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How well does the Food Consumption Score capture diet quantity, quality and adequacy across regions in the Democratic Republic of the Congo (DRC)?

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Abstract
The Food Consumption Score (FCS), a food frequency indicator developed by the World Food Programme (WFP) that aims to capture both diet quantity and quality of household food consumption, has been validated only against calorie intake in a limited number of rather small countries. This article examines the potential of FCS to capture variation in diet quantity and quality using the 2004/5 Household Consumption and Expenditure Survey (HCES) conducted in the DRC. In addition to quantifying the strength of association between FCS and a series of benchmark variables, a set of nutrient-consistent regional adequacy levels is proposed as an alternative to the standard WFP's cut-off in identifying food insecure households. We point out several key issues. First, for a country the size of the DRC, but possibly in other settings too, it is necessary to adopt a geographically disaggregated approach to account for regional diversity in food systems and resulting diets. Second, FCS can indeed capture qualitative aspects of food consumption in addition to quantitative ones. Third, increasing the number of food groups, removing their associated weights or truncating their food group score does not structurally improve FCS's correlation with the benchmark variables. Fourth, the WFP's threshold is only weakly consistent in terms of nutrient adequacy, marginally relevant to each of the country's regions and markedly less sensitive and specific compared to the set of nutrient-consistent regional thresholds, which we propose based on the empirical relation between FCS and the mean adequacy ratio (MAR). Lastly, despite several methodological challenges, this work demonstrates the potential use of HCES to conduct this sort of food security validation exercises.

Keywords Food Consumption Score · Mean adequacy ratio · Household consumption and expenditure surveys · The Democratic Republic of the Congo

1 Introduction

Since its inception in 1996, the Food Consumption Score (FCS) developed by the World Food Programme (WFP) has increasingly been used to monitor and evaluate the access dimension of food security in countries and to program and scale the agency's interventions around the globe (WFP 2008). In total, not less than 2000 baseline, monitoring and emergency assessments have been conducted by WFP worldwide, each of them heavily reliant on the computation of this particular food access indicator. Yet, in contrast to its widespread application, the validation of the methodology underlying FCS has received little attention, especially with respect to diet quality, defined in this study as micronutrient adequacy (Leroy et al. 2015). Micronutrients matter: a sufficient amount of vitamins and minerals must be provided by the diet for an individual to live an active and healthy life, as described in the definition of food security.

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The few existing validation studies have mainly focused on the link between FCS and energy intake in only ten countries: Haiti, Burundi and Sri Lanka (Wiesmann et al. 2009), Lao PDR (Baumann et al. 2013) and in El Salvador, Guatemala, Honduras, Malawi, Nepal and Uganda (Lovon and Mathiassen 2014). Of course, more validation work exists, of which the underlying documentation is either not publicly accessible (Leroy et al. 2015) or relates to other types of validation (see Kennedy et al. 2010; Maxwell et al. 2013; Jones et al. 2013). Although the results of these validation studies are encouraging, the extent to which FCS is a useful proxy of food access in any other country, both in terms of macro- *and* micronutrients, remains an empirical question. Indeed, because FCS is in essence a weighted sum of weekly consumption frequencies of eight separate food groups, this index hides information about the precise individual food items within any particular food group, about the precise combination of food group frequencies and about the actual food quantities (above condiment level) consumed. As a result, two populations with average food diets characterized by the same FCS can potentially have very different nutritional intake levels, depending on the exact nutrient content of the individual food items in both diets.

In this article, FCS's potential to capture adequacy in household nutrient access is explored for different regions in the Democratic Republic of the Congo (DRC). Given its continental dimensions and diverse agro-ecological conditions, the DRC provides an ideal laboratory to examine FCS and its association with nutrient adequacy. As such, this study contributes to the small but growing literature on FCS validation while providing guidance to better interpretation of this food access proxy. To conduct the analysis, we relied on the 2004/5 Household Consumption and Expenditure Survey (HCES). Although the use of HCES to estimate nutrient intake (especially micronutrients) is controversial, much depends on the quality and precise survey methodology adopted (Fiedler and Mwangi 2016a; Murphy et al. 2012).

The remainder of this article is organized as follows. Given the importance of appropriate data for this analysis, the following section devotes considerable attention to assessing the survey's quality and relevance. Relying on other validation work, the subsequent section explains the methodological approach adopted, which first details how FCS and benchmark variables are derived before examining their association using three specifications. Each specification refers to a different combination of benchmark variable and level of geographical disaggregation. This section also explains how nutrient adequacy is assessed. After some initial descriptive statistics and triangulation with other nutritional studies in the DRC, the results of these specifications and assessments are discussed in detail follwed by a conclusion.

2 Data

In 2004/5 the National Institute of Statistics of the DRC conducted a national HCES, following a methodology called *Enquête 1–2-3*, in which each number refers to a separate module: 1) individual employment, 2) informal sector, and 3) household consumption. In total, 12,097 households and their individual members were surveyed, and the resulting data are said to be representative of the urban and rural sectors of each of the country's 11 provinces. Combining sector and province, 21 *regions* could be identified. For this article, we mainly rely on the survey's third module, which covers 923,178 food consumption records related to 214 food items. For each item consumed, data are available on quantities, unit prices and total expenditure. The food consumption data of HCES-DRC (2004/5) are used here to derive both the FCS index of each household and its corresponding nutritional intakes. This approach is different from most other validation studies. In general, food security indicators are obtained through dedicated questionnaires while nutritional intakes are estimated from specialized surveys that rely on direct observation or detailed food intake diaries, such as observed-weighed food records (OWFR) and 24-h recall (24HR) surveys. Using the same data source to derive both the indicator to validate and the benchmark variables are likely to produce more accurate validation results, because the measurement error associated with the use of 7-day recall questionnaires on aggregate food groups, typically used to collect data to construct FCS, is simply avoided (see Martin-Prevel et al. 2010).

One may question the appropriateness of using household consumption surveys to evaluate FCS's capacity to capture variation and adequacy in nutrient intake. Indeed, compared to HCES, specialized nutrition-focused surveys are able to account for differences in intra-household allocation and are better at capturing the nutritional content of mixed and prepared dishes. In contrast, HCES generally do not contain enough information on these dishes to reliably compute individual nutritional intakes using local recipes, yield and retention factors, and waste estimates. Yet, the FCS developers never claimed that their methodology would result in a proxy of *individual* food security, nor that its reach should be interpreted beyond the *access* dimension (Jones et al. 2013; Leroy et al. 2015). Moreover, as FCS and HCES share the same unit of analysis (the household), the latter might be well equipped to validate the assigned properties of the former. A final and more substantial argument in favour of using HCES for nutritional purposes relates to the largely unknown relationship that exists between this survey type and the established gold standards. At the origin of this observation, Fiedler and Mwangi (2016a) not only cite the limited number of comparable surveys to test for it, but they also point to the more constrained spatial and demographic coverage associated with OWFR and 24HR, together with the heterogeneous nature and quality linked to HCES. Besides, for the DRC, we are not aware of any nutrition-focused survey that would be representative at any reasonable scale.

To better grasp the fitness of HCES-DRC (2004/5) to run this type of analysis and correctly interpret its findings, the following subsections will run through a list of reliability and relevance criteria. It also explains in detail how we address some of the identified dataset limitations.

2.1 Reliability and relevance criteria for food security analysis

To evaluate the appropriateness of HCES-DRC (2004/5), we rely on the checklist developed by Smith et al. (2014) which they use to assess the reliability and relevance of food data collected by 100 national HCES. Table 1 provides an overview of the different criteria and issues at stake, together with a formal assessment of HCES-DRC (2004/5).

In terms of reliability (i.e. the compliance with good practices in survey design and method), HCES-DRC (2004/5) is doing well. For five of the seven broad criteria listed, the survey fully complies with best practice. More particularly, diaries have been used to increase accuracy in recall; for each food data entry, the mode of acquisition has been made explicit; the comprehensiveness and specificity of the at-home food lists comply with all underlying criteria set forward; and the data collected on food consumed away from home respond to the three quality requirements defined. However, the survey leads to some confusion on whether respondents are supposed to report on food acquisition or consumption; where the latter seems to be reserved for the diary module and the former applies to a 12-month recall module of exceptional food outlays. As stated by Jones et al. (2013), this ambiguity between acquisition and consumption seems to be typical for many HCES. In addition, the one-round data collection of this HCES does not account for seasonality, and therefore does not adhere to best practice.

Moving to criteria particularly relevant for food security assessments, the picture looks less pretty. This is not surprising: HCES are multipurpose data collection efforts whose data are also used, for instance, to measure poverty, compile food balance sheets, calculate consumer prices and inform national account statistics (Smith et al. 2014). A first issue relates to the use of non-metric units (such as ‘bowls’, ‘heaps’, or ‘piles’) in which food is typically acquired in many African contexts. Yet, contrary to the observation of Smith et al. (2014), a metric conversion of food data collected by HCES-DRC (2004/5) *is* possible using a separate and non-publicly available dataset which allows derivation of metric prices and thus metric food quantities for 90% of the most important food items (see Marivoet (2010) for a fuller description of the procedures followed).

