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Looking beyond calories—when food quality and sourcing matters

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ABSTRACT

Farming systems are key to achieving the Sustainable Development goals of Zero Poverty and Zero Hunger. Yet, more than half of food-insecure people live in rural areas. Persistent yield gaps, poverty traps, disinterest in investing in agricultural activities, and population growth put pressure on agricultural landscapes, threatening food security and preservation of natural resources. In addition, narratives around food security often focus on caloric intake and overlook dietary complexity. This is a transdisciplinary study that assesses the complexity of food insecurity across smallholder farming systems, as affected by farmers' goals, drivers, assets, and economic performance. The study was conducted in Donomadé, a marginalized village in Togo, West Africa. Through 81 surveys and 28 in-depth interviews, qualitative and quantitative data on demography, market integration, production systems, and farmers' perspectives on agriculture were gathered. A household Archetypal Analysis was performed. The mean adequacy ratio (MAR) was calculated based on the consumption of one Adult Male Equivalent (AME) of 18 nutritional elements (including macronutrients, micronutrients, and vitamins). The MAR was used to compare food security across archetypes. Twenty percent of the households would be considered food secure if only caloric intake was considered. However, no household was completely food secure when assessing the MAR for 18 nutritional elements. The MAR varied across the five archetypes identified (A–E). Archetypes D and E had the highest MAR of 0.82 and 0.85, respectively. These archetypes had the lowest land pressure, expressed in AME per hectare. Archetypes A, B, and C had a MAR of 0.35, 0.53, and 0.32, respectively. They differed in income source, land pressure, and desire to abandon agricultural activities. Households' food security was also impacted by how much food they sold and bought. Only archetype E bought more food than they sold. Food security levels vary across households. Narratives concentrated around caloric intake can lead to an underestimation of the issue of food insecurity. Due to lack of alternative sources of income, households are forced to sell part of their production. Most of the time, the food sold is not compensated by the food bought, creating deeper gaps in households' food security.

1. Introduction

Farming systems are key to achieving the Sustainable Development Goals of Zero Poverty and Zero Hunger, and yet, more than half of food-insecure people live in rural areas (Shackleton et al., 2019). Currently, around 650 million people around the world suffer from insufficient caloric intake, which has been increasing since 2014 and intensified by the COVID-19 pandemic (FAO et al., 2021; IFPRI, 2021). Going beyond calories, 2 billion people suffer from micronutrient deficiencies (IFPRI, 2014).

Despite slow improvements in malnutrition-related issues in West Africa, trends indicate that most countries will not achieve the Sustainable Development Goal of Zero Hunger by 2030 (Chadare et al., 2022). Giller et al. (2021) argue in favor of agriculture for meeting the increasing demand for nutritious food. However, they highlight persistent yield gaps, land fragmentation, and farmers' overall lack of interest in agricultural activities as major challenges for improving food and income security. Thus, improving food security in rural areas requires an understanding of the socio-economic, nutritional, and technical

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List of abbreviations

FAO	Food and Agriculture Organization
IMPACT	Integrated Modelling Platform for Mixed Animal Crop
IFPRI	International Food Policy Research Institute
SI	Système International (International System of Units)
TLU	Tropical Livestock Unit
AME	Adult Male Equivalent
AE	Adult Equivalent
OECD	Organization for Economic Co-operation and Development
MAR	Mean Adequacy Ratio
NAR	Nutrient Adequacy Ratio
DRI	Dietary Reference Intake
VSS	Village Food Self-sufficiency
PSS	Potential Food Self-sufficiency
ASS	Actual Self-sufficiency
AFC	Actual Food Consumption
AA	Archetypal Analysis

challenges smallholder farmers face (Ogunniyi et al., 2021; Shilomboleni et al., 2019).

While a few recent agriculture-related studies consider the complexity of human nutrition (Andriamparany et al., 2021; Timler et al., 2020), several other studies still only use macronutrient intake (often caloric intake) to make assumptions about food self-sufficiency and food security (Giller et al., 2021; Hunter et al., 2017; Nechifor et al., 2021; Sileshi and Gebeyehu, 2021). According to FAO, food security "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." (FAO et al., 2014). Self-sufficiency happens when the consumption needs are met by own production rather than buying or importing (Minot and Pelijor, 2010).

Caloric intake is commonly used as a proxy for food security in the literature (Abarca-Gómez et al., 2017; Cassidy et al., 2013; FAO, 2016; Fones et al., 2020; Nechifor et al., 2021; Xia et al., 2022), with FAO promoting its use through its reports since the 1970s (Ickowitz et al., 2019). Apart from the importance of proper consumption of calories for the human diet, calories are a 'global food currency', as they are easy to measure (Ickowitz et al., 2019), standardized, and comparable between different food sources (Giller et al., 2021). However, little attention is being paid to micronutrient deficiency-related disorders, which can retard growth and cognitive development, impair immunological functioning, and increase the risk of non-communicable diseases (Galani et al., 2022). Micronutrient deficiency is a cause of serious concern in Africa. Chadare et al. (2022) show that several West African countries will probably not reach their targets to reduce anemia among women of reproductive age and stunting in children under five by 2030.

