



Ouedraogo, Arnaud ¹ – Rouamba, Songanaba ² – Yaméogo, Joseph ^{3*}
– Zongo, Mahamadou ⁴

Agricultural Diversification and Food Security of Women Farmers in Two Contrasting Rural Sites in Burkina Faso (West Africa)

ABSTRACT

This study examines the impact of agricultural diversification on household food security in two contrasting rural sites, Baskoudre and Foutrigui. It employs a cross-sectional comparative design based on primary data collected from 160 female farmers (80 per site). The data were analyzed using descriptive statistics and multiple linear regression models. The main explanatory variables are the Simpson Diversification Index (SDI) and the Simply Crop Density (SCD), supplemented by control variables such as age, educational level, and household size. The analyses were conducted to determine the direction and significance of the relationships between agricultural diversification and food security. The results show that agricultural diversification generally has a positive effect on food security, although the strength of this effect varies across contexts. In Baskoudre, both the SDI and SCD have a positive and statistically significant influence on the FCS and the IDDS, indicating that diversified agricultural systems improve both dietary quality and diversity. Household size and educational level also emerge as important determinants at this site. In Foutrigui, the SDI remains positively and significantly associated with both food security indicators, whereas the SCD exhibits weak or slightly negative effects on the FCS. Socio-demographic variables are generally non-significant in this site, suggesting the presence of more pronounced structural constraints.

Keywords: agricultural diversification; food security; Burkina Faso, diversity, Baskoudre and Foutrigui

Research article / Received: 3 June 2026 / Revised: 26 June 2026 / Accepted: 15 August 2026

© Author(s) 2027

How to cite: Ouedraogo, A., Rouamba, S., Yaméogo, J., & Zongo, M. (2027). Agricultural diversification and food security of women farmers in two contrasting rural sites in Burkina Faso (West Africa). *Modern Geografía*, 22(1), 131–170. <https://doi.org/10.15170/MG.2027.22.01.07>

¹ PhD, Associate Professor, Norbert ZONGO University, Koudougou, Department of Geography, Burkina Faso, Email: arnaudobf@gmail.com

² PhD, Associate Professor, Norbert ZONGO University, Koudougou, Department of Geography, Burkina Faso, Email: songanaba@gmail.com

³ PhD, Assistant Professor Ziniaré University Center/Joseph KI-ZERBO University Department of Human Sciences and Society, Burkina Faso, Corresponding author, Email: josephyameogo10@gmail.com

⁴ Bachelor's Degree, Ziniaré University Center/Joseph KI-ZERBO University, Department of Human Sciences and Society, Burkina Faso, Email: mahamadouzongo73@gmail.com

INTRODUCTION

In West Africa, agricultural and food systems have been undergoing profound transformations for several decades as a result of the combined effects of climate variability, natural resource degradation, rural poverty, and recurring security crises. In this region, where rain-fed agriculture constitutes the primary source of livelihood for rural populations, climate-related disruptions directly affect agricultural production capacity and exacerbate food insecurity (Mortimore, 1989; Nicholson, 2013; Sultan & Gaetani, 2016; Sultan et al., 2019). Increasingly erratic rainfall (Yaméogo, 2025a; Yaméogo, 2025b; Ogunbode et al., 2025; Yaméogo et al., 2026), recurrent droughts (Gautier et al., 2016; Yaméogo, 2025b), floods, and rising temperatures (Kwawuvi et al., 2023; Yaméogo, 2024) are compromising agricultural yields and increasing the long-term vulnerability of rural livelihoods (Biasutti, 2019; IPCC, 2021; IPCC, 2022; Yaméogo et al., 2022). Compounding these environmental challenges are increasingly complex security crises characterized by the spread of armed conflict, forced population displacement, and the disruption of economic and agricultural activities in several Sahelian countries, notably Burkina Faso, Mali, and Niger (FAO, 2023; UNHCR, 2024).

In the Sahel region, the interaction between climate change, pressure on natural resources, and security instability exacerbates the socioeconomic vulnerabilities of farming households. The reduction in arable land, the growing scarcity of water resources, and tensions over access to natural resources contribute to social fragility and profoundly affect rural production systems (Homer-Dixon, 1999; Turner, 2004; Benjaminsen et al., 2012). Rural populations are therefore exposed to both climate-related and security-related risks, resulting in a gradual deterioration in living conditions, declining agricultural incomes, and worsening food insecurity. According to the World Food Programme, several million people in West Africa and the Sahel remain in a state of acute food insecurity due to the combined effects of climate shocks, armed conflicts, and economic disruptions (WFP, 2023).

In Burkina Faso, this situation has become particularly alarming over the past decade. As a country heavily dependent on rain-fed agriculture, Burkina Faso is simultaneously confronting the effects of climate variability and security instability, both of which are severely affecting agricultural and pastoral systems. Rainfall deficits, recurrent drought conditions, and soil degradation are reducing agricultural productivity, while insecurity has led to massive population displacement, the abandonment of farmland, and the disruption of trade routes (INSD, 2020; FAO, 2023). In several rural regions of the country, farming households are experiencing substantial declines in food production and deteriorating economic conditions, resulting in increased food and nutritional vulnerability. According to the World Food Programme (2023), approximately 2.3 million people are currently facing acute food insecurity in Burkina Faso, with the highest prevalence recorded in the Sahelian and northern regions. Similarly, FEWS NET (2024) reports that cereal production in some northern provinces has declined by 20–40% over the past decade, mainly due to recurrent climatic shocks, insecurity, and restricted access to agricultural land.

In response to these challenges, nongovernmental organizations, international institutions, and development agencies have intensified their efforts to strengthen the resilience of rural households.

These initiatives generally focus on promoting sustainable livelihoods aimed at improving food security and increasing the incomes of vulnerable populations. Among the most commonly implemented strategies are crop diversification, income-generating activities, vegetable production, agroecological practices, sustainable land management, small ruminant husbandry, cash transfer programs, and initiatives supporting rural entrepreneurship (Scoones, 1998; Ellis, 2000; Barrett et al., 2001; FAO, 2018). Collectively, these approaches seek to reduce households' dependence on a single agricultural activity and enhance their capacity to adapt to climate-related and security-related crises.

Among these strategies, crop diversification occupies a central role in rural resilience programs across sub-Saharan Africa. It involves integrating multiple crops into production systems to mitigate risks associated with climate variability, fluctuations in agricultural markets, and crop failures (Altieri, 1999; Lin, 2011; Pretty & Bharucha, 2014). Studies by Frempong and Annim (2017), Sibhatu et al. (2015), Powell et al. (2015), Bellon et al. (2016), and Nyamayevu et al. (2025) demonstrate that agricultural diversification improves dietary diversity among rural households by increasing the variety of available food products. Other studies have also shown that crop diversification contributes to stabilizing agricultural incomes and reducing the economic vulnerability of family farms (Ellis, 2000; Fraval et al., 2020; Sanfo, 2022). However, the effectiveness of these strategies varies according to socioecological conditions, household characteristics, and the degree of access to productive resources, including those provided through NGO support.

Consequently, evaluating crop diversification strategies is essential for assessing their contribution to improving the living conditions of rural households. This study is situated within this framework and is based on the hypothesis that crop diversification enhances the dietary diversity of rural households. Accordingly, the research aims to analyze the extent to which crop diversification strategies, supported by interventions promoting rural resilience, contribute to improving food security among farming households in the Koulsé region of Burkina Faso. More specifically, the study seeks to: (i) characterize the sociodemographic profile of farmers at the two study sites; (ii) determine the level of crop system diversification and the food security status of farmers at each site; and (iii) analyze the main effects of diversification on the food security of producers at the two sites.

LITERATURE REVIEW

Theoretical Foundations of Crop Diversification

Crop diversification represents an essential strategy for farming households living in environments characterized by high climate variability, economic instability, and increasing pressure on natural resources. It involves spreading agricultural activities across multiple crops to reduce dependence on a single source of income or food production. In vulnerable rural areas, this strategy is seen as a means of managing risks, strengthening household resilience, and conserving natural resources.

First, the theory of agricultural risk management provides a useful framework for understanding this strategy. Moscardi and De Janvry (1977) explain that farming households diversify their crops to reduce fluctuations in their income. Similarly, Ellis (2000) and Morduch (1995) show that diversification is a logical response to climatic and economic uncertainties. It thus functions as a protective mechanism, enabling households to limit losses resulting from various shocks. Next, the sustainable livelihoods approach offers a broader perspective by incorporating the various types of resources available to rural households. Chambers and Conway (1992), followed by Scoones (1998), demonstrate that households combine multiple resources to secure their living conditions. DFID (1999) specifies that these resources include natural, human, financial, and social capital. In this vein, Reardon et al. (2001) and Ellis (2000) view diversification as an important means of reducing rural poverty and stabilizing farm incomes. Furthermore, socio-ecological systems theory provides a comprehensive understanding of the relationships between rural societies and their environment. Holling (1973) demonstrates that systems evolve through different phases: growth, crisis, reorganization, and adaptation. Gunderson and Holling (2002) emphasize that diversity plays an essential role in the stability of systems. For their part, Folke et al. (2004, 2010, 2016) demonstrate that diversity in activities and functions strengthens systems' capacity to resist and adapt to disturbances. The agroecological approach also highlights the environmental benefits of crop diversification. Altieri (1999), Gliessman (2007, 2015), and Wezel et al. (2020) show that diversified agricultural systems improve soil fertility, reduce the degradation of natural resources, and promote the sustainability of agroecosystems. Tiftonell (2014) also emphasizes that diversified systems often perform better in environments subject to severe ecological constraints.

Finally, research on climate resilience confirms the importance of crop diversification in rural areas. The Intergovernmental Panel on Climate Change (2021) notes that agricultural systems are highly vulnerable to climate variability and extreme events. Lobell et al. (2011) show that these disturbances directly affect agricultural yields and increase the risks of food insecurity. Jayne et al. (2014) also emphasize the role of local constraints, such as access to markets, inputs, and land, in the effectiveness of diversification strategies.

Crop System Diversity and Food Availability

The scientific literature widely recognizes that crop system diversity is a key driver of improved food availability. By increasing the number of crop species, farms reduce their dependence on a single crop and increase the overall quantity of food available for subsistence and commercial sale. This diversification also helps reduce risks associated with climatic, biological, or economic hazards that could affect a particular crop.

According to Snapp et al. (2010), cereal-legume mixtures in Southern Africa make it possible to simultaneously increase agricultural yields and food availability through improved soil fertility resulting from biological nitrogen fixation. In the same vein, Altieri and Nicholls (2017) emphasize that diversified agroecological systems exhibit greater production stability in the face of climate

disturbances than monocultures. This production stability is a key determinant of food security, particularly in regions subject to high climate variability.

More recent studies confirm these findings. Renard and Tilman (2019) demonstrate that crop diversity helps stabilize agricultural yields in the long term through mechanisms of functional complementarity among crop species. Similarly, Tamburini et al. (2020) show that agricultural diversification simultaneously improves productivity and several ecosystem services, such as pollination, soil fertility, and biological pest control. A global meta-analysis conducted by Beillouin et al. (2019) also concludes that agricultural diversification strategies increase the sustainability of production systems while promoting food availability.

These findings are particularly relevant in West Africa, where family farming systems remain highly dependent on weather conditions. In Burkina Faso, Sanfo (2022) shows that crop diversification helps improve food security for farming households, but that this effect depends heavily on access to agricultural inputs and productive technologies. The benefits associated with diversification appear greater when producers have sufficient resources to effectively leverage crop diversity. More recently, Sawadogo and Sawadogo (2025) demonstrate that, in a context marked by growing insecurity, farming households that diversify their production are better able to maintain their food availability than specialized farms. These results suggest that diversification acts as a mechanism to stabilize production in the face of the multiple shocks affecting Sahelian agricultural systems.

Crop System Diversity and Dietary Diversity

One of the most well-documented contributions of agricultural diversification concerns its influence on household dietary diversity. Dietary diversity is a widely recognized indicator of the nutritional quality of diets and represents an essential component of food security (Ruel, 2003a).

Jones et al. (2014), based on a meta-analysis conducted in several developing countries, highlight a positive relationship between agricultural production diversity and household dietary diversity. The authors show that households growing a greater number of crop species generally consume a more varied diet that is richer in essential micronutrients. These findings are corroborated by Sibhatu et al. (2015), who demonstrate that increasing the number of crops produced significantly improves dietary diversity, particularly in rural areas with limited market integration.

Recent research confirms the importance of this relationship. Bellon et al. (2016) emphasize that agricultural diversification promotes the conservation and consumption of nutrient-rich traditional crops. Kerr et al. (2021) also show that diversified agroecological systems improve access to fruits, vegetables, and legumes, thereby contributing to better nutritional quality in diets.