Second, regarding the conversion of food quantities into their nutritional equivalents, one should be able to match each food item listed with its equivalent record within a Food Composition Table (FCT). Unfortunately, no national FCT exists for the DRC. As a result, we resorted to FAO’s West African FCT (Stadlmayr et al. 2012), which validated and assigned unique INFOODS[1] component identifiers to food composition data from nine West African countries, while also providing edible conversion factors. Similar data from other sources, like the FCT for Biodiversity (FAO 2016), the FCT of Tanzania (Lukmanji et al. 2008) and USDA data were equally considered to fill out some blanks or to cross-check certain values. In addition, the Classification of Individual Consumption by Purpose (COICOP) adopted by HCES-DRC (2004/5) does not guarantee a perfect match between food consumption data and nutritional content, mainly because the COICOP food labels are underspecified. For example, information on the exact variety or breed, cultivar or ripeness level of the food is generally lacking. Despite this shortcoming, most of the other important distinctions, in terms of colour (pale/orange/deep orange flesh mangos) or food processing stage (maize kernels/flour), could be made or indirectly retrieved.

A third important issue for food security analysis concerns the computation of total nutrient intakes per household. Given the presence of unidentifiable food consumption both at home or away from home, one risks underestimating true intake levels. To address this issue, one typically derives price-per-nutrient ratios from the identifiable part of food consumption before applying these ratios to the expenditure level of the unidentifiable items (as pioneered by Subramanian and Deaton 1996). This price-per-nutrient procedure, although acceptable for calories, becomes much less reliable for micronutrients due to their food-specific nature.

Finally, total nutrient intakes per household should be corrected for differences in the number and characteristics of all people sharing the meals being prepared. Apart from age and sex recorded for all present household members and visitors, HCES-DRC (2004/5) unfortunately does not describe the exact meal participation of each, nor does it contain information on pregnancy and lactation status of women, individual body weight or physical activity levels. This of course limits the precise calculation of required nutritional intakes, thus limiting the accuracy of the assessment of diet adequacy.

To cope with the shortcomings highlighted in Table 1, the following subsections first deal with two of the most important issues at stake, before addressing the remaining issues in a more conceptual manner.

[1] International Network of Food Data Systems (INFOODS) is a worldwide network and forum steered by FAO to improve the quality, availability, reliability and use of food composition data (see: www.fao.org/infoods).

Table 1 Checklist of reliability and relevance criteria applied to HCES-DRC (2004/5)

Criterion or issue	HCES-DRC (2004/5)
Reliability of survey design and method	
1. Recall period for at-home food data collection should be less than 2 weeks	- Diaries have been used, which is considered to equal a 1 day-recall period (ok)
2. Three modes of acquisition of at-home food data should be distinguished	- Purchases (ok) - Own production (ok) - In-kind receipts (ok)
3. Complete enumeration of foods acquired or consumed requires the adherence to six criteria	- Rule-out leading question on consumption (ok) - Rule-out, short-recall-period leading question on acquisition (ok) - Rule-out leading question on food purchases (ok) - Own production question refers to food harvested rather than consumed (ok) **- Ambiguity whether to report on acquisition or consumption (not ok)** - Usual month surveys: Ambiguity whether to report consumption in any month or months with positive consumption (ok)
4. Comprehensiveness of the at-home food list should adhere to three criteria	- All 14 basic food groups are represented (ok) - At least 40% of food items are processed (ok) - Food items are all food-exclusive (ok)
5. Specificity of the at-home food list should adhere to two criteria	- At least 10 of the basic food groups have the minimum number of food items (ok) - Less than 5% of food items span more than one food group (ok)
6. Quality of data collected on food consumed away from home should adhere to three criteria	- Data explicitly collected on food consumed away from home (ok) - Recall period 2 weeks or less (ok) - Data collected on both purchase and in-kind receipts (ok)
7. At least 2–4 rounds in a year should be conducted to account for seasonality of food consumption patterns	**- Only one round in a limited number of months, though the survey also comprised a module on exceptional food acquisition over the past 12 months (not ok)**
Relevance for food security analysis	
1. Metric conversion of foods acquired or consumed at home should be possible (no best practice recommended)	- By means of a non-publicly available dataset covering metric food weights collected during 2–-3 days, standard metric prices could be derived for 90% of the most important food items (ok)
2. Calculating edible portions and nutrient content of foods should be possible using food composition tables	- No specific FCT exists for the DRC, but comfort was found in other African FCT to match each food item within the survey's food list with its corresponding FCT entry (ok)
3. Derivation of total calorie, protein and micronutrient consumption should be possible using both food quantities consumed at home and away from home	**- A method to compensate for unidentified consumption based on outlays with known nutritional content is generally acceptable for calorie intake, but considered too inaccurate for the estimation of other nutrients (not ok)**
4. Calculation of adult male equivalent (AME) indicators and nutrient insufficiencies should be possible using data on the number and characteristics of food partakers	- Data are collected on the number, age and sex of all present household members, including visitors (ok) **- Date are not collected on meal participation, nor on the pregnancy/lactation status, the body weight or physical activity level of both household members and visitors (not ok)**

Source: Adapted from Smith et al. (2014)

The bold entries highlight the main shortcomings of HCES-DRC (2004/5) to conduct food security analyses.

2.2 Modifications to increase reliability and relevance of HCES-DRC (2004/5)

A first issue relates to unidentified food consumption. This is food recorded in household diaries, but for which no corresponding nutritional content could be derived. This observation could result from erratic price information, unreliable metric conversion rates or difficulties in matching food labels to their corresponding FCT records. To address this issue, we first computed for each household a series of food-group-specific nutrient prices by relying on outlays with known nutritional content. These prices were then used to impute a nutritional mark-up (or increase) for the unidentified part of food consumption, *only if* the share of identifiable outlays within total outlays were high enough. The latter condition avoids that compensation for unidentified consumption being based on idiosyncratic food items, which are atypical of the diet consumed by the household. Yet, when no mark-up could be performed, households were removed from the sample if the overall unidentifiable part of food consumption was higher than 5%. As summarized by Table 2, a total of 3,024 households were removed from the analysis since they had too large a fraction of unidentified food consumption.

A second issue concerns the ambivalence on the nature of food data collected by recall and diary modules: whereas acquisition is reported through recall, consumption is generally referred to within the diary module. Recall data reflect exceptional acquisitions in bulk to be gradually depleted and consumed by the household in smaller quantities afterwards. However, the survey agency had removed those data entries from the diary records when the same food item also occurred in the recall module to avoid double counting. While being an acceptable procedure in many cases, it is problematic for the correct derivation of FCS, which is based on daily frequencies of food group consumption. Indeed, if food entries have been removed from the diary data, then FCS might seriously underestimate true consumption frequencies for households having reported food with recall. To address this issue, all families with food recall records have been removed from the sample as well, leaving 5,594 households for further analysis (see Table 2).

A similar confusion between acquisition and consumption might still be at play *within* the diary module, as reporting is generally easier on purchases than on actual consumption. Besides, the questionnaire itself has added to this confusion by labelling this module "daily *purchase*".[2] To assess the magnitude of this problem, we inspected the variability of daily calorie intakes per adult male equivalent (AME) and labelled it as unreliable if the third highest and third lowest calorie intakes during the 15-day diary period were respectively above 5,000 and below 500 kcal/AME. This decision rule allows for one exceptionally high and one exceptionally low food intake per week, before the household was removed from the sample for presumed reasons of reporting on acquisition. Apart from suspicious volatility in calorie intakes and fully in line with previous validation work (Lovon and Mathiassen 2014; Wiesmann et al. 2009), we also removed all households with an average calorie intake level above 5,000 or below 500 kcal/AME. After checking for outliers in consumption, the final sample for this validation exercise consisted of 4,232 households (35% of the original sample), which in total recorded 326,881 individual consumption lines from a list of 212 different food items.

2.3 Additional conceptual issues

Another issue highlighted above is the problem of seasonality, which involves both the number of rounds and exact timing during which households were surveyed. For HCES-DRC (2004/5), households were only surveyed once over a period of 2–3 weeks, ranging from October/November 2004 in Kinshasa (pilot area) to April/September 2005 for the other provinces. Accordingly, the one-round visit risks to be only representative for those specific weeks of the year – and the necessary removal of households with a 12-month food recall (see above) has rendered the most obvious solution to this issue impossible. Although seasonality may jeopardize the representative character of any food security analysis based on HCES-DRC (2004/5), climatic conditions throughout the country often allow for successive harvests per year depending on crop (WFP 2014). As a result, the difference in food security between lean, growing and harvesting seasons may be somewhat reduced.

A last issue with the data concerns the lack of information on pregnancy/lactation status of women, body weight and physical activity levels as well as on meal participation by both the household members and visitors. As a result, the AME scales adopted in this article are solely based on age and sex, and thus only partially account for variability in individual nutritional requirements. However, to address the potential bias resulting from expected differences in physical activity level between more sedentary urban dwellers and their rural counterparts, the findings of this article will be discussed separately for both sectors. Further, as HCES-DRC (2004/5) does not document who has eaten or missed any type of meal during the diary period, we were unable to convert AME into corresponding equivalent nutrition units (ENU). This however is a

[2] Yet, the precise question on each recorded food item was clearly about *effective consumption* per day.