We propose that the narrative in agricultural and food security-related studies should shift away from focusing exclusively on caloric intake as a proxy for food security and adopts other quantifiable variables that permit a more nuanced understanding of the underlying causes of food insecurity. Nutrition-sensitive agriculture, or NSA, has the benefit of improving food quality, increasing health benefits, all with a lower environmental footprint (Herforth and Ballard, 2016; Sharma et al., 2021; Shetty, 2018). Recent studies in NSA (Novotny et al., 2021; Ruel et al., 2018; Timler et al., 2020) use the adequacy ratio to capture the diversity in food production and consumption.

In this study, we borrow the concept of mean adequacy ratio (MAR) from several studies on human nutrition (Becquey et al., 2012; Jun et al., 2019; Torheim et al., 2004) to compare food security between households in southern Togo, West Africa. Togo ranks in the lowest tier of the World Hunger Index, with some 25% of its population suffering from severe food insecurity (WFP, 2022). Here, we address three main questions: 1) What are the potential implications of only assessing caloric intake instead of other nutritional elements? 2) What types of households are struggling to achieve food security, and why? 3) How can food insecurity be avoided? We use the archetype statistics considering socio-economic factors to explore food security levels beyond the conventional caloric intake, drawing from the rich diversity and complexity of farming systems and households.

2. Materials and methods

2.1. Study area

The study was conducted in Donomadé, southern Togo. According to local authorities, around 100 households and a total of 600 people live in the village. The main activity is rainfed agriculture, with two cropping seasons a year. Cropping systems are diverse and monocultures are rarely found. Maize is the most common staple crop grown, followed by cassava and peanut. Market access is restricted. Most of the time, farmers sell their crops to a single local merchant, neighbors, or itinerants. Occasionally, they sell their products in nearby communities.

2.2. Data collection

The data collection consisted of two phases. First, a household survey was elaborated. The survey was adapted from the IMPACT Lite survey (IFPRI, 2018) and translated to the local language, Ewe. It contained 19 groups of questions about household structure, family nutrition, crop and animal production, labor use, and economic performance. Eighty-one out of the 100 household heads were surveyed at random in May 2021. Information on family nutrition was based on the food they buy regularly (weekly, monthly, trimestral, etc.). For the second data collection phase, an in-depth, semi-structured interview was developed. The questions focused on understanding farmers' motivations and goals, changes in farming systems, and socio-economic barriers. Twenty-eight household heads were revisited in July 2021 and interviewed based on their availability.

2.3. Data processing

Indicators regarding household characteristics, food security, production, and economic performance were derived from the surveys and interviews (Table 1). Quantifiable data captured in surveys were transformed from local to International System Units. The local area unit, *carré*, was measured in meters in the field. Different crops were weighed in several recipients (e.g., bags, baskets, bowls, and tanks). Interviews were first transcribed from Ewe to French. The transcriptions were coded in Nvivo 12 and later transformed into ordinary scales for analysis. Households with missing data were removed from the analysis. A total of 78 surveys and 28 interviews were retained.

2.3.1. Household

Since household composition was recorded in terms of gender and age of each household member, the adult male equivalent (AME) was used to standardize household size (Weisell and Dop, 2012). The AME was used to calculate households' nutritional requirements and land pressure. For economic-related variables, the adult equivalent (AE) was obtained using OECD equivalent scale, which is based on the different economic and resource needs of adults and additional family members (Chanfreau and Burchardt, 2008; Hagenaars et al., 1994).

2.3.2. Food security

Food security was expressed as the mean adequacy ratio (MAR) per year. MAR is calculated from the intake of individual nutrients and their requirement, expressed in nutrient adequacy ratio (NAR) (Madden and Yoder, 1970; Steyn et al., 2006). The NAR was calculated for 18

Table 1
Indicators and units analyzed.

Domain	Indicator	Unit and description
Household	Household size	AME (adult male equivalent)
	Household head gender	male or female
	Household head age	years
	Land cultivated	ha
	Land owned	%
	Land pressure	AME ha^{-1}
Food security	Actual food self-sufficiency	Mean adequacy ratio (%)
	Potential food self-sufficiency	Mean adequacy ratio (%)
	Food consumption	Mean adequacy ratio (%)
	Nutritional elements deficient in the diet	Number of elements
Production	Cultivated species	Number of species
	Livestock holding	TLU (tropical livestock units)
	Input use	0 = no artificial input use 1 = artificial input use
	Crop diversification strategies	0 = no desire to change 1 = increase animal production 2 = add business activities to crop and animal production 3 = leave crop and animal production 4 = leave crop production and focus on animal production
	Future of agriculture	0 = would never abandon agriculture 1 = would abandon agriculture given the opportunity
Economic	Income type	In addition to selling crops and animals, households also: 0 = raw production 1 = raw production + food processing 2 = raw production + food processing + manual labour 3 = raw production + non-agricultural labour
	Crop production	USD AE^{-1} yr^{-1}
	Animal production	USD AE^{-1} yr^{-1}
	Off-farm income	USD AE^{-1} yr^{-1}
	Total income	USD AE^{-1} yr^{-1}
	Expenses	USD AE^{-1} yr^{-1}

nutritional elements. It expresses the relationship between the availability of element i (e.g., vitamin A) and its requirement based on the Dietary Reference Intakes (DRIs). The availability of an element i is calculated from its content in different food sources j (e.g., bean, cassava, maize). A NAR lower than 100% indicates a deficiency in the supply of j.

