of these exposures leads to evidence-based decision-making processes, providing for improved risk management at national and international levels.

The dietary exposure of a given population to food chemicals

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can be assessed by different approaches (FAO/WHO, 1985; WHO, 2009). The most refined approach for obtaining food chemical concentration data to be used in dietary exposure assessments involves purchasing the foods people eat and analysing these foods. Assessing the occurrence of chemicals of interest in foods as consumed in order to effectively estimate the dietary exposure for different population groups requires an efficient, cost-effective, and accurate method, such as Total Diet Studies (TDS). The TDS approach has been promoted and endorsed by the World Health Organization (WHO) along with the Food and Agriculture Organization of the United Nations (FAO) since the 1960s (WHO, 1968) and more recently in 2011 in a joint guidance document from European Food Safety Authority (EFSA), WHO and FAO (EFSA, 2011b).

TDS are designed to measure the average amount of a given substance ingested by a studied population. This public health oriented approach differs from classical chemical surveillance programs because: (1) it focuses on chemicals in the total diet rather than in specifically targeted food commodities and (2) it takes into consideration, to a certain extent, the impact of home cooking on the decomposition or formation of chemicals, as the foods are prepared as for consumption before analyses (WHO, 2007).

The core food approach was first described in 1982 for the US Total Diet Study (Pennington, 1983; Egan et al., 2007) and has since been used as a common tool by other food safety agencies around the World (EFSA, 2011a; WHO, 2009). A TDS enables identification of foods that are most highly consumed by a study population (in terms of quantity) and which foods contribute most to intakes of energy, nutrients, and other food chemicals. A core food list gathers the main foods representing at least 90% by weight of the average total diet. These foods are sampled and analyzed for the assessment of nutritional intakes or dietary exposure to other food chemicals of a given population.

Two specific aspects characterize a TDS: (1) the representativeness of the sampling and (2) the preparation of the samples "*as consumed*", so that it represents a pertinent public health risk assessment tool, as far as food safety and nutrition are concerned.

The four key steps of a TDS implementation within a specific population include (1) the identification of core foods (2) the derivation of both the average and the high-consumers daily food consumption (3) the sampling, preparation (i.e. prepared and cooked as per the typical consumer behavior), and laboratory analyses of the sampled core foods for nutrients and/or other food chemicals and (4) the exposure assessment and risk characterization obtained from consumption data multiplied by food chemicals concentration data.

Between 2006 and 2010, a TDS was implemented in the city of Yaoundé, Cameroon for the purpose of screening pesticides (Gimou et al., 2008) and metals and trace elements (Gimou et al., 2014). This first ever TDS implemented in Sub-Saharan Africa used a food list including 63 food items obtained from the pooling of national food items from the Cameroonian Household Budget Survey. The Sub-Saharan Africa Total Diet Study (SSA-TDS) is a wider project aiming to investigate a more extended number of food chemicals, within a larger study population.

The SSA-TDS was implemented by FAO in Benin, Cameroon, Mali and Nigeria between 2014 and 2017, together with the four national food safety authorities, in close collaboration with Center Pasteur of Cameroon (CPC) and WHO (FAO, 2014a).

Due to budget constraints, the national stakeholders of the four countries decided to select only two population groups per country. The basis for the selection of the two different population groups per country was distinct dietary behaviors, associated with distinct agro-ecological areas. These study centers include in each country (1) the most densely populated city (Bamako, Cotonou, Duala and Lagos), among which three are located by the Atlantic Ocean Coast, and (2) another study center located in a non-coastal area (the Sikasso Region of Mali, the Borgou Department of Benin, the North Region of Cameroon and the State of Kano of Nigeria).

The design and main methodological choices, forming the basis of the Sub-Saharan Africa Total Diet Study (SSA-TDS) in terms of selection of core foods, food sampling approach, food sample preparation and chemical substances looked for, which represent the main challenges for implementing and adapting the TDS approach for developing countries, are presented here below.

2. Materials and methods

2.1. Food classification and food consumption data

Food consumption data were derived from household budget surveys (HBS) available in Benin, Cameroon, Mali, and Nigeria. The four HBS gather data from a total of 72,979 households and include both the estimated value of food produced by households for their own consumption and the amount spent for each food commodity recorded by national institutes of statistics and expressed in local currency and recorded over a two-week period.

Data recorded by the four national institutes of statistics used heterogeneous food nomenclature, including the total number of distinct food items recorded ranging from 163 (Mali) to 284 (Cameroon). In order to generate comparable food consumption data among the 4 countries, two additional and harmonized levels were added to the food classification as shown in Fig. 1.

The adopted strategy consisted of setting up a corresponding table for each country between the national food items representing 100% of the average national diet and two additional levels that are of a higher ranking. The two additional levels are (1) 84 food subgroups, among which core foods are selected for the purpose of the study and considered to be the maximum pooling level for sampling and (2) 13 food groups taken from the food classification used in the West African Food Composition Table (FAO, 2012). These corresponding tables were filled for each country starting with the lowest ranking level (i.e. for each national food item table), entering edible fraction conversion factors, yield factor (reflecting weight change during the cooking process) and energy content either obtained from the West African Food Composition Table (FAO, 2012) or the French Food Composition Table (ANSES, 2013).

In order to obtain a standardized unit to describe the energy intake of the study population, the sex and age of every household member was systematically recorded in each of the four national household budget surveys (HBS), and converted into adult male equivalents (AME) using the equivalence scale from Nigeria (Table 1).

The relevance of using AME for estimating household energy requirement was summarized by the United Nations University (Weisell and Dop, 2012). Estimating the energy requirement of a household serves to select households whose declared food expenditure corresponds to a realistic range of energy intake.

Food consumption data were estimated as daily consumption of food "as consumed" in grams per adult male equivalent per day derived using the following three-step process: (1) food expenditure and food produced by households for their own consumption reported by national HBS in local currency recorded over a two-week period and converted into "daily quantity of raw food commodity purchased" with the help of a unit price database provided by each national institute of statistics (2) quantities of raw food commodity purchased or produced for household consumption converted into "daily quantity of edible raw food commodity" with edible fraction conversion factors identified in the West African

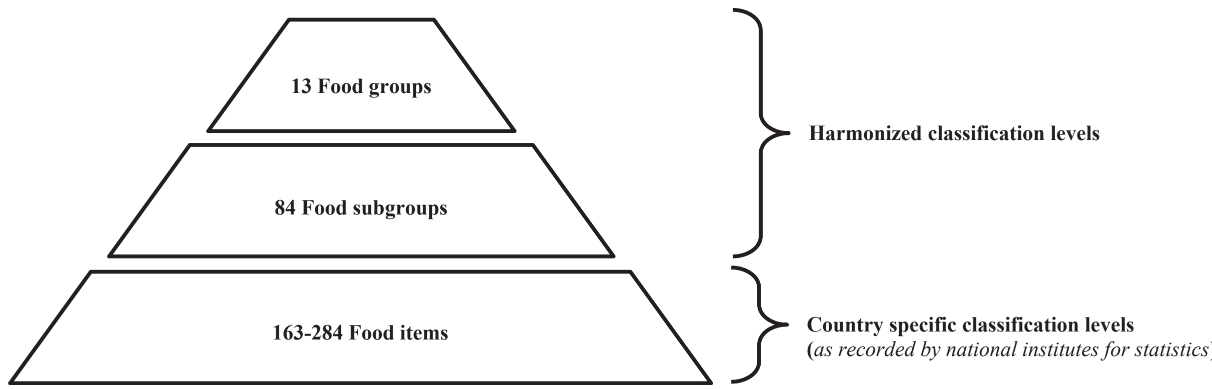

Fig. 1. Hierarchy of the food classification consisting of 3 strata representing each 100% of the average national total diet.

Table 1
Adult equivalence scale (source: National Bureau of Statistics, Nigeria).

Age Group	Male	Female
Less than 1 year	0.25	0.25
1 to less than 4 years	0.45	0.45
4 to less than 7 years	0.62	0.62
7 to less than 11 years	0.69	0.69
11 to less than 15 years	0.86	0.76
15 to less than 19 years	1.04	0.76
19 to less than 26 years	1.00	0.76
26 to less than 51 years	1.00	0.76
51 years and above	0.79	0.66

Food Composition Table (FAO, 2012) (3) quantity of edible raw food converted into "daily amount of food as consumed" with yield factors (FAO, 2012).

In order to eliminate biases due to under-reporting or over-reporting families, normal reporting households were selected within the range from 1200 kcal/AME/day to 5100 kcal/AME/day. Under-reporting and over-reporting households were discarded from datasets. These extremes correspond to the mean energy requirement of an adult male of 60 kg (FAO, 2001) minus 45% for the lower limit and plus 45% for the higher limit. These margins were selected on the basis of the hypothesis that 1SD = 15%, in order to include households energy requirements ± 3SD. After applying these limits, 61% of the 72,979 recorded households were selected to form a dataset of 44,431 normal reporting households.

The general description of the original food purchase datasets for the four countries before and after selection of normal reporting households is displayed in Table 2.