In West Africa, several recent studies have shown similar results. Shiratori et al. (2023), in a study conducted in rural Burkina Faso, observed that households with more diversified agricultural production have better nutritional adequacy and greater dietary diversity. The authors demonstrate that legumes, vegetable crops, and certain traditional crops play a key role in improving dietary

quality. Similarly, Addai et al. (2024), in northern Ghana, demonstrate that diversified farms exhibit higher levels of dietary diversity, although the observed effects vary depending on farm size and market access.

However, the literature also highlights that this relationship is not systematic. Koppmair et al. (2017) and Chegere and Stage (2020) show that the direct effect of crop diversification tends to diminish when households have better access to markets. In these situations, agricultural income often becomes a more decisive factor in dietary diversity than on-farm consumption. Thus, the effects of agricultural diversification on nutrition appear to depend on both the productive characteristics of farms and their level of economic integration.

Crop System Diversity, Resilience, and Reduced Vulnerability

Beyond its effects on food availability and diversity, crop system diversification is often cited as a key factor in the resilience of farming households. Resilience refers to the ability of agricultural systems to withstand, adapt to, and transform in the face of environmental, economic, or social disruptions.

According to Lin (2011), agricultural diversification is an effective risk management strategy because different crops respond differently to droughts, diseases, or pest infestations. This heterogeneity reduces the likelihood of total production losses and promotes the stability of farm incomes. Darnhofer (2014) also considers biological diversity to be one of the main pillars of agricultural system resilience.

The work of Reckling et al. (2023) shows that diversified farms have a greater capacity to adapt to climate change due to the increased number of production options. Mbow et al. (2023) also emphasize that diversified agricultural systems are one of the most effective strategies for strengthening climate resilience in Africa.

In Sahelian countries, where farming households face simultaneous challenges such as droughts, natural resource degradation, fluctuations in agricultural prices, and insecurity, diversification emerges as a key strategy for reducing vulnerability. In Burkina Faso, Sawadogo (2023) shows that combining multiple productive activities, including agricultural crops and non-timber forest products, significantly improves household food security and reduces their exposure to lean seasons. Research conducted in several rural areas of West Africa also indicates that farms combining food crops, cash crops, livestock, and complementary activities generally demonstrate greater resilience in the face of climate and economic crises.

Diversification also contributes to households' economic resilience. According to Ellis (2000), diversifying sources of production helps spread income risks and reduce exposure to market shocks. This conclusion remains relevant in current Sahelian contexts, where price fluctuations, security disruptions, and climate constraints exacerbate the vulnerability of rural households.

The existing literature shows that crop system diversity generally has a positive effect on food security through three main mechanisms: improved food availability, increased dietary diversity,

and enhanced resilience of farming households. Recent research conducted in West Africa broadly confirms these findings while highlighting the importance of the economic, institutional, and security context in which farms operate.

However, several limitations persist in the existing literature. First, studies often analyze crop diversity, economic vulnerability, and food security separately, without examining their interactions. Second, research on Sahelian areas simultaneously affected by climate variability and insecurity remains relatively limited. Third, few studies use composite indices to jointly analyze the diversity of cropping systems, the economic vulnerability of households, and their level of food security. These gaps underscore the need to examine how the diversity of farming systems affects the economic vulnerability of farming households and, consequently, their food security in rural Sahelian contexts.

METHODS

Study Areas

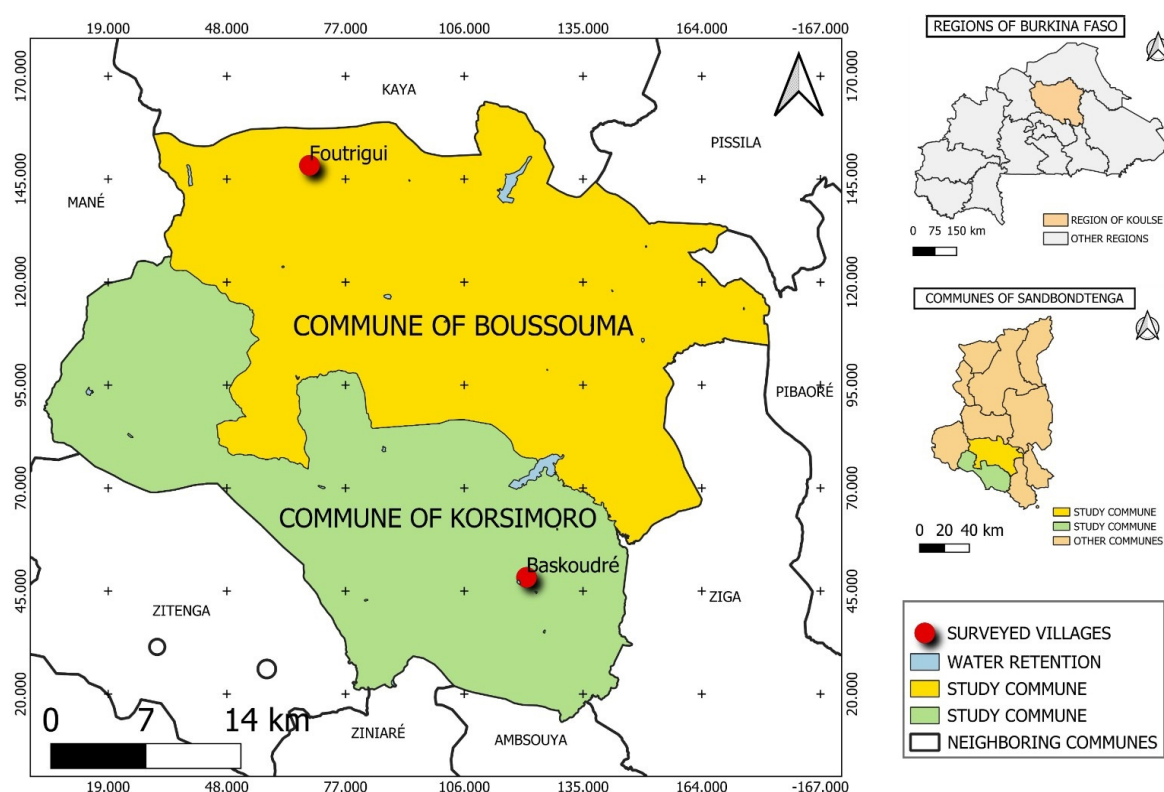
The study was conducted in two rural communities in the Koulché Region of Burkina Faso: Baskoudré and Foutrigui. These two villages are located in the rural communes of Korsimoro and Boussouma, respectively, within Sanmatenga Province. The sites were selected because of their food insecurity, which is reflected in the extent to which residents engage in vegetable farming. Furthermore, Baskoudré, which has benefited from external support through a development project, experiences more severe security challenges and greater climate variability. This places the village in a situation of higher food vulnerability than Foutrigui.

The village of Baskoudré, the main study site in the municipality of Korsimoro, is located approximately 8 km southeast of the municipal capital. Like many villages in the region, Baskoudré faces severe climatic constraints characterized by erratic rainfall, land degradation, and a gradual decline in agricultural yields. These environmental challenges have been compounded by the deterioration of the security situation since 2015, which has further exacerbated food and economic vulnerabilities among rural households. Despite these constraints, local communities have developed various resilience strategies, primarily based on vegetable farming activities. As part of this initiative, women farmers in Baskoudré have benefited from a multipurpose vegetable garden established under the PRESI-OKDD project to strengthen the livelihoods of vulnerable households. Today, this garden serves as an important space for agricultural production and economic support for rural women. The selection of Baskoudré is therefore justified by the presence of a structured initiative aimed at enhancing community resilience and improving local living conditions.

The second study site is the village of Foutrigui, located in the rural commune of Boussouma, approximately 20 km from Kaya. The commune of Boussouma comprises five administrative sectors and 62 villages. It is crossed by National Road 3 (RN3) and covers an area of approximately 770 km². It is bordered to the northeast by the communes of Kaya, Pissila, and Pibaoré; to the west by

the commune of Mané; and to the southeast by the communes of Korsimoro and Ziga. The village of Foutrigui is situated about 17 km northwest of the commune's administrative center. Like Baskoudré, Foutrigui relies heavily on agriculture and market gardening for household subsistence. However, unlike the previous site, women farmers in Foutrigui have not benefited from a structured support project or the modern development of market gardening areas. Agricultural and market gardening activities in the area are primarily driven by local initiatives undertaken by rural women, who make use of a pond located near the production area. Despite challenges related to inadequate equipment, limited access to productive resources, and climatic constraints, the women of Foutrigui continue their market gardening activities to support household food security and income generation. Figure 1 below shows the geographic location of the study villages.

Figure 1. Location of the Two Villages Studied



The comparative analysis of Baskoudré and Foutrigui allows for an examination of the differences between a site receiving institutional support through a developed vegetable garden area and characterized by high food insecurity, and a site relying primarily on local community initiatives and characterized by lower food insecurity. This comparative approach makes it possible to assess the contribution of resilience and livelihood interventions to improving the food and economic conditions of rural households facing the combined effects of climate and security crises.

Sample Size and Data Collection

The study employed a multi-stage sampling technique. Initially, Baskoudré and Foutrigui were selected through purposive sampling in the communes of Korsimoro and Boussouma (Sanmatenga Province, Koulsé Region). These two sites differ in terms of external support. In Baskoudré, a multipurpose vegetable garden area was established under the PRESI-OKDD project to strengthen household resilience, particularly among women producers. In contrast, in Foutrigui, vegetable farming relies mainly on local initiatives supported by a nearby pond, with little or no external intervention. This difference provides a relevant basis for a comparative analysis of livelihood strategies.

Following site selection, a list of farming households was compiled with the assistance of local authorities and community leaders. Households were then randomly selected at each site to ensure that the sample was representative and to minimize selection bias. The sample size was determined using Cochran's formula:

$$n = \frac{Z^2 p(1-q)}{e^2} \quad (1)$$

$$n = \frac{1.96^2 * 0.21 * 0.5}{0.05^2} = 161.34$$

Where n represents the sample size, z is the standard normal value corresponding to the selected confidence level (1.96 for 95%), p denotes the estimated population proportion (0.21), and q is defined as 1 – p (with p = q = 0.5 in cases of uncertainty regarding the population). The term e refers to the margin of error, which was fixed at 0.05.

Following the selection process, a total of 160 households were included in the study, divided equally between the two study sites: Baskoudré (80 households) and Foutrigui (80 households). This balanced distribution was adopted to ensure comparability between the two sites and to facilitate the identification of characteristics associated with the socio-economic contexts and agricultural practices specific to each location. Table 1 below presents the distribution of surveyed households by study site.

Table 1. Distribution of Respondents by Study Site

Study sites	Sample size	Percentage	Cropping system	Main species types used in the plots
Baskoudre	80	50	Mixed	Adansonia digitata, Moringa oleifera, Allium cepa, Manihot esculenta, Zea mays, and Solanum tuberosum
Foutrigui	80	50	Mixed	Allium cepa, Zea mays, and Solanum melongena
Total	160	100		

Source: Field surveys, September 2025

Data collection relied on a combination of structured household questionnaire surveys and field observations. The survey involved the collection of primary data from women producers in the two study areas, Baskoudré and Foutrigui. Data collection took place in September 2025 in both villages.

The survey was conducted directly with women farmers using a pre-designed questionnaire and without the involvement of intermediaries. Interviews were scheduled according to the availability of the respondents, as the survey coincided with the winter season, which is characterized by intensive agricultural activities. The survey was administered individually and enabled the collection of information regarding respondents' socio-economic characteristics and vegetable production activities. The main tools used for data collection were the questionnaire and a mobile phone.

Ethical Considerations

Prior to data collection, all participants provided informed written consent after receiving clear information about the objectives and procedures of the study. Participants were also informed of their right to withdraw voluntarily from the research at any stage without any negative consequences. The study complied with the ethical principles outlined in the Declaration of Helsinki. To ensure confidentiality and anonymity, respondents' identities were protected, and no real names were recorded in either the dataset or the reporting process.

In accordance with institutional research regulations, the study protocol was reviewed by the relevant ethics committee, which waived the requirement for formal ethical approval and additional authorization because the research involved non-invasive socio-economic surveys with voluntary adult participants and did not collect sensitive personal or medical data.

Data Processing Method

Measure of Diversity: Simpson Diversification Index (SDI)

The index used in this study is the Simpson Diversification Index (SDI), which is widely employed to measure the level of diversification of income sources or livelihood activities among farming households. The SDI is derived from the Simpson Diversity Index, originally developed in ecology by Simpson (1949) to measure the heterogeneity of biological populations. Subsequently, this analytical framework was adapted to economic and rural studies to analyze livelihood diversification.