$$NAR_i = \frac{\sum_{j=1}^{n} Nutrient\_content_{i,j} * Weight_j}{DRI_i * AME} * 100 \quad (1)$$

MAR is obtained by averaging all the NAR (eq. (2)). For this calculation, NAR is capped at 100% to avoid producing surpluses compensating deficiencies. As such, MAR is an indicator of the extent to which the total requirement for several nutritional elements is being met.

$$MAR = \sum_{i=1}^{n} \frac{NAR_i}{n} \quad (2)$$

Food self-sufficiency at the village level (VSS) was estimated using the total crop production, animal production, and AME of the 78 households surveyed to calculate the MAR. For each household, we estimated the MAR based on their potential food self-sufficiency (PSS), actual self-sufficiency (ASS), and actual food consumption (AFC). The PSS considers the total household crop and animal production. ASS was obtained by subtracting the volume of food sold from the total production. AFC combines the food purchased in the market to the ASS.

2.4. Data analysis

An Archetypal Analysis (AA, Cutler and Breiman, 1994) was selected for this study. AA is a multivariate analysis that identifies points (not necessarily observed) that lie within the boundaries of the scattered data. As such, it differs from cluster analysis, where points are close to the cluster average. Instead, archetypes represent extreme cases (or outliers) that may have been lost within clusters based on principle component or factor analysis (Tessier et al., 2021; Tittonell et al., 2020). The information that these outliers provide is however key when considering livelihoods and food security, by accounting for a wider diversity of strategies that may not be represented in average values. In AA, the set of identified archetypes aim to characterize all multivariate observations (Eugster and Leisch, 2009), and the analysis has been shown to be sensitive to representativeness and loading, even with small sample sizes (Tittonell et al., 2020). It is increasingly being used to categorize regional-level response patterns of populations, for example regarding land use (Levers et al., 2018; Oberlack et al., 2016), and climat change (Sietz et al., 2017).

The archetypal analysis was performed on the variables described in Table 1. The algorithm was run 10 times for each archetype k (Table A1). A scree-plot with Residual Sum of Squares of the best algorithms (Fig. A1) was used to identify the number of archetypes using the "elbow method." The "archetypes" package for R was used to perform this AA, and a detailed description of the method is given by Eugster and Leisch (2009).

3. Results

3.1. Self-sufficiency at the village level

Given the current population size of Donomadé and their total agricultural production, the village is not self-sufficient. The production fell short to meet the population's demand for kcal, protein, fat, Ca, K, as well as for vitamins A, B2, B12, and C (). Vitamin A was the most limiting element, with a total production that could feed around 4% of the total population. Based on the requirement for 18 nutritional elements, 71% of the total population's needs were met (MAR).

3.1.1. Self-sufficiency at the household level

Households do not usually consume everything they produce. Their actual self-sufficiency is lower than their potential self-sufficiency (Fig. 2., Fig. 3.), i.e., their actual food consumption (food intake from their own production plus produce from the market) is lower than the potential self-sufficiency (if no products were sold on the market). In other words, households exported more food than they bought.

Carbohydrates, Fe, and P were the only elements every household was able to consume in sufficient quantities (orange bars in Fig. 3.). More than 50% of the households did not consume enough fat, Ca, vitamins A, B2, B12, and C. Similarly to the results observed at the village level (Fig. 1, vitamin A was the most limiting element at the household level (Fig. 3.). Although several households were able to consume adequate amounts of several elements, no household had a MAR of 1. Reaching a MAR of 1 would not be possible for any household, even if they consumed all the food they produced.

3.2. Food insecurity across archetypes

Five archetypes were identified. Following Tessier et al. (2021) and Tittonell et al. (2020), a household was considered a full member of a specific archetype when its loading was superior to 0.66 to that archetype. Twenty-three households were attributed a membership to a given archetype and five households did not make the membership threshold of 0.66.

Archetype A had the largest membership (n = 9) and the second lowest MAR (35%, Table 2). It consisted of households experiencing