2.2. Selection of core foods

Four national core food lists were established (one per country) as the result of a selection process from a harmonized list of 84 food subgroups (Fig. 1). Representativeness criteria were set with two objectives (1) the coverage by core foods of the average total diet and (2) the coverage of each of the 13 food groups by the selected core foods. Each national list applies to the two study centers selected by each country, with a decision tree (Fig. 2) defining whether composite samples shall be collected locally, or nationally.

2.3. Core food representation versus total diet

In each of the 4 countries, the food subgroups (also named core foods in this study when selected for sampling) were ranked on the basis of their average consumption in grams per adult male equivalent per day and selected in descending order from the most consumed until reaching coverage of 90% of the total average national diet.

2.4. Core food representation versus main food groups

In order to ensure that the various food groups of the diet are adequately represented in the sampling approach, inclusion criteria for the establishment of the core food list were set as follows:

- If the national average consumption of the food group represents more than 1% of the total average national diet in weight, then the total average daily consumption of the food subgroups selected from this food group shall represent 90% of the food consumption of this group or more.

Table 2
Description of national household budget surveys used for setting up food consumption patterns.

Country	Benin	Cameroon	Mali	Nigeria	SSA Total diet study
Data source	National Institute for Statistics and Economic Analysis (INSAE)	National Institute for Statistics (NIS)	National Institute for Statistics (INSTAT)	National Bureau of Statistics (NBS)	TOTAL
National identification of survey	EMICoV	ECAM 3	MICS-ELIM	HNLSS	–
Year of survey implementation	2011	2007	2010	2010	–
Total number of households	17,667	11,347	8987	34,978	72,979
Number of selected households	13,967	8471	7834	14,159	44,431
Percentage of selected households	79%	75%	87%	40%	61%

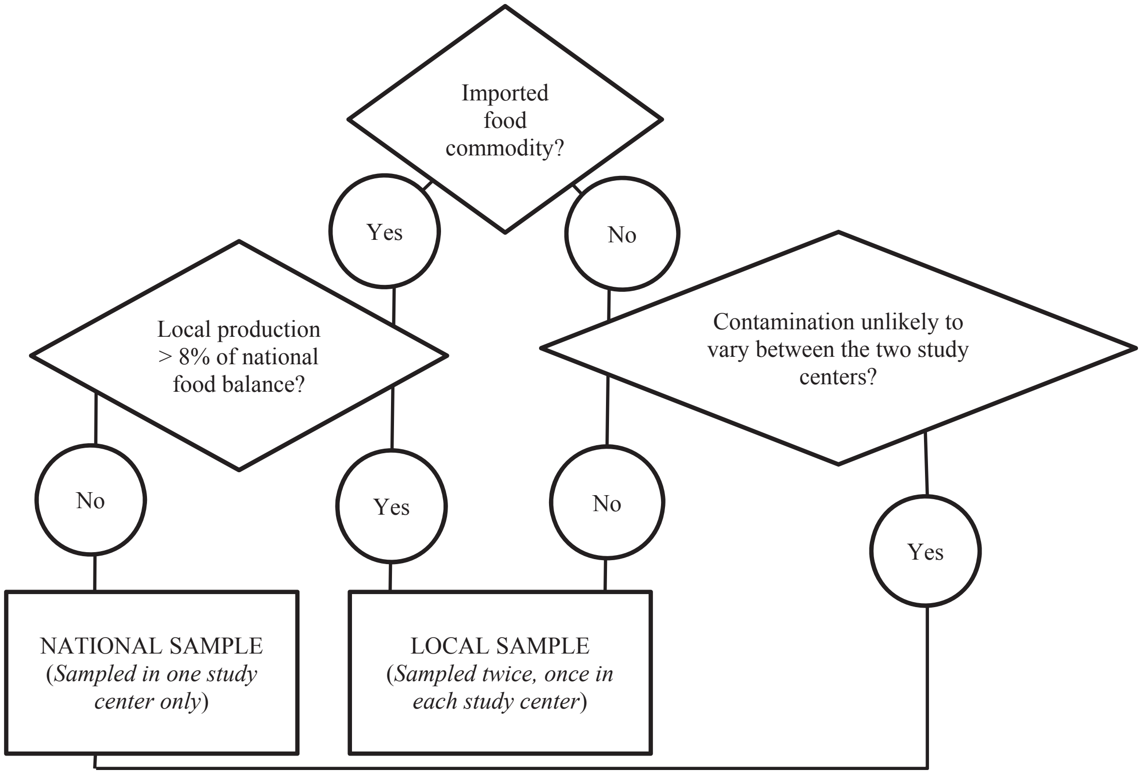

Fig. 2. Decision tree for choosing if a food commodity shall be nationally or locally sampled.

- If the food group average consumption in grams per adult male equivalent per day represents less than 1% of the total average national total diet in weight, then the total average daily consumption of the food subgroups selected from this food group shall represent at least 50% of the food consumption of this food group.

These criteria enable significant coverage of each food group with selected core foods, whilst making sure that the sampling approach focuses on most consumed food commodities. The logic is that, if core foods were also selected within food groups representing less than 1% in weight of the average national diet so as to cover 90% of the food group consumption (same criterion for all food groups), it was estimated that the number of samples needed would increase by 20% whereas the coverage in weight of the average total diet would only be 1% higher, which would not be cost effective.

2.5. Specifications of food composite samples

2.5.1. Inclusion of local specificity of samples

The SSA-TDS terminology slightly differs from the one used in the New Zealand and in the French TDS (Sirot et al., 2009). Instead of using the notion of "*regional food list*" versus "*national food list*", the SSA-TDS addresses the same concern by contrasting "*national sampling*" to "*local sampling*" from one single national food list. The SSA-TDS only includes two study centers per country, with supposedly distinct food consumption patterns and food supply. Because the variance in food chemical concentration pattern for some food commodities is prone to be higher than others, a decision was made as to its local sampling (food commodity sampled in both study centers) or if the food can reasonably be sampled nationally (collected in only one of the two study centers), as described in Fig. 2.

Local sampling is chosen by default in the absence of evidence that the food chemical concentration pattern is unlikely to vary between the two study centers or to impact significantly the resulting dietary exposure assessment. In contrast, a national sampling approach is chosen for food commodities which are mainly (1) imported, (2) industrially processed, or (3) mostly produced and/or consumed in the area where it is collected. In those later cases, although the food chemical concentration pattern is likely to vary from one location to the other, it is unlikely to significantly impact the dietary exposure pattern, which justifies the need of only one sample for both locations.

2.5.2. Food sampling methodology

2.5.2.1. Number of subsamples by composite sample. The SSA-TDS uses the individual food approach with twelve subsamples of the same food commodity per composite sample. The number of 12 subsamples of equal weight, representing each one 12th or slightly more than 8% of any specific composite sample was defined according the statistical basis published from the FP7 research program on TDS exposure (European Commission, 2016b), which was used as a benchmark and replicated in our study. The true standard deviation of concentration and the true mean concentration of a given substance in a food commodity in relation with the number of subsamples collected and pooled per composite sample were investigated. The width of the 95% confidence interval for the estimate of the true mean concentration was summarized, according to the number of pooled subsamples. In a situation where the true SD is unknown, which is the case for our study, hypotheses range from low variability (SD = 30% of true mean concentration) to high variability (SD = 100% of true mean concentration). The pooling of twelve subsamples turns out to be a cost effective approach, with limited impact on the confidence interval of food chemicals concentration.

The adequate selection of representative subsamples to form individual composites is a major consideration of the sampling plan design (Tsukakoshi, 2011). In TDSs implemented in developed countries, it is common that the allocation of subsamples is proportional to market shares, which often refers to trademarks owned by known operators and clearly identifiable on the shelves of supermarket (Sirot et al., 2009). In developing countries however, this principle remains but needs to be adapted to the local food supply and distribution context. Most food commodities sold at the retail level in Africa, especially locally produced ones, do not bear any distinctive sign, brand, batch number, expiry date, or even a label. Food distribution in the Sub-Saharan Africa countries of this study mostly takes place in daily or weekly markets, involving a large number of ever-changing stakeholders.

2.5.2.2. Subsamples selection criteria. A specific sampling approach is used in the framework of the SSA-TDS that involves 3 major components: (1) the proportion of various origins, from which a given food commodity is imported, in the country where the sampling is taking place (2) the breakdown of the various food items recorder by the national institutes of statistics, at the most detailed level of ranking of the food classification and (3) information collected during field market surveys with regard to the flows of food commodities (Fig. 3).

As far as the sampling is concerned, preference is given to wholesale markets, which enabled the differentiation of the origin of the twelve collected subsamples, and thus to ensure that the intrinsic variability of subsamples is adequately taken into account in the pooled sample. Twelve distinct batches are collected randomly from wholesale markets located in the study center area.

The average national food balance sheet over five years was calculated from the International Trade Center (ITC) database for imported and exported food quantities (ITC, 2016), whereas local food production was extracted from the FAOSTAT database (FAO, 2014b). ITC data also include the origin(s) of food and the proportion of the each source in the food supply, which was reflected in the proportions of subsample of each origin of significant important (i.e. more than 8% or one twelfth of the food commodity supply).

The pooling level chosen for composite samples in this study is the second stratum of the classification pyramid (Fig. 1), consisting of 84 subgroups, including the selected core foods (Table 4). More detailed information available for some food commodities at the bottom stratum of the hierarchy can be exploited to define the proportions of each kind of subsample, which reflect the average behavior of the study populations. Because these data are available for each of the eight study centers enrolled in the project, as well as for the whole national population, these proportions are specific to each location, from where a sample is collected.