The application of the SDI to agricultural and rural systems has been progressively consolidated through numerous studies. Shiyani and Pandya (1998) were among the first authors to use this index to analyze agricultural diversification within production systems. Similarly, Khatun and Roy (2012) employed the SDI to examine livelihood diversification strategies in rural areas. Subsequent research has further reinforced its use in the empirical analysis of agricultural income diversification. In this regard, Joshi et al. (2006) examined the diversification of agricultural systems in relation to structural changes in agriculture, while Imai (2010) highlighted the role of rural livelihood diversification in reducing poverty and improving the resilience of farming households. Consequently, the SDI has become a widely accepted composite indicator for measuring the degree of income diversification,

taking into account both the number of income sources and their relative distribution within farming households. The Simpson Diversification Index is expressed as:

$$SDI = 1 - \sum_{i=1}^N P_i^2 \quad (2)$$

Where:

SDI = Simpson Diversification Index;

N = total number of income sources;

P_i = proportion of total income derived from source i .

The proportion P_i is calculated as follows:

$$P_i = \frac{Y_i}{Y_T} \quad (3)$$

Where:

Y_i = income from source i ;

Y_T = total household income.

The SDI ranges from 0 to 1. Values closer to 1 indicate a higher level of diversification, whereas values closer to 0 reflect lower diversification (Islam et al., 2024).

Measuring Diversity: Simple Crop Density (SCD)

Crop diversification is widely recognized in the scientific literature as a key strategy for adaptation and risk reduction among farming households facing climatic, economic, and food security constraints. From a rural livelihoods perspective, Ellis (2000) emphasizes that the diversification of productive activities constitutes a fundamental mechanism for risk management and income stabilization in uncertain environments. Similarly, Barrett et al. (2001) demonstrate that agricultural diversification helps reduce household vulnerability to production and market shocks.

Empirically, the measurement of diversification relies on several complex indicators, such as the Shannon, Simpson, and Herfindahl indices, which are often applied when detailed data on land allocation or income distribution are available. However, in many rural surveys, detailed information on the exact distribution of cultivated land among crops is either unavailable or incomplete. In such contexts, several authors recommend the use of simplified indicators based on readily observable variables. Joshi et al. (2004, 2006) show that, in studies of agricultural diversification in South Asia, the use of simple proxies, such as the number of crops cultivated, remains relevant when data are limited while retaining acceptable explanatory power. Similarly, Pingali and Rosegrant (1995) emphasize that agricultural diversification can be understood through simple structural measures, particularly in the context of smallholder farming systems.

This richness-based approach is consistent with research on diversity quantification, which argues that, in data-constrained contexts, counting the number of cultivated units can serve as an operational

proxy for diversification, although it does not capture the degree of evenness in the distribution of land among crops (Magurran, 2004; Stirling, 2007). From this perspective, Simple Crop Density (SCD) can be defined as a summary indicator that relates the number of crops cultivated to the total cultivated area in order to estimate the degree of diversification of a production system relative to its land constraints. In other words, it represents a measure of crop diversity per unit area and is particularly useful when available data do not permit the estimation of indices weighted by land-area shares. The formula is expressed as follows:

$$SCD = \frac{N_c}{S_t} \quad (4)$$

SCD = Simple Crop Density

N_c = number of crops cultivated by the household;

S_t = total cultivated area (e.g., in m^2).

The interpretation of the results is based primarily on the value obtained. A high SCD value indicates a high degree of crop diversification, meaning that the household cultivates several different crops on a relatively small area of land.

Food Diversity Measurement

The Food Consumption Score (FCS)

It is an indicator used to assess the quality and diversity of household diets. It makes it possible to evaluate households' access to a varied diet as well as the potential coverage of nutritional needs, particularly for micronutrients. This indicator was developed by the World Food Programme. Several authors have used the FCS in food security and nutrition analyses. For instance, Maxwell and Caldwell (2008) demonstrate that the FCS is a relevant tool for measuring food access among vulnerable households. Wiesmann et al. (2009) emphasize that this indicator allows for an assessment of dietary diversity and consumption stability. Kennedy et al. (2010) highlight the importance of dietary diversity in improving the nutritional quality of households. For their part, Hoddinott and Yohannes (2002) consider the SCA a reliable indicator for food security analyses in rural settings. Finally, FANTA (2006) notes that the SCA is widely used in studies on food and nutritional vulnerability.

The FCS is calculated based on the frequency of consumption of the main food groups during the seven (7) days preceding the survey. Each food group is assigned a weighting coefficient based on its nutritional value. The more diverse and nutritious a household's diet is, the higher its score. The food groups generally included are: grains and tubers, legumes, vegetables, fruits, meat and fish, milk and dairy products, sugar, oil and fats. The general formula for the Food Consumption Score is as follows:

$$FCS = \sum_{i=1}^n f_i^* p_i \quad (5)$$

Where:

FCS = Food Consumption Score ;

f_i = frequency of consumption of food group i over the past seven days;

p_i = weighting factor assigned to food group i ;

n = total number of food groups taken into account.

The weightings used by the World Food Programme are generally based on food groups (Table 2).

Table 2. Food Groups and Weighting Factors

Food groups	Weighting factor
Cereals and tubers	2
Legumes	3
Vegetables	1
Fruits	1
Meat and fish	4
Milk and dairy products	4
Sugar	0.5
Oils and fats	0.5

The FCS is therefore calculated by multiplying the frequency of consumption for each food group by its nutritional weight, and then adding up all the resulting values. A high score generally indicates a more varied diet of higher nutritional quality. Table 3 below shows the FCS levels and their interpretation.

Table 3. FCS Levels and Interpretation

Food consumption categories	FCS threshold	Interpretation
Poor food consumption	$FCS < 21$	Corresponds to a situation of severe food insecurity
Borderline food consumption	$21.5 < FCS < 35$	Corresponds to a situation of moderate food insecurity
Acceptable food consumption	$FCS > 35$	Corresponds to a situation of food security

Source: Jones et al. (2013)

Individual Dietary Diversity Score (IDDS)

The Individual Dietary Diversity Score (IDDS) is an indicator that measures the diversity of an individual's diet over a given period, typically the 24 hours preceding the survey. It is used to assess dietary quality and serves as a proxy for nutritional adequacy, particularly in terms of micronutrients. This indicator is recommended by the Food and Agriculture Organization and is widely used in nutrition and food security studies.

The IDDS is based on the principle that a more diverse diet is associated with better nutritional status. It involves counting the number of different food groups consumed by an individual during the reference period. The higher the number of food groups consumed, the more satisfactory the dietary diversity is considered to be. The food groups generally taken into account are: cereals and tubers, pulses, vegetables, fruit, meat and fish, milk and dairy products, eggs, oils and fats, sweets. Mathematical formula for the IDDS:

$$IDDS = \sum_{i=1}^n S_i \quad (6)$$

Where:

IDDS = Individual Dietary Diversity Score;

S_i = 1 if food group i is consumed, 0 otherwise;

n = total number of food groups considered.

Thus, the higher the score, the greater the dietary diversity, which is generally associated with better nutritional quality and better health.

Multiple Linear Regression Model

The multiple linear regression model is one of the most widely used econometric tools for analysing the relationship between a dependent variable and several explanatory variables. It enables the specific effect of a given factor on a phenomenon under study to be assessed, whilst simultaneously controlling for the influence of other variables that may affect that phenomenon. According to Gujarati & Porter (2009) and Greene (2012), multiple regression is an extension of simple regression that allows an economic variable to be explained on the basis of a set of observable determinants. Similarly, Wooldridge (2010) emphasises that this approach is particularly well-suited to empirical analyses in applied economics, as it allows for the estimation of conditional relationships between economic variables whilst reducing biases associated with omitted variables. The general form of the model is as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots \dots \dots \beta_k X_{ki} + \varepsilon \quad (7)$$

Y_i = represents the dependent variable for household i , i.e. the food security indicator

$X_{1i}, X_{2i}, \dots \dots \dots X_{ki}$ represent the explanatory variables;

β_0 is the constant;

$\beta_1, \dots \dots \dots \beta_k$ are the coefficients to be estimated;

ε is the random error term.

In this study, a multiple linear regression model is used to analyse the effect of diversification of production systems and/or sources of income on household food security at the two sites. The main objective was to determine the extent to which variations in the level of diversification influence food security indicators, particularly the Food Consumption Index (FCS) and the Food Diversity Index (FDS), after accounting for socioeconomic factors characteristics of the households. The empirical specification of the model is as follows:

(i) Model based on the Food Consumption Score (FCS):

$$FCS_i = \beta_0 + \beta_1 \text{diversification index} + \sum_{k=2}^K \beta_k X_{ki} + \varepsilon \quad (8)$$

(ii) Model based on the Individual Dietary Diversity Score (IDDS):

$$IDDS_i = \beta_0 + \beta_1 \text{diversification index} + \sum_{k=2}^K \beta_k X_{ki} + \varepsilon \quad (9)$$

Where,

FCS = Food Consumption Score ;

IDDS = Individual Dietary Diversity Score ;

Diversification index = Simply Crop Density and Simpson Diversification Index

$X_{1i}, X_{2i}, \dots, X_{ki}$ = represent the explanatory variables (household size, age group, level of education);

β_0 is the constant;

RESULTS

Sociodemographic Characteristics of Female Producers at the Two Sites

Analysis of the sociodemographic characteristics of female producers reveals statistically significant differences between the Baskoudre and Foutrigui sites ($p < 0.000$) (Table 4). This table highlights differences primarily related to age, educational attainment, and household size, reflecting distinct socio-demographic realities that are likely to influence farming strategies as well as household food security.

Regarding the age of the respondents, the 35–45 age group constitutes the majority of the total sample, accounting for 62.5% of female farmers. This proportion is particularly high in Foutrigui, where it reaches 77.5%, compared with 47.5% in Baskoudré. Conversely, women aged 25–35 are more strongly represented in Baskoudré (42.5%) than in Foutrigui (8.8%). These results indicate that agricultural and market gardening activities are mainly carried out by women of working age who potentially possess substantial productive experience. The relatively higher proportion of young

women producers in Baskoudré may also reflect greater participation of younger women in agricultural activities or the stronger economic attractiveness of market gardening in this locality.

Table 4. Sociodemographic Characteristics of Female Producers

Variables	Categories	Baskoudré (%)	Foutrigui (%)	Total (%)	P-value
Age group	25–35 years	34 (42.5)	7 (8.8)	41 (100)	0.000
	35–45 years	38 (47.5)	62 (77.5)	100 (100)	
	45–55 years	8 (10.0)	11 (13.7)	19 (100)	
Education level	None	19 (23.8)	70 (87.5)	89 (100)	0.000
	Quranic school	16 (20.0)	0 (0.0)	16 (100)	
	Primary level	39 (48.8)	10 (12.5)	49 (100)	
	Secondary level	6 (7.5)	0 (0.0)	6 (100)	
Household size (number of persons)	4 persons	4 (5.0)	0 (0.0)	4 (100)	0.000
	5 persons	22 (27.5)	0 (0.0)	22 (100)	
	6 persons	28 (35.0)	0 (0.0)	28 (100)	
	7 persons	10 (12.5)	34 (42.5)	44 (100)	
	8 persons	3 (3.8)	38 (47.5)	41 (100)	
	9 persons	3 (3.8)	0 (0.0)	3 (100)	
	10 persons	7 (8.8)	8 (10.0)	15 (100)	
	11 persons	3 (3.8)	0 (0.0)	3 (100)	

The educational profile of female producers reveals significant disparities between the two sites. Overall, more than half of the respondents (55.6%) have no formal education. This situation is particularly pronounced in Foutrigui, where 87.5% of women have no formal education, compared with only 23.8% in Baskoudré. In contrast, Baskoudré records relatively high proportions of women who have attended primary school (48.8%) and Koranic school (20%). The proportion of female farmers who have completed secondary education remains low across the entire sample (3.8%). These findings reflect a generally low level of human capital, which is likely to constrain access to agricultural innovations, technical training, and economic opportunities. However, the relatively higher educational attainment observed in Baskoudré may facilitate the adoption of agricultural diversification techniques, more efficient farm management practices, and improved access to information on nutrition and agricultural markets.

Household size also differs significantly between the two localities. In Baskoudré, households comprising five and six members are the most common, accounting for 27.5% and 35% of households, respectively. In contrast, large households predominate in Foutrigui, particularly those consisting of seven members (42.5%) and eight members (47.5%). This difference suggests greater demographic pressure in Foutrigui. From an economic perspective, larger households may represent an advantage through the availability of family labour for agricultural activities. However, they may also increase food requirements and household consumption costs, thereby reducing per capita food availability when productive resources remain limited.

Overall, these socio-demographic characteristics highlight contrasting socio-economic contexts between the two study areas. The differences observed in terms of age, education, and household size are likely to influence the capacity to adopt agricultural diversification strategies, agricultural productivity, and household food security. These variables therefore appear to constitute important structural factors that should be taken into account when analysing the determinants of food security and the agricultural performance of rural women farmers.

Status of Crop Diversification at the Two Study Sites

The Simple Crop Density (SCD) measure assesses the level of crop diversification practised by farming households. High values indicate greater crop diversity, whereas low values reflect a strong concentration on a limited number of crops. Analysis of Figure 2 using the SCD indicator highlights significant differences in the degree of crop diversification between Baskoudré and Foutrigui.