Table 2 Shrinking sample size after various accommodations

	Initial dataset	After elimination of households with		
		Unidentified consumption	12-month recall consumption	Outlier consumption = final dataset
Number of households	12,097	9,073	5,594	4,232
- Kinshasa	964	849	416	392
- Bas-Congo	988	754	415	376
- Bandundu	1,334	905	525	400
- Equateur	1,447	913	669	509
- Orientale	1,269	822	452	308
- Nord-Kivu	1,079	833	833	570
- Maniema	858	664	661	429
- Sud-Kivu	811	629	388	325
- Katanga	1,352	1,057	354	288
- Kasai-Oriental	1,006	859	548	392
- Kasai-Occidental	989	788	333	243
Number of food entries	923,178	706,430	415,257	326,881
- Diary module	908,045	695,192	415,257	326,881
- Recall module	15,133	11,238	0	0
Number of food items	214	214	214	212

Source: HCES-DRC (2004/5)

common shortfall of almost all HCES (Fiedler and Mwangi 2016b; Weisell and Dop 2012). This lack of precision in estimating nutritional requirements compounds the measurement error of the mean adequacy ratio (MAR), which is used as a key benchmark variable to examine the performance of FCS. Comparisons across regions would still be possible under the assumption that over- or underestimation in nutritional requirements are spatially random. For pregnancy and lactation, as fertility rates have become more uniform throughout the DRC (Romaniuk 2011), the true underestimation of food insecure households due to missing data on pregnant or lactating women will probably be similar across different regions too. A stronger assumption however is that meal partaking patterns of household members and visitors would be similar across the country as well.

3 Methodology

The methodology used in this article aims to respond to two core research questions. First, how well does FCS capture variation in diet quantity and diet quality. And second, how adequate are the standard FCS thresholds in distinguishing food secure from food insecure households, and how do they compare to some alternative sets.

3.1 Computation of FCS and benchmark variables

To extract FCS from HCES data, the food frequency table developed by the Vulnerability Analysis and Mapping (VAM) unit of WFP in Kinshasa was applied to the food consumption data (Appendix). This implied, first, the assignment of all 212 individual food items to each of the 16 food clusters identified in the VAM module using a standard threshold for condiments. Subsequently, daily consumption frequencies were derived over a randomly selected 7-day interval running from day 3 through day 9 within the 15-day diary period of HCES-DRC (2004/5). The condiment level was fixed at 7.5 g per AME per day for identifiable food consumption, and at its corresponding monetary threshold (separately estimated for each of the 16 food groups and 56 regional clusters) for unidentifiable food consumption. As the weight limit is expressed in AME, it corresponds to the teaspoon threshold of 5 g per person used in Wiesmann et al. (2009). Once the consumption frequency for each food cluster was determined, the standard FCS methodology was followed, which involves: (i) the summation of food cluster frequencies within each of the eight basic food groups, (ii) the truncation of any food group score above 7 to a maximum of 7, (iii) the multiplication of these truncated food group scores with their corresponding weights, and (iv) the summation of these weighted food group scores to finally obtain FCS. The weights assigned to each FCS food group were the following:

"2" for cereals and tubers, "3" for pulses, "1" for vegetables and fruit, "4" for dairy products, meat and fish, and "0.5" for sugar and oil (WFP 2008).

As for our benchmark variables, intakes were estimated using the full diary period (approx. 15 days). Apart from food energy, the following 14 micronutrients were considered: calcium, iron, magnesium, zinc, thiamine, riboflavin, niacin, folate and vitamins A, B6, B12, C, D and E. All intakes were expressed per day and per calorie- or nutrient-specific AME following the latest requirements in human nutrition (FAO 2001; WHO/FAO 2004; WHO 2007). As adult reference, we chose a 30-years old male person with a moderate physical activity level (PAL) of 1.75, a very low bioavailability for dietary iron (5%) and a low bioavailability for dietary zinc (15%). As we did not have information on pregnancy or lactation status in women, we could not account for their increased dietary requirements. Similarly, it was unknown whether children of 0 to 6 months of age were breastfed and to what extent. Therefore, the nutritional requirements for children aged 0 to 6 months were arbitrarily set equal to those of non-breast-fed infants. To facilitate validation of FCS as a measure of diet quantity *and* quality, MAR of household nutrient intake has been derived to act as the benchmark variable following common practice by averaging the individual adequacy ratios of calories and the 14 micronutrients, after those exceeding one have first been truncated to one (Becquey et al. 2010).

3.2 Association between FCS and benchmark variables

After a first discussion of descriptive statistics and triangulation with external sources, we started to investigate the relationship between FCS and its benchmark variables by applying correlation analysis to the following three specifications.

A first specification disaggregates urban and rural correlations between FCS and daily calorie intake per AME. Here as well as for the other two specifications we also assessed the effect of slight changes to the standard FCS methodology: according to previous studies (Lovon and Mathiassen 2014; Wiesmann et al. 2009), the correlation generally improves when (i) the truncation procedure is removed, (ii) all food group scores receive equal weights and (iii) the number of food groups increases. As this specification fully aligns with other validation work, our results can be easily compared with other country settings.

A second specification replicated the previous one but was applied to smaller geographical areas. Given the size and diversity of the DRC together with its inefficient food markets (Marivoet 2016), this regional analysis quantifie the importance of accounting for local diets. By setting thresholds of poor, borderline and acceptable food consumption a bit higher for societies where oil and sugar are frequently consumed by all households (WFP 2008), WFP to some extent already accounts for local diet diversity.

A third specification further extends the previous one by investigating the correlation between FCS and MAR based on intake levels of calories and 14 micronutrients. As the aim of FCS is to capture variation in both diet quantity *and* quality, this correlation analysis represents an essential contribution to this validation literature. As for the previous specifications, the effect of slight changes to the standard FCS methodology was examined to verify whether they consistently improve the association between the food proxy indicator and the benchmark variable.

Apart from correlation analysis, the overall strength of the relationship between FCS and MAR is further quantified using different measures and functional forms. A first measure concerns the Area Under the Curve (AUC) value (Baumann et al. 2013; Lovon and Mathiassen 2014; Wiesmann et al. 2009), which reflects the overall suitability of the proxy indicator. This area statistic is based on the Receiver Operating Characteristic (ROC) curve, which measures the degree of "sensitivity" and "specificity" in which FCS correctly discriminates households as food secure or insecure (Baumann et al. 2013; Lovon and Mathiassen 2014; Wiesmann et al. 2009). A cut-off of 2,750 kcal per day per AME[3] was set to define food secure households when only diet quantity is considered. When considering both diet quantity and quality, the MAR cut-off was set at 0.90. The choice for setting the minimal MAR equal to 0.90 is mainly operational as it represents the highest cut-off for which each region in the DRC at least has one food secure household to be able to derive all ROC statistics. A rule-of-thumb considers AUC values below 0.60 as not acceptable, whereas an AUC above 0.70 is good (Wiesmann et al. 2009). Further, three generic functional forms (linear, polynomial and logarithmic) were tested and goodness-of-fit will be discussed later. Equation (1), (2) and (3) provide the algebraic expression of the three models, in which X equals FCS and Y refers either to daily calorie intake per AME or MAR, depending on the precise specification under review.

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad \text{(linear)} \tag{1}$$

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \varepsilon \quad \text{(polynomial)} \tag{2}$$

$$\ln(Y) = \beta_0 + \beta_1 \ln(X) + \varepsilon \quad \text{(logarithmic)} \tag{3}$$

[3] This cut-off corresponds to the dietary energy requirements of a 30-years old male with a body weight of 60 kg and a PAL of 1.75 (FAO 2001).

3.3 Adequacy of various FCS thresholds

Three sets of FCS cut-offs were assessed in terms of their compliance with the principles of consistency and relevancy. This approach was inspired by the literature on poverty line methodologies, whereby consistency refers to a need for comparability and relevancy[4] and requires thresholds to be sensitive to the local setting (Arndt and Tarp 2017). Despite a trade-off being observed in practice between both principles, they can theoretically be reconciled by setting a fixed threshold in the utility domain while deriving its local equivalents in commodities or money-metric terms (Marivoet and De Herdt 2015). Although it is difficult to determine base levels for an abstract concept such as utility, minimum levels for food consumption are much easier to establish, because recommended daily intakes have been clinically determined. Based on this knowledge and the most appropriate functional form observed in the previous section, we estimated a set of regionally relevant but nutrient-consistent FCS cut-offs and compared their ROC statistics with those observed under the standard WFP threshold or when the ROC-optimal regional cut-offs were to be used.

4 Results and discussion

4.1 Descriptive statistics and triangulation with external sources

The extensive dataset preparation work resulted in a considerable reduction of the original sample. We therefore first provide some descriptive statistics of this reduced dataset and compare the results with findings from other nutritional studies in the DRC. The objective was to verify to what extent the final dataset used for this exercise aligns with available knowledge and to identify the origins of any substantial deviation.

Figure 1 displays weekly food frequencies for each of the eight constituent food groups by FCS levels. At lower consumption levels, the national dish "*fufu na pondu*" which is a flour paste based on varying combinations of maize and cassava, combined with cassava leaves and prepared with substantial amounts of palm oil, dominates. At higher consumption levels, this dish is often complemented with fish as a source of animal proteins. When households become richer, gradually more sugar and pulses are added to the diet while the consumption of dairy products only occurs after FCS reaches 60. The share of fruit in the total food basket seems negligible across all consumption levels. Except for pulses and fruit, which seem to play a less important role in our data, the composition of Fig. 1 broadly aligns with the findings of the Comprehensive Food Security and Vulnerability Analysis (CFSVA) conducted in 2011/12 (WFP 2014).

Contrary to its composition, the FCS *level* is markedly different between our final dataset and CFSVA (2011/12). This can be seen in Table 3, which presents the mean FCS by province and sector for each data source. Focusing on the rural sector and except for Nord-Kivu and Equateur, FCS is on average 10 points higher in 2011/12 compared to 2004/5. This difference may simply reflect the improvement in food security over time. Indeed, whereas HCES-DRC (2004/5) took place just after the second Congo War (1998–2003), CFSVA was conducted during a politically more stable and less violent episode. Yet, another reason for the observed difference in mean FCS levels relates to the removal of households with recall data, which was necessary to correctly account for daily food frequencies (see above). Given the fact that this recall module mainly consists of food items purchased in bulk, this operation might have removed households with a richer diet. The latter explanation is supported by the fact that mean calorie intake levels based on the full sample as computed by Marivoet (2016) were markedly higher for all provinces and sectors, except for the cities in Orientale and the rural sector of Bandundu and Sud-Kivu, than the same estimates based on the reduced sample (see Table 3). In any case, estimates of caloric intake all remain in a realistic range, except for Kinshasa and Sud-Kivu (both sectors) where dietary consumption seems to be underestimated.