Based on the sampling plan, covering more than 90% of the average total diet, each study center was visited and questionnaires were submitted to local market leaders in order to identify (1) the main purchase areas (2) whether market places are wholesale or retail (3) the origins of food commodities (4) main cultivars or varieties (5) the seasonality, and (6) the average price for retail and wholesale. This information was used to define, for each applicable criterion, the breakdown of the twelve subsamples of equal size needed to obtain a representative food composite sample.

2.5.2.3. Seasonality. In order to capture the seasonal variance of food chemical concentration patterns, the SSA-TDS methodology takes into considerations two sampling waves, which are analyzed independently. Seasonal variability may reflect differences in the occurrence of food chemicals during the rainy season and the dry season, or due to different agricultural or post-harvest conditions and practices applied to the food supply throughout various times of the year.

The first sampling campaign includes all 13 food groups (cereals, tubers, legumes, vegetables, fruits, nuts and seeds, meat, eggs, seafood, dairy products, beverages and miscellaneous), and the seven analyte groups (metals and trace elements, mycotoxins, pesticides residues, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCB and PCDD/F), perfluoroalkoxy alkanes (PFAs), and brominated flame retardants (BFRs)). Tap water is also collected as a representative composite sample in each study center.

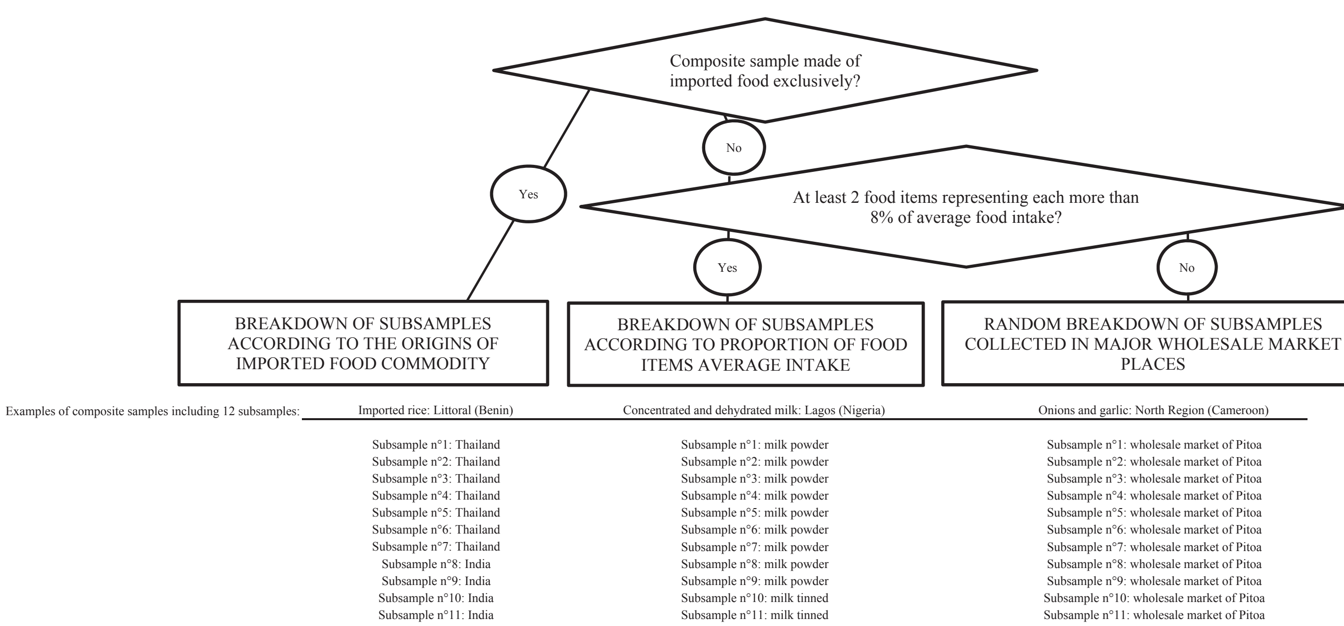

Fig. 3. Decision tree and breakdown of subsamples in composite samples.

Table 3
Analytical grid describing in each food group the selected core foods (matrices) tested against the seven analyte groups.

	Analyte groups	Minerals and Trace Elements	Mycotoxins	Pesticides residues	Polycyclic Aromatic Hydrocarbons	Polychlorinated Biphenyls and Dioxins, Perfluoroalkoxy alkanes, Brominated flame retardants
Food groups	Cereals	All matrices	All matrices	All matrices	Not tested	Not tested
	Tubers	All matrices	Dried tubers	All matrices	Dried tubers	Not tested
	Legumes	All matrices	All matrices	All matrices	Not tested	Not tested
	Vegetables	All matrices	Onion and Garlic	All matrices	Not tested	Not tested
	Fruits	All matrices	Not tested	All matrices	Not tested	Not tested
	Nuts & Seeds	All matrices	All matrices	All matrices	Not tested	Not tested
	Meat	All matrices	All matrices	All matrices	Not tested	All matrices
	Eggs	All matrices	All matrices	All matrices	Not tested	All matrices
	Seafood	All matrices	Smoked fish	All matrices	Smoked fish	All matrices
	Dairy	All matrices	All matrices	All matrices	Concentrated and dehydrated milk	All matrices
	Oil & Fat	All matrices	All matrices	All matrices	Oil and fat	All matrices
	Beverages	All matrices	Traditional & fermented drinks	All matrices	Not tested	Not tested
	Miscellaneous	All matrices	All but salt	All matrices	Peper, coffee, chocolate and broth	Coffee, chocolate and broth

Due to limited resources, the second sampling campaign focuses on core foods included in 5 main food groups, (cereals, tubers, legumes, vegetables and fruits). Tap water is also collected as a representative composite sample in each study center during the second wave. The second sampling campaign enables the screening of two analyte groups (mycotoxins and pesticides residues), the concentration of which is likely to vary due to agricultural practices, climatic and post-harvest conditions, which differ through the various times of the year.

2.5.3. Preparation of food as consumed

Subsamples are collected and prepared individually according to recipe books (Vinakpon-Gbaguidi, 2003; Nya-Njike, 1998; Gautier and Mallet, 2006; Madubike, 2013) , using inert kitchen utensils. These references are considered as representative of the diet of the study populations and were therefore selected by the national competent authorities. By the expression “prepared individually” it is meant that no salt, oil, nor spices are added to the composite samples, and that, unlike in real situations, core foods from different food subgroups are not mixed together. These recipe books allow the identification of the processes used in the preparation of the foods, especially cooking time and temperature. However, actual recipes are not prepared, as each composite sample only contains one core food or ingredient. The inedible parts are removed at the preparation stage, as a typical consumer would do. Distilled water is used to prepare food as consumed, instead of tap water, which is also part of the sampling. The quantity of water added during the cooking process of each of the 12 subsamples is measured by weighting the food at each stage of the process.

2.5.4. Core analyte list

The seven analyte groups included in this study are pesticides, metals and trace elements, mycotoxins, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCB and PCDD/F) perfluoroalkoxy alkanes (PFAs) and brominated flame retardants (BFRs). These groups are described in the results section of this paper, as a core food chemicals list.

The choice of analyte groups was made by the national stakeholders (e.g. 30–50 food safety professionals per country), and was discussed with a scientific committee, without applying the methodology proposed by the EU TDS Exposure project (Papadopoulos et al., 2015).

2.5.5. Food chemical analysis

Analytical performance (LOD/LOQ) often becomes a limiting factor for risk assessors. In order to avoid as much as possible uncertainties in dietary exposure that could result from the inclusion of censored data with high analytical limits, special care was taken in the selection of testing laboratories so as to reach adequate limits of quantification for risk assessment purposes. In order to help laboratories to achieve this, calculations were made to assess satisfactory analytical limits. When a substance is not detected or cannot be quantified, two scenarios (upper bound and lower bound), based on the value of analytical limits, were used to estimate exposure. In the upper-bound scenario (UB), all results below analytical limit are considered to be equal to the analytical limit. In this TDS, as in the French infant TDS (Hulin et al., 2014), we estimated the maximum value of analytical limits of quantification (LOQ), so as to obtain a total UB exposure value of no more than 30% of the reference point or point of departure (e.g. acceptable daily intake (ADI) or tolerable daily intake (TDI)) in the case of non-detection or quantification of the substances looked for in all tested samples.

For margin of exposure (MOE) calculations (e.g for 13 PAHs, PCBs congeners and some mycotoxins), the harmonized approach for risk assessment of substances, which are both genotoxic and carcinogen established by WHO and EFSA applies (WHO, 2006; EFSA, 2005). The approach consists of verifying that analytical limits corresponds to a total UB exposure with a MOE above 10,000 compared to the applicable level of toxicological significance, and therefore associated with low levels of concern. For each selected substance, laboratories were required to reach targeted LOQs. All analytical limits, as well as which limit was used for the UB scenario (LOD or LOQ) targeted prior to analysis and actually reached by laboratories will be described in future articles dealing with the analytical results of this TDS.