Figure 2. The State of Crop Diversification According to Simple Crop Density (SCD) at the Two Study Sites

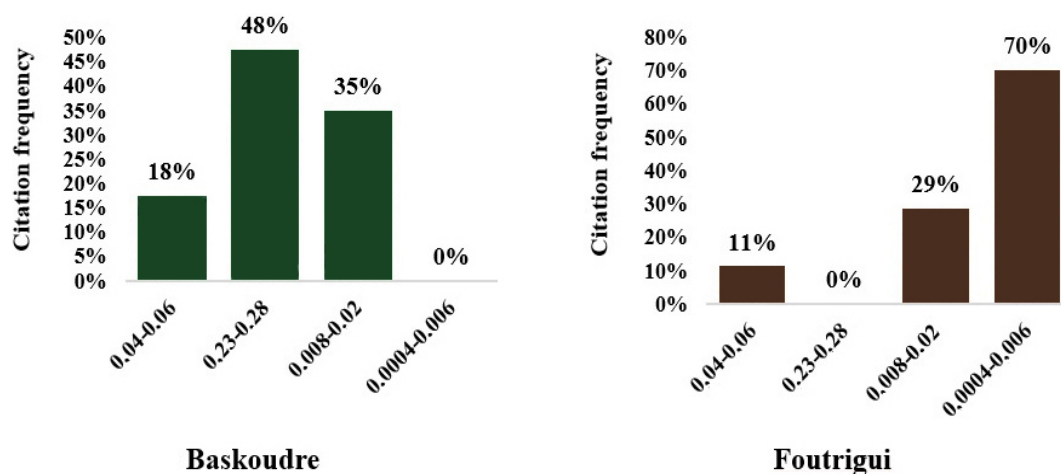


Figure 2 shows that Baskoudré exhibits a relatively high level of crop diversification. Nearly 48% of households have an SCD ranging from 0.23 to 0.28, representing the highest diversification category observed in the study. Furthermore, 35% of households fall within the range of 0.008–0.02, while 18% are located within the range of 0.04–0.06. No households fall within the very low crop-density category of 0.0004–0.006. These results reflect relatively diversified farming practices in Baskoudré, characterized by the cultivation of several different crops. Such diversification may help reduce risks associated with climatic hazards, improve incomes, and enhance food availability.

In Foutrigui, the situation is considerably less favourable. The majority of farming households (70%) have a very low SCD value, ranging from 0.0004 to 0.006, indicating a high degree of agricultural specialization. Approximately 29% of households fall within the 0.008–0.02 range, whereas only 11% reach the 0.04–0.06 category. No households are represented in the highest diversification category (0.23–0.28). This concentration within the lower SCD categories indicates that producers in

Foutrigui cultivate only a limited number of crops, which may increase their vulnerability to climatic shocks, pest outbreaks, and fluctuations in agricultural markets.

The Simpson Diversification Index (SDI) measures the degree of diversification in crops or agricultural activities. Higher index values indicate greater diversification of the production system, whereas lower values reflect a higher degree of specialization and lower diversity in agricultural production. The analysis of SDI values presented in Figure 3 highlights significant differences in the level of diversification of agricultural production systems between Baskoudré and Foutrigui.

Figure 3. The State of Diversification According to the Simpson Diversification Index (SDI) at the Two Study Sites

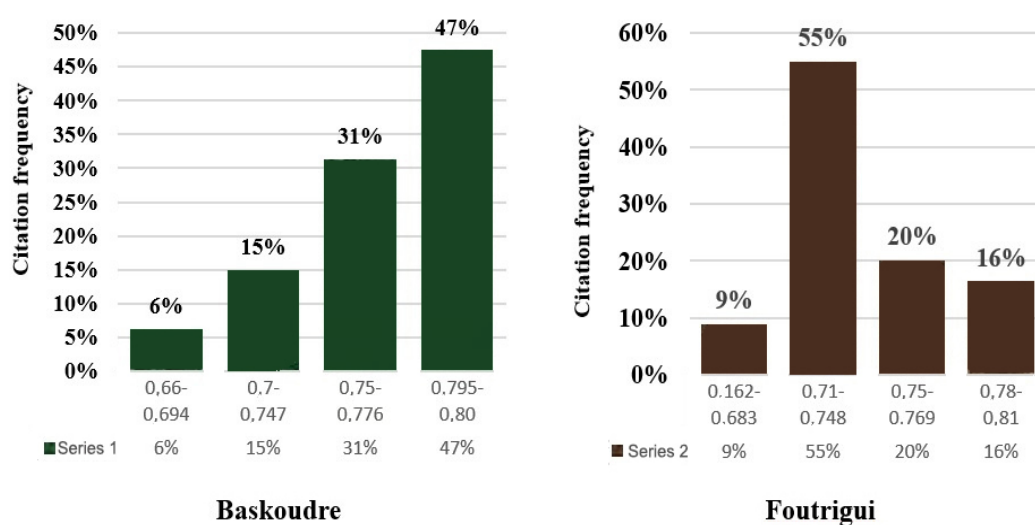


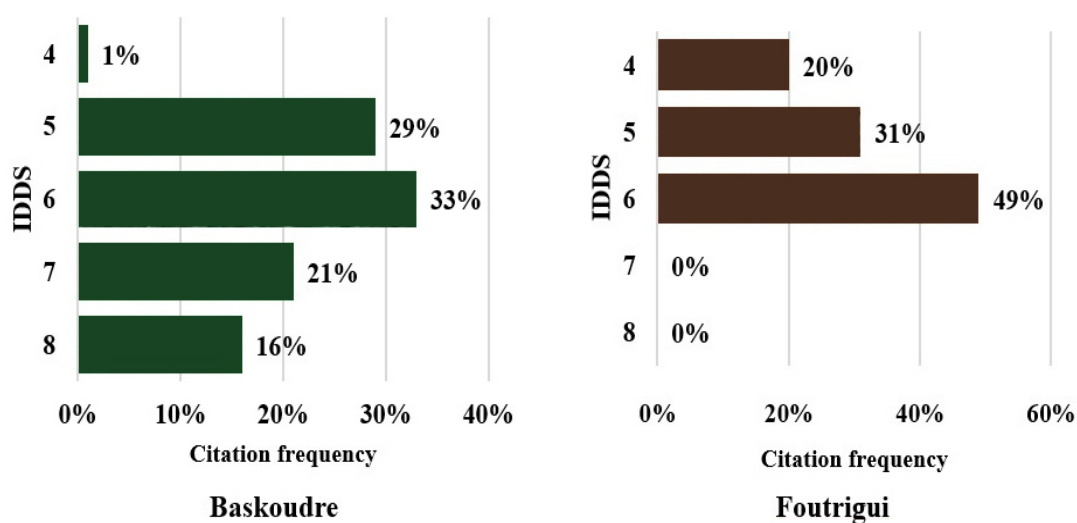
Figure 3 indicates that diversification levels in Baskoudré are relatively high. The majority of producers (47%) have an SDI ranging from 0.795 to 0.80, reflecting moderate to high agricultural diversification. In addition, 31% of households record an SDI between 0.75 and 0.776, while 15% fall within the range of 0.70–0.747. This distribution suggests that producers in Baskoudré engage more actively in the diversification of crops and agricultural activities, which may contribute to improved food availability, reduced agricultural risks, and increased household incomes.

In Foutrigui, the situation differs markedly. The majority of farmers (55%) have an SDI ranging from 0.71 to 0.748, indicating a relatively lower level of diversification and a greater degree of specialization. Approximately 20% of households fall within the range of 0.75–0.759, while only 16% reach levels between 0.75 and 0.769. In addition, 9% of households have low SDI values ranging from 0.162 to 0.683. These findings suggest that agricultural systems in Foutrigui rely on a limited number of crops or activities, which may increase household vulnerability to climatic, economic, and food-related shocks.

The State of Food Security at the Two Study Sites

Indices such as the Individual Dietary Diversity Score (IDDS) and the Food Consumption Score (FCS) are used to assess the state of food security at the two sites. The IDDS is used to assess the number of food groups consumed by individuals over a given period. A high score indicates a more diverse diet and better nutritional quality, whilst a low score indicates a diet limited to a few food groups. Analysis of the Individual Dietary Diversity Score (IDDS) reveals significant differences in dietary diversity between households in Baskoudre and Foutrigui (Figure 4).

Figure 4. The State of Dietary Diversity According to the Individual Dietary Diversity Score at the Two Sites



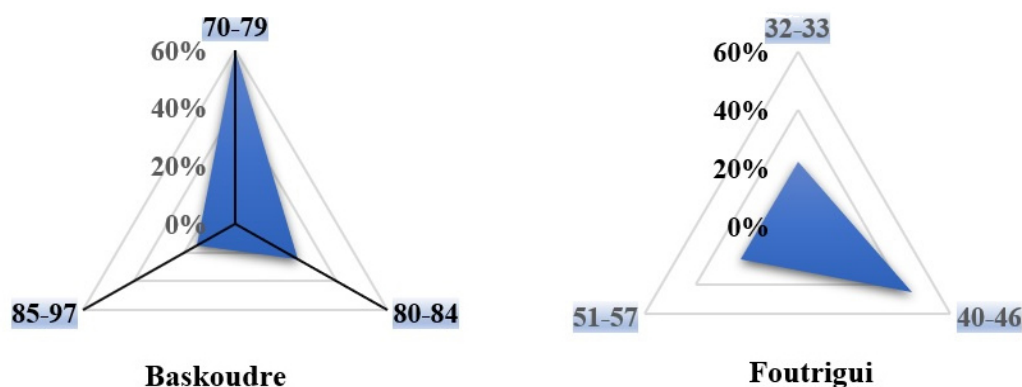
In Baskoudre, the results show a relatively high level of dietary diversity. Households with a score of 6 account for the largest proportion (33%), followed by those with a score of 5 (29%). Furthermore, 21% of households achieve an IDDS of 7 and 16% a score of 8, indicating a very varied diet. The proportion of households with a low score of 4 is very small (1%). These results suggest that the majority of households in Baskoudre have access to several food groups, notably cereals, pulses, vegetables, fruit and animal products. This situation reflects a better quality of diet and relatively favourable nutritional security.

In Foutrigui, dietary diversity appears more limited. The majority of households have a score of 6 (49%), whilst 31% have a score of 5. However, no households achieve the high scores of 7 or 8. Conversely, 20% of households have a low score of 4, indicating a poorly diversified diet for a significant proportion of the population. This absence of high scores reflects low consumption of certain nutrient-rich food groups, which may be linked to economic constraints, low food availability or a lack of diversification in agricultural production systems. A comparison of the two localities therefore shows that Baskoudre has greater dietary diversity than Foutrigui. The high proportion of high scores in Baskoudre suggests a more balanced diet and potentially greater food security.

Conversely, the concentration of households in Foutrigui around average and low scores indicates greater nutritional vulnerability.

The Food Consumption Score (FCS) is an indicator developed by the World Food Programme to assess the frequency of consumption of different food groups, weighted according to their nutritional value. A high score generally indicates better food security and a more balanced diet (Figure 5).

Figure 5. The State of Dietary Diversity According to the Food Consumption Score at the Two Sites



This figure shows that, in Baskoudre, households have relatively high food consumption scores. The majority of households (60%) have an FCS between 70 and 79, whilst 25% are between 80 and 84 and 15% between 85 and 97. The absence of low scores indicates that households have a diverse diet and regularly consume energy- and nutrient-rich foods. The very high scores observed indicate good food availability as well as relatively satisfactory access to a variety of food products such as cereals, pulses, vegetables, oils and animal products. This reflects a favourable food security situation in this locality.

In Foutrigui, the scores are significantly lower than in Baskoudre. Nearly 23% of households have an FCS score of between 32 and 33; 45% between 40 and 46, and 23% between 51 and 57. Although some households achieve moderate scores, no household has scores as high as those observed in Baskoudre. The relatively low FCS values reflect a less varied diet and, for certain food groups with high nutritional value, probably less frequent consumption. This situation may be linked to low food availability, limited incomes or a lack of diversification in agricultural production systems.

The Effect of Diversification on Household Food Security at the Two Sites

The effect of diversification on food security was assessed using the Food Consumption Score (FCS) and the Individual Dietary Diversity Score. The results show that agricultural diversification (SDI) appears to be a relatively robust and positive determinant of the FCS in both areas, confirming its central role in improving food security. In contrast, the effects of SCD are more ambiguous and vary according to context (positive in Baskoudre, slightly negative in Foutrigui), suggesting that agricultural intensification does not produce the same effects everywhere (Figure 5).

