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Validity of household survey indicators to monitor food security in time and space: Burkina Faso case study

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Abstract

Background: The timely and accurate identification of food insecurity situations represents a challenging issue. Household surveys are routinely used in low-income countries and are an essential tool for obtaining key food security indicators that are used by decision makers to determine the targets of food security interventions.

Methodology: This paper investigates the spatial and temporal quality of the food security indicators obtained through household surveys. The empirical case of Burkina Faso is used in this paper, where a large-scale rural household survey has been conducted yearly since 2009. From this data set, three food security indicators (the Food Consumption Score, the Household Dietary Diversity Score and the Coping Strategies Index) are calculated at the regional level for each year during the 2009–2017 period.

Results: Results highlight that observed spatiotemporal variations in these indicators are consistent with the major regional food shocks reported in food warning system reports and are significantly correlated with variations computed from other sources of data, such as satellite images, rainfall and food prices.

Conclusion: These results raise new research questions on food security monitoring systems and on the use of heterogeneous data and multiple food security indicators.

Keywords: Indicators, Food consumption score, Household Dietary Diversity Score, Coping strategies index, Household surveys, Spatiotemporal analysis

Introduction

The food situation in Africa is worsening again after an improvement of several years. Progress in reducing hunger in West Africa stabilized between 2000 and 2014. During these years, the prevalence of undernourishment progressively decreased from 12.3 to 10.7% before increasing again to almost 15% in 2019 and reaching a worrying projection of 23% for 2030 [14]. Burkina Faso ranks among the most affected countries by food insecurity in West Africa, recording a prevalence of undernourishment of 21.3% between 2015 and 2017 [12]. The situation in the region is strongly impacted by the "triple burden of malnutrition", namely, undernutrition, micronutrient deficiency and obesity. By 2017, three key indicators of food security—the prevalences of childhood wasting, childhood stunting, and adult obesity—were 7.6%, 27.3% and 4.5%, respectively, which are some of the most critical rates in West Africa [13]. Several interrelated (climatic, socioeconomic and political) reasons

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have led to the deterioration of the food situation in Burkina Faso over the past few years.

Dissatisfaction regarding food security measurement persists, especially in the wake of food and financial crises [16]. To prevent food crises and design appropriate interventions, food security agricultural monitoring systems have been set up by non-governmental organizations and state organizations, such as GIEWS created by the FAO (Global Information and Early Warning System of the Food and Agriculture Organization) or FEWS-NET funded by USAID (Famine Early Warning Systems Network of the United States Agency for International Development). These systems rely on collaborations with stakeholders at local and national levels, on the use of data collected from households and markets, and on the use of agrometeorological data extracted from Earth observation data that are jointly analyzed by food security experts [15]. Within countries, governments may have set their own food security monitoring systems that utilize individual nutritional data.

It has now been clearly established that food security is a complex concept and results from the interactions among several agro-environmental, socioeconomic and biological factors. There is no consensus on how food security should be measured or on what data should be preferentially collected. Food security monitoring systems integrate multiple sources of data, among which household surveys represent a fundamental source of information [4, 21, 40]. At the national level, governments tend to rely heavily on their own surveys both to compute proxies of domestic cereal production and to characterize food security at local levels. At the global level, the World Food Program [54], the FAO and the World Bank produce food security indicators from food consumption data collected in household surveys [34].

According to [16], four criteria are needed to gauge the usefulness of a food security indicator: its cost effectiveness, its capacity to deliver timely information, its nutritional relevance, and its temporal and spatial validity. Compared to indicators derived from individual consumption surveys, indicators derived from household surveys provide information on a similar time frame, but they are more cost effective as they do not enter into the very detailed quantification of consumed food items. On the other hand, in terms of nutritional relevance, household surveys provide indicators that are thus considered as less detailed but are still valid proxies for food security situations [27, 57]. On the temporal and spatial validity of food security indicators, most studies led have either focused on the spatial or on the temporal dimension. On the spatial dimension, household data indicators are commonly aggregated to generate food security maps that are used to determine the targets of food interventions (see https://hungermap.wfp.org/), and the spatial validity has been investigated by studies conducted at the country [41], city [50], and household [57] scales. However, these studies are generally conducted for one specific time period. On the temporal dimension, longitudinal studies have been led to gauge the capacity of household indicators to adequately measure food security trends over time [32].