The type of analysis performed on each composite sample primarily depends on the likelihood of finding food chemicals in the matrix. The analytical grid represented in Table 3 describes which matrices are tested against which analyte groups.

2.5.6. Data analysis

Households' food purchase data, food prices, edible fraction conversion factors, yield factors, and energy content were processed with the SPSS 18.0 (IBM) software. The *t*-test for comparing mean consumption of cereals was completed with XLSTAT (AddinSoft).

Table 4
Selection of core foods from food subgroups on the basis of mean national daily consumption in grams per adult male equivalent.

Food group	Code	Food subgroup	BENIN				CAMEROON				MALI				NIGERIA			
			% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study
CEREALS	1.1	RICE	80	133.8	445.7	7.3	78	221.0	735.5	11	98	573.5	1419.2	33	76	211.7	860.9	13
	1.2	MAIZE	99	740.7	1709.3	41	69	384.9	1808.5	20	51	139.5	821.2	7.9	46	223.7	1452.7	13
	1.3	WHEAT/BREAD	35	14.1	152.2	NS	74	43.6	157.6	2.2	82	26.7	114.9	1.5	58	15.7	100.8	0.9
	1.4	PASTA	27	28.9	283.7	1.6	17	8.3	136.4	NS	31	7.7	89.2	NS	12	3.6	98.8	NS
	1.5	SORGHUM	13	53.3	896.1	2.9	12	122.8	2294.5	6.3	51	228.7	1270.4	13	44	250.4	1364.2	15
	1.6	MILLET	6	21.5	691.4	1.2	3	9.1	1291.5	NS	74	411.7	1525.6	23.5	34	181.2	1345.7	11
	1.7	OTHER CEREALS	14	12.6	253.3	NS	22	9.8	160.3	NS	20	15.6	433.6	NS	9	18.4	663.1	NS
TUBERS	2.1	CASSAVA FRESH	19	17.3	262.8	0.9	61	109.7	615.6	5.6	22	1.9	35.1	0.1	20	28.8	565.0	1.7
	2.2	CASSAVA DRY	69	206.8	799.3	11	37	83.3	927.3	4.3	23	8.7	121.7	0.5	50	268.0	1614.5	16
	2.3	YAM FRESH	46	78.8	490.8	4.3	32	27.8	264.7	1.4	34	2.8	25.3	0.2	50	84.4	531.9	5.0
	2.4	YAM DRY	6	8.2	394.8	NS	NR				0	0.03	.	NS	9	8.6	344.5	NS
	2.5	POTATO FRESH	2	0.5	78.3	NS	23	23.4	289.3	1.2	39	3.9	31.9	0.2	6	3.0	203.9	NS
	2.6	POTATO DRY	NR				1	2.2	2106.3	NS	NR				NR			
	2.7	SWEET POTATO	8	5.7	186.8	NS	41	47.7	332.0	2.4	68	12.7	54.4	0.7	14	6.2	179.8	NS
	2.8	COCOYAM	NR				12	21.5	484.5	1.1	2	0.2	37.7	NS	15	8.9	222.6	0.5
	2.9	MACABO	NR				51	67.8	378.0	3.5	NR				NR			
	2.10	OTHER TUBERS	NR				1	0.8	483.9	NS	16	3.03	57.30	NS	3	3.7	446.6	NS
LEGUMES	3.1	BEANS	67	88.0	338.8	4.8	71	81.4	349.9	4.2	72	27.2	104.9	1.5	68	71.9	384.1	4.3
	3.2	GROUNDNUTS	24	3.0	36.2	NS	85	36.4	123.4	1.9	89	18.8	57.5	1.1	33	7.0	101.7	0.4
	3.3	PEAS	NR				2	1.6	212.8	NS	9	1.5	87.6	NS	13	40.0	864.0	2.4
	3.4	SOJA	NR				2	1.0	137.2	NS	NR				4	3.4	331.3	NS
	3.5	OTHER LEGUMES	NR				5	0.3	17.8	NS	5	0.5	28.9	NS	8	5.0	306.7	NS
VEGETABLES	4.1	TOMATO	89	81.9	305.5	4.5	75	31.7	110.7	1.6	89	16.1	53.7	0.9	72	21.4	106.8	1.3
	4.2	CARROTS	2	0.1	12.7	NS	11	1.5	43.7	NS	17	0.2	3.7	NS	NR			
	4.3	GREEN LEAVES	37	3.6	32.5	NS	73	78.3	287.0	4.0	64	4.4	20.1	0.2	6	0.6	32.9	NS
	4.4	COURGETTES, CUCUMBER & GROUND PEPER	8	0.8	28.4	NS	23	1.3	18.4	NS	57	5.5	27.4	0.3	11	1.2	36.9	NS
	4.5	CABBAGE	1	0.1	20.1	NS	10	5.0	126.3	NS	52	2.0	10.8	0.1	3	0.3	41.1	NS
	4.6	ONION & GARLIC	80	12.8	45.5	0.7	73	8.0	32.6	0.4	91	9.6	33.2	0.5	74	8.0	33.9	0.5
	4.7	OKRO = GOMBO	39	4.7	35.3	0.3	62	9.7	46.7	0.5	70	3.3	12.6	0.2	59	19.8	132.8	1.2
	4.8	PARSLEY, CELERY, BASIL & LEEK	NR				49	3.6	22.3	NS	NR				NR			
	4.9	OTHER VEGETABLES	39	4.7	35.7	NS	21	1.4	23.0	NS	56	2.6	14.7	NS	57	15.1	122.6	0.9
FRUITS	5.1	BANANA	6	0.7	33.5	NS	48	69.0	461.6	3.5	47	3.1	25.0	0.2	14	1.9	65.1	0.1
	5.2	PLANTAIN	3	0.7	58.3	NS	52	73.8	416.8	3.8	27	2.4	30.8	0.1	18	14.3	284.0	0.9
	5.3	MANGO	0	0.0	19.9	NS	7	1.2	48.1	NS	79	11.7	46.9	0.7	3	0.9	162.0	NS
	5.4	PINEAPPLE	4	1.3	101.4	NS	8	1.6	65.4	NS	3	0.1	13.4	NS	4	0.6	56.3	NS
	5.5	CITRUS (ORANGE, LEMON, LIME…)	12	3.7	98.1	0.2	30	8.3	87.0	0.4	63	2.9	15.4	0.2	19	3.5	71.3	0.2
	5.6	AVOCADO	1	0.1	36.0	NS	17	2.5	45.0	NS	7	0.3	9.6	NS	2	0.5	125.8	NS
	5.7	PAWPAW	2	0.5	75.3	NS	8	3.1	120.5	NS	20	0.7	10.9	0.04	6	1.7	114.1	0.1
	5.8	MELON / WATERMELON	0	0.1	68.6	NS	5	1.9	107.2	NS	57	19.0	104.8	1.1	6	0.9	73.5	0.1
	5.9	OTHER FRUITS	1	0.1	37.9	NS	28	2.3	26.7	NS	77	4.1	15.1	NS	0	0.0	36.9	NS

(*continued on next page*)

Table 4 (*continued*)