Table 5. The Effect of Simply Crop Density and the Simpson Diversification Index (SDI) on FCS

Variables	Baskoudre			Foutrigui		
	Standardized Coefficients	t	Sig.	Standardized Coefficients	t	Sig.
	Beta			Beta		
Constant		2.071	0.042		4.076	0.000
Age	-0.54	-1.472	0.152	-0.036	-0.315	0.754
Household size (number of persons)	0.335	3.09	0.003	0.066	0.523	0.603
Education level	0.514	-2.727	0.007	-0.114	-0.970	0.335
Simply Crop Density (SCD)	0.364	1.381	0.017	-0.036	0.315	0.0454
Simpson Diversification Index (SDI)	0.407	-1.555	0.012	0.066	0.523	0.0403

From this table, it is clear that in the Baskoudre area, several variables have a statistically significant influence on the FCS. Household size is positively and significantly associated with the FCS ($\beta = 0.335$; $p = 0.003$), indicating that larger households tend to have a higher food consumption score, likely due to a larger workforce or income diversification strategies. Educational attainment also appears significant ($p = 0.007$), but the sign of the standardised coefficient (negative $t = -2.727$) suggests a negative relationship: paradoxically, higher educational attainment appears to be associated with a lower FCS, which could reflect migration of educated individuals or a mismatch between educational attainment and local agricultural employment opportunities. The Simply Crop Density (SCD) is significant and positive ($\beta = 0.364$; $p = 0.017$), indicating that crop intensification or density improves household food consumption. Similarly, the Simpson Diversification Index (SDI) is significant ($p = 0.012$) and appears to indicate an overall positive relationship with the FCS ($\beta = 0.407$), confirming that crop diversification contributes to improved food security. In contrast, age has no significant effect ($p = 0.152$), meaning that it is not a direct determinant of the FCS in this area.

In the Foutrigui area, the results are different and, overall, less pronounced. Age, household size and level of education are not statistically significant ($p > 0.05$), indicating that they do not provide a robust explanation for variations in the FCS in this locality. In contrast, the SCD is significant ($p = 0.0454$), but with a slightly negative coefficient, suggesting that an increase in crop density could be associated with a slight decrease in the FCS. This result may reflect constraints on intensification (soil depletion, land pressure or high production costs). The SDI is also significant ($p = 0.0403$) and positive, indicating that crop diversification improves household food consumption, likely by reducing the risks associated with dependence on a single crop.

The Simpson Diversification Index (SDI) is the most stable and significant determinant of the Individual Dietary Diversity Score (IDDS) in both regions, highlighting the central role of agricultural diversification in improving diet quality (table 6).

In the Baskoudre area, the results indicate that age has no significant effect on the IDDS ($p = 0.518$), meaning that dietary diversity does not vary according to individuals' life stages. Household size is positively associated with the IDDS and is marginally significant at the 10% threshold ($p = 0.085$), suggesting that larger households may have greater dietary diversity, likely due to a better distribution of productive activities and food sources. Educational attainment is significant ($p = 0.037$) and has a

significant positive effect, indicating that education improves dietary diversity, likely through better nutritional knowledge, better resource management and better access to markets.

Table 6. The Effect of Crop Density and the Simpson Diversification Index (SDI) on the IDDS

Variables	Baskoudre			Foutrigui		
	Standardized Coefficients	t	Sig.	Standardized Coefficients	t	Sig.
	Beta			Beta		
Constant		2.071	0.042			
Age	0.448	0.593	0.518	0.140	0.336	0.738
Household size (number of persons)	0.213	1.747	0.085	0.040	0.336	0.738
Education level	5.584	2.727	0.037	0.158	1.340	0.184
Simply Crop Density (SCD)	3.178	5.649	0.005	0.204	1.809	0.074
Simpson Diversification Index (SDI)	2.099	8.851	0.001	0.262	2.130	0.036

Agricultural variables play an even more decisive role. The Simply Crop Density (SCD) is highly significant ($p = 0.005$) and has a significant positive effect on the IDDS ($\beta = 3.178$; $t = 5.649$), suggesting that crop intensification contributes to improving individuals' dietary diversity. Similarly, the Simpson Diversification Index (SDI) is highly significant ($p = 0.001$) and strongly positive ($\beta = 2.099$; $t = 8.851$), confirming that the diversification of production systems is a major factor in improving dietary diversity in this area.

In the Foutrigui area, the effects are generally weaker. Age, household size and level of education are not statistically significant ($p > 0.05$), indicating that they do not robustly explain variations in the IDDS in this locality. The SCD is marginally significant ($p = 0.074$) and positively associated with the IDDS ($\beta = 0.204$), suggesting that agricultural intensification could slightly improve dietary diversity, likely through increased availability of food products. The SDI is significant ($p = 0.036$) and positively associated with the IDDS ($\beta = 0.262$), confirming that crop diversification also plays a positive role in improving dietary diversity in Foutrigui, although the effect is more moderate than in the Baskoudre area.

Socio-Demographic Characteristics of Producers in Multi-Cropping Systems

The socio-demographic differences observed between Baskoudré and Foutrigui reflect distinct socio-economic realities that may influence agricultural production systems, diversification capacities, and household food security in rural areas. Several authors have shown that the demographic and social characteristics of producers play a decisive role in the adoption of agricultural innovations, farm productivity, and the improvement of household food security (Ellis, 2000; Barrett et al., 2001; Anderson & Leiserson, 1980).

The predominance of women aged 35–45 in both localities confirms that agricultural activities rely mainly on women of economically active age. This situation is common in African agricultural systems, where adults constitute the primary agricultural labour force. According to Abdulai and

CroleRees (2001), experience accumulated with age generally enhances farm management capacity and production-related decision-making. Similarly, Doss (2001) emphasizes that adult women play a central role in family farming systems in Sub-Saharan Africa, particularly in the production of food and vegetable crops.

The relatively higher proportion of young female producers in Baskoudré may constitute a favourable factor for agricultural innovation and crop diversification. Feder et al. (1985) show that younger farmers tend to adopt technical innovations more rapidly due to their greater openness to change and stronger willingness to take risks. Rogers (2003) likewise confirms that age significantly influences the diffusion and adoption of agricultural innovations. Consequently, the substantial proportion of young women in Baskoudré may facilitate the introduction of new farming practices, the diversification of production systems, and improvements in agricultural income.

Educational attainment represents one of the major differences between the two sites. The results reveal a very high proportion of women without formal education in Foutrigui, whereas Baskoudré exhibits comparatively higher educational levels. This finding is particularly important when analysing agricultural and food-related performance. Schultz (1964) considers education an investment in human capital that enhances farmers' productive capacities. According to Asfaw and Admassie (2004), educated producers are more likely to adopt agricultural innovations, access extension services more effectively, and utilize productive resources more efficiently.

The low level of education observed in Foutrigui may therefore limit women producers' access to modern agricultural technologies, technical training, and market information. In many African countries, rural illiteracy remains a major obstacle to agricultural development and improvements in food security (FAO, 2011). Conversely, the relatively higher level of education in Baskoudré may promote better farm management, greater organizational capacity, and a faster adoption of crop diversification strategies.

Moreover, women's education plays a crucial role in household nutritional and dietary practices. According to Smith and Haddad (2000), women's education is one of the most important factors contributing to the reduction of malnutrition in developing countries. Gladwin et al. (2001) also show that educated women generally place greater emphasis on dietary diversification, nutritional hygiene, and household food resource management. Consequently, the educational differences observed between Baskoudré and Foutrigui may have significant implications for household food and nutritional security.

Differences in household size also reflect contrasting socio-economic contexts. Large households predominate in Foutrigui, whereas Baskoudré is characterized more by medium-sized households. According to Lipton (1983), large rural families often represent an economic strategy aimed at ensuring the availability of family labour for agricultural work. Pingali and Rosegrant (1995) likewise emphasize that, in traditional African farming systems, household size is an important determinant of labour availability.

However, large households may also exert considerable pressure on available food resources. Maxwell and Frankenberger (1992) explain that increasing household size raises food consumption requirements and may reduce per capita food availability when economic resources remain limited. Similarly, Hoddinott and Yohannes (2002) show that large households are often more vulnerable to food insecurity, particularly in rural areas characterized by limited income diversification.

In the context of Foutrigui, the high proportion of households comprising seven to eight members may therefore exacerbate difficulties in accessing sufficient and diversified food. According to Sen (1981), food security depends not only on food availability but also on households' economic capacity to access these resources on a sustainable basis. Consequently, large households with limited agricultural incomes may be more exposed to food vulnerability.

The socio-demographic differences observed between the two sites may also influence agricultural diversification capacities. Barrett et al. (2001) indicate that households possessing stronger human capital—particularly in terms of education and experience—are generally better able to diversify their agricultural activities and income sources. Ellis (2000) similarly emphasizes that diversification constitutes an essential strategy for reducing economic and climatic risks among rural African households.

Status of Diversification in Multi-Cropping Systems

The results obtained from the Simple Crop Density (SCD) and the Simpson Diversification Index (SDI) clearly highlight substantial differences in the level of agricultural diversification between Baskoudré and Foutrigui. This heterogeneity confirms that rural agricultural systems can vary considerably depending on local socio-economic and institutional contexts, as emphasized by Chambers and Conway (1992) and Scoones (1998), who identify diversification as a key pillar of sustainable livelihoods.

The relatively high level of diversification observed in Baskoudré reflects a stronger integration of multiple agricultural enterprises within production systems. According to Barrett and Swallow (2006), agricultural diversification constitutes an essential rural risk-management strategy, enabling households to reduce their exposure to climatic and economic shocks. Furthermore, Birthal et al. (2007) demonstrate that crop diversification contributes to stabilizing farm incomes and improving household food security.

The situation observed in Baskoudré may also be interpreted as the outcome of greater adaptive capacity among producers. Dercon (2002) argues that households with greater flexibility in production choices are better able to cope with environmental uncertainties. Similarly, Ellis and Freeman (2004) note that agricultural diversification is often associated with more dynamic rural systems that are better integrated into markets.

Conversely, the strong concentration of low SCD and SDI values in Foutrigui indicates a high degree of agricultural specialization. This situation may reflect a heavy dependence on a limited

number of crops, thereby increasing household vulnerability. According to Barrett (2008), poorly diversified agricultural systems are particularly exposed to the risk of chronic poverty because of their limited capacity to adapt to external shocks. Likewise, Dorward et al. (2009) explain that agricultural specialization in low-productivity contexts may restrict opportunities for income growth and reinforce food insecurity. From this perspective, Foutrigui appears to represent an agricultural system in which structural constraints limit diversification, particularly with regard to access to productive resources and market opportunities.

Furthermore, Jayne et al. (2010) show that, in many rural African regions, low diversification is frequently associated with subsistence agriculture dominated by a small number of staple crops. This situation reduces households' capacity to absorb economic and food-related shocks, especially when agricultural yields are unstable.

The differences observed between the two sites may also be analysed from the perspective of institutional and economic constraints. Barrett et al. (2010) argue that agricultural diversification depends strongly on access to rural infrastructure, markets, and extension services. Consequently, areas that are better integrated into markets tend to develop more diversified and profitable agricultural systems.

From this perspective, Baskoudré appears to benefit from more favourable conditions for diversification, which may strengthen household resilience. Hazell and Wood (2008) emphasize that agricultural diversification is a key factor in reducing vulnerability in rural areas exposed to climatic shocks. In addition, Klasen and Waibel (2013) demonstrate that diversification of production systems is closely associated with reduced food security risks, particularly among vulnerable farming households. Thus, the high SCD and SDI values observed in Baskoudré may be linked to greater economic and food security.

In contrast, the low level of diversification observed in Foutrigui may be interpreted as a constrained rather than a voluntary strategy. According to Fafchamps (1992), rural households often adopt poorly diversified agricultural systems when faced with constraints related to capital, labour, or market access. Such conditions limit their capacity to invest in multiple crops and expand their income sources. Finally, Barrett et al. (2008) indicate that diversification is an important determinant of food security and rural well-being. Households that diversify their production systems and economic activities more extensively are generally better protected during periods of crisis.

Status of Food Security in Multi-Cropping Systems

The results derived from the Individual Dietary Diversity Score (IDDS) and the Food Consumption Score (FCS) reveal significant disparities in food security between Baskoudré and Foutrigui. Overall, Baskoudré exhibits a more favourable food security situation than Foutrigui, reflecting differences in food access, availability, and dietary diversification. These findings are consistent with studies

emphasizing that dietary diversity is a key indicator of the nutritional quality of rural households (Ruel, 2003b; Swindale & Bilinsky, 2006).

Regarding the IDDS, the results indicate higher dietary diversity in Baskoudré, with a substantial proportion of households achieving high scores (6–8 food groups). According to Kennedy et al. (2007), high dietary diversity is strongly associated with better nutritional adequacy, particularly with respect to micronutrient intake. Similarly, Arimond and Ruel (2004) demonstrate that an increase in the number of food groups consumed serves as a reliable proxy for the overall quality of household diets. The prevalence of high scores in Baskoudré may also reflect better economic and physical access to a wider variety of foods. Hoddinott and Yohannes (2002) note that households with more diversified diets generally have better access to food markets and more diversified income sources. Furthermore, Kremen and Miles (2012), and Fanzo et al. (2013) indicate that dietary diversification is often associated with increased consumption of vegetables and animal-source foods, both of which are essential for nutritional security.