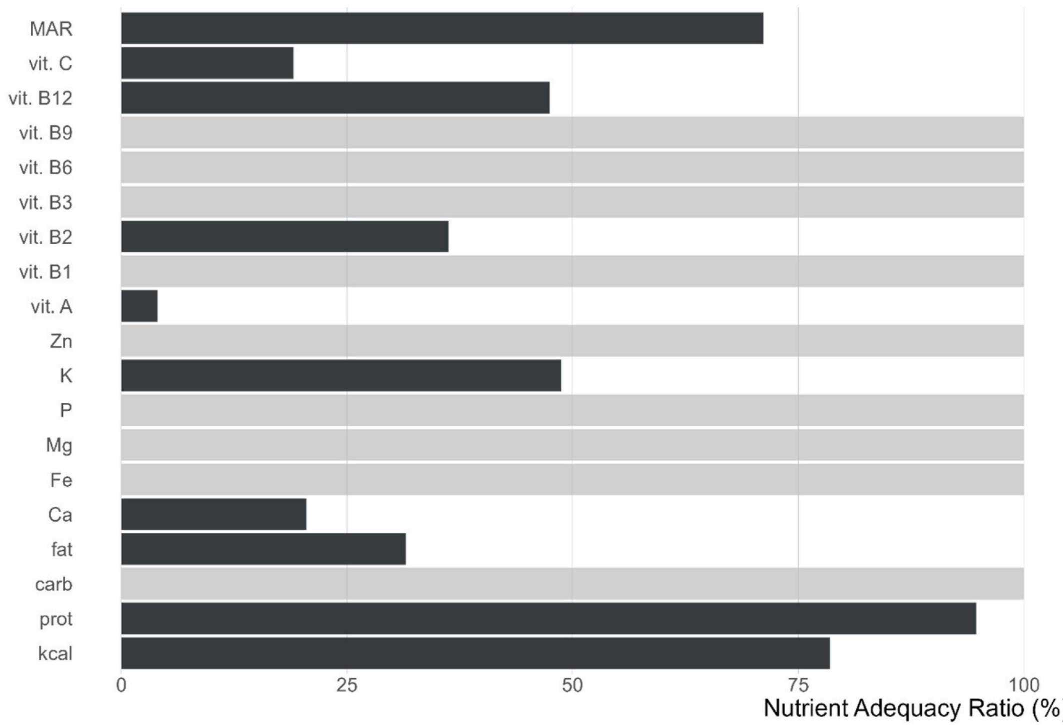

Fig. 1. Nutritional self-sufficiency. This is the capacity to meet consumption needs from own production, measured at the village level. Bars represent whether the relation between the village's production of a given element is sufficient (light gray) or insufficient (dark gray) to meet the population's demand for that element. MAR is the mean adequacy ratio of all the other elements.

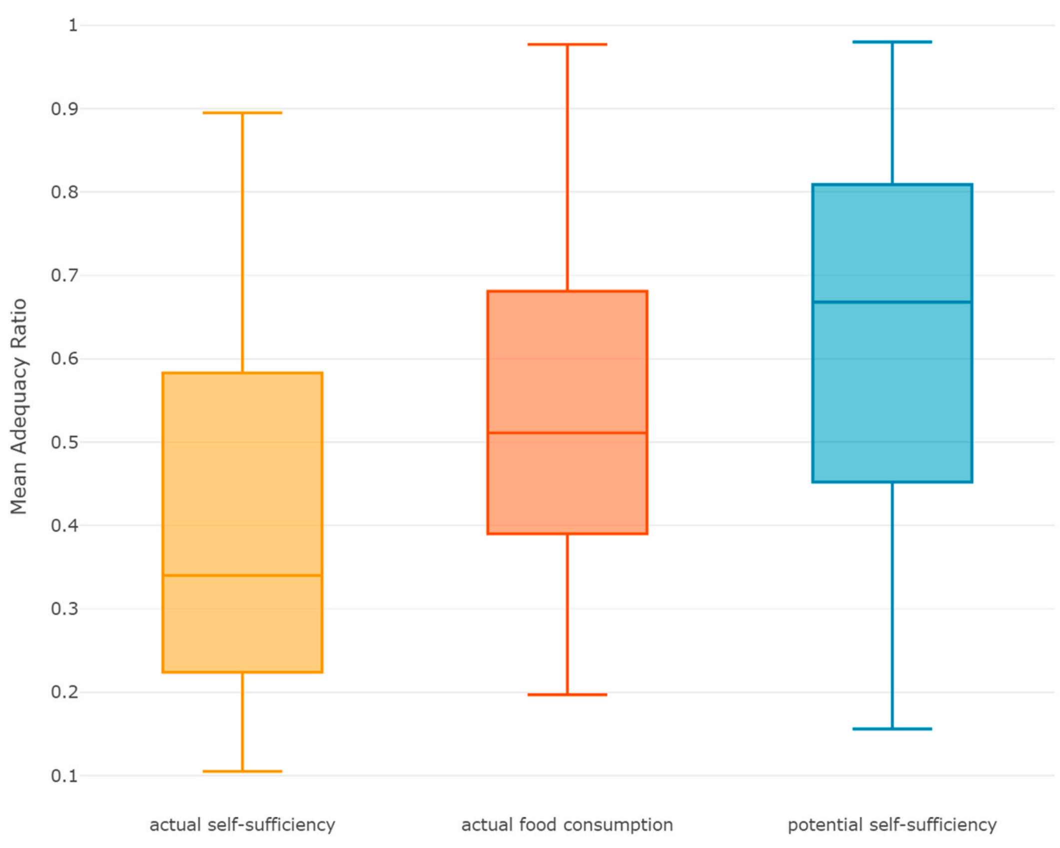

Fig. 2. Mean Adequacy Ratio. MAR is based on households' actual self-sufficiency, actual food consumption, potential self-sufficiency, and food availability.

