IRJEMS International Research Journal of Economics and Management Studies
ISSN: 2583 – 5238 / Volume 5 Issue 1 December 2026 / Pg. No: 13-31
Paper Id: IRJEMS-V5I1P103, Doi: 10.56472/25835238/IRJEMS-V5I1P103

Original Article

Impact of Agricultural Innovations on Household Food Security: Evidence from Togo

[1]EGOULOU Essokiza, [2]LOKONON Kounagbè Odilon Boris
[1]*Department of Economics, University of Kara, Kara, Togo.*
[2]*Department of Economics, University of Parakou, Parakou, Benin.*

Received Date: 17 December 2025 Revised Date: 30 December 2025 Accepted Date: 01 January 2026 Published Date: 04 January 2026

Abstract: *The objective of this essay is to analyze the effect of adopting agricultural innovations on household food security in Togo. The study relates to a sample of 11,898 households drawn from the Harmonized Household Living Conditions Survey (EHCVM, 2021). Several indicators are used, including the Food Consumption Score (FCS), the Household Dietary Diversity Score (HDDS), and a composite food security index. Econometric analyzes based on ordered probit, generalized ordered probit, and ordered logit models show that the adoption of innovations significantly improves food consumption and dietary diversity. However, the overall index reveals that more than half of households remain food insecure, and adoption may exert a short-term negative effect due to investment costs. These findings imply that the diffusion of innovations must be supported by complementary policies, such as social protection mechanisms, women's inclusion, land tenure security, and improved market access. The study shows that agricultural innovations are a necessary but insufficient condition for achieving sustainable and equitable food security.*

Keywords: *Agricultural Innovations, Food Safety, Generalized Ordered Probit, Ordered Probit, Togo.*
JEL: *Q16, Q18, Q132*

I. INTRODUCTION

Food security, a multidimensional concept defined and interpreted differently, remains a strategic priority affecting people's livelihoods and the national economy, and is also the foundation of national stability (Saboori et al., 2023; Moodi et al., 2023). This concept, initially perceived quantitatively, now incorporates broader dimensions, both objective and subjective, including the availability, access, utilization, and stability of food (Temple et al., 2015). However, Food security is defined as a country's ability to produce enough safe and healthy food to meet the nutritional needs of its population (Zhang et al., 2022; Liu & Zhou, 2021). However, in recent years, challenges such as the overexploitation of natural resources, climate change, excessive soil degradation, and geopolitical instability have impacted food security (Tokhayeva et al., 2020). These challenges are particularly acute in sub-Saharan Africa, where reliance on rain-fed agriculture, low yields, and high exposure to climate shocks exacerbate the vulnerability of farming households. In the face of these challenges, agricultural innovations are emerging as strategic levers for improving productivity, strengthening the resilience of production systems, and contributing to food security.

Indeed, the theoretical literature assumes that agricultural innovations improve food security. For example, the literature highlights a positive effect of agricultural innovations on food security for several reasons. First, technological innovations accelerate the iterative upgrading of food diversity and contribute to stimulating food production (Yan et al., 2023; Xu et al., 2022). Second, technological innovations enable improvements in the efficiency of the food consumption and distribution chain (Wolfert et al., 2023; Mantravadi & Srai, 2023). Third, technological innovations and the digitization of financial inclusion lead to higher agricultural yields and ensure food security (Liu & Ren, 2023; Alyahya et al., 2022). Through these mechanisms, innovation is seen as a key factor in the development of quality agricultural products and the sustainability of food systems (Zhao et al., 2024).

Despite these theoretical advances, food insecurity remains a global concern. Indeed, in 2022, 2.4 billion people worldwide suffered from food insecurity, 11.3% of whom were in a severe situation (FAO et al., 2023). In Africa, more than half the population was affected by 2017, with alarming projections for the 2030s. In Togo, the figures are also worrying, with more than 16.1% of its population undernourished in 2021 and nearly 24% of children under five suffering from chronic malnutrition (PAM, 2022). This situation is partly due to low agricultural productivity, itself caused by the very limited and uneven adoption of agricultural innovations (Vall et al., 2013).

Following the 2007-2008 food crisis, investments in agricultural research and the dissemination of innovations were intensified to improve food security for rural households living in poor regions of the world (Shilombolenia et al., 2019).

However, the adoption of these innovations remains highly uneven. In Africa, although agricultural innovations, particularly fertilizers, improved seeds, information and communication technologies, and mechanization, are recognized as essential policy tools for promoting sustainable agriculture (FAO, 2018; Haile et al., 2017), their dissemination and use are hampered by financial, institutional, and human constraints. Dependence on external funding, difficulty in investing sufficiently in research and development, and limited infrastructure constitute the major obstacles (PARI, 2016).

In Togo, despite the implementation of policies favorable to agricultural innovation, farming households continue to face significant constraints, including low levels of education, high input costs, a lack of technical training, and inadequate rural infrastructure. At the continental level, the Comprehensive Africa Agriculture Development Programme (CAADP), launched in 2003, aimed for 6% annual agricultural growth to reduce poverty. However, the low adoption of agricultural innovations, particularly improved seeds and fertilizers, limits the achievement of these objectives (Kara & Kithu, 2020).

In a context marked by increasing environmental