Studies on the spatio-temporal validity of food security indicators derived from household surveys are missing. This paper argues that, despite the biases inherent in household surveys [2, 8, 59], food security indicators derived from household surveys can be used to detect food crises on a sub-national scale and for different years. The approach is based on official household survey data collected in Burkina Faso over the last decade ("Materials and methods" section). The analysis is built on three household indicators that are commonly used as proxies of food access at the household level: *HDDS* (Household Dietary Diversity Score), *FCS* (Food Consumption Score) and *rCSI* (reduced Coping Strategy Index) [27]. In "Results and discussion" section, the spatiotemporal concordances of the three indicators in terms of the food security situation at the regional scale is analyzed ("Analysis of the spatiotemporal variability in food security" subsection), along with their consistency with indicators from other data sources ("Consistency between household surveys and other data sources" subsection). "Conclusion" section draws conclusions about the strengths and limitations of household surveys in delivering food security information and about future research directions regarding food security monitoring systems and the use of heterogeneous data.

Materials and methods

The study area: Burkina Faso

Burkina Faso is a developing country located in West Africa, where food security is closely linked to agricultural production. It is a Soudano-Sahelian country with a semiarid climate in the north and a subhumid climate in the south, characterized by two seasons: a long dry season (approximately 8 months) and a short rainy season. Rainfall is generally low, irregular and unevenly distributed [47]. The rainy season is shorter and less intense in the north, which allows for the production of traditional rainfed cereals (millet, sorghum) and cattle breeding only. In the south, the rains last longer and are sufficient to enable crop diversification (sorghum, millet, maize, rice, cotton and groundnuts) (see Fig. 1). Food security largely depends on the production of rainfed agriculture, which is undermined by the effects of climate change (an intensification of severe climatic events, including droughts and floods, affecting food availability [47]) and by the

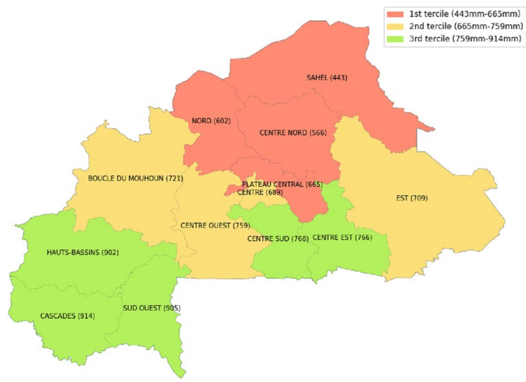

Fig. 1 Climate zones in Burkina Faso, based on May to October cumulative rainfall calculated over the 2014–2017 period for the 13 regions of Burkina Faso. Source: Daily CHIRPS precipitation data set

Table 1 Overview of food security indicators at different scales

Indicator	Scale
FAO Undernourishment [52]	National
Global Hunger Index [20]	National
Global Food Security Index [48]	National
Food Consumption Score [58]	Household
Household Dietary Diversity Score [24]	Household
Coping Strategies Index [31]	Household
Food expenditures [45]	Household
Household Hunger Scale [1]	Household
Anthropometric measures [28]	Individual
Caloric intake [7]	Individual

consequences of conflicts in the northern and eastern parts of the country (a decrease in food production and distribution networks due to population displacement [25]). These two phenomena are responsible for an economic slowdown, which has been worsened by the still fragile world economic context.

The analytical framework

Measuring food security at the household level

The concept of food security is complex and multifaceted, arising from many interrelated and interdependent factors. Food security is guaranteed "when all people have, at all times, physical and economic access to sufficient, safe and nutritious food" [44]. This definition involves four dimensions: the availability of appropriate quantities of food of adequate quality; access among all people to the resources needed to procure food; the stability of access to food over time despite natural or economic crises; and the adequate utilization of food (e.g., hygiene, storage, cooking). As a result, there are many food security indicators (Hoddinott [18] evaluated approximately 450 food security indicators), and it is important to use several indicators to fully estimate food security given its complexity [6, 32]. The plurality of existing indicators and the lack of consensus on how to compare food security situations has led to the development of composite indicators [42] whose construction is not neutral for a policy point of view [43]. It is nowadays recognized than the use of one single indicator gives an incomplete picture of food security [30] and that multiple indicators should be used to capture the complexity of food insecurity [32, 35]. In this paper, three food security indicators are used, who had been obtained at the household level, through surveys. The diversity in the types of food security indicators implies diversity in data collection scales, ranging from national and regional scales (country population, country cereal balance sheets, vegetation indexes, rainfall estimations, food prices) to household and individual scales (consumption proxies, caloric intakes and anthropometric measures) (Table 1). Indicators derived from individual observations are considered the most relevant for characterizing food security, but they are very costly, as they imply either measuring consumption directly or measuring health status. Indicators derived from remote sensing imagery may be delivered in a more timely manner and be cheaper than individual-level data, but they do not always match consumption measures well. Falling in between these extremes, indicators generated at the household scale through surveys are good compromises. They are considered a cost-effective means to proxy food consumption, and they have become central to the analysis of food security, as they adequately capture the food access dimension of food security [27]. Most food security indicators are constructed from data collected at the household level, and several indicators used at the regional or national level are derived from household data (through aggregation).