In contrast, the situation observed in Foutrigui, characterized by the absence of high IDDS scores, reflects a less diversified and potentially less balanced diet. According to the Food and Agriculture Organization (FAO, 2013), low dietary diversity is strongly associated with a higher risk of nutritional deficiencies, particularly in essential vitamins and minerals. In this context, the concentration of households within the medium and low score categories indicates greater nutritional vulnerability.

The results of the Food Consumption Score (FCS) confirm this pattern. In Baskoudré, the high scores observed reflect more frequent and diversified food consumption. According to Wiesmann et al. (2009), the FCS is a robust indicator for assessing food security because it incorporates both consumption frequency and nutritional quality. The authors demonstrate that high scores are generally associated with acceptable or good levels of food security. Furthermore, Maxwell and Coates (2012) emphasize that households with high FCS values often combine diversified agricultural production with regular access to markets. This situation appears consistent with that of Baskoudré, where diversified farming systems may contribute to improved food availability and more balanced consumption across food groups.

In Foutrigui, low FCS values reflect a more concerning situation. According to Ballard et al. (2011), low or borderline FCS values generally indicate insufficient or poorly diversified food consumption, often linked to economic constraints. Similarly, Webb et al. (2006) show that food-insecure households tend to reduce the consumption frequency of protein-rich and micronutrient-dense foods, thereby negatively affecting overall dietary quality.

The differences observed between the two sites can also be interpreted in light of the work of Smith and Subandoro (2007), who highlight that food security depends strongly on the interaction between agricultural production, household income, and market access. Consequently, Baskoudré appears to benefit from more favourable conditions that support greater food stability. Furthermore, Frempong and Annim (2017) demonstrate that household dietary diversity is closely associated with agricultural diversification. Households that cultivate a wider range of crops are more likely to consume more

diversified diets. This relationship helps explain the better IDDS and FCS outcomes observed in Baskoudré.

From a broader perspective, Barrett (2010) emphasizes that food security depends not only on food production but also on households' economic capacity to access food. Therefore, the low scores observed in Foutrigui may reflect structural constraints related to income limitations, insufficient agricultural production, or weak market integration. Finally, Pinstrup-Andersen (2009) stresses that improvements in food security require an integrated approach combining agricultural diversification, income enhancement, and access to basic services.

In this context, the results suggest that Baskoudré is closer to a resilient food system, whereas Foutrigui remains more vulnerable to food insecurity risks. Overall, the analysis of IDDS and FCS clearly demonstrates that Baskoudré exhibits better food security outcomes than Foutrigui, characterized by more diversified, more frequent, and higher-quality food consumption. These findings confirm the importance of agricultural and economic diversification as major determinants of food security in rural areas.

Effect of Diversification on Household Food Security in the Two Study Sites

The results of the econometric models indicate that agricultural diversification, measured through the Simpson Diversification Index (SDI) and the Simple Crop Density (SCD), generally exerts a positive influence on household food security, assessed using the Food Consumption Score (FCS) and the Individual Dietary Diversity Score (IDDS). However, the magnitude—and in some cases the direction—of these effects varies across local contexts, confirming that the relationship between diversification and food security is highly dependent on socio-economic and agroecological conditions. These findings are consistent with the analyses of Reardon and Barrett (2000), Ellis (2000), and Reardon et al. (2007), who emphasize that diversification constitutes a central, yet context-specific, strategy for enhancing rural resilience.

Effect on the Food Consumption Score (FCS)

In Baskoudré, several variables significantly influence the FCS. Household size is positively associated with food security, which may be explained by better utilization of family labour and diversification of economic activities. This result is consistent with the work of Chayanov (1966) and De Haan (1999), who show that family structure strongly influences rural household production and consumption strategies. However, Fafchamps (1992) nuances this relationship by highlighting that large households may also be more vulnerable in contexts of low agricultural productivity.

The positive role of SCD and SDI in Baskoudré confirms that crop intensification and diversification improve food consumption outcomes. These findings are consistent with the conclusions of Mariyono (2019), Hazell and Haddad (2001), and Lin (2011), who demonstrate that agricultural diversification

enhances food system stability and reduces vulnerability to climatic and economic shocks. Similarly, Fan and Brzeska (2016) note that agricultural diversification improves overall productivity and rural household incomes.

However, the negative effect of education level on FCS in Baskoudré may appear counterintuitive. This result can be interpreted in light of Collier (1998) and Lucas (2005), who show that education may facilitate rural–urban migration, thereby reducing direct engagement in local agricultural production. In addition, Barrett (2008) and Davis and Bezemer (2004) indicate that more educated households tend to diversify their income sources outside agriculture, which may alter local food consumption patterns.

In Foutrigui, the results are generally less pronounced. The lack of significance of socio-economic variables (age, education, household size) suggests that structural constraints dominate food consumption dynamics. This finding is consistent with the analyses of Dercon (2002) and Carter and Barrett (2006), who show that in contexts of chronic poverty, individual-level factors play a limited role compared to resource constraints. SCD shows a negative effect on FCS in Foutrigui, which may reflect unsustainable intensification practices. According to Tilman et al. (2002) and Matson et al. (1997), poorly managed agricultural intensification can lead to soil degradation and declining productivity, thereby negatively affecting food security. In contrast, SDI remains positive and significant, confirming its stabilizing role, as also demonstrated by Smith and Frankenberger (1994).

Effect on the Individual Dietary Diversity Score (IDDS)

The results show that SDI is the most stable and important determinant of IDDS in both study areas. This confirms that agricultural diversification directly improves diet quality. This finding is consistent with the work of Kennedy et al. (2009), Arimond and Ruel (2006), and Lachat et al. (2018), who establish a strong relationship between production diversity and dietary diversity.

In Baskoudré, both SCD and SDI have strongly positive effects on IDDS. These results are consistent with the findings of Jones et al. (2014), Herforth (2010), and Ahamed et al. (2024), who show that agricultural diversification is a key determinant of dietary diversity and household nutritional quality. Furthermore, Ruel and Alderman (2013) emphasize that diversified agricultural systems are strongly associated with improved micronutrient intake. The positive role of education on IDDS in Baskoudré is also consistent with the work of Glewwe (1999) and Thomas and Strauss (1997), who demonstrate that women's education significantly improves household nutrition, particularly through better food allocation decisions and improved knowledge of nutritional needs.

In Foutrigui, the effects are weaker but remain positive for SDI. This result aligns with the analyses of Sibhatu and Qaim (2018), who show that even in constrained contexts, agricultural diversification improves dietary diversity, although its effect is limited by economic constraints. The weak effects of socio-economic variables in Foutrigui may be explained by structural constraints in the local agricultural system. According to Dorward et al. (2005) and Jayne and Rashid (2013), low-productivity

rural areas are characterized by food security determinants dominated by limited access to inputs, markets, and infrastructure.

CONCLUSIONS

This study examined the relationship between agricultural diversification and household food security in two contrasting rural contexts, Baskoudré and Foutrigui, using the Food Consumption Score (FCS) and the Individual Dietary Diversity Score (IDDS) as indicators of food security outcomes. The findings demonstrate that agricultural diversification, measured through the Simpson Diversification Index (SDI) and the Simple Crop Density (SCD) index, is generally associated with improved food security. However, the magnitude and consistency of these effects vary substantially across local contexts.

The results indicate that diversification contributes more strongly to improved food consumption and dietary diversity in Baskoudré, where households appear better able to translate agricultural diversity into nutritional gains. In contrast, the weaker and sometimes mixed effects observed in Foutrigui suggest that diversification alone is insufficient to enhance food security when structural constraints such as limited market access, restricted productive assets, and less favourable production conditions persist. These findings therefore reinforce the argument that the benefits of diversification are highly context-dependent and mediated by broader socio-economic and institutional environments.

From a broader perspective, this study contributes to ongoing debates on rural resilience and sustainable food systems in sub-Saharan Africa by showing that diversification should not be viewed merely as an agricultural strategy but as part of a wider territorial and livelihood system. Its effectiveness depends on complementary investments in infrastructure, market integration, extension services, and human capital development. Policies promoting crop diversification are therefore likely to generate greater food security benefits when combined with interventions that address local barriers to production, commercialization, and access to resources.

Several limitations should be acknowledged. The cross-sectional nature of the data constrains the ability to establish causal relationships and to capture long-term dynamics between diversification and food security. In addition, food security was assessed through consumption-based indicators, which, while widely used, may not fully reflect seasonal variations and other dimensions of food security. Future research could employ longitudinal data and mixed-method approaches to better understand how diversification strategies evolve over time and interact with climatic, economic, and institutional changes.

Overall, the study highlights the central but conditional role of agricultural diversification in strengthening household food security. Rather than a universal pathway to resilience, diversification emerges as a context-specific strategy whose success depends on the broader enabling environment in which rural households operate. Strengthening this environment is therefore essential for transforming agricultural diversity into sustainable food and nutrition security outcomes.

Declarations

Funding

This research and the preparation of the manuscript received no specific external funding.

Competing interests

The authors declare that there are no financial or non-financial competing interests relevant to the content of this article.

Author contributions

Conceptualization: [O.A.; Methodology: [O.A.; R.S; Y.J]; Data curation: [Z.M]; Formal analysis: [Y.J]; Investigation: [Z.M]; Visualization: [Y.J]; Writing – original draft: [O.A]; Writing – review & editing: [O.A.; R.S; Y.J]. All authors have read and approved the final version of the manuscript.

Data availability

The data are available from the corresponding author upon reasonable request.

Ethical approval

Not applicable: this study did not involve human participants, animal experiments, or sensitive personal data requiring ethical approval.

Informed consent

Not applicable.

Use of AI tools

The author(s) used Claude to translate the full text of the manuscript from French into English. The translation was checked and corrected by the author(s). The author(s) used Deepl solely for language and style editing. All suggested changes were reviewed individually.

Publisher/editorial disclaimer

The statements and opinions expressed in this article are solely those of the author(s) and do not necessarily reflect the official position of the publisher or the editorial board.

REFERENCES

- Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics*, 90(1), 26–43.
- Addai, K. N., Ng'ombe, J. N., & Temoso, O. (2024). Average and heterogeneous effects of smallholder farm sizes on dietary diversity in northern Ghana. *Review of Development Economics*, 28(2), 697–718. <https://doi.org/10.1111/rode.13076>
- Abdulai, A., & CroleRees, A. (2001). Determinants of income diversification amongst rural households in southern Mali. *Food Policy*, 26(4), 437–452. [https://doi.org/10.1016/S0306-9192\(01\)00013-6](https://doi.org/10.1016/S0306-9192(01)00013-6)
- Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, 16(3), 268–281. <https://doi.org/10.1016/j.gloenvcha.2006.02.006>
- Ahamed, J. U., Marium, B., Begum, I. A., Ding, S., Ahmed, T., Molla, M. M. U., & Alam, M. J. (2024). Impact of agricultural intervention on income and employment in hoar wetland areas of Bangladesh. *Urban Agriculture & Regional Food Systems*, 9(1), e70001. <https://doi.org/10.1002/uar2.70001>
- Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment*, 74(1–3), 19–31. [https://doi.org/10.1016/S0167-8809\(99\)00028-6](https://doi.org/10.1016/S0167-8809(99)00028-6)

- Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, 140(1), 33–45. <https://doi.org/10.1007/s10584-013-0909-y>
- Anderson, D., & Leiserson, M. W. (1980). Rural nonfarm employment in developing countries. *Economic Development and Cultural Change*, 28(2), 227–248. <https://doi.org/10.1086/451162>
- Arimond, M., & Ruel, M. T. (2004). Dietary diversity is associated with child nutritional status: Evidence from 11 demographic and health surveys. *The Journal of Nutrition*, 134(10), 2579–2585. <https://doi.org/10.1093/jn/134.10.2579>
- Asfaw, A., & Admassie, A. (2004). The role of education on the adoption of chemical fertilizer under different socioeconomic environments in Ethiopia. *Agricultural Economics*, 30(3), 215–228. <https://doi.org/10.1111/j.1574-0862.2004.tb00190.x>
- Ayantunde, A. A., De Leeuw, J., Turner, M. D., & Said, M. (2011). Challenges of assessing the sustainability of (agro)-pastoral systems. *Livestock Science*, 139(1–2), 30–43. <https://doi.org/10.1016/j.livsci.2011.03.019>
- Ballard, T., Coates, J., Swindale, A., & Deitchler, M. (2011). *Household dietary diversity score (HDDS) for measurement of household food access: Indicator guide*. FANTA/USAID.
- Barrett, C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy*, 33(4), 299–317. <https://doi.org/10.1016/j.foodpol.2007.10.005>
- Barrett, C. B. (2010). Measuring food insecurity. *Science*, 327(5967), 825–828. <https://doi.org/10.1126/science.1182768>
- Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Policy*, 26(4), 315–331. [https://doi.org/10.1016/S0306-9192\(01\)00014-8](https://doi.org/10.1016/S0306-9192(01)00014-8)
- Barrett, C. B., & Swallow, B. M. (2006). Fractal poverty traps. *World Development*, 34(1), 1–15. <https://doi.org/10.1016/j.worlddev.2005.06.008>
- Bellon, M. R., Ntandou-Bouzitou, G. D., & Caracciolo, F. (2016). On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in southern Benin, West Africa. *PLoS ONE*, 11(9), e0162535. <https://doi.org/10.1371/journal.pone.0162535>
- Beillouin, D., Ben-Ari, T., & Makowski, D. (2019). Evidence map of crop diversification strategies at the global scale. *Environmental Research Letters*, 14(12), 123001.
- Benjaminsen, T. A., Alinon, K., Buhaug, H., & Buseeth, J. T. (2012). Does climate change drive land-use conflicts in the Sahel? *Journal of Peace Research*, 49(1), 97–111. <https://doi.org/10.1177/0022343311427343>
- Biasutti, M. (2019). Rainfall trends in the African Sahel: Characteristics, processes, and causes. *WIREs Climate Change*, 10(4), e591. <https://doi.org/10.1002/wcc.591>
- Birthal, P. S., Joshi, P. K., & Gulati, A. (2007). *Vertical coordination in high-value commodities: Implications for smallholders* (MTID Discussion Paper No. 85). International Food Policy Research Institute.