Food group	Code	Food subgroup	BENIN				CAMEROON				MALI				NIGERIA			
			% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study	% Consumers	Mean daily consumption (g/AME/day)	P95 consumers only (g/AME/day)	% Total Diet covered by study
NUTS & SEEDS	6.1	COCONUT	2	0.2	34.3	NS	2	0.3	52.1	NS	4	0.1	5.2	NS	4	0.7	79.5	NS
	6.2	CASHEW NET	0.1	0.01	.	NS	0.05	0.002	.	NS	NR				0	0.1	143.7	NS
	6.3	PALM NUT	16	0.8	14.3	0.05	11	3.0	76.9	0.2	NR				3	0.3	49.6	0.02
	6.4	OTHER NUTS/ SEEDS	10	0.5	12.7	NS	39	2.7	23.2	NS	4	0.5	38.7	0.03	29	3.8	55.2	NS
MEAT	7.1	BEEF	16	3.3	59.1	0.2	43	8.3	55.0	0.4	82	10.4	45.7	0.6	55	7.8	48.1	0.5
	7.2	POULTRY	7	0.9	37.6	NS	19	1.6	34.1	NS	63	1.8	9.7	NS	5	1.0	58.7	NS
	7.3	MUTTON/GOAT	5	0.5	29.9	NS	8	1.3	65.1	NS	60	2.9	15.7	NS	15	1.5	35.1	NS
	7.4	PORK	2	0.2	23.9	NS	4	0.5	30.4	NS	0	0.004	.	NS	1	0.2	35.3	NS
	7.5	PROCESSED MEAT	3	1.5	144.3	NS	3	0.2	23.2	NS	14	0.7	18.9	NS	0	0.0	113.0	NS
	7.6	GAME MEAT	NR				9	1.3	51.5	NS	3	0.05	7.1	NS	3	0.4	61.2	NS
	7.7	INSECTS	NR				1	0.1	23.3	NS	NR				NR			
	7.8	OTHER MEAT	2	0.2	23.8	NS	1	0.1	28.1	NS	3	0.1	8.4	NS	2	0.1	23.0	NS
EGGS	8.1	POULTRY EGGS	14	1.4	28.8	0.1	25	3.3	42.9	0.2	24	16.9	263.2	1.0	10	1.6	69.0	0.1
SEAFOOD	9.1	SEA FISH	31	4.9	43.4	NS	67	15.2	63.6	0.8	72	3.1	14.3	NS	65	10.6	57.8	0.6
	9.2	FRESH WATER FISH	NR				12	1.8	48.6	0.1	20	0.4	5.8	NS	NR			
	9.3	SMOKED FISH	80	9.0	32.3	0.5	62	4.9	21.8	0.2	72	6.4	22.2	0.4	15	1.9	45.9	NS
	9.4	PROCESSED FISH	6	2.1	101.5	NS	11	0.7	19.8	NS	NR				1	0.1	34.6	NS
	9.5	CRUSTACEANS/ MOLLUSCS	8	0.2	9.2	NS	28	0.7	7.3	NS	0.1	0.0001	.	NS	23	0.9	15.0	NS
	9.6	OTHER SEAFOOD	NR				2	0.1	8.4	NS	6	0.3	15.4	NS	NR			
DAIRY	10.1	FRESH/ FERMENTED MILK	11	5.1	192.1	0.3	14	2.2	57.6	NS	70	7.2	37.0	0.4	11	2.5	89.0	NS
	10.2	CONCENTRATED/ DEHYDRATED MILK	8	4.0	184.0	0.2	20	5.3	97.3	0.3	63	11.6	64.5	0.7	22	8.0	123.2	0.5
	10.3	OTHER DAIRY PRODUCTS	14	2.4	47.4	NS	3	0.3	37.0	NS	5	0.3	11.7	NS	5	0.9	66.7	NS
OIL & FAT	11.1	PALM OIL	64	17.5	70.0	1.0	66	28.3	105.8	1.4	22	1.0	13.3	NS	74	16.9	73.7	1.0
	11.2	GROUNDNUT OIL	59	15.5	66.5	0.8	15	3.1	70.0	NS	56	8.6	41.6	0.5	32	4.7	52.1	0.3
	11.3	OTHER VEGETAL OIL	15	1.6	27.2	NS	34	8.8	70.8	0.5	71	6.3	28.4	0.4	16	3.1	67.1	0.2
	11.4	OTHER FAT/OIL	10	0.9	27.4	NS	22	0.8	15.3	NS	13	2.8	137.3	0.2	5	0.7	60.4	NS
BEVERAGES	12.1	WATER	15	67.2	1473.2	3.7	14	10.9	302.7	0.6	6	2.3	179.3	0.1	13	5.6	198.5	0.3
	12.2	FRUIT JUICE	NR				3	0.6	71.3	NS	34	1.2	13.6	NS	2	0.6	116.2	NS
	12.3	TRADITIONAL SOFT DRINK	7	5.3	295.2	0.3	10	3.7	128.2	NS	NR				15	6.1	179.7	0.4
	12.4	TRADITIONAL FERMENTED DRINK	2	0.4	111.9	NS	24	31.8	473.1	1.6	NR				5	2.4	182.3	0.1
	12.5	INDUSTRIAL FERMENTED DRINK	20	7.2	135.4	0.4	72	38.3	223.7	2.0	NR				6	2.0	127.6	0.1
	12.6	INDUSTRIAL SOFT DRINK	9	4.2	164.6	NS	29	6.7	92.4	0.3	21	2.6	42.4	0.2	19	6.5	137.5	0.4
	12.7	SPIRITS	8	1.7	79.1	NS	3	0.3	37.3	NS	NR				2	0.2	44.7	NS
	12.8	OTHER DRINKS	NR				4	0.6	51.2	NS	NR				5	0.8	88.7	NS

MISCELLANEOUS	13.1	SUGAR	36	5.8	52.0	NS	51	10.6	70.0	0.5	99	50.5	115.5	2.9	53	6.0	37.6	0.4
	13.2	SALT	77	9.1	31.7	0.5	69	13.0	48.4	0.7	98	14.1	33.5	0.8	59	6.9	33.8	0.4
	13.3	BROTH/ BOUILLON CUBE	87	5.7	18.3	NS	88	2.8	7.9	NS	90	3.0	7.4	NS	74	9.7	49.6	0.6
	13.4	HONEY	0.4	0.02	21.2	NS	2	0.1	17.8	NS	0	0.0	8.5	NS	1	0.3	87.5	NS
	13.5	TEA	2	0.7	107.6	NS	10	0.2	5.7	NS	72	1.4	5.3	NS	12	0.7	22.5	NS
	13.6	COFFEE	3	0.6	72.0	NS	8	0.0	1.4	NS	60	0.8	4.2	NS	0	0.0	46.2	NS
	13.7	CHOCOLATE	2	0.3	66.1	NS	22	0.7	11.7	NS	4	0.1	9.0	NS	10	1.2	47.5	NS
	13.8	BABY MILK POWDER	1	0.2	69.2	NS	1	0.4	150.3	NS	1	0.2	55.6	NS	1	0.1	46.5	NS
	13.9	CHILI PEPPER	96	12.6	42.5	0.7	59	2.7	12.5	NS	97	15.8	56.0	NS	80	11.7	53.9	0.7
	13.10	OTHER MISCELLANEOUS	98	106.0	417.0	5.8	98	127.9	628.8	6.5	81	8.8	39.2	0.5	65	13.1	90.3	0.8
		TOTAL	100	1829	3373	94.9	100	1955	3350	95.6	100	1755	2910	96.9	100	1676	3146	95.5

NS: non-selected food subgroup.
NR: non-recorded food subgroup (national statistics).

3. Results and discussion

3.1. Food consumption data

Estimates of daily consumption were calculated for each province or city of the four countries, for (1) the mean consumption based on the whole selected population in grams per adult male equivalent per day and for (2) consumption of high-level consumers, defined as those at the 95th percentile (P95) of consumers. The estimates are also expressed in grams per adult male equivalent per day and at the three strata of the food classification (food groups, food subgroups including the selected core foods and food items) described in Fig. 1.

Table 4 shows the mean national daily consumption data of populations for the 4 countries of the study presented at the second stratum of the SSA-TDS food classification pyramid (Fig. 1), consisting 84 food subgroups, among which core foods are selected.

By far, the most consumed food commodities (in mean weight per adult male equivalent per day) in each country are starchy products: maize (Benin: 740,7, Cameroon: 384,9, Mali: 139,5 and Nigeria: 223,7 g/AME/day), rice (Benin: 133,8, Cameroon: 221,0, Mali: 573,5 and Nigeria: 211,7 g/AME/day), sorghum (Benin: 53,3, Cameroon: 122,8, Mali: 228,7 and Nigeria: 250,4 g/AME/day), millet (Benin: 21,5, Cameroon: 9,1, Mali: 411,7 and Nigeria: 181,2 g/AME/day) and cassava dry (Benin: 206,8, Cameroon: 83,3, Mali: 8,7 and Nigeria: 268,0 g/AME/day).

The variety of core foods recorded (from 70 for Benin to 83 for Cameroon) is suitable for exposure assessment, as the sampled core foods enable the identification of the main contributors to the mean dietary exposure to food chemicals in each study center. The mean daily food consumption of core foods of the 8 study centers are displayed in Table 5.

3.2. Food consumption patterns

Dietary tendencies or patterns are better shown at the top stratum and the most aggregated level of the SSA-TDS food classification pyramid (Fig. 1), which consists of 13 food groups.

Staple foods (cereals and tubers) in particular represent the major part of the average total diet.

The dietary exposures for the various study populations may vary significantly within the same country, as a consequence of specific consumer behaviors, regardless of the concentration of substances of public health interest the diet For example, out of 8 study centers, 3 are located in coastal areas (Duala, the Littoral of Benin and Lagos) and 5 in non-coastal areas (Bamako, the Borgou region of Benin, Kano, the North of Cameroon and Sikasso), which can be associated with distinct food consumption patterns. In our study, populations located in densely populated coastal areas consume in average 597 g/AME/day of cereals, whereas the average daily consumption of populations located in non-coastal areas is 1247 g/AME/day (Table 6), which is significantly different (p-value: 0,001).

The next steps of the implementation of this study will enable the identification of specific exposure patterns effectively associated with the food consumption patterns described above.

3.3. Core food list

The core foods are identified and selected among food subgroups at the second stratum of the SSA-TDS food classification (Table 4). As it is the case for the 13 food groups defining the top stratum of the hierarchy, subgroups of the second level are harmonized among all study centers. In the adopted strategy, this stratum defines the aggregation level fit for producing food

Table 5
Study centers mean daily consumptions of food subgroups in grams per adult male equivalent per day.