The Permanent Agricultural Survey data in Burkina Faso

In Burkina Faso, the Permanent Agricultural Survey of rural households has been conducted annually by the Ministry of Agriculture since 1982. This survey is a policy tool used in the field of agriculture and food security that provides decision-makers and food organizations with provincial crop forecasts during the growing period (around August) and with agricultural production estimates during the harvest period (around October). Since 2009, information on household food consumption has also been collected to calculate food security indicators after harvest (around December). Collected data are nationally representative and agricultural production estimates and food security indicators derived from this official survey are key elements used in national and regional food security warning systems [39]. The Permanent Agricultural Survey provides indeed the only available and nationally representative data set that explores the spatial and temporal dimensions of food security.[1] The data set used in this paper covers the 2009 to 2017 period and contains information from 41,751 farm households, i.e., an average of 4,640 farm households per year. The number of households varies from year to year. A farm household is defined as a household practicing at least one of the following activities: temporary crop cultivation (either rainfed or irrigated crops), fruit growing, or animal husbandry. Such households are distributed throughout 887 municipalities over 45 provinces and 13 regions. The paper is built upon three indicators that are validated as proxies of the food access dimension of food security [27] and that were obtained through the Permanent Agricultural Survey. The *FCS* and *HDDS* food security indicators have been calculated from 2009 to 2017 and the *rCSI* indicator has been calculated from 2014 to 2017 (information about coping strategies is available as of 2014).

As in any survey, biases can affect the reliability of the data obtained from household surveys. Some authors have shown that since the early 2000s, the quality of survey data has declined, as people are increasingly solicited to participate in surveys and are increasingly concerned about protecting their privacy [33]. The non-observance biases related to the failure to collect information (coverage and sampling bias, non-consent bias, non-response bias) [26] and the measurement bias due to measurement error during collection (related to the investigator, the respondent or the questionnaire) [22] are the two main types of biases. In "Results and discussion" section, some biases and data limitations are discussed based on an analysis of the Permanent Agricultural Survey guidelines produced by the Burkinabe Ministry of Agriculture [39].

The household food security indicators

This paper focuses on three indicators: the Food Consumption Score (*FCS*), the Household Dietary Diversity Score (*HDDS*) and the reduced Coping Strategies Index (*rCSI*). These indicators furnish useful information on food frequency, quantity and quality and on households' economic access to food, and are some of the indicators that are most widely used in the research community by international organizations and governments [21, 32, 51].

Table 2 Food groups and corresponding weights used to compute the Food Consumption Score (*FCS*). Source: Wiesmann et al. [58]

Food group	Weight (nutritional value)
Cereals and tubers	2
Pulses	3
Vegetables and leaves	1
Fruits	1
Animal proteins	4
Dairy products	4
Sugars	0.5
Oils	0.5
Condiments	0

Food Consumption Score (*FCS*): *FCS* is a measure of nutrient and energy intake. It represents an estimation of the cumulative frequency with which the various food groups are consumed over 7 days in each household surveyed. The frequency of consumption for each food group is weighted by its nutrient value (Eq. 1; Table 2). Thresholds set by the World Food Program are used to differentiate food consumption between households, as follows: acceptable (> 42), limit (28–42), and low (< 28) [58]

$$\mathrm{FCS} = \sum_{i=1}^{9} x_i \cdot p_i \tag{1}$$

$x_i \in$ {Frequency of consumption for each food group i}, $p_i \in$ {Weight of food group i}

Household Dietary Diversity Score (*HDDS*): The *HDDS* captures the number of food groups consumed in the last 24 h and is considered an acceptable proxy for food consumption [23]. There is no consensus on the number of groups to use and their boundaries [24]. In this paper, the *HDDS* (Eq. 2) is computed according to FAO guidelines, based on 12 food groups (cereals; roots and tubers; vegetables; fruits; meat products; eggs; fish and seafood; legumes, nuts and seeds; milk and dairy products; oils and fat; sweets; and condiments, spices and beverages; [46]).

$$\mathrm{HDDS} = \sum_{i=1}^{12} x_i \tag{2}$$

$x_i \in$ {0: food i is not consumed, 1: food i is consumed}

Reduced Coping Strategies Index (*rCSI*): The *rCSI* takes into account the severity of the strategies that households

[1] Data from the Permanent Agricultural Survey are not publicly available but can be obtained upon request at the Ministry of Agriculture of Burkina Faso. A Living Standard Measurement Survey was led in 2014 in Burkina Faso by the Institut National de Statistique et de Démographie: data are publicly available. Statistical Pearson tests have been led between indicators obtained from the Permanent Agricultural Survey and from the Living Standard Measurement Survey in 2014: Pearson correlations are significantly positive, indicating that results are consistent.