The fact that the reduced sample contains households characterized by a poorer diet can be further confirmed by examining a set of individual nutrient intakes. Figure 2 displays deficiency ratios in terms of calories and 10 other nutrients, calculated using different approaches, but all based on the same HCES-DRC (2004/5). The first approach, followed by Ulimwengu et al. (2012), employs the full sample, provides no mark-up for unidentified consumption and relies on a FCT which was available and deemed appropriate at the time of the analysis. According to this approach, deficiency ratios are relatively modest for vitamin A and C with ratios below 15%, while being a bit higher for vitamin B6 (around 25%). These ratios are considerably higher for proteins, calories, vitamin E and folate, where average deficiency ranges from 59% to 69%. Deficiency ratios become really alarming for riboflavin, iron, zinc and vitamin B12, with rates well above 80% (Ulimwengu et al. 2012). Following the same approach but reducing the sample size to 4,232 households (see intermediate version 1), most deficiency ratios increased – thus confirming the hypothesis that our final sample consisted of households with poorer diets. The *decrease* of deficiency rates observed for vitamin A and C should not be read as an exception to this finding, as these nutrients are especially found in palm oil and cassava leaves, two cheap food items eaten in large quantities by the poor.

[4] To avoid conceptual confusion with one of the ROC statistics mentioned above, we refer here to the principle of 'relevancy' instead 'specificity' – the latter being more commonly used in the poverty literature.

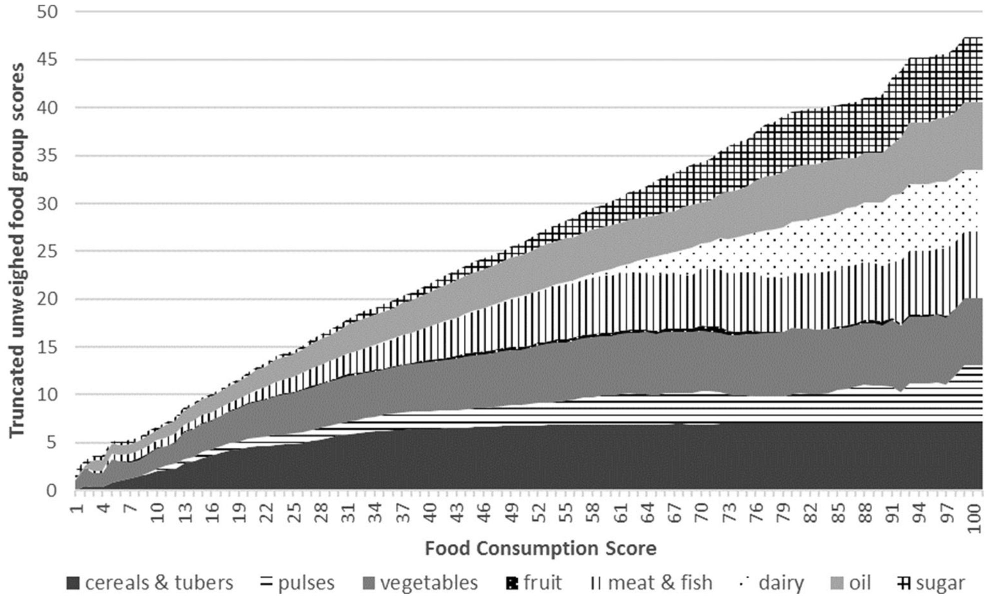

Fig. 1 Contribution of truncated food group scores to FCS, DRC (2004–5). Source: HCES-DRC (2004/5)

Further refining the approach by applying a food-group-specific nutrient mark-up for the non-identified part of household food consumption (see intermediate version 2) results in lower deficiency ratios for all nutrients with regard to the levels previously attained under version 1. Then, making use of a more recent and integrated set of FCT records (see above) substantially alters the overall outlook of food insecurity. First, the application of edible conversion factors has an important effect overall, but especially on nutrient intakes of vegetables, fruit, meat and fish (i.e. food items with inedible skin, kernels and bones). This, together with a more realistic and lower vitamin C and B6 entry for cassava flour, results in lower actual intakes for both vitamins, which in turn explains the markedly higher deficiency ratios observed. At the same time, we observe substantially lower deficiency rates for vitamin

Table 3 Triangulation of food consumption score and calorie intake

	Mean food consumption score			Mean calorie intake per equivalent adult			
	HCES-DRC (2004/5)		CFSVA	HCES-DRC (2004/5)			
	Our estimates		(2011/12)	Our estimates		Marivoet (2016)	
	N = 4,232		*N* = 24,884	N = 4,232		*N* = 12,087	
	Urban	Rural	Rural	Urban	Rural	Urban	Rural
Kinshasa	54.5	na	na	1661	na	1818	na
Bas-Congo	45.8	46.3	54.7	1976	2771	2212	3331
Bandundu	45.8	40.8	52.1	2257	2622	2511	2585
Equateur	50.2	45.7	44.6	2544	2983	3027	3593
Orientale	35.2	33.0	47.3	2463	2579	2156	3825
Nord-Kivu	34.4	29.7	47.6	2255	2647	2708	3408
Maniema	40.2	34.1	48.2	3011	2904	3805	3472
Sud-Kivu	41.4	31.9	46.1	1615	1542	1722	1427
Katanga	44.4	40.9	49.3	2067	2698	3256	3939
Kasai-Oriental	41.4	33.7	45.7	2343	2342	3077	2732
Kasai-Occidental	40.8	41.3	48.6	2395	2813	2690	2847
Total	45.4	37.9	48.0	2107	2542	2454	3186

Source: HCES-DRC (2004/5), WFP (2014), Marivoet (2016)

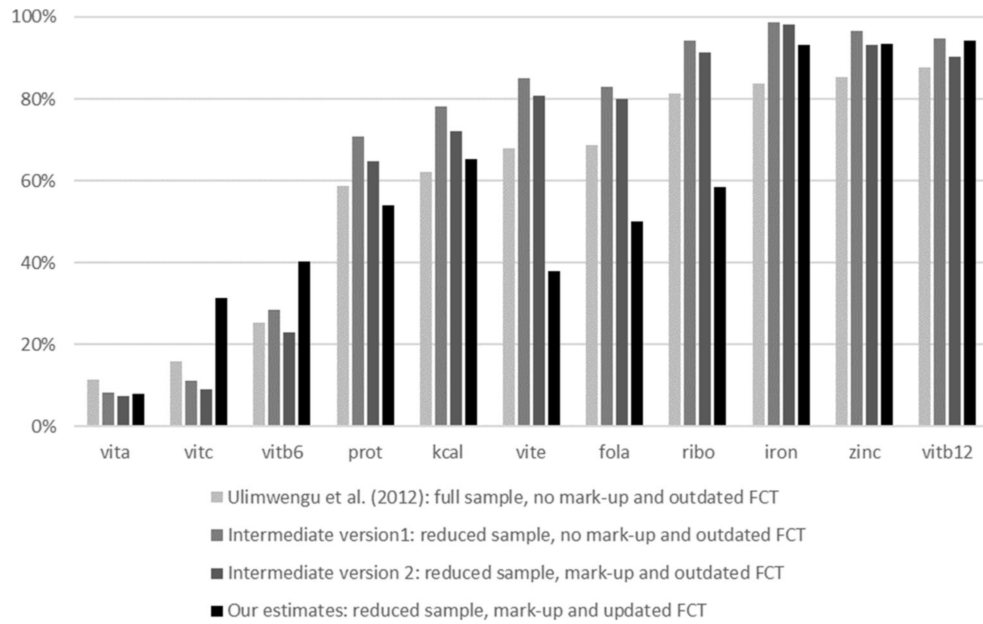

Fig. 2 Nutrient deficiency ratios under varying approaches. Source: HCES-DRC (2004/5), Ulimwengu et al. (2012)

E, folate and riboflavin. Closer inspection of the nutrient content of both series revealed that the updated FCT assigns considerably more vitamin E to oil as well as more folate and riboflavin to cassava leaves, compared to FCT used by Ulimwengu et al. (2012). For the remaining nutrients, the change in FCT seems to matter less, either because the nutrient content of different food items is very similar across both FCT or the cumulative effect of any such difference largely levels out. Given that deficiency rates largely remain the same, these explanations seem to hold especially for vitamin A, B12, iron and zinc, and to a lesser extent for proteins and calories.

We conclude that the HCES-DRC (2004/5) data is suitable to conduct the present validation exercise. First, the food group composition underpinning FCS corresponds well with the one obtained through a standard CFSVA survey, as well as with common knowledge about the country's food diet. Second, compensating for unidentified consumption has a small yet tangible effect on the estimated nutrient intakes, which in turn must improve their association with FCS. And third, using an updated FCT illustrates the substantial impact on measures of nutritional intake of food. The reduction in sample size and overrepresentation of poorer, nutrition insecure, households need to be kept in mind when interpreting the results. Yet, in the context of this article, data representativeness is less important than finding a solid base to study the structural relationship between household's FCS and its underlying nutritional intake. In addition to the extensive dataset operations and controls implemented (see above), the quality of the final sample is further supported by the fact that all essential data for this validation study are derived from the same source and thus refer to the same timeframe.