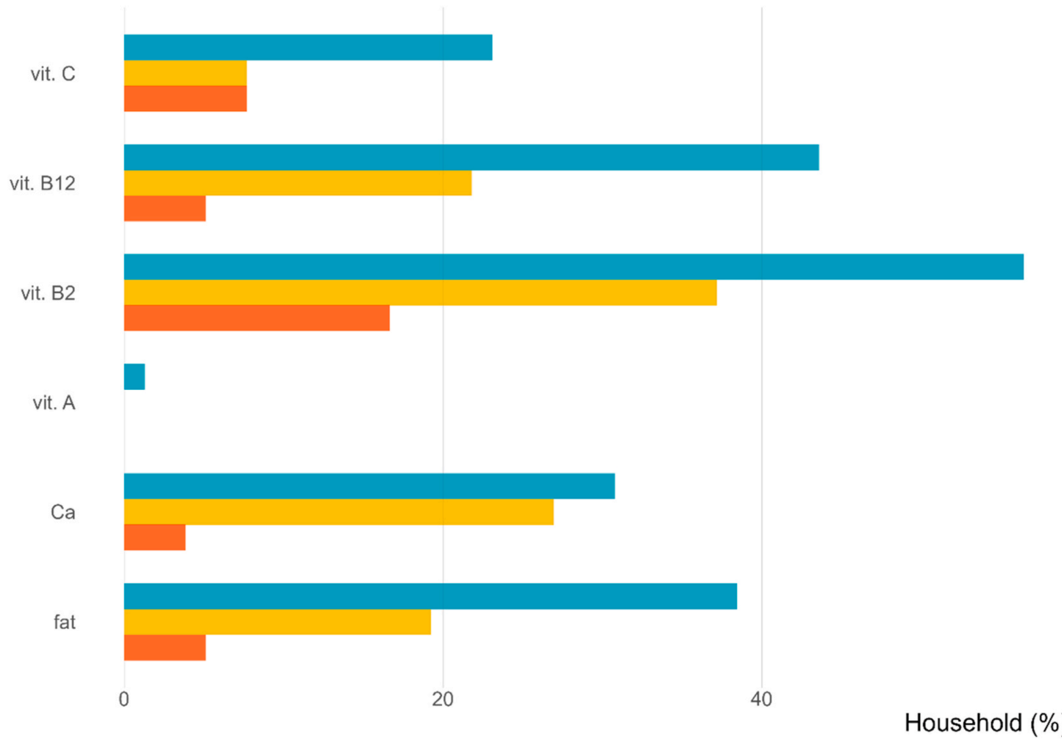

Fig. 3. Nutrient Adequacy Ratio. NAR is measured at the household level for the 6 most limiting nutritional elements. Food sources are: actual self-sufficiency (Orange), actual food consumption (yellow), potential self-sufficiency (teal). NAR for all the 18 nutritional elements can be found in Fig. A2.

Table 2
Archetypes. Parameters, archetypes A–E (in bracketts the number of households), and details (full archetype description in Table A2).

	arch A (n = 9)	arch B (n = 3)	arch C (n = 3)	arch D (n = 7)	arch E (n = 1)	description
Crop diversification strategies	1.9	0.6	2	1	1	0 = no changes in cropping systems 1 = one or more crops were abandoned 2 = one or more crops were introduced 3 = crops were abandoned and introduced
Desires	1.3	2	2.4	3	2	0 = no desire to change 1 = increase animal production 2 = add business activities to crop and animal production 3 = leave crop and animal production 4 = leave crop production and focus on animal production
Land ownership	34	73	33	11	100	% of the total land that is rented
Number of species	3.6	3.7	7.4	4.5	3	number of crop species grown
Income type	1	2.6	0.7	2.6	3	In addition to selling crops and animals, households also: 0 = raw production 1 = raw production + food processing 2 = raw production + food processing + manual labor 3 = raw production + non-agricultural labor
Future of agriculture	0.1	0.5	0.4	0.6	0	0 = would never abandon agriculture 1 = abandon agriculture given the opportunity
Land pressure	10.2	6.8	3.2	1.8	0.5	adult male equivalent per hectare
Net income	−55	−39	79	−27	2654	net income per household member (adjusted by the OECD equivalent) and expressed in USD yr^{-1}
NDN	17.6	14.9	15.3	5.9	4	number of nutritional elements deficient in the household diet
MAR (actual food consumption)	35	53	32	82	85	mean adequacy ratio (%) and expressed in USD yr^{-1}

*A 0.0018 West African Franc (CFA) to 1 US dollar rate was applied.

high land pressure (10.2 AME ha^{-1}) and a high deficiency of nutritional elements (Fig. 3.). This archetype had a desire to increase its animal production. Their net income was the lowest of all archetypes (−55 USD yr^{-1}). Most of these households' income came from selling raw products and/or processed crops (e.g., production of cassava flour, palm oil, and roasted peanuts). Despite their low net income and MAR, households from archetype A expressed no desire to abandon agricultural activities, usually stating that without agriculture they would not be able to feed themselves.

Archetype B (n = 3) had an intermediate MAR of 53%. Households associated with this archetype usually engaged in off-farm activities. They rented more than half of the land they cultivated, resulting in potential conflicts with landowners who can bar certain activities (e.g., agroforestry). Households from archetype B had the second-lowest net income (−39 USD yr^{-1}) and expressed some desire to abandon agricultural activities.