Table 3 Food groups and corresponding weights used to calculated the reduced Coping Strategies Index (*rCSI*). Source: Maxwell [31]

Behavior	Weight
Use less popular and less expensive foods	1
Borrow food or seek help from a friend or relative	2
Limit the size of portions during meals	1
Reduce adult consumption to feed children	3
Reduce the number of meals per day	1

use to cope with deficits in their food consumption. It is an estimate of the cumulative frequency of five potential food reduction strategies used over 7 days within each household surveyed. The frequency of each behavior is weighted by its severity (Eq. 3; Table 3):

$$\mathrm{rCSI} = \sum_{i=1}^{5} x_i \cdot p_i \tag{3}$$

$x_i \in \{\text{Frequency of behavior } i\}, \ \ p_i \in \{\text{Behavior weight}\}$

These three food security indicators are calculated for Burkina Faso using the food consumption data that have been collected through the Permanent Agricultural Survey since 2009. These indicators, defined at the households level, are then averaged at the province and region scales. The distribution of the indicators averaged by province is given Fig. 2. In "Consistency between household surveys and other data sources" subsection, they are also centered reduced (i.e., by subtracting the average and dividing by the standard deviation) in relation to provinces and years for comparison with food security proxies.

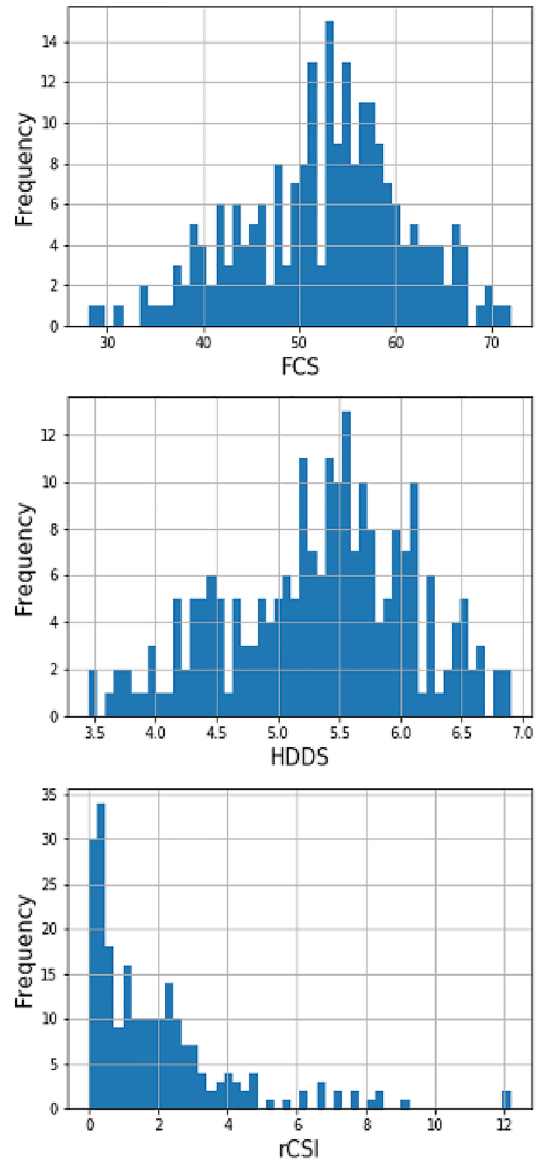

Fig. 2 Histograms of annual *FCS*, *HDDS* and *rCSI* distributions from 2014 to 2017, averaged by province

Other food security proxies

Other food security proxies that are routinely used in food security alert and monitoring systems have been identified [15], namely, a vegetation index, rainfall estimation, and market food prices:

1. Vegetation index: Moderate resolution imaging spectroradiometer (MODIS) satellite images of the composite Normalized Difference Vegetation Index (NDVI), taken over 16 days at 250 m resolution (MOD13Q1 V6 product) [36]. The S2 prototype land cover map at 20 m for Africa from 2016 [9] is used to mask the pixels that are located outside the cropland.
2. Rainfall: Climate hazards group infrared precipitation with station (CHIRPS) data, with a frequency of 10 days and a resolution of 6 km [5].
3. Food price: Monthly maize prices by market, provided by the Société Nationale de Gestion du Stock de Sécurité Alimentaire (SONAGESS) in Burkina Faso (personal communication, 2019).