4.2 Specification 1: Association between FCS and calorie intakes at sector level

Figure 3 shows that calorie elasticities of FCS are positive and markedly higher for the rural than for the urban sector. Generally, rural families are engaged in agriculture and therefore require more energy. Rural dwellers also have limited access to a diverse set of food items and are likely to spend any additional resources to calorie-dense food that is locally available. Therefore, higher FCS levels will more often imply higher calorie intakes in the rural sector compared to the urban sector, where a more diverse palette of food is both available and accessible. In addition, non-linear regression models capture more variation than the linear model, especially for the rural sector. Among the two non-linear models tested, the logarithmic model performs best with an adjusted R-squared of 3.9% for the urban and 18.0% for the rural sector, compared to respectively 2.0% and 15.1% for the 2nd degree polynomial model. However, as reflected by the amorphous scatterplots, the strength of association between FCS and calorie intake is generally very weak for all three models tested and especially for the urban sector.

To explain the weak performance of FCS in capturing the variation in calorie intake, we first assess the effect of slight changes to its underlying construction. Apart from strengthening the association between calorie intake and the proxy indicator, these changes may also be helpful to better understanding of some of the particularities of food access in the DRC.

A first change which may affect the relationship concerns truncation of food group scores above 7. Being more calorie-dense, this truncation is most important for the food group of

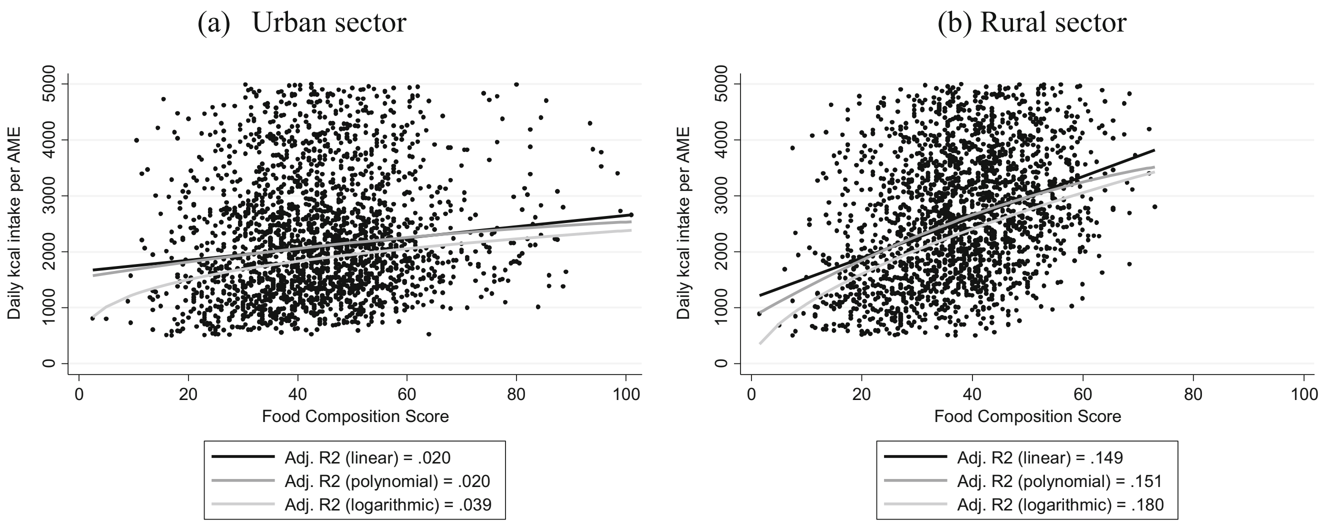

Fig. 3 Scatter plot of FCS against calorie intake per AME per sector, DRC (2004/5). Source: HCES-DRC (2004–5)

main staples. Indeed, any increase in consumption frequencies of cereals and tubers above the sum of 7 goes unnoticed in terms of FCS level, but will likely entail an increase in calorie intake. However, according to Table 4, the effect of truncation on the performance of FCS is minimal for the rural sector and is not apparent for the urban areas of the country. More precisely, when no truncation is performed (which by construction results in an increase of the number of food groups), the correlation coefficient of the rural sector only slightly increases from 0.39 to 0.41, and that of the urban sector decreases from 0.14 to 0.11. This result is consistent with Fig. 1, which shows that households in 2004/5 start to eat main staples on a daily basis only after having reached an FCS of 70.

A second change relates to the weighing scheme applied before final summation into FCS. Some food groups with

Table 4 Pearson's and Spearman's correlation coefficients of different food frequency indicators with calorie intake per capita or AME, various countries (2004–2011)

Specification	FCS	Alternative food frequency indicators				
Number of food groups	8	8	12	15–24	15–24	120–219
Truncation	yes	yes	yes	no	no	no
Weighting	yes	no	no	yes	no	no
Country	Correlation coefficients					
DRC (2004/5) – urban	.14***	.12***	.05*	.11***	.07***	−.02
DRC (2004/5) – rural	.39***	.39***	.39***	.41***	.39***	.35***
Burundi (2007) – rural	.27**	.28**	.34**	.33**	.34**	.40**
Haiti (2008) – north & northeast	.44**	.45**	.49**	.46**	.47**	.52**
Sri Lanka (2005/6) – tsunami-regions	−.01	.04	.05^{+}	.02	.08**	.17**
El Salvador (2011) – rural	.33**	.35**	na	na	na	na
Guatemala (2011) – rural	.36**	.39**	na	na	na	na
Honduras (2011) – rural	.20**	.22**	na	na	na	na
Nepal (2010/11) – urban	.22**	.22**	na	na	na	na
Nepal (2010/11) – rural	.25**	.27**	na	na	na	na
Uganda (2009/10) – urban	.31**	.29**	na	na	na	na
Uganda (2009/10) – rural	.32**	.31**	na	na	na	na

Whereas for the DRC, Burundi, Haiti and Sri Lanka, Pearson's correlation coefficients have been used, the other countries display Spearman's correlation coefficients. The number of food groups and food items considered for the alternative indicators depends on the food frequency module adopted by the WFP in each country and on the specificities of the benchmarking survey

$^{+}$ = significant at .10, * = significant at .05, ** = significant at .01, *** = significant at .001

Source: HCES-DRC (2004–5); Wiesmann et al. (2009); Lovon and Mathiassen (2014) strong potential to differentiate across calorie levels may receive relatively low weights, while other food groups without such potential get higher weights. Removing the weights then increases the overall correlation between FCS and calorie intake. Yet, for both the urban and rural sectors, correlation coefficients drop slightly when no weights are applied (see Table 4), suggesting that the actual weighing scheme is more supportive in capturing calories. However, also here, the effect is minimal.

A third change to improve the correlation between FCS and calorie intake is by disaggregating food groups. If different items from the same food group are consumed in combination or at different times during the day (for example a rice dish at noon and bread for dinner), then they are counted only once within that food group but several times if individual food items were considered. As a result, the correlation between FCS and calorie intake might improve by relying on less aggregate food categories, at least if multiple consumption of calorie-dense food items were common throughout the day. Again, this issue of repetitive calorie-rich intakes per day does not seem to be at play in both sectors in the DRC, as correlation coefficients in Table 4 either markedly decrease or remain stable with increasing levels of food group disaggregation.

Compared to the countries studied by Wiesmann et al. (2009) and Lovon and Mathiassen (2014), the DRC validation results lead to different conclusions. For all countries except Uganda, each change to the FCS methodology improved the correlation between the food frequency indicator and calorie intake. For the DRC, only the removal of the truncation procedure had a noticeable, albeit minimal, effect on the strength of association, and only in the rural sector. With respect to the strength of the association itself, the data reveal a substantial difference between the rural and the urban sector of the DRC. Whereas the correlation coefficients observed for the rural sector roughly fall within the range observed in other country settings, the urban sector, with a correlation coefficient of 0.14 and an adjusted R-squared of 0.039 (for the logarithmic model), is clearly doing much worse than case studies of any other country, except for Sri Lanka.

4.3 Specification 2: Association between FCS and calorie intakes at regional level

To investigate the poor performance of FCS in capturing calories in the urban sector of the DRC, this second specification replicates the same correlation analysis at the provincial level. We attempt to account for regional differences in agro-ecological conditions, market access and corresponding diets. All previous validation work took place in rather small countries, with an accumulated territory smaller than half the size of the DRC (WB 2017) and presumably with a lower regional diversity. It may be that the poor performance of FCS in capturing calories in Congolese cities is the result of collapsing diverse regional dietary patterns into the same correlation analysis, thus hiding stronger associations at the regional level. In other words, the same FCS may correspond on average to very different calorie intake levels for each region, but within each region these differences might be considerably smaller.

Table 5 suggests that collapsing diverse regional dietary patterns may indeed reduce the performance of FCS as a calorie intake proxy. Compared to the total urban sector, correlation coefficients between FCS and calorie intake at the provincial level are significantly higher for Kinshasa, Bas-Congo, Bandundu and Nord-Kivu (ranging from 0.53 to 0.39) and still noticeably higher for Katanga, Equateur and Kasai-Oriental (ranging from 0.27 to 0.18). For the rural sector, considerable variation across different provinces is apparent, with correlation coefficients ranging from a low 0.13 for the rural areas of Sud-Kivu and Katanga to 0.57 in Kasai-Oriental. All rural sectors by province yield significant correlations.