- Carter, M. R., & Barrett, C. B. (2006). The economics of poverty traps. *Journal of Development Studies*, 42(2), 178–199. <https://doi.org/10.1080/00220380500405261>
- Chambers, R., & Conway, G. R. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century* (IDS Discussion Paper No. 296). Institute of Development Studies.
- Chayanov, A. V. (1966). *The theory of peasant economy*. University of Wisconsin Press.
- Chegere, M. J., & Stage, J. (2020). Agricultural production diversity, dietary diversity and nutritional status: Panel data evidence from Tanzania. *World Development*, 129, 104856.
- Collier, P. (1998). *Social capital and poverty* (World Bank Social Capital Initiative Working Paper). World Bank.
- Darnhofer, I. (2014). Resilience and why it matters for farm management. *European Review of Agricultural Economics*, 41(3), 461–484.
- Davis, J. R., & Bezemer, D. (2004). *The development of the rural non-farm economy in developing countries* (ODI Natural Resource Perspectives). Overseas Development Institute.
- De Haan, A. (1999). Livelihoods and poverty: The role of migration. *The Journal of Development Studies*, 30(2), 1–12.
- Denning, G. (2025). Sustainable intensification of agriculture: The foundation for universal food security. *npj Sustainable Agriculture*, 3(1), 7.
- Dercon, S. (2002). Income risk, coping strategies, and safety nets. *The World Bank Research Observer*, 17(2), 141–166. <https://doi.org/10.1093/wbro/17.2.141>
- DFID. (1999). *Sustainable livelihoods guidance sheets*. Department for International Development.
- Dorward, A., Anderson, S., Bernal, Y. N., Vera, E. S., Rushton, J., Pattison, J., & Paz, R. (2009). Hanging in, stepping up and stepping out: Livelihood aspirations and strategies of the poor. *Development in Practice*, 19(2), 240–247. <https://doi.org/10.1111/j.1467-7679.2009.00419.x>
- Doss, C. R. (2001). Designing agricultural technology for African women farmers: Lessons from 25 years of experience. *World Development*, 29(12), 2075–2092. [https://doi.org/10.1016/S0305-750X\(01\)00088-2](https://doi.org/10.1016/S0305-750X(01)00088-2)
- Ellis, F. (1998). Household strategies and rural livelihood diversification. *The Journal of Development Studies*, 35(1), 1–38. <https://doi.org/10.1080/00220389808422553>
- Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press.
- Ellis, F., & Freeman, H. A. (2004). Rural livelihoods and poverty reduction strategies in Africa. *Journal of Development Studies*, 40(5), 1–30.
- Fafchamps, M. (1992). Cash crop production, food price volatility, and rural market integration in developing countries. *American Journal of Agricultural Economics*, 74(1), 90–99. <https://doi.org/10.2307/1242943>
- Fan, S., & Brzeska, J. (2016). Sustainable food security and nutrition: Demystifying conventional beliefs. *Global Food Security*, 11, 11–16.

- Fanzo, J., Hunter, D., Borelli, T., & Mattei, F. (2013). *Diversifying food and diets: Using agricultural biodiversity to improve nutrition and health*. Routledge.
- Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, 33(2), 255–298. <https://doi.org/10.1086/451461>
- FEWS NET. (2023). *Crop prospects for 2023 and 2024 are average except for declines in the Sahel*.
- Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3), 253–267. <https://doi.org/10.1016/j.gloenvcha.2006.04.002>
- Folke, C., Carpenter, S., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society*, 15(4). <https://doi.org/10.5751/ES-03610-150420>
- Folke, C., Biggs, R., Norström, A. V., Reyers, B., & Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and society*, 21(3). <https://doi.org/10.5751/ES-08748-210341>
- Food and Agriculture Organization. (2011). *The state of food and agriculture: Women in agriculture – Closing the gender gap for development*. FAO.
- Food and Agriculture Organization. (2013). *The state of food insecurity in the world 2013: The multiple dimensions of food security*. FAO.
- Food and Agriculture Organization of the United Nations. (2024). *The state of food security and nutrition in the world 2024*. FAO.
- Food and Agriculture Organization. (2018). *The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition*. FAO.
- Food and Nutrition Technical Assistance (FANTA). (2006). *Household dietary diversity score (HDDS) for measurement of household food access: Indicator guide*. Academy for Educational Development.
- Fraval, S., Hammond, J., Wichern, J., Oosting, S. J., de Boer, I. J. M., & Teufel, N. (2020). Making the most of imperfect data: A critical evaluation of standard information collected in farm household surveys. *Experimental Agriculture*, 55(2), 230–250. <https://doi.org/10.1017/S0014479718000388>
- Frempong, R. B., & Annim, S. K. (2017). Dietary diversity and child malnutrition in Ghana. *Heliyon*, 3(5), e00297.
- Frison, E. A., Smith, I. F., Johns, T., Cherfas, J., & Eyzaguirre, P. B. (2011). Agricultural biodiversity, nutrition, and health: Making a difference to hunger and nutrition in the developing world. *Food and Nutrition Bulletin*, 27(2), 167–179.
- Gladwin, C. H., Thomson, A. M., Peterson, J. S., & Anderson, A. S. (2001). Addressing food security in Africa via multiple livelihood strategies of women farmers. *Food Policy*, 26(2), 177–207. [https://doi.org/10.1016/S0306-9192\(00\)00043-8](https://doi.org/10.1016/S0306-9192(00)00043-8)

- Glewwe, P. (1999). Why does mother's schooling raise child health in developing countries? Evidence from Morocco. *Journal of Human Resources*, 34(1), 124–159. <https://doi.org/10.2307/146305>
- Gliessman, S. R. (2007). *Agroecology: The ecology of sustainable food systems* (2nd ed.). CRC Press.
- Gliessman, S. R. (2015). *Agroecology: The ecology of sustainable food systems* (3rd ed.). CRC Press. <https://doi.org/10.1201/b17881>
- Gautier, D., Denis, D., & Locatelli, B. (2016). Impacts of drought and responses of rural populations in West Africa: a systematic review. *Wiley Interdisciplinary Reviews: Climate Change*, 7(5), 666–681.
- Greene, W. H. (2012). *Econometric analysis* (7th ed.). Pearson Education.
- Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill/Irwin.
- Gunderson, L. H., & Holling, C. S. (2002). *Panarchy: Understanding transformations in human and natural systems*. Island Press. <https://doi.org/10.5822/978-1-61091-313-8>
- Hazell, P. (2009). *The Asian Green Revolution* (IFPRI Discussion Paper). International Food Policy Research Institute.
- Hazell, P., & Haddad, L. (2001). Agricultural research and poverty reduction. *Food Policy*, 26(5), 499–517.
- Hazell, P., & Wood, S. (2008). Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society B*, 363(1491), 495–515. <https://doi.org/10.1098/rstb.2007.2166>
- Hoddinott, J., & Yohannes, Y. (2002). *Dietary diversity as a food security indicator* (FCND Discussion Paper No. 136). International Food Policy Research Institute.
- Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4, 1–23. <https://doi.org/10.1146/annurev.es.04.110173.000245>
- Homer-Dixon, T. F. (1999). *Environment, scarcity, and violence*. Princeton University Press.
- Imai, K. S., Gaiha, R., & Thapa, G. (2010). Does agricultural diversification reduce poverty in rural India? *Journal of Development Studies*, 46(7), 1188–1208.
- Institut National de la Statistique et de la Démographie. (2020). *Annuaire statistique 2020 du Burkina Faso*. INSD.
- Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press. <https://doi.org/10.1017/9781009325844>
- Intergovernmental Panel on Climate Change. (2022). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. <https://doi.org/10.1017/9781009325844>
- IPCC. (2021). *Climate change 2021: The physical science basis*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>

- Islam, M. S., Jahan, H., Ema, N. S., & Ahmed, M. R. (2024). Determinants of crop diversification and its impact on farmers' income: A case study in Rangpur District, Bangladesh. *JSFA Reports*, 4(10), 352–361. <https://doi.org/10.1002/jsf2.216>
- Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in Sub-Saharan Africa. *Agricultural Economics*, 44(6), 1–15. <https://doi.org/10.1111/agec.12073>
- Jayne, T. S., Chamberlin, J., & Benfica, R. (2014). Africa's unfolding agricultural transformation. *Annual Review of Resource Economics*, 6, 255–282. <https://doi.org/10.1146/annurev-resource-100913-012706>
- Jayne, T. S., Chamberlin, J., & Headey, D. (2010). Land pressures, the evolution of farming systems, and development strategies in Africa. *Food Policy*, 35(2), 120–131. <https://doi.org/10.1016/j.foodpol.2009.10.003>
- Jones, A. D., Ngure, F. M., Pelto, G., & Young, S. L. (2013). What Are We Assessing When We Measure Food Security? A Compendium and Review of Current Metrics. *Advances in Nutrition*, 4(5), 481–505. <https://doi.org/10.3945/an.113.004119>
- Jones, A. D., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi. *Food Policy*, 46, 1–12. <https://doi.org/10.1016/j.foodpol.2014.02.001>
- Joshi, P. K., Bithal, P. S., & Minot, N. (2006). Sources of agricultural growth in India: Role of diversification. *Agricultural Economics Research Review*, 19(2), 151–165.
- Joshi, P. K., Gulati, A., & Cummings, R. W. (2004). *Agricultural diversification in South Asia: Beyond food grains*. Oxford University Press.
- Kennedy, G., Ballard, T., & Dop, M. C. (2010). *Guidelines for measuring household and individual dietary diversity*. Food and Agriculture Organization.
- Kerr, R. B., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., Parros, P., Mutyambai, D. M., Prudhon, M., & Wezel, A. (2021). Can agroecology improve food security and nutrition? A review. *Global Food Security*, 29, 100540. <https://doi.org/10.1016/j.gfs.2021.100540>
- Khatun, D., & Roy, B. C. (2012). Rural livelihood diversification in West Bengal: Determinants and constraints. *Journal of Economic and Social Development*, 8(1), 58–68.
- Klasen, S., & Waibel, H. (2013). *Vulnerability to poverty: Theory, measurement and determinants*. Palgrave Macmillan.
- Kremen, C., & Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: Benefits, externalities, and trade-offs. *Ecology and Society*, 17(4), 40. <https://doi.org/10.5751/ES-05035-170440>
- Koppmair, S., Kassie, M., & Qaim, M. (2017). Farm production, market access and dietary diversity in Malawi. *Public Health Nutrition*, 20(2), 325–335. <https://doi.org/10.1017/S1368980016002135>
- Kwawuvi, D., Mama, D., Agodzo, S. K., Bessah, E., Yangouliba, G. I., & Aklamati, W. S. (2023). Potential consequences for rising temperature trends in the Oti River Basin, West Africa. *Frontiers in Climate*, 5, 1184050.