These three proxies are first aggregated monthly (maximum NDVI and the sum of the rainfall and the prices) and by province for the months from May to October (the agricultural period) and are then transformed into deviations (normalized) by being centered reduced in relation to all the provinces and months presented.

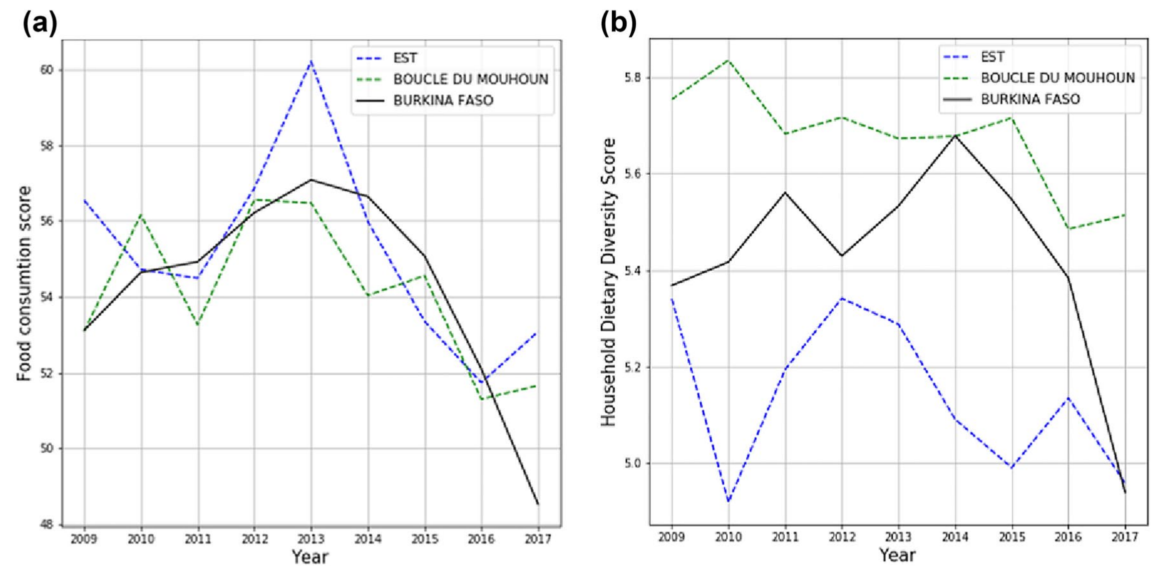

Fig. 3 Evolution of the mean annual **(a)** Food Consumption Score (*FCS*) and **(b**) Household Dietary Diversity Score (*HDDS*) in Burkina Faso (solid line) and in the Est and Boucle du Mouhoun regions (dashed lines) for the 2009–2017 period. Source: Permanent Agricultural Survey data

Finally, the deviations are aggregated into annual mean deviations.

"Consistency between household surveys and other data sources" subsection analyzes the correlations between the normalized food security proxies (rainfall, NDVI and maize price) and the normalized food security indicators computed from the Permanent Agricultural Survey (*FCS*, *HDDS* and *rCSI*), at province level, between 2014 and 2017 (179 observations per indicator).

Results and discussion

Analysis of the spatiotemporal variability in food security

This section analyzes and compares the spatiotemporal variations in the *FCS*, *HDDS* and *rCSI* indicators, and discuss these variations in light of the information contained in independent data sources such as food security bulletins and reports.

To illustrate the inter-annual variability in food security in Burkina Faso, the annual values of the *FCS* and *HDDS* indicators have been used, calculated from the Permanent Agricultural Survey data over the 2009–2017 period (Fig. 3). The *rCSI* indicator is not depicted here, as a 4-year period (2014–2017) is too short for temporal analysis. At the national scale, the results of the Permanent Agricultural Survey show an increase in the average *FCS* and *HDDS* values between 2009 and 2013, followed by a sharp drop between 2013 and 2017 (resulting in the lowest value of the period in 2017). The two indicators provide different estimates of the prevalence of food insecurity, but depict generally similar food security trends over time. This confirms previous results where the *FCS* and *HDDS* were highly correlated [49].