Archetype C (n = 3) had a MAR similar to archetype A, despite having much lower land pressure (3.2 AME ha^{-1}). Archetype C was the only one that used artificial inputs (e.g., fertilizers, herbicides, and pesticides, Table A2). Most of their income came from raw and processed crops. Their net income was the second highest, at 79 USD yr^{-1}.

Archetype D (n = 7) consisted of households with relatively low land pressure (1.8 AME ha^{-1}) and high MAR compared to others (82%). Households in this archetype had the lowest proportion of rented land (11%). Their net income was close to zero.

Finally, archetype E had only one member. This archetype had the lowest land pressure (0.5 AME ha^{-1}) and MAR (85%). There was a strong desire to incorporate other economic activities into their crop and animal production. This archetype had the highest net income of 2654 USD yr^{-1}.

Households from all archetypes, except E, did not compensate for the nutritional elements lost by selling their food with elements consumed from purchased food (Fig. 4.). Most households' MAR came from their food production rather than from the market (Figs. 4., 5).

4. Discussion

4.1. Understanding food insecurity

None of the five archetypes described in this study could reach complete food security. However, food security varied largely between households. Those with the lowest performance obtained around 20% of their nutritional needs while the most food-secure households had 97% of their nutritional requirements satisfied. This substantial nutritional gap between households reflect the varied challenges families face to reach food security. Households close to reaching their food security fail to do so because they are not consuming large enough quantities of specific elements (notably vitamin A). For them, producing and consuming food rich in these missing elements (e.g., vitamins A, B12, C) is key. For instance, sweet potato of the orange variety is rich in vitamin A, and farmers in Donamade are familiar with this species, making it a strong candidate for improving vitamin A supply. Vitamin fortified food is also an effective solution against nutrient deficiencies, but may not be feasible in places where the food industry is not well developed and farmers' access to these products is restricted (Chadare et al., 2019).

In addition to also having low consumption of the same key elements, the extremely poor (archetype A) face further challenges. The combination of small available arable land (less than 1 ha), large family size (more than 4 AME), and negative net income all contribute to high food insecurity levels. A common solution found in the literature is to increase agricultural output and reduce the yield gap (Aramburu Merlos et al., 2015; Licker et al., 2010; Schierhorn et al., 2014; van Ittersum et al., 2013). However, Giller et al. (2021) show that in land-constrained places, even if yield gaps were closed, most households would still be self-insufficient, as the land they possess is too small. The same authors highlight that agricultural production should be coupled with other

Fig. 4. Food supply per archetype. Supply of dietary energy (kcal), protein (g), carbohydrate (g), fat (g), calcium (mg), iron (mg), magnesium (mg), phosphorus (mg), potassium (mg), zinc (mg), vitamin A (μg), B2 (mg), B3 (mg), B6 (mg), B9 (μg), B12 (μg), C (mg). Red bars represent the average AME for a given archetype. Food sources are food produced and consumed (gray), food bought and consumed (green), food sold (pink).