Further, no structural improvement results from implementing small changes to the FCS methodology. Indeed, increasing the number of food groups generally does not improve the correlation between the food proxy indicator and calorie intake. Similarly, the removal of weights only substantially increases the correlation coefficients for the cities in Equateur and Maniema as well as the villages of Nord-Kivu, Maniema, Sud-Kivu and Katanga. For all other regions, the standard FCS or its non-truncated version leads to the highest correlations with coefficients of both specifications being relatively close to each other.

The main conclusion of this section is that any investigation of food access in a country as large and diverse as the DRC can only be meaningful when a spatially refined approach is adopted. When considering regions of the DRC, the association between FCS and calorie intake largely falls within the range observed in other (relatively small) countries. Yet, for some regions, the correlation coefficients are still low, possibly because the analysis is still too aggregated or that a sole focus on calories prevents us grasping the fuller picture. Indeed, low correlations between FCS and calorie intake should not be of immediate concern, as the former does not intend to be a perfect substitute for the latter, but rather attempts to capture variation in both diet quantity *and* quality. From this point of view, less than perfect correlations might be a necessity to enabling the capture of some aspects of diet quality, which are considered in the following section.

4.4 Specification 3: Association between FCS and MAR at regional level

After changing our benchmark variable from calorie intake to MAR, which is the mean of the individual adequacy ratios of

Table 5 Pearson's correlation coefficients of different food frequency indicators with calorie intake per AME, DRC (2004–5)

Specification	FCS	Alternative food frequency indicators				
Number of food groups	8	8	12	16	16	212
Truncation	yes	yes	yes	no	no	no
Weighting	yes	no	no	yes	no	no
Province per sector	Correlation coefficients					
Urban sector DRC	.14***	.12***	.05*	.11***	.07***	−.02
- Kinshasa	.53***	.49***	.45***	.54***	.49***	.33***
- Bas-Congo	.42***	.40***	.33***	.41***	.35***	.30***
- Bandundu	.39***	.39***	.35***	.36***	.35***	.18**
- Equateur	.20**	.24***	.15*	.17**	.23**	.09
- Orientale	−.14	−.09	−.10	−.13	−.09	−.10
- Nord-Kivu	.40***	.39***	.33***	.39***	.33***	.33***
- Maniema	.11	.17*	.13+	.16*	.14+	.09
- Sud-Kivu	.19	.20+	.18	.27*	.21+	.20
- Katanga	.27**	.22*	.08	.26**	.10	.09
- Kasai-Oriental	.18**	.22***	.20**	.24***	.19**	.08
- Kasai-Occidental	.15+	.14+	.10	.10	.12	.11
Rural sector DRC	.39***	.39***	.39***	.41***	.39***	.35***
- Bas-Congo	.21**	.18*	.16*	.22**	.15*	.12
- Bandundu	.32***	.23**	.24***	.37***	.25***	.14*
- Equateur	.36***	.36***	.33***	.39***	.35***	.26***
- Orientale	.35***	.32***	.31***	.35***	.30***	.28***
- Nord-Kivu	.40***	.50***	.46***	.40***	.46***	.46***
- Maniema	.44***	.51***	.51***	.46***	.51***	.47***
- Sud-Kivu	.13*	.16*	.16**	.15*	.17**	.20**
- Katanga	.13+	.25***	.13+	.09	.11	.05
- Kasai-Oriental	.57***	.58***	.58***	.63***	.58***	.53***
- Kasai-Occidental	.39***	.35***	.36***	.43***	.37***	.28**

The province of Kinshasa formally has no rural sector

+ = significant at .10, * = significant at .05, ** = significant at .01, *** = significant at .001

Source: HCES-DRC (2004–5)

calories and 14 micronutrients, the same analysis was replicated and results are shown in Table 6.

A noticeable increase is apparent when comparing the correlation coefficients between FCS and MAR with those previously obtained (Table 5). For all 21 regions except three (the rural sector of Equateur, Orientale and Kasai-Oriental), the association is stronger, increasing by 0.03 in urban Katanga to 0.26 in rural Bandundu. With the new benchmark, 13 out of 21 regions display a minmal correlation coefficient of 0.30, while the remaining regions have coefficients between 0.21 and 0.28 (except for urban Orientale showing insignificant results). In conclusion, the effect of adding diet quality to the validation analysis makes FCS a better proxy indicator for the access dimension of food security. This effect is, however, variable, suggesting that in some regions FCS broadly captures variation in calorie intake, whereas in other regions it is more a measure of diet quality.

Similar observations as with calorie intake as the benchmark variable apply with respect to small changes in FCS methodology. First, increasing the number of food groups seems to increase the correlation coefficient of rural Sud-Kivu only. Second, removing the weights from the construction of FCS results in better fits in only six regions (the urban sector of Bandundu, Equateur and Kasai-Oriental and the rural areas of Nord-Kivu, Maniema and Katanga). For all other regions, the standard FCS methodology or its non-truncated version yields better fits. When the non-truncated version performs better, the results of the standard FCS are often close to it. FCS in many regions does however capture more variation in terms of MAR when food group scores are not truncated. Given the empirical build-up of FCS in the DRC, as shown in Fig. 1, this observation can be traced back to the category of vegetables, which, according to the VAM-WFP food frequency table, is spread over three separate

Table 6 Pearson's correlation coefficients of different food frequency indicators with MAR, DRC (2004–5)

Specification	FCS	Alternative food frequency indicators				
Number of food groups	8	8	12	16	16	212
Truncation	yes	yes	yes	no	no	no
Weighting	yes	no	no	yes	no	no
Province per sector	Correlation coefficients					
Urban sector DRC	.17***	.12***	.02	.12***	.05*	−.06**
- Kinshasa	.59***	.54***	.50***	.61***	.55***	.37***
- Bas-Congo	.48***	.39***	.30***	.45***	.33***	.29***
- Bandundu	.53***	.55***	.51***	.48***	.50***	.34***
- Equateur	.32***	.36***	.24***	.29***	.32***	.11
- Orientale	.01	.01	−.00	.02	.02	−.00
- Nord-Kivu	.48***	.42***	.35***	.46***	.35***	.32***
- Maniema	.25**	.27***	.21**	.28***	.24**	.20**
- Sud-Kivu	.28*	.31*	.25*	.33**	.27*	.22^{+}
- Katanga	.30**	.24*	.10	.31**	.13	.08
- Kasai-Oriental	.28***	.32***	.28***	.31***	.28***	.19**
- Kasai-Occidental	.26**	.24**	.18*	.22**	.23**	.21**
Rural sector DRC	.44***	.45***	.42***	.44***	.43***	.39***
- Bas-Congo	.25***	.19*	.17*	.26***	.19*	.16*
- Bandundu	.58***	.57***	.55***	.60***	.56***	.44***
- Equateur	.35***	.33***	.30***	.37***	.32***	.23***
- Orientale	.35***	.33***	.29***	.35***	.28***	.25***
- Nord-Kivu	.50***	.61***	.59***	.50***	.58***	.58***
- Maniema	.55***	.62***	.58***	.54***	.58***	.52***
- Sud-Kivu	.21***	.26***	.25***	.22***	.25***	.29***
- Katanga	.23**	.29***	.14^{+}	.18*	.13^{+}	.04
- Kasai-Oriental	.46***	.45***	.41***	.49***	.41***	.36***
- Kasai-Occidental	.44***	.39***	.36***	.45***	.38***	.33***

The province of Kinshasa formally has no rural sector

$^{+}$ = significant at .10, * = significant at .05, ** = significant at .01, *** = significant at .001

Source: HCES-DRC (2004–5)

food clusters: orange coloured, dark green leafy and other vegetables. As a result, truncation might negatively affect the strength of association between FCS and MAR, especially given the frequent intake of dark green leafy vegetables in the DRC, which are rich in calcium, iron, riboflavin and vitamin C. Being similarly spread over more than one VAM-WFP food cluster, the same reasoning also applies to the categories of meat and fish, which are rich in niacin and vitamins D and B12. However, given that those food items are often more expensive, fewer Congolese households reach truncation level.

4.5 Goodness-of-fit measures

By incrementally refining the validation domain, from national to regional, and from calorie intake to MAR, the above analysis showed that correlations between FCS and the benchmark variable structurally improved, while the standard version of FCS was repeatedly among the best specifications. To further quantify the predictive power of FCS to identify food (in)secure households as well as to assess how well, overall, FCS captures variation in diet quantity and quality, Table 7 presents the regional AUC values and the adjusted R-squared coefficients under three different functional forms, linear, polynomial and logarithmic. As a reference, the same goodness-of-fit measures are also displayed for calorie intake as the benchmark variable.

In line with the findings above, FCS generally becomes a more suitable food security indicator when it is approached as a proxy of both diet quantity and quality. For all regions except eight, AUC values substantially increase when replacing calorie intake by MAR as the benchmark variable. As a result, more than half of all regions now report an AUC value close to or above 0.70, which is considered "good", and only three (i.e.