Since 2009, many shocks have affected food security in Burkina Faso. Three events stand out because of their seriousness and have been widely reported in newspapers and NGOs' reports: the repeated floods in 2009 and 2010 [3, 37], the severe drought in 2011 that led to a famine [55, 60], and the general deterioration of the security situation that has affected the whole country since 2014 [10], worsening globally each year and degenerating into a food and humanitarian crisis [11]. With regard to the floods of 2009 and 2010, two regions were particularly affected, the Est and Boucle du Mouhoun regions, which had among the highest number of victims in 2009 [3]. Indeed, the data reveal that while Burkina Faso experienced an overall increase in its *FCS* and *HDDS* over the period 2009 to 2011, these two regions experienced a decrease in their *FCS* and *HDDS* values over at least 1 year between 2010 and 2011 (Fig. 3). The effect of the drought in 2011 is not clearly visible in the Permanent Agricultural Survey data. The *HDDS* decreased slightly in 2012, while the *FCS* increased in the same year. This could be explained by the fact that the *FCS* indicator collected during this household survey does not capture a decrease in caloric intake, which is a key indicator of a food crisis. The *rCSI* might have captured this effect, but it is only available from 2014 onward. The years 2012 and 2013 were two favorable years in terms of climate, which is reflected in a rise in the *HDDS* and *FCS* at the national level. In contrast, 2014 and 2015 were rain deficit years, which is reflected in the decrease in both the *HDDS* and

FCS. Overall, it seems that both the *HDDS* and *FCS* indicators are able to capture the inter-annual variability in food security and notably to gauge the severe decrease of food security that is related to the occurrence of armed conflicts since 2015. In structurally food insecure areas as the eastern and the northern parts of Burkina Faso, the occurrence of violent conflicts had been severely impacting the ability of rural households to feed themselves.

To analyze the spatial variability in food security, three maps have been provided to represent the spatial distribution of the *FCS*, *HDDS* and *rCSI* indicators in Burkina Faso over the 2014–2017 period (Fig. 4). Figure 4a shows the distribution by region of the proportion of households with a low *FCS* (i.e., below 28). Figure 4b and c shows the *rCSI* and *HDDS* distributions by region. There is no cut-off point for determining critical *HDDS* [19] and *rCSI* [31] values, and the class thresholds in Fig. 4b and c have been set empirically to illustrate the regional variability. The results show that between 2014 and 2017, the *FCS* and *HDDS* were lowest in the center of the country (Centre Nord, Plateau Central and Centre regions) and highest in the southwest (Cascades and Hauts–Bassins regions) and Sahel regions, while the *rCSI* was most critical in the north and the east of the country (Centre Nord, Sahel and Est regions) and better in the southwest (Cascades and Hauts–Bassins regions).

Several bulletins indicate that the Centre Nord, the Est and the Sahel are the most food insecure regions. Conversely, the regions in which food security is higher are the Hauts-Bassins, Cascades and Centre regions [38, 56, 61]. This directly reflects the agro-climatic conditions that are favorable in southern regions and unfavorable in eastern and northern regions. For most regions, the data obtained from the Permanent Agricultural Survey are consistent with NGOs' reports: the Cascades and Hauts-Bassins regions present the best *HDDS* (6.3 and 5.8, respectively) and *rCSI* (0.72 and 0.73, respectively) values, while the Est and Centre Nord regions have the worst *HDDS* (4.98 and 4.6, respectively) and *rCSI* (2.54 and 2.47, respectively) values. In the Sahel region, the results are more contrasting: The region has the worst *rCSI* score (2.76), which is consistent with NGOs' reports and the structural classification of this region as being in a food crisis, but has both an *HDDS* and a *FCS* higher than the average. An interpretation of this discrepancy could be that the *HDDS* and *FCS* take into account food groups such as meat and dairy products that may not be consistent in terms of caloric intake but that are nutritionally important food items. The relatively high levels of *HDDS* and *FCS* in the northern regions can be related to cultural food consumption habits. It appears that *rCSI* indicator is a good proxy for caloric consumption and reflects agro-climatic conditions, northern and eastern regions being "deficit regions", where grain production is regularly affected by drought while southern and western regions are "surplus regions", where production exceeds self consumption. This example shows how crucial it is to use several indicators to explain a phenomenon, and it appears that the *HDDS* and *FCS* are less useful for detecting food crises in the Sahel than the *rCSI*. Finally, the Centre region has critical *HDDS* and *rCSI* values (4.83 and 2.57, respectively), which contradicts what appears in the NGO reports [38, 61]. An interpretation of these discrepancies could be that in the Centre region, the population of surveyed farmers is not representative of the total population. Indeed, unlike the other regions