Food group	Code	Food subgroup	BENIN				CAMEROON				MALI				NIGERIA			
			Littoral		Borgou		Duala		North		Bamako		Sikasso		Lagos		Kano	
			Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study	Mean daily consumption (g/AME/day)	% Total Diet covered by study
CEREALS	1.1	RICE	136	7	79	4	203	13	170	8	803	42	266	18	321	20	230	15
	1.2	MAIZE	576	29	766	41	124	8	922	44	121	6	419	29	80	5	242	16
	1.3	WHEAT/BREAD	42	NS	7.0	NS	77	5	42	2	50	3	9.2	1	55	3	21	1
	1.4	PASTA	79	4	26	1	18	NS	3.6	NS	10	NS	6.3	NS	23	NS	2.7	NS
	1.5	SORGHUM	0.8	0.04	186	10	0.3	0.02	243	12	127	7	213	15	1.7	0.1	448	29
	1.6	MILLET	1.5	0.1	26	1	0.4	NS	1.4	NS	191	10	253	17	3.6	0.2	255	17
	1.7	OTHER CEREALS	13.6	NS	4.2	NS	14	NS	27	NS	8.7	NS	4.9	NS	19	NS	51	NS
TUBERS	2.1	CASSAVA FRESH	3.5	0.2	22	1	66	4	15	1	0.7	0.04	1.4	0.1	7.0	0.4	6.8	0.4
	2.2	CASSAVA DRY	156	8	66	4	48	3	13	1	24	1	13	1	367	22	12	1
	2.3	YAM FRESH	51	3	222	12	28	2	7.5	0.4	5.1	0.3	3.1	0.2	157	10	14	1
	2.4	YAM DRY	12	NS	29	NS	NR				44.3%	NS	0.01	NS	24	1	0.03	0.002
	2.5	POTATO FRESH	2.7	NS	0.04	NS	29	2	1.1	0.1	9.6	1	3.3	0.2	6.3	NS	3.1	NS
	2.6	POTATO DRY	NR				0.8	NS	5.3	NS	NR				NR			
	2.7	SWEET POTATO	2.1	NS	0.4	NS	30	2	45	2	12	1	14	1	5.1	NS	7.3	NS
	2.8	COCOYAM	NR				16	1	2.6	0.1	0.1	NS	0.7	NS	3.5	0.2	0.6	0.04
	2.9	MACABO	NR				48	3	4.4	0.2	NR				NR			
	2.10	OTHER TUBERS	NR				0.000	NS	0.2	NS	1.3	NS	6.3	NS	0.1	NS	0.000	NS
LEGUMES	3.1	BEANS	48	2	41	2	58	4	71	3	25	1	29	2	141	9	53	3
	3.2	GROUNDNUTS	1.7	NS	2.2	NS	30	2	74	4	20	1	17	1	1.5	0.1	7.0	0.5
	3.3	PEAS	NR				0.8	NS	4.3	NS	4.0	NS	2.2	NS	3.8	0.2	0.6	0.04
	3.4	SOJA	NR				0.2	NS	0.2	NS	NR				0.5	NS	3.0	NS
	3.5	OTHER LEGUMES	NR				0.1	NS	0.8	NS	0.1	NS	2.8	NS	2.2	NS	1.0	NS
VEGETABLES	4.1	TOMATO	160	8	76	4	36	2	16	1	30	2	11	1	46	3	17	1
	4.2	CARROTS	0.6	NS	0.04	NS	3.0	NS	0.03	NS	0.6	NS	0.1	NS	NR			
	4.3	GREEN LEAVES	9.1	NS	0.4	NS	43	3	88	4	6.7	0.4	4.7	0.3	0.2	NS	0.1	NS
	4.4	COURGETTES, CUCUMBER & GROUND PEPER	1.4	NS	1.7	NS	1.5	NS	0.9	NS	12	1	5.8	0.4	0.4	NS	0.3	NS
	4.5	CABBAGE	0.3	NS	0.1	NS	4.6	NS	0.1	NS	3.9	0.2	1.3	0.1	0.3	NS	0.1	NS
	4.6	ONION & GARLIC	21	1	7.8	0.4	9.6	1	6.5	0.3	19	1	6.5	0.4	11	1	7.9	1
	4.7	OKRO = GOMBO	4.5	0.2	2.5	0.1	3.0	0.2	18	1	2.7	0.1	4.1	0.3	4.7	0.3	19	1
	4.8	PARSLEY, CELERY, BASIL & LEEK	NR				7.7	NS	0.3	NS	NR				NR			
	4.9	OTHER VEGETABLES	7.3	NS	0.6	NS	2.0	NS	3.1	NS	5.5	NS	1.8	NS	14	1	5.3	0.3
FRUITS	5.1	BANANA	1.6	NS	0.4	NS	93	6	3.0	0.1	11	1	2.2	0.2	0.9	0.1	1.4	0.1
	5.2	PLANTAIN	2.5	NS	0.1	NS	57	4	2.3	0.1	8.2	0.4	1.3	0.1	31	2	0.6	0.04
	5.3	MANGO	0.05	NS	0.01	NS	0.2	NS	0.7	NS	20	1	15	1	0.5	NS	0.4	NS
	5.4	PINEAPPLE	7.6	NS	0.01	NS	3.3	NS	0.0	NS	0.3	NS	0.2	NS	1.7	NS	0.04	NS
	5.5	CITRUS (ORANGE, LEMON, LIME…)	10	1	1.3	0.1	15	1	2.6	0.1	7.7	0.4	2.3	0.2	8.1	0.5	4.2	0.3
	5.6	AVOCADO	0.7	NS	0.04	NS	1.8	NS	0.5	NS	0.9	NS	0.4	NS	0.3	NS	0.1	NS
	5.7	PAWPAW	1.3	NS	0.20	NS	5.5	NS	0.2	NS	1.6	0.1	1.2	0.1	1.0	0.1	0.1	0.01
	5.8	MELON / WATERMELON	0.2	NS	0.000	NS	1.1	NS	7.0	NS	39	2	15	1	2.9	0.2	0.5	0.03
	5.9	OTHER FRUITS	0.5	NS	0.002	NS	1.0	NS	2.0	NS	4.5	NS	4.8	NS	0.0	NS	0.04	NS

NUTS & SEEDS	6.1	COCONUT	0.4	NS	0.1	NS	0.2	NS	0.000	NS	0.1	NS	0.2	NS	0.2	NS	0.1	NS
	6.2	CASHEW NET	0.01	NS	0.05	NS	0.000	NS	0.000	NS	NR				0.000	NS	0.003	NS
	6.3	PALM NUT	1.7	0.1	0.1	0.003	0.8	0.05	0.01	0.0005	NR				0.1	NS	0.000	NS
	6.4	OTHER NUTS/ SEEDS	0.4	NS	0.9	NS	2.1	NS	1.0	NS	0.1	0.01	0.2	0.02	0.6	0.04	3.0	0.2
MEAT	7.1	BEEF	2.3	0.1	18	1	6.9	0.4	14	1	21	1	7.0	0.5	19	1	3.0	0.2
	7.2	POULTRY	3.5	NS	0.3	NS	1.6	NS	1.7	NS	3.9	NS	1.6	NS	3.1	NS	0.4	NS
	7.3	MUTTON/GOAT	0.9	NS	0.7	NS	0.04	NS	4.7	NS	1.4	NS	1.0	NS	1.0	NS	1.9	NS
	7.4	PORK	0.2	NS	0.03	NS	0.6	NS	0.7	NS	0.01	NS	0.002	NS	0.000	NS	0.003	NS
	7.5	PROCESSED MEAT	5.5	NS	2.2	NS	0.7	NS	0.001	NS	2.6	NS	0.3	NS	0.3	NS	0.000	NS
	7.6	GAME MEAT	NR				0.2	NS	0.5	NS	0.1	NS	0.1	NS	0.0	NS	0.01	NS
	7.7	INSECTS	NR				0.000	NS	0.000	NS	NR				NR			
	7.8	OTHER MEAT	0.4	NS	0.2	NS	0.02	NS	0.000	NS	0.05	NS	0.1	NS	0.1	NS	0.02	NS
EGGS	8.1	POULTRY EGGS	5.4	0.3	0.3	0.02	6.5	0.4	0.5	0.02	64.4	3.4	8.4	0.6	15.0	0.9	1.2	0.1
SEAFOOD	9.1	SEA FISH	13.1	NS	3.0	NS	25	1.6	3.4	0.2	6.0	NS	1.9	NS	18.4	1.1	2.7	0.2
	9.2	FRESH WATER FISH	NR				0.4	0.0	6.8	0.3	0.1	NS	0.4	NS	NR			
	9.3	SMOKED FISH	9.0	0.4	3.2	0.2	5.0	0.3	2.8	0.1	7.1	0.4	7.1	0.5	3.3	NS	0.01	NS
	9.4	PROCESSED FISH	9.4	NS	1.4	NS	1.6	NS	0.1	NS	NR				1.8	NS	0.000	NS
	9.5	CRUSTACEANS/ MOLLUSCS	1.5	NS	0.02	NS	0.7	NS	0.02	NS	0.000	NS	0.000	NS	0.5	NS	0.01	NS
	9.6	OTHER SEAFOOD	NR				0.1	NS	0.02	NS	0.7	NS	0.3	NS	NR			
DAIRY	10.1	FRESH/ FERMENTED MILK	28	1.4	4.0	0.2	4.8	NS	1.9	NS	10	0.5	4.4	0.3	0.5	NS	1.7	NS
	10.2	CONCENTRATED/ DEHYDRATED MILK	16	0.8	1.7	0.1	7.9	0.5	2.6	0.1	21	1.1	3.9	0.3	34	2.0	6.5	0.4
	10.3	OTHER DAIRY PRODUCTS	1.8	NS	8.2	NS	0.4	NS	0.01	NS	0.3	NS	0.1	NS	0.8	NS	0.1	NS
OIL & FAT	11.1	PALM OIL	9.2	0.5	1.4	0.1	31	2.0	0.3	0.01	1.9	NS	0.4	NS	17	1.1	17.8	1.2
	11.2	GROUNDNUT OIL	26	1.3	10	0.6	3.0	NS	6.1	NS	11	0.6	3.0	0.2	3.7	0.2	9.6	0.6
	11.3	OTHER VEGETAL OIL	1.5	NS	4.4	NS	7.8	0.5	13	0.6	5.1	0.3	6.5	0.4	13	0.8	0.2	0.0
	11.4	OTHER FAT/OIL	1.7	NS	1.8	NS	2.3	NS	0.2	NS	2.6	0.1	0.8	0.1	4.2	NS	0.03	NS
BEVERAGES	12.1	WATER	80	4.0	99	5.3	51	3.2	9.2	0.4	4.3	0.2	1.3	0.1	58	3.5	0.8	0.1
	12.2	FRUIT JUICE	NR				2.2	NS	0.7	NS	3.7	NS	0.5	NS	2.1	NS	0.1	NS
	12.3	TRADITIONAL SOFT DRINK	39	1.9	6.1	0.3	8.4	NS	11	NS	NR				3.4	0.2	10.3	0.7
	12.4	TRADITIONAL FERMENTED DRINK	0.2	NS	0.000	NS	7.4	0.5	47	2.2	NR				0.1	0.0	0.1	0.0
	12.5	INDUSTRIAL FERMENTED DRINK	13	0.7	9.0	0.5	56	3.6	13	0.6	NR				6.8	0.4	0.000	0.0
	12.6	INDUSTRIAL SOFT DRINK	16	NS	2.6	NS	13	0.8	2.3	0.1	6.7	0.4	1.6	0.1	22	1.4	0.7	0.0
	12.7	SPIRITS	0.6	NS	2.6	NS	0.2	NS	0.01	NS	NR				0.000	NS	0.000	NS
	12.8	OTHER DRINKS	NR				1.4	NS	0.5	NS	NR				1.0	NS	3.9	NS