Table 7 AUC values and adjusted R-squared coefficients of different functional forms, DRC (2004–5)

Provinces per sector	KCAL = f(FCS)				MAR = f(FCS)			
	AUC	Linear	Polynomial	Logarithmic	AUC	Linear	Polynomial	Logarithmic
DRC (2004/5) – urban	.525	.020	.020	.039	.615	.029	.033	.040
- Kinshasa	.770	.278	.283	.317	.713	.350	.348	.369
- Bas-Congo	.712	.175	.171	.211	.661	.230	.237	.290
- Bandundu	.679	.150	.153	.225	.691	.273	.349	.346
- Equateur	.626	.035	.032	.044	.669	.098	.094	.102
- Orientale	.372	.013	.004	.008	.747	.008	−.006	−.009
- Nord-Kivu	.667	.157	.155	.192	.716	.224	.225	.230
- Maniema	.548	.005	.012	.019	.615	.055	.064	.059
- Sud-Kivu	.589	.020	.016	.030	.570	.061	.053	.063
- Katanga	.648	.062	.068	.043	.520	.083	.074	.082
- Kasai-Oriental	.514	.030	.034	.065	.682	.075	.077	.095
- Kasai-Occidental	.530	.014	.029	.030	.693	.063	.086	.072
DRC (2004/5) – rural	.666	.149	.151	.180	.747	.193	.197	.196
- Bas-Congo	.587	.040	.035	.039	.585	.057	.052	.051
- Bandundu	.574	.098	.151	.283	.809	.331	.350	.405
- Equateur	.676	.130	.127	.140	.651	.120	.118	.104
- Orientale	.664	.121	.119	.138	.614	.118	.116	.093
- Nord-Kivu	.689	.160	.175	.210	.783	.248	.291	.312
- Maniema	.701	.192	.200	.234	.699	.300	.375	.401
- Sud-Kivu	.500	.013	.034	.019	.844	.040	.053	.025
- Katanga	.586	.010	.008	.024	.713	.047	.050	.054
- Kasai-Oriental	.748	.324	.319	.301	.947	.203	.200	.197
- Kasai-Occidental	.672	.141	.173	.209	.766	.184	.176	.172

The province of Kinshasa formally has no rural sector

Source: HCES-DRC (2004–5)

the urban sector of Sud-Kivu and Katanga as well as the rural sector of Bas-Congo) do not reach the acceptable level of 0.60. Relying on adjusted R-squared coefficients, one can also observe a marked increase in the overall strength of association when using MAR as the reference instead of calorie intake, except for the rural sector of Equateur, Orientale and Kasai-Oriental. Furthermore, the logarithmic functional form describes best the relationship between FCS and MAR for 10 out of 21 regions. For the remaining 11 regions, either the linear (7) or polynomial (4) model provides a better fit, with the logarithmic version being second-best or close in value (except for the rural sector of Sud-Kivu). On the other hand, quite some variation in the strength of association exists, ranging between only 2.5% (rural Sud-Kivu) and 40.5% (rural Bandundu) of total variation in MAR being explained by FCS. These figures serve as an important reminder that FCS above all remains a *proxy* indicator. In any case, the range of variation again emphasizes the importance of adopting a region-specific approach.

4.6 Adequacy thresholds

So far, this analysis solely investigated FCS's potential to capture variation in diet quantity and quality, for which the results have been generally encouraging. ROC analyses also suggest that FCS has an acceptable predictive power of food security in most contexts. A useful application of this food security indicator for policy and decision making is its utilisation as a binary indicator to distinguish food secure from food insecure populations. In this section, we first propose a set of nutrient-consistent regional thresholds, after which we discuss its merits compared to the standard WFP threshold and to the regional ROC-optimal thresholds.

To derive the set of nutrient-consistent regional cut-offs, we estimated the relationship between FCS and MAR for each of the 21 regions using a logarithmic model (Eq. (4)). The region-specific regression coefficients were then used to convert a MAR-threshold of 0.90 into its regional FCS equivalent. This set of thresholds is reported in Table 8 together with their corresponding ROC statistics. Given

Table 8 Sensitivity and specificity levels for three sets of FCS thresholds, DRC (2004–5)

Provinces per sector	% below MAR = 0.90	Nutrient-consistent thresholds				Standard WFP threshold				ROC-optimal thresholds			
		Cut-off	Sensitivity	Specificity	% below cut-off	Cut-off	Sensitivity	Specificity	% below cut-off	Cut-off	Sensitivity	Specificity	% below cut-off
Urban sector													
Kinshasa	96.9	72.9	0.85	0.40	84.0	42.5	0.23	1.00	22.4	63.0	0.72	0.71	70.7
Bas-Congo	89.6	53.4	0.72	0.43	70.4	42.5	0.40	0.87	36.9	45.5	0.52	0.78	49.2
Bandundu	91.2	50.4	0.65	0.53	63.8	42.5	0.38	0.86	35.6	51.5	0.69	0.53	66.7
Equateur	79.5	52.5	0.60	0.73	53.5	42.5	0.18	0.96	15.4	51.0	0.54	0.80	47.3
Orientale	95.9	33.7	0.45	1.00	43.3	42.5	0.77	0.38	76.6	36.0	0.51	1.00	48.9
Nord-Kivu	86.1	38.3	0.68	0.60	63.9	42.5	0.84	0.46	80.0	35.5	0.60	0.74	55.3
Maniema	82.9	41.2	0.55	0.60	52.4	42.5	0.57	0.51	55.8	40.5	0.54	0.64	51.2
Sud-Kivu	98.0	44.7	0.57	1.00	55.4	42.5	0.50	1.00	49.2	45.0	0.57	1.00	55.4
Katanga	94.6	49.0	0.62	0.45	61.5	42.5	0.38	0.55	38.1	na	na	na	na
Kasai-Oriental	98.3	44.3	0.61	0.69	60.6	42.5	0.52	0.69	51.5	44.5	0.61	0.69	60.6
Kasai-Occidental	96.3	43.1	0.59	0.67	57.7	42.5	0.55	0.67	53.9	45.5	0.68	0.67	66.4
Rural sector													
Bas-Congo	92.9	47.8	0.54	0.48	54.0	42.5	0.36	0.73	35.6	47.0	0.51	0.57	50.9
Bandundu	88.7	48.8	0.77	0.63	72.8	42.5	0.55	0.97	48.7	43.5	0.59	0.97	52.7
Equateur	79.0	47.1	0.56	0.65	51.6	42.5	0.34	0.85	30.0	50.5	0.70	0.52	65.7
Orientale	92.7	34.9	0.58	0.56	57.0	42.5	0.79	0.27	78.3	38.5	0.67	0.55	65.4
Nord-Kivu	92.9	33.6	0.63	0.74	60.7	42.5	0.91	0.57	87.6	43.5	0.92	0.57	88.3
Maniema	91.0	38.6	0.73	0.46	71.6	42.5	0.82	0.44	79.9	35.0	0.58	0.78	54.9
Sud-Kivu	97.7	32.9	0.52	0.98	50.6	42.5	0.85	0.37	84.3	41.0	0.79	0.98	76.9
Katanga	90.3	42.1	0.60	0.75	56.1	42.5	0.60	0.75	56.1	42.5	0.60	0.75	56.1
Kasai-Oriental	99.5	37.5	0.63	1.00	62.3	42.5	0.80	1.00	79.5	48.5	0.94	1.00	93.9
Kasai-Occidental	90.1	45.7	0.67	0.63	64.4	42.5	0.52	0.84	48.3	44.0	0.59	0.84	54.7

The province of Kinshasa formally has no rural sector. For the urban sector of Katanga, no ROC-optimal cut-off could be identified with a sensitivity and specificity level both above 0.50

Source: HCES-DRC (2004–5)

the country's diversity in agro-ecological conditions in the functioning of its food markets, as well as in its cultural eating habits, it should be expected that the same level of nutritional adequacy is achieved in different regions by very different combinations of food items and thus different FCS levels. Indeed, whereas rural dwellers in Sud-Kivu only need an FCS of 33 to reach a MAR of 0.90, the inhabitants of Kinshasa typically seem to require a much higher food frequency intake, reflected by a minimal FCS of 73, to reach the same adequacy level.

$$\ln\left(FCS_{ij}\right) = \beta_{0j} + \beta_{1j}\ln\left(MAR_{ij}\right) + \varepsilon_{ij} \quad \text{for all households } i \text{ in region } j = 1, \ldots, 21 \tag{4}$$

Two factors may contribute to the variation in nutrient-consistent thresholds. The first relates to the generic weighing scheme used to compute FCS. Although this scheme broadly reflects the nutrient density of each of the eight food groups, conflation between energetic and micronutrient content could impact the predictive power of FCS, depending on diet characteristics. For example, fruit and vegetables are typically poor in calories but rich in several micronutrients. They were attributed half the weight assigned to cereals and tubers, which are characterized by lower micronutrient density but higher energetic value. Therefore, diets particularly rich in fruit and vegetables would probably correspond to adequate micronutrient intake, which may not be reflected in FCS, as compared to a monotonous, cereal- or tuber-centred diet. Also, the exact nutrient composition of individual food items belonging to the same group can differ considerably. For example, multicoloured beans typically eaten in Sud-Kivu might be more nutritionally dense than other pulses possibly eaten elsewhere. More generally, the same weight associated with any food group can represent either an over- or underestimation of the true nutrient content of any constituent item eaten in any particular setting. The second factor refers to the possible variation in portion size (beyond the condiment level), for which the FCS methodology provides no control. Using the same example, the average meal size in rural Sud-Kivu might be bigger than in Kinshasa, thus resulting in higher nutrient intakes for the same food frequency in the former compared to the latter region.