- Lachat, C., Raneri, J. E., Smith, K. W., et al. (2018). Dietary species richness as a measure of food biodiversity. *Proceedings of the National Academy of Sciences*, 115(1), 127–132. <https://doi.org/10.1073/pnas.1709194115>
- Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience*, 61(3), 183–193. <https://doi.org/10.1525/bio.2011.61.3.4>
- Lipton, M. (1983). *Poverty, undernutrition, and hunger* (World Bank Staff Working Papers). World Bank.
- Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production. *Science*, 333(6042), 616–620. <https://doi.org/10.1126/science.1204531>
- Lucas, R. E. (2006). Migration and economic development in Africa: A review of evidence. *Journal of African Economies*, 15(suppl_2), 337–395.
- Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Publishing.
- Mariyono, J. (2019). Stepping up from subsistence to commercial intensive farming to enhance welfare of farmer households in Indonesia. *Asia & the Pacific Policy Studies*, 6(2), 246–265.
- Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.1111/j.1540-6261.1952.tb01525.x>
- Martin, G., Magne, M. A., Cristobal, M. S., & Bamière, L. (2019). Diversification and resilience in agricultural systems: A review. *Agronomy for Sustainable Development*, 39(2), Article 20. <https://doi.org/10.1007/s13593-019-0578-6>
- Matson, P. A., Parton, W. J., Power, A. G., & Swift, M. J. (1997). Agricultural intensification and ecosystem properties. *Science*, 277(5325), 504–509.
- Maxwell, D., & Caldwell, R. (2008). *The coping strategies index: Field methods manual* (2nd ed.). CARE and World Food Programme.
- Maxwell, D., & Coates, J. (2012). *How do indicators of household food security measure up?* Feinstein International Center, Tufts University.
- Maxwell, S., & Frankenberger, T. R. (1992). *Household food security: Concepts, indicators, measurements*. UNICEF/IFAD.
- Morduch, J. (1995). Income Smoothing and Consumption Smoothing. *Journal of Economic Perspectives*, 9(3), 103–114
- Mortimore, M. (1989). *Adapting to drought: Farmers, famines and desertification in West Africa*. Cambridge University Press.
- Moscardi, E., & de Janvry, A. (1977). Attitudes toward risk among peasants. *American Journal of Agricultural Economics*, 59(4), 710–716. <https://doi.org/10.2307/1239398>
- Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M. G., Sapkota, T., Tubiello, F. N., & Xu, Y. (2023). Food systems

and climate resilience in Africa. In *Climate change adaptation and food security* (pp. 115–140). Springer.

- Nicholson, S. E. (2013). The West African Sahel: A review of recent studies on the rainfall regime and its interannual variability. *ISRN Meteorology*, 2013, 453521. <https://doi.org/10.1155/2013/453521>
- Nyamayevu, D., Nyagumbo, I., Li, R. Q., Liang, W. L., & Silva, J. V. (2025). Crop diversification as a pathway to achieve Sustainable Development Goals 1 (No Poverty) and 2 (Zero Hunger) among smallholder farms of Sub-Saharan Africa: A structured narrative review. *Sustainable Development*.
- Ogunbode, T. O., Afolabi, C. O., Opabunmi, B. A., & Adekiya, A. O. (2025). Climate dynamics in the tropical environment: distinguishing between change and variability. *Environmental Research Communications*, 7(12), 122002.
- Pingali, P. (2007). Agricultural growth and economic development: A view through the globalization lens. *Agricultural Economics*, 37(s1), 1–12. <https://doi.org/10.1111/j.1574-0862.2007.00231.x>
- Pingali, P. L., & Rosegrant, M. W. (1995). Agricultural commercialization and diversification: Processes and policies. *Food Policy*, 20(3), 171–185. [https://doi.org/10.1016/0306-9192\(95\)00012-4](https://doi.org/10.1016/0306-9192(95)00012-4)
- Pinstrup-Andersen, P. (2009). Food security: Definition and measurement. *Food Security*, 1(1), 5–7. <https://doi.org/10.1007/s12571-008-0002-y>
- Powell, B., Thilsted, S. H., Ickowitz, A., Termote, C., Sunderland, T., & Herforth, A. (2015). Improving diets with wild and cultivated biodiversity from across the landscape. *Food Security*, 7(3), 535–554. <https://doi.org/10.1007/s12571-015-0466-5>
- Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, 114(8), 1571–1596. <https://doi.org/10.1093/aob/mcu205>
- Reardon, T., & Barrett, C. B. (2000). Agroindustrialization, globalization and rural livelihoods. *Agricultural Economics*, 23(3), 195–205. <https://doi.org/10.1111/j.1574-0862.2000.tb00272.x>
- Reardon, T., Delgado, C., & Matlon, P. (1992). Determinants and effects of income diversification amongst farm households in Burkina Faso. *The Journal of Development Studies*, 28(2), 264–296. <https://doi.org/10.1080/00220389208422232>
- Reardon, T., Berdegue, J., Barrett, C. B., & Stamoulis, K. (2007). Household income diversification into rural nonfarm activities. In S. Haggblade, P. Hazell & T. Reardon (Eds.), *Transforming the rural nonfarm economy: opportunities and threats in the developing world* (pp. 115–140). Johns Hopkins University Press.
- Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- Renard, D., & Tilman, D. (2019). National food production stabilized by crop diversity. *Nature*, 571(7764), 257–260. <https://doi.org/10.1038/s41586-019-1316-y>

- Reckling, M., Watson, C. A., Whitbread, A., & Helming, K. (2023). Diversification for sustainable and resilient agricultural landscape systems: M. Reckling et al. *Agronomy for Sustainable Development*, 43(4), 44. <https://doi.org/10.1504/IJEPEE.2023.131060>
- Ruel, M. T. (2003a). Is dietary diversity an indicator of food security or dietary quality? *The Journal of Nutrition*, 133(11), 3911S–3917S. <https://doi.org/10.1093/jn/133.11.3911S>
- Ruel, M. T. (2003b). Operationalizing dietary diversity: A review of measurement issues and research priorities. *The Journal of Nutrition*, 133(11), 3911S–3926S. <https://doi.org/10.1093/jn/133.11.3911S>
- Ruel, M. T., & Alderman, H. (2013). Nutrition-sensitive interventions. *The Lancet*, 382(9890), 536–551. [https://doi.org/10.1016/S0140-6736\(13\)60843-0](https://doi.org/10.1016/S0140-6736(13)60843-0)
- Sanfo, Z. (2022). Analysis of the effect of crop diversification on food security in Burkina Faso. *African Scientific Journal*, 3(14), 583.
- Schultz, T. W. (1964). *Transforming traditional agriculture*. Yale University Press.
- Shiratori, S., Tobita, Y., Sawadogo-Compaoré, E. M. F. W., Koura, A. R., Kizuki, M., Kobayashi, J., & Hamajima, N. (2023). Food security, nutritional supply, and nutrient sources in rural Burkina Faso. *Nutrients*, 15(10), 2285. <https://doi.org/10.3390/nu15102285>
- Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper No. 72). Institute of Development Studies.
- Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation*. Oxford University Press.
- Shiyani, R. L., & Pandya, H. R. (1998). Diversification of agriculture in Gujarat: A spatio-temporal analysis. *Indian Journal of Agricultural Economics*, 53(4), 604–614.
- Sibhatu, K. T., & Qaim, M. (2018). Meta-analysis of the association between production diversity, diets, and nutrition in smallholder farm households. *Food Policy*, 77, 1–18. <https://doi.org/10.1016/j.foodpol.2018.04.013>
- Sibhatu, K. T., Krishna, V. V., & Qaim, M. (2015). Production diversity and dietary diversity in smallholder farm households. *Proceedings of the National Academy of Sciences*, 112(34), 10657–10662. <https://doi.org/10.1073/pnas.1510982112>
- Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163, 688. <https://doi.org/10.1038/163688a0>
- Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, 107(48), 20840–20845. <https://doi.org/10.1073/pnas.1007199107>
- Smith, L. C., & Frankenberger, T. R. (1994). *The impact of food aid*. IFPRI.
- Smith, L. C., & Haddad, L. (2000). *Explaining child malnutrition in developing countries* (IFPRI Research Report No. 111). International Food Policy Research Institute.
- Smith, L. C., & Subandoro, A. (2007). *Measuring food security using household expenditure surveys*. IFPRI.

- Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface*, 4(15), 707–719. <https://doi.org/10.1098/rsif.2007.0213>
- Sultan, B., & Gaetani, M. (2016). Agriculture in West Africa in the twenty-first century: Climate change and impacts scenarios, and potential for adaptation. *Frontiers in Plant Science*, 7, 1262. <https://doi.org/10.3389/fpls.2016.01262>
- Sultan, B., Defrance, D., & Iizumi, T. (2019). Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Scientific Reports*, 9, 12834. <https://doi.org/10.1038/s41598-019-49167-0>
- Sawadogo, S. (2023). Contribution of non-timber forest products to food security of households bordering the Pô-Nazinga-Sissili ecological complex in Burkina Faso. *International Journal of Economic Policy in Emerging Economies*, 17(3), 420–443. <https://doi.org/10.1504/IJEPEE.2023.131060>
- Sawadogo, N., & Sawadogo, S. (2025). Effect of crop diversification on the rural household's food security in a context of security crisis: The role of gender. *Agricultural Economics Review*, 26(1), 12–27.
- Swindale, A., & Bilinsky, P. (2006). Development of a universally applicable household food insecurity measurement tool: Process, current status, and outstanding issues. *The Journal of Nutrition*, 136(5), 1449S–1452S. <https://doi.org/10.1093/jn/136.5.1449S>
- Tamburini, G., Bommarco, R., Wanger, T. C., Kremen, C., Van der Heijden, M. G. A., Liebman, M., & Hallin, S. (2020). Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science Advances*, 6(45), eaba1715. <https://doi.org/10.1126/sciadv.aba1715>
- Thrupp, L. A. (2000). Linking agricultural biodiversity and food security: The valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, 76(2), 265–281. <https://doi.org/10.1111/1468-2346.00133>
- Thomas, D., & Strauss, J. (1997). Health and wages: Evidence on women. *Journal of Econometrics*, 77(1), 1–22. [https://doi.org/10.1016/S0304-4076\(96\)01811-8](https://doi.org/10.1016/S0304-4076(96)01811-8)
- Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability. *Nature*, 418(6898), 671–677. <https://doi.org/10.1038/nature01014>
- Tittonell, P. (2014). Ecological intensification of agriculture. *Agricultural Systems*, 121, 24–34. <https://doi.org/10.1016/j.cosust.2014.08.006>
- Turner, M. D. (2004). Political ecology and the moral dimensions of “resource conflicts”: The case of farmer–herder conflicts in the Sahel. *Political Geography*, 23(7), 863–889. <https://doi.org/10.1016/j.polgeo.2004.05.009>
- United Nations High Commissioner for Refugees. (2024). *Global trends: Forced displacement in 2024*. UNHCR.

- Webb, P., Coates, J., Frongillo, E. A., Rogers, B. L., Swindale, A., & Bilinsky, P. (2006). Measuring household food insecurity: Why it's so important and yet so difficult to do. *The Journal of Nutrition*, 136(5), 1404S–1408S. <https://doi.org/10.1093/jn/136.5.1404S>
- Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements. *Agronomy for Sustainable Development*, 40, 1–13. <https://doi.org/10.1007/s13593-020-00646-z>
- Wiesmann, D., Bassett, L., Benson, T., & Hoddinott, J. (2009). *Validation of the World Food Programme's Food Consumption Score and alternative indicators of household food security* (IFPRI Discussion Paper No. 00870). International Food Policy Research Institute.
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data* (2nd ed.). MIT Press.
- World Bank. (2008). *World development report 2008: Agriculture for development*. World Bank.
- World Food Programme. (2023). *Hunger hotspots: FAO-WFP early warnings on acute food insecurity*. WFP.
- Yaméogo, J., Ndoutourlengar, M., & Rouamba, S. (2022). Perceptions of climate risks, socio-environmental impacts and adaptation strategies: the case of market gardeners in the lowlands of Nédialpoun, Zoula Village (Burkina Faso). *IIARD International Journal of Geography and Environmental Management*, 8(2), 20-35. <https://doi.org/10.56201/ijgem.v8.no2.2022.pg20.35>
- Yaméogo, J. (2024). Changes in the seasonal cycles of extreme temperatures in the Sudano-Sahelian domain in West Africa: a case study from Burkina Faso. *Meteorology Hydrology and Water Management. Research and Operational Applications*, 12(2), 1-25. <https://doi.org/10.26491/mhwm/194451>
- Yaméogo, J. (2025a). Annual rainfall trends in the Burkina Faso Sahel : a comparative analysis between Mann–Kendall and innovative trend method (ITM). *Discover Applied Sciences*, 7(3), 221. <https://doi.org/10.1007/s42452-025-06675-1>
- Yaméogo, J. (2025b). Spatio-temporal analysis of drought trends recorded during the wettest months in the Mouhoun-Comoé basin in Burkina Faso (Africa): An analysis using Z-score and linear regression. *Geographica Pannonica*, 29(2), 65–83. <https://doi.org/10.5937/gp29-56313>
- Yaméogo, J., Koala, S., Rouamba, S., & Yanogo, P. I. (2026). Spatial distribution and temporal trends in precipitation concentration indices over Burkina Faso from 1993 to 2023. *Discover Environment*, 4(1), 54. <https://doi.org/10.1007/s44274-026-00564-z>