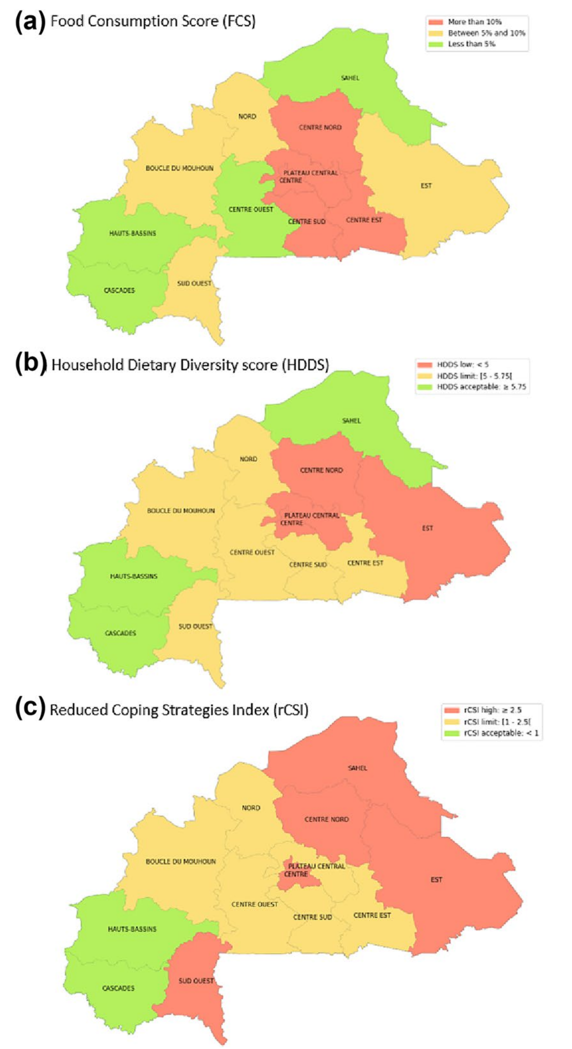

Fig. 4 Three-class maps of the **(a)** percentage of households with a low Food Consumption Score (*FCS*) (i.e., < 28), **(b)** average Household Dietary Diversity Score (*HDDS*), and **(c)** average reduced Coping Strategies Index (*rCSI*), calculated at the regional scale for the 2014–2017 period. Source: Permanent Agricultural Survey data

Table 4 Correlations between the three annual food security indicators' deviations (*FCS*, *HDDS* and *rCSI*) and the annual mean deviations of NDVI, rainfall and maize prices for the year (Yt) in which the food security indicators were collected and for the previous year (Yt − 1) between 2014 and 2017 (**p*-value < 0.05; ***p*-value < 0.01; ****p*-value < 0.001)

	NDVI Yt	Rainfall Yt	Maize price Yt	NDVI Yt − 1	Rainfall Yt − 1	Maize price Yt − 1
FCS	− 0.02	0.13	− 0.16*	− 0.02	− 0.02	− 0.13
HDDS	0.16*	0.30***	− 0.28***	0.17*	0.16*	− 0.25***
rCSI	− 0.21**	− 0.01	0.19*	− 0.20**	− 0.29***	− 0.01

where approximately 80% of workers have jobs related to agriculture, the Centre region contains the city capital Ouagadougou and its agglomeration [17]. If the results of the Permanent Agricultural Survey indicate that farmers in the Centre region are food insecure, this finding cannot be generalized to the rest of the population because of undercoverage bias.

Overall, it seems that *HDDS*, *FCS* and *rCSI* relate to different dimensions of food security: *rCSI* is a valid indicator for detecting food insecurity situations that can arise in specific regions because of a lack of access, while *HDDS* and *FCS* are valid indicators to detect food insecurity situations that are characterized by a low quality of the diets, either related to low access or cultural food consumption habits. In such a situation, using more than one indicator is advisable, as each indicator portrays different aspects of food insecurity. While the *FCS* and *HDDS* tend to indicate situations of low nutrient density diets, the *rCSI* tends to indicate situations of low caloric intake.

Consistency between household surveys and other data sources

In this section, the correlations between the three food security indicators' annual deviations (*FCS*, *HDDS* and *rCSI*) and indirect food security proxy variables are analyzed. The proxy variables used are the annual mean deviations of NDVI, rainfall and maize prices calculated for the year in which the food security indicators were collected and for the previous year (Table 4). The food security indicators obtained from the household surveys are globally poorly correlated with the proxies that represent only one aspect of food insecurity, with a maximum correlation of 0.3.

The NDVI correlates positively with the *HDDS* and negatively with the *rCSI*, which confirms the expected effect that good crop conditions generally lead to high crop production and thus to potential agricultural incomes (stored grains or marketed surplus), resulting in higher caloric intakes (no need to implement food reduction strategies, so *rCSI* decreases) and increased food consumption (possibility of eating more diverse foods, so HDDS increases). However, a high level of food consumption is not equivalent to having a diet with high nutritional value because the correlation between NDVI and the *FCS* is not significant. This could be interpreted as farm households having more diverse diets but that this diversity may be related to the consumption of food items that are not beneficial from a nutritional point of view, such as oils, sugar and drinks.