(continued on next page)

Table 5 (*continued*)

Food group	Code	Food subgroup	BENIN Littoral Mean daily consumption (g/AME/day)	BENIN Littoral % Total Diet covered by study	BENIN Borgou Mean daily consumption (g/AME/day)	BENIN Borgou % Total Diet covered by study	CAMEROON Duala Mean daily consumption (g/AME/day)	CAMEROON Duala % Total Diet covered by study	CAMEROON North Mean daily consumption (g/AME/day)	CAMEROON North % Total Diet covered by study	MALI Bamako Mean daily consumption (g/AME/day)	MALI Bamako % Total Diet covered by study	MALI Sikasso Mean daily consumption (g/AME/day)	MALI Sikasso % Total Diet covered by study	NIGERIA Lagos Mean daily consumption (g/AME/day)	NIGERIA Lagos % Total Diet covered by study	NIGERIA Kano Mean daily consumption (g/AME/day)	NIGERIA Kano % Total Diet covered by study
MISCELLANEOUS	13.1	SUGAR	8.5	NS	5.0	NS	7.8	0.5	27	1.3	53	2.8	34	2.3	5.7	0.3	8.7	0.6
	13.2	SALT	2.5	0.1	7.1	0.4	12	0.8	10	0.5	9.6	0.5	11	0.7	2.3	0.1	8.7	0.6
	13.3	BROTH/ BOUILLON CUBE	6.4	NS	4.0	NS	2.9	NS	2.7	NS	3.8	NS	2.3	NS	5.5	0.3	8.6	0.6
	13.4	HONEY	0.1	NS	0.03	NS	0.1	NS	0.1	NS	0.001	NS	0.001	NS	0.04	NS	0.1	NS
	13.5	TEA	1.7	NS	1.0	NS	0.1	NS	0.8	NS	1.5	NS	0.7	NS	2.4	NS	2.0	NS
	13.6	COFFEE	2.2	NS	0.2	NS	0.03	NS	0.1	NS	1.1	NS	0.7	NS	0.02	NS	0.000	NS
	13.7	CHOCOLATE	0.7	NS	0.05	NS	1.2	NS	0.04	NS	0.3	NS	0.1	NS	3.2	NS	0.3	NS
	13.8	BABY MILK POWDER	1.1	NS	0.04	NS	0.8	NS	0.1	NS	0.5	NS	0.2	NS	0.5	NS	0.000	NS
	13.9	CHILI PEPER	17	0.8	4.6	0.2	3.4	NS	0.8	NS	46	NS	8.7	NS	30	1.8	11	0.7
	13.10	OTHER MISCELLANEOUS	335	16.6	104	5.6	204	13.0	111	5.3	16	0.8	6.6	0.5	20	1.2	7.8	0.5
		TOTAL	**2017**	**90.8**	**1874**	**95.5**	**1563**	**93.3**	**2099**	**95.7**	**1893**	**94.2**	**1457**	**96.6**	**1645**	**94.8**	**1524**	**94.8**

NS: non-selected food subgroup.
NR: non-recorded food subgroup (national statistics).

composite samples. Therefore, it is defined on the basis of the homogeneity of its subcomponents (ex: rice, maize …) and takes into consideration a number of processes, likely to impact contamination levels (ex: dried cassava, smoked fish …). In order to target core foods which contribute the most to the diet, each food group includes one specific subgroup, which gathers poorly defined or rare food commodities (ex: other cereals, other tubers …). The strategy adopted includes avoiding, when possible, these poorly defined food subgroups, the sampling of which would not be pertinent, because of the lack of information with regard to the actual nature of these food subgroups. Criteria defining the proportions of the food supply (e.g. type, variety, origin) are reflected in the breakdown of the twelve subsamples. Each criterion representing a proportion of 8% of the food supply or more is included in the pooled sample (Fig. 3).

The food balance sheet enabled us to identify the origin of imported food commodities. In the case of food commodities which are both imported and locally grown (ex: rice) the SSA-TDS strategy consists of producing two distinct composites, to be able to identify a source of contamination. This approach, including two composite samples, is compatible with a more precise subsequent exposure assessment based on the actual proportions of imported and locally produced food items.

The result of the core foods selection and the sampling plan are summarized in Table 7.

Some of the 84 foods subgroups defined in the food classification at level 2 of Fig. 1 were not recorded (from 1 non-recorded food subgroup for Cameroon to 14 in the case of Benin) by national institutes of statistics. However 100% of the average total diet is considered as recorded with a number of food subgroups: 70 for Benin, 83 for Cameroun, 71 for Mali and 77 for Nigeria. The selected core foods amount to 27 for Benin, 36 for Cameroun, 38 for Mali and 40 core foods in the case of Nigeria. In spite of the heterogeneous food classifications of the four original datasets, also reflected in the variability of the number of selected core foods (CV = 15%), the coverage of the average total diet by the selected core foods is very similar among the 8 study centers (CV = 2%).

3.4. Sampling strategy

The number of samples required to cover 100% of the core foods recorded in the household budget surveys once per study center is 602 (Table 7). Thanks to (1) the core foods selection methodology and (2) the introduction of national samples when applicable (sampled only once but applying to the two national study centers for exposure assessment), the number of selected core foods drops to 204 required samples (34%). This cost effective approach enables the coverage of 94,8 ± 2,1% of the average total diet by weight, including 92,3 ± 2,1% of the total diet covered by locally sampled core foods.

Taking into consideration the tap water composite samples compiled by each study center and two sampling campaigns, the subsamples collected in the eight city centers amounted to a total of 4020 purchases (63% for the first and 37% for the second campaign). As pooled samples include 12 subsamples each, the study gathers 204 composite samples of core foods plus 8 tap water composite samples for the first sampling campaign and 115 composite samples of core foods plus 8 tap water composite samples for the second campaign. Every composite sample undergoes up to 7 multi-analyte screening tests, which represents a total of 766 analyses (77% for the first and 23% for the second campaign).

3.5. Food chemicals list

Trace elements and metals selected include heavy metals

Table 6
Comparison of the mean consumption of cereals in grams per adult male equivalent per day in coastal and non coastal study centers.

Variable	Observations	Minimum (g/AME/day)	Maximum (g/AME/day)	Mean (g/AME/day)	SD (g/AME/day)
COASTAL AREAS	3	437	849	597	221
NON COASTAL AREAS	5	1094	1409	1247	121
Difference					−650
t (Observed value)					−5.5
|t| (Critical value)					2.4
DF					6
p-value (Two-tailed)					0.001
alpha					0.05

t-test for two independent samples/Two-tailed test:
95% confidence interval on the difference between the means: [-939;-362[
Test interpretation.
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is lower than the significance level alpha = 0,05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk to reject the null hypothesis H0 while it is true is lower than 0,15%.

Table 7
Coverage of total diet in weight by the sampling plan.