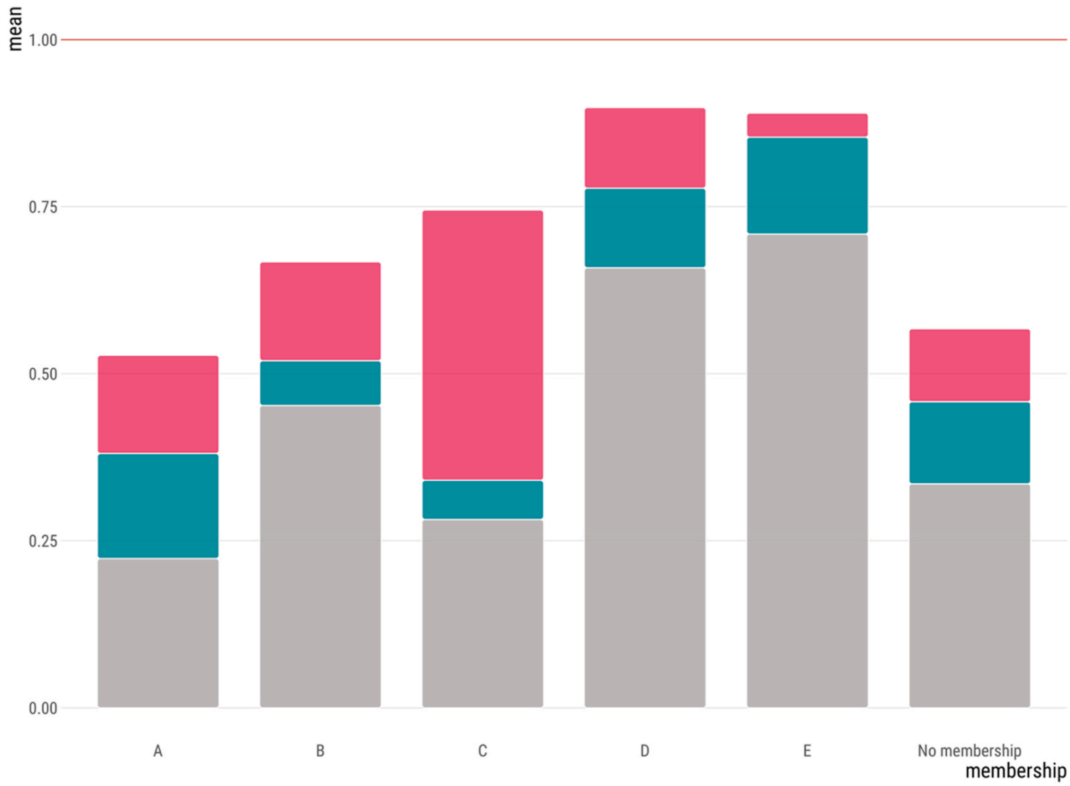

Fig. 5. MAR and food supply. Contribution of each food source to the mean adequacy ratio shown per archetype. Food sources are food produced and consumed (gray), food bought and consumed (green), food sold (pink).

off-farm activities. In Togo, the lack of easy access to larger villages reduced the job opportunities available to most households.

4.2. Livelihood strategies

Based on the sustainable livelihood framework (Ashley and Carney, 1999), poverty eradication actions must be aligned with people's livelihood strategies, social environment, and ability to adapt. The framework is also embedded in five livelihood assets (human, physical, social, financial, and natural) that define households' strategic options and potential outputs (income, food security, well-being, inter alia). Results from this study show that households have varying degrees of these assets, and consequently outputs. Because of the high population density in Donomadé, human capital (or labor) is high. Social assets such as networks, groups, and access to wider institutions in the village are available to most people. Households tend to belong to different groups within the community and gain support in return. The other three assets are arguably the most deficient. Physical assets refer to the basic infrastructure and production equipment essential to the production systems. The physical access to Donomadé and its integration into larger urban centers is poor. This makes it difficult for farmers to sell their products and leaves them vulnerable to itinerants' prices, which are usually lower. Access to equipment is also very restricted and production systems rely solely on human force for all activities. Financial assets such as access to microcredits and pensions are virtually inexistent. Finally, natural assets, particularly land, are scarce to most households. In addition, according to farmers the lack of irrigation and erratic rain are the biggest cause of reduced yields. Such a restricted availability of these assets to most households severely impacts their strategic options. Regarding the natural asset, water is the major limitation according to farmers, as noted by one respondent in "If you have made the field and you have sown well and it rains properly, you can achieve what you planned. It's when it doesn't rain that your plans can't be achieved."

Despite agriculture failing to provide most of the households' basic needs, it is often the only activity on which farmers can rely. One of the interviewees said "If the production is not good, even if you sell the animals, you cannot achieve what you want, since it is the belly that will take everything." Every household interviewed stated that "crop production means food", "animal production means cash." For instance, one farmer said "Agriculture and animal production help us to get what we need. If you raise your animals and have something troubling you, you can sell them to solve your problems. Agriculture [on the other hand] helps us with our food needs." Most food-insecure households do not engage in off-farm activities, but they desire to do so. This can be illustrated by the following statement "If I have a project that requires large investments, I cannot rely on agriculture to accomplish it because [agriculture] does not prosper any longer. That is why I want to add commerce and animal production." Such answers demonstrate that several farmers perceive agriculture as an integral component of their livelihoods, yet agriculture alone is not enough.

Undeniably, agriculture is pivotal to households' food security through self-sufficiency. Indeed, results from this study show that most households' source of nutrients comes from their production and only a small portion comes from purchased food. Yet, households from archetypes B and C largely lose their self-sufficiency due to selling part of their produce. Surprisingly, having external sources of income (see archetype D) did not lead to higher consumption of purchased food (except for archetype E). Instead, off-farm income allowed households to sell less and consume more of the food they produce. Such an outcome raises the chicken and egg question of whether off-farm income is directly associated with self-sufficiency loss, as farmers invest less time in agricultural activities, or whether it provides farmers with enough money to not be forced to sell large parts of their production while providing the opportunity to invest in agriculture.

Agriculture in Donomadé is neither economically viable enough nor productive enough to meet the population's nutritional demands. Yet, archetype D shows there is a way out of the trap through off-farm income. For this, investments should target at increasing access to markets, improving physical infrastructure, and stimulating micro-credits (Dzanku and Sarpong, 2011; Fan et al., 2013; Godfray et al., 2010; Gore, 2015). That is not to say that research and policies should not aim at improving and supporting agriculture. As shown by Christiaensen et al. (2011), agriculture is still pivotal in reducing poverty, especially for the poorest people. Donomadé, and several similarly marginalized places in Togo and other countries, are unlikely to become more integrated in the market any time soon. Food self-sufficiency is thus key to keeping food insecurity at bay. For places like Donomadé to be able to reach their food self-sufficient status, not only should yield gaps be closed but also special attention paid to growing and consuming a larger variety of food sources.