Rainfall correlates positively with the *HDDS* and the correlation with the *FCS* and the rCSI are not significant. The interpretation is the same as that provided for the NDVI (higher crop production, fewer food reduction strategies, increased food consumption, but not necessarily more nutritious consumption).

Maize prices correlate negatively with the *HDDS* and positively with the *rCSI*. Considering that most farm households are net buyers (they produce less maize than what they consume, and thus they have to buy part of their maize consumption from the market), this confirms the intuition that an increase in maize prices is detrimental to food security because households have lower economic access to maize and are obliged to reduce their consumption of grains and of other food items (increase in *rCSI* and decrease in *HDDS*).

Overall, it appears that the *FCS* has very little correlation with the indirect proxy variables of food security and that the *HDDS* and *rCSI* are more strongly correlated with the indirect proxy variables. The correlations of the *HDDS* and *rCSI* with the indirect proxy variables for the same year are significant (5 out of 6 significant correlations) but are also comparable to the indirect proxy variables of the previous year (5 out of 6 significant correlations). This indicates that food security is linked not only to the current climatic and economic context but also to elements of the past climatic and economic context that have an impact on food security. The comparison results are similar with normalized or non-normalized food security indicators for comparison to proxies deviations. One result is thus that there are concordances between the indicators and proxies of food security but that these concordances are limited, probably because food security consists of a complex combination of these proxies that cannot be fully captured through correlation calculations. One alternative explanation could be that our data set does not enable any seasonal analysis of what is going on within a year. Food consumption can differ widely between the harvest season and the lean season, but data are lacking to appraise the intra-annual evolution of food security situations. This could be further investigated in the future.

Conclusion

This paper analyzes the contribution of household surveys to our understanding of food security situations. Previous studies have established that indicators derived from household surveys are reliable in qualifying food consumption and are cheaper to obtain than individual consumption indicators [27, 32]. Our study shows that indicators derived from household surveys contain consistent spatial (structural) and inter-annual (conjunctural) information and that they can be used to monitor food crises at the sub-national scale despite their inherent biases. In particular, we show that household surveys provide information on food security that permits the identification of key trends that are consistent with food security warning systems, as well as with climatic and economic variables related to food security.

However, our study also highlights three drawbacks related to the use of indicators derived from household surveys: the first one is that it takes time to calculate indicators from household surveys; the second one is that in the context of armed conflicts, it can be risky to conduct household surveys; and the third one is that indicators from household surveys provide only a partial view of food security situations. The fact that the process is time consuming is related to the definition of the sampling strategy, to the design of the questionnaire and its administration across a considerable number of households, and finally to the data entry, cleaning and analysis by experts. On the opposite, data on crop conditions and rainfall obtained from remote sensing imagery can be obtained more quickly, which is a major advantage. The fact than collecting data within households in conflict affected areas can be hazardous is clearly an argument in favor of mobilizing other data sources to predict food security situations. The fact that indicators derived from household surveys provide only a partial view is a drawback common to the use of any indicator. Variations in food security indicators correlate only partially with the climatic and economic factors that are considered to be indirect proxies of food security. Each indicator or proxy tends to focus on a specific component of food security, and the choice to consider several complementary indicators and proxies provides a more complete picture of food security situations.

In summary, if household surveys are a reliable tool for the characterization of food security situations and their spatial and temporal diversity, such surveys provide only a partial understanding of food security and have to be combined with other data sources that may not directly measure food consumption but rather its determinants. A major task is to understand how climatic, agronomic, economic, policy-related, and security-related events are interlinked and cause food insecurity at a given time and in a given place. This is a huge challenge given the complexity of food security. One way to address such challenging tasks would be to resort to data science techniques, and notably machine learning algorithms which are being increasingly used to extract relevant information from complex and heterogeneous data in the field of food security [29, 53]. This type of research could contribute to food security warning and monitoring systems by detecting famines more quickly and accurately. The use of multiple data sources to generate knowledge on local food security situations is of special importance in the contexts where information in the ground may be lacking because of armed conflicts, which are nowadays considered as the primary driver of ongoing food crises in the world (72% of the people facing acute food insecurity in 2021 are living in conflict-affected countries[2]). Indeed, the conduction of household surveys could be a risky activity in armed conflict contexts, so that food security monitoring systems should encourage analysis combining heterogeneous data, obtained from different sources and processed through machine learning.

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Author contributions
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Declarations

Ethics approval and consent to participate
The authors confirm compliance with the ethical policies of the journal.

Consent for publication
We confirm that the manuscript has been read and approved by all named authors.

[2] https://www.fsinplatform.org/sites/default/files/resources/files/GRFC%202022%20KM%20ENG%20ARTWORK.pdf.

Competing interests

The authors declare no conflicts of interest.

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