	Country	Benin		Cameroon		Mali		Nigeria		SSA Total Diet Study			
	Study center	Littoral	Borgou	Duala	North	Bamako	Sikasso	Lagos	Kano	Total	Mean	SD	CV
NUMBER OF CORE FOODS	Recorded core foods	70	70	83	83	71	71	77	77	602	75	6	7%
	Locally sampled core foods	24	18	33	19	35	19	33	23	204	26	8	28%
	National core food sampled elsewhere	3	9	3	17	3	19	7	17	78	10	7	71%
	Total sampled core foods	27	27	36	36	38	38	40	40	282	35	5	15%
COVERAGE OF AVERAGE DAILY INTAKE (g/AME/d)	Recorded core foods	2017	1874	1563	2099	1893	1457	1645	1524	–	1759	241	14%
	Locally sampled core foods	1826	1734	1455	1892	1824	1339	1541	1373	–	1623	213	14%
	National core food sampled elsewhere	7	55	4	115	4	77	19	72	353	44	43	95%
	Total sampled core foods	1833	1789	1459	2007	1828	1416	1560	1445	–	1667	222	13%
COVERAGE OF TOTAL DIET (%)	Recorded core foods	100	100	100	100	100	100	100	100	–	100	0	0%
	Locally sampled core foods	90.5	92.5	93.1	90.2	96.4	91.8	93.7	90.1	–	92.3	2.1	2%
	National core food sampled elsewhere	0.3	2.9	0.2	5.5	0.2	5.3	1.2	4.7	20.3	2.5	2.4	93%
	Total sampled core foods	90.8	95.5	93.3	95.7	96.6	97.1	94.9	94.8	–	94.8	2.1	2%

commonly monitored in food safety risk assessment as well as elements likely to migrate from cooking pots to food matrices. These are aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb) and tin (Sn) as a core list.

The core mycotoxins list includes a list of 23 substances screened in the FAO/WHO project on mycotoxins in sorghum (FAO, 2015) implemented in Burkina Faso, Ethiopia, Mali and Sudan (2012–2014). These are aflatoxins (B1, B2, G1, G2), altenuene, alternariol, alternariol monomethylether, deoxynivalenol (including 3-actetyldeoxynivalenol and 15-actelydeoxynivalenol), diacetoxyscirpenol, fumonisins (B1, B2, B3), fusarenon X, HT2 toxin, neosolaniol, nivalenol, ochratoxin A, roquefortine C, sterigmatocystin, T-2 toxin and zearalenone. The choice of those analytes is based on the expectation to find these substances (FAO, 2015) and will be extended, as recent advances in Africa have shown the occurrence of toxins never reported before in Cameroonian food (Abia et al., 2017).

An extraction from the European Commission Rapid Alert System for Food and Feed 2000–2016 showed that 99% of the alerts involving pesticides concentration above maximum residue limits in force involve 10 phytosanitary products (endosulfan, chlorpyrifos, profenefos, dichlorvos, dimethoate, ethephon, omethoate, trichlorfon, cypermethrin, lambda cyhalorthrin and permethrin) out of 109 substances recorded in Benin, Cameroun, Mali and Nigeria (European Commission, 2016a).

The availability of multi-analyte screening tests for organochlorine, organophasphorous and pyrethroids enables to cover all of these 10 actives substances, as well as the pesticides included in the Stockholm Convention, as a core pesticides residues list.

The PAHs selected for this study are the 13 genotoxic and carcinogenic substances evaluated by the Joint FAO/WHO Expert Committee on Food Additives, (WHO, 2006). These PAHs are benzo(*a*)pyrene, benzo(*a*)anthracene, benzo(*b*)fluoranthene, benzo(*j*) fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)pyrene, dibenzo(a,i)pyrene, dibenzo(a,e)pyrene, dibenzo(a,l)pyrene, dibenzo(a,h)anthracene, indeno(123-*cd*)pyrene and 5-methylchrysene.

The 12 coplanar or dioxin-like PCBs (PCB 77, PCB 81, PCB 105, PCB 114, PCB 118, PCB 123, PCB 126, PCB 156, PCB 157, PCB 167, PCB 169 and PCB 189) identified by the Joint FAO/WHO Expert Committee on Food Additives (WHO, 2002) as well as 6 non dioxin-like “indicator PCBs” (PCB 28, PCB 52, PCB 101, PCB 138, PCB 153 and PCB 180) plus PCB 128, for which adequate data were available to perform a risk characterization (WHO, 2015), are included in the core food chemicals list, as well as 10 polychlorinated dibenzo-*p*-dioxins and 7 polychlorinated dibenzofurans.

In addition to these food chemicals, 15 perfluoroalkoxy alkanes (PFAs) and 13 brominated flame retardants (BFRs) are going to be screened in the food samples.

3.6. Risks and limitations of this strategy

Although the percentage of selected households seemed rather inclusive for 3 countries as shown in Table 2 with 79% for Benin, 75% for Cameroon, and 87% in the case of Mali, we could not find a suitable explanation as to why the dataset from Nigeria only enabled to select 40% of the households, based on estimated energy requirements ± 45%. The significant number of households selected from the original datasets of household budget surveys (44.431 households) for the four countries needs to be balanced with the fact that the design of this study focuses on 8 study centers, covering in total 7.291 households or 16% of total normal reporting households. Although the whole dataset was used to establish nationally representative core food lists, the exposure assessment and sampling will reflect the exposure of two populations per country, but will hardly be considered as representative for the whole country. The European Food Safety Authority (EFSA, 2014) recommends the inclusion of 6 age groups containing each at least 260 subjects in dietary surveys and suggests not to discard over and under-reporting households. The SSA-TDS does not comply with these recommendations, and will not enable the estimation of the individual exposures for study subjects. Because the daily consumption data are derived from food expenditure data, based on questionnaires submitted to the head of household, they do not reflect the individual diet by gender or by age group either.

In particular, breast milk is not included in the core food list, because it is not recorded as a commercial food item. Weaning foods, although identified as a food subgroups, were not selected in the food list due to their low contribution to the total diet of the general population.

From this study, it is therefore impossible to target specific population groups, exposed to a particular risk, without additional data, thereby justifying further studies to cover the identified gaps.

The selection of core foods is solely based on mean daily consumption. Due to the lack of data describing the contamination patterns in Africa, the selection of core foods does not focus, in its design, on food commodities considered as high contributors to the dietary exposure or highly contaminated core foods. However, the fact that each food group is significantly represented (50% or 90% depending on the proportion of the total diet by weight covered by food group) means that a large variety of core food are included in the sampling, thus reducing the risk of skipping high contributors. However, the risk that a highly contaminated food item representing a low mean daily consumption is not taken into consideration exists, and cannot totally be ruled out.

The fact that we are preparing composite samples from one single core food with inert kitchen utensils presents a number of limits. This methodological choice enables the assessment of the contribution to the dietary exposure of each core food individually. However, it means that (1) the interaction between distinct core foods (for example due to osmosis or chemical phenomena such as Maillard reaction) and (2) the interaction between food contact materials and food matrices (Weidenhamer et al., 2017), both occurring during food preparation at household level and likely to impact the food chemical concentration of samples, are not taken into consideration. Therefore, this TDS methodology is more suited for screening environmental food chemicals, than for the purpose of detecting neo-formed substances such as acrylamide. This limit has impacted the selection of substances to look for. However, a few samples of the most consumed matrices will be prepared twice, with both traditional utensils and with inert kitchen utensils, in an attempt to capture a difference of concentration of elements in food samples.

The attempt to capture the seasonal variation of the concentration to food chemicals is another limitation of this study. In this methodology, we intend to focus on the most consumed food commodities (cereals, tubers, legumes, vegetables and fruits) food chemicals, which are highly likely to vary in terms of occurrence between dry and rainy seasons (mycotoxins and pesticides). This means that we will not be able to capture the variation of occurrence of the other food chemicals, nor the variation in occurrence of pesticides residues and mycotoxins in nuts and seeds, meat, eggs, fish, dairy products, oil and fats, beverages, and miscellaneous.

Finally we are aware that although cost effective, our approach tends to focus on main sources of the food supply (national sampling enabling to reduce the number of samples needed to cover the average total diet in weight). This means that the variation of the concentration of food chemicals will not be systematically be captured. It will however be the case for at least 90% of the average total diet.

4. Conclusions

We developed the core food model in this regional Sub-Saharan Africa Total Diet Study. The purpose of this TDS is to investigate a large number of food chemicals through a food sampling plan, which aims to be representative of the dietary habits of a large population of four African countries. This TDS has been adapted to the African context with limited resources, but nonetheless with a consistent and harmonized methodology. It complies with WHO and FAO recommendations and can, to a certain extent, be compared with other TDS implemented at international level by various national food safety authorities. Moreover this program is intended to provide concentration and dietary exposure data in Africa, as well as supporting international scientific advice for utilization by the Codex Alimentarius Commission. Therefore, it will contribute to consumer protection with regard to food safety issues, whilst providing evidences, likely to be used by the international community to tackle technical barriers to trade.

This study provides a baseline of concentrations and dietary exposure that can be used for comparison for future surveys in Africa. These types of baseline data are useful if risk management measures are implemented and if the impact of those can be evaluated.

Moreover, this TDS is likely to provide valuable information to the international risk assessment community concerning chemical concentrations and levels of dietary exposure for a specific area of the World, where this type of information may not be as common as in other areas of the World. This TDS can also be used to identify further work or research for either specific food chemicals or specific population groups, depending on the result of the study.

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