The diversity of households can be described as alternate systems (Tittonell, 2014). Based on this assumption, farmers can transition from one archetype to another. Transitioning to a different state requires investment to overcome initial inertia and leaves households vulnerable (Tittonell, 2020). In theory, archetypes A–C could move to more food secure states as exemplified by archetypes D and E. These transitions are, however, unlikely to happen. Archetype E is a unique and restricted type, as it is closely related to the village chief. Therefore, other households have very little chance of moving up to archetype E and vice-versa. Moving to archetype D would require households to have more land to compensate for their land pressure. Only households from archetype A would potentially invest in more land, as archetype B is marked by household heads who want to abandon agriculture.

4.3. Limitations

Determining precise estimations of food bought and consumed remains a challenge. We mitigated this issue by asking respondents about the food they buy and consume on a regular basis. Although such a method has its caveats as it only accounts for food farmers buy on a regular basis, it is robust enough to obtain the larger picture regarding usual food consumption. Another limitation is related to using the MAR to assess the state of food security. By capping nutrient adequacy at 100% when calculating MAR, we disregard overconsumption of nutrients, which can be related to overweight. An MRA of 100% only means that the need for nutrients is met, but it does not guarantee that these nutrients will be properly absorbed by the body, e.g., Zn and Fe absorption might depend on the food consumed (Institute of Medicine, 2006). The distribution within a household might not be equal and family members can still have nutrient deficiencies even when the household has access to enough food (Pinstrup-Andersen, 2009). Our approach allowed us to assess annual food access. As such, we did not assess months with low and high food production, both of which are common for rural households (Anderzén et al., 2020; Bilinsky and Swindale, 2007; Reincke et al., 2018; Stoudmann et al., 2019).

Compared to calories, MAR can be hard to interpret. MAR is tightly associated with multiple nutrients and the number of people to be fed. The simplicity of using only calories allow us to derive metrics such as production of calories per area, which is not possible for MAR. On the other hand, MAR considers food diversity and is thus connected to agrobiodiversity. Since this is the first study to use MAR in an agricultural context, there is a potential for studies to connect food production diversity and better nutrition.

Regarding our archetype analysis, the limitations of this approach relate to converting narratives into scores (e.g., yes or no responses translated into 0 or 1), discussed by Tittonell et al. (2020). Despite this limitation, archetypes are represented as extreme cases (or outliers) (Tessier et al., 2021; Tittonell et al., 2020), and assessing them can offer a unique insight into food security levels, as it allows to identify which characteristics are more closely associated with the most food secure and insecure households.

4.4. Implications

There is an increasing interest in going beyond caloric needs for better human nutrition in agriculture-related studies (Estrada-Carmona et al., 2020; Novotny et al., 2021; Remans et al., 2011; Timler et al., 2020). Yet, calorie consumption remains the central pillar when discussing undernourishment in major reports on food security (Baquedano et al., 2021; FAO et al., 2021). Results from this study call for a more robust approach to consider other aspects of malnutrition and undernourishment. If we had only looked at calorie consumption, we could have concluded that more than 75% of assessed households consumed sufficient calories. However, not a single household consumed enough food to meet their requirements for 18 nutritional elements combined (MAR of 100%). Consequently, assumptions about food security can vary greatly based on how it is assessed; estimations based solely on caloric intake can underestimate food insecurity levels. Although this study was performed in a small village in southern Togo, it can be safely assumed that similar problems would be observed in other regions of the world, as several studies have reported problems of micronutrient and vitamin deficiencies (Brito et al., 2015; Cediel et al., 2015; Lopez de Romaña and Cediel, 2017; Zuma et al., 2018). Therefore, we suggest future studies to consider a similar approach to the one presented in this research when estimating food security on a global level.

5. Conclusions

Despite progress against poverty and malnutrition, food insecurity is still high in rural areas and around 2.5 times more people are affected by micronutrient deficiency than by insufficient caloric consumption. This calls for a shift from assessing agricultural production only in terms of caloric production to considering several equally important microelements. The diversity found in farming systems is reflected in different levels of food security. Understanding the key differences between households is key to targeting actions that are more likely to succeed in fighting back the food insecurity problem. For better-off households, micronutrient deficiency could be improved by having access to food rich in specific elements. This could either be done by producing crops rich in elements like vitamin A. Educational programs should target awareness regarding elements that are usually lacking in people's diets and recommend alternative foods. Larger families with little land face a dilemma when it comes to selling or consuming their production—agriculture for them is neither capable of providing sufficient income nor food to feed their family. In addition, most food-insecure households generate little income from off-farm activities, which reduces their options even further. Off-farm income offers households an option to retain and consume their production, thereby potentially improving households' self-sufficiency. Giller (2020) argues that farming systems must go through a structural change to allow farms to grow and be more viable. He also says that these changes must be followed by developments in economic sectors outside agriculture. We agree with this argument. Notwithstanding, until these developments occur, food self-sufficiency is a key component in households' food security. While reducing yield gaps might not be sufficient to achieve food security, it can improve it.

Credit author statement

Ivan P. Novotny: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. Nastasia Boul Lefeuvre: Conceptualization, Data curation, Writing – review & editing. Natasha Stoudmann: Writing – review & editing, literature review. Anne Dray: Writing – review & editing, Funding acquisition. Claude A. Garcia: Writing – review & editing, Funding acquisition. Patrick O. Waeber: Conceptualization, Writing – review & editing, Funding acquisition

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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