Compared to these nutrient-consistent regional cut-offs, the uniform application of the WFP thresholds is only consistent in the trivial sense that the same numeric cut-offs are used; and it is only sufficiently relevant to local context if we content ourselves with the nation-wide upgrade by seven for societies characterized by a diet where oil and sugar is consumed on a daily basis, as decided upon by WFP in Kinshasa (WFP 2014). Indeed, the initial WFP thresholds of 35.5 (to distinguish acceptable from poor or borderline food consumption) are typically revised to 39 for either oil or sugar consuming societies, and to 42.5 for societies where both these food items are consumed almost daily (WFP 2008). Yet, to be more context sensitive, one should at least verify the extent to which the national assumption on oil and sugar consumption also applies to each of the country's regions. But more importantly, one should not only look at the regular consumption of oil and sugar to define cut-offs, nor at any other particular food group, but at the nutrient content of the *complete* diet in each region and its relationship with FCS. Summarised by Eq. (4), this is precisely the approach adopted to generate the set of nutrient-consistent regional thresholds.

Despite its uniform character and contrary to the findings of other validation studies using calories as the benchmark variable (Lovon and Mathiassen 2014; Wiesmann et al. 2009), the threshold of WFP used in the DRC provides an overall good fit for the rural sector of the country. In this sector, nutrient-consistent cut-offs range between 32.9 in Sud-Kivu and 48.8 in Bandundu. The same level, however, is generally too low to correctly categorize *urban* households as food secure or insecure: for 7 out of 11 provinces, nutrient-consistent cut-offs are markedly higher than 42.5. In terms of ROC statistics, the proposed thresholds are more appropriate than the uniform cut-off, given that eight regions record both sensitivity and specificity values equal or above 0.60, compared to only two for the WFP threshold. The ROC optimal thresholds, which are identified by maximising the sum of sensitivity and specificity and provided that both are above 0.50, obviously have better ROC values overall. However, these thresholds do not result in more regions having sensitivity and specificity levels both equal or above 0.60. Similarly, the incidence rates of households with an FCS below the nutrient-consistent thresholds align reasonably well with the incidence rates based on the MAR cut-off, and certainly do not perform much worse than the incidence rates following the ROC-optimal thresholds. For 10 out of 21 regions, the percentage of households with FCS below the nutrient-consistent cut-offs comes closest to the percentage of families with MAR below 0.90, compared to eight regions for the ROC-optimal cut-offs and seven for the standard WFP cut-offs.[5] As such, the nutrient-consistent thresholds used in this work not only perform relatively well in terms of identifying food insecure households but also regarding the estimation of malnourishment across regions in the DRC.

Given their attractive properties, we prefer the use of the regional thresholds derived in this section to further study and profile food insecure populations in the DRC. To

[5] For three regions (i.e. urban Sud-Kivu, urban Kasai-Oriental and rural Katanga), the incidence rates were the same in at least two occurrences following the application of the three cut-offs.

summarise, these cut-offs are more disaggregated, nutrient-consistent and locally relevant by construction and have household sensitivity and specificity values as well as regional targeting power close to levels attained by the ROC optimal thresholds. More broadly, given the general availability of HCES in many other countries, the use of nutrient-consistent regional FCS cut-offs could be equally tested and applied in other settings.

5 Conclusions

This article examines the potential of the Food Consumption Score (FCS) to capture variation in diet quantity and quality in different regions of the Democratic Republic of Congo (DRC); whether any change to the standard methodology is warranted; and how well the uniform threshold of the World Food Programme (WFP) reflects nutrient adequacy. For this validation study, we made use of the country's 2004/5 Household Consumption and Expenditure Survey (HCES-DRC) to derive FCS and two benchmark variables against which the food proxy was assessed. For the benchmark variables, we relied on calorie intake and computed a Mean Adequacy Ratio (MAR) based on calories, 14 micronutrients and the recommended intakes for each. While HCES-DRC (2004/5) shares the same unit of analysis and food security dimension as FCS, several dataset operations were necessary, especially to deal with unidentified food consumption and to reduce the ambiguity on the nature of food data being reported. These procedures resulted in a substantially reduced but more credible dataset to study the structural relationship between FCS and nutrient intakes.

Repeating the same correlation analysis across gradually more refined specifications allowed us first to compare our results with existing FCS validation work, before discussing the sequential effect of a more regional perspective and the inclusion of diet quality information. Starting with calorie intake as the benchmark variable, the average strength of association in the rural sector broadly aligns with the results obtained in other country settings. Yet, adjusted R-squared and correlation coefficients are much lower in the urban than in the rural sector, suggesting that FCS may be less effective in capturing variation in diet quantity of urban households. This latter observation may in part be traced back to the aggregate perspective: when the same analysis is repeated at the regional level, the association between FCS and calorie intake markedly improves to broadly reach the levels observed in other studies. Underpinning this observation, one can assume various types of local city food markets exist, each providing a different range of food items and each yielding distinct calorie levels for the same FCS combination. These observations underline the importance of a sufficiently local perspective when measuring food access.

Shifting from calorie intake to MAR as the benchmark variable, the correlation results further improve for most Congolese regions, which is encouraging for an indicator which also aims at capturing aspects of diet quality. Among the three functional forms considered, the logarithmic model seems to best describe the overall relation and AUC values are at least "good" (above 0.70) for the majority of Congolese regions while being "unacceptable" (under 0.60) for only 4 out of 21. On the other hand, with a minimum of 3.6% and a maximum of 40.1% of total variation explained (under the logarithmic model), the association remains weak and varies considerably across regions. With respect to possible changes to the standard FCS methodology, the findings in this article do not point to any structural improvement within reach. Neither the disaggregation of food groups nor the removal of weights seems to be better strategies than the current standard. Moreover, even though the removal of truncation proves to be superior in several regions, the standard FCS method often remains second-best or close in value.

FCS in its current form may therefore be considered as a reasonable proxy for the access dimension of food security in the DRC: it captures variation in both diet quantity and quality to an acceptable extent, however marked regional differences in performance exist. This encouraging picture in favour of FCS is somewhat ruptured if one uses this food security proxy in combination with the uniform thresholds typically put forward by WFP to measure food insecurity. Indeed, the FCS cut-off defined for the DRC has not been anchored in terms of nutritional intakes, nor did it consider much information regarding local diets. For these reasons, this study proposes an alternative set of cut-offs, which are based on the estimated relation between (the log of) FCS and (the log of) MAR for each of the 21 regions in the country. The proposed cut-offs are not only more locally relevant, nutrient-consistent by construction, and thus genuinely comparable across regions; they also appear to be markedly more sensitive and specific in categorising food insecure/secure households and better in predicting malnourishment rates across regions compared to the standard WFP threshold, while performing roughly equal in the latter respects compared to the ROC-optimal thresholds.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest with any organisation or individual.

Appendix: FCS module used by WFP in the DRC

SCORE DE CONSOMMATION ALIMENTAIRE

Il s'agit ici des aliments consommés **au cours des 7 derniers jours**

<table>
<tr><th colspan="5">CONSOMMATION ALIMENTAIRE</th></tr>
<tr><td colspan="5">Combien de jours durant les 7 derniers jours les membres de votre ménage ont-ils consommé les produits alimentaires suivants et comment ces aliments ont-ils été acquis ?

(écrire 0 pour les produits non consommés)</td></tr>
<tr><th colspan="2" rowspan="2">Produits alimentaires</th><th rowspan="2">Votre ménage a –t-il consommé hier ?

0=Oui 1=Non</th><th rowspan="2">Nombre de JOURS de consommation durant les 7 derniers jours ?

(0 à 7)</th><th>Sources des aliments consommés (Voir les codes ci-dessous)</th></tr>
<tr><th>Source principale</th></tr>
<tr><td>1</td><td>Céréales : sorgho, mil, maïs, blé Riz et pain/galette, beignets, farine, pâtes alimentaire</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>2</td><td>Racines, tubercules : pomme de terre, patates douces, igames, et autres tubercules</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>3</td><td>Légumineuse/noix : niébés, arachides, amande, et/ou autre noix</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>4</td><td>Légumes de couleur orange légumes riches en Vitamine A : carotte, poivron rouge, citrouille</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>5</td><td>Légumes à feuilles vertes foncées (manioc, patates, niébé etc.)</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>6</td><td>Autres légumes : oignon, tomates, concombre, haricot vert, petit pois etc.</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>7</td><td>Fruit de couleur orange (Fruits riches en Vitamine A) : mangue, papaye etc.)</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>8</td><td>Autres Fruits : banane, pomme, citron, mandarine, orange, goyave etc.</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>9</td><td>Viande : chèvres, moutons, bœuf, poulets, chameaux</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>10</td><td>Foie, rognon, cœur et/ou autres abats rouges</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>11</td><td>Poisson d'eau douce /mer /conserves de poisson</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>12</td><td>Œufs</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>13</td><td>Lait et Autres produits laitiers : Lait frais/ caillé, yaourt, fromage, autres produits laitiers <u>SAUF</u> margarine / beurre ou de petites quantités de lait pour le thé / café (Lait<u> en poudre</u> : seulement si des verres de lait en poudre sont consommés)</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>14</td><td>Huile/gras/beurre : huile de cuisson, beurre, margarine, autres gras/huile</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>15</td><td>Sucre ou produits sucrés : miel, confiture, beignets, bonbons, biscuits, pâtisseries, gâteaux et autre produits sucré</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>16</td><td>Epices/Condiments : thé, café/cacao, sel, ail, épices, levure/poudre à pâte, tomate/sauce piquante, autres condiments y compris petite quantité de lait pour le thé/café</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td colspan="5">CODE des sources :

1 = Propre production/jardins 6 = Dons d'amis/ de voisins/invitation

2 = Pèche/chasse 7 = Achat dans magasin principal

3 = Collecte 8 = Aide alimentaire (transferts monétaires ou bons alimentaires)

4 = Travail contre nourriture 9 = Achat dans marché du quartier

5 = Emprunt, (crédit de la boutique) 10 = Autre (à préciser)</td></tr>
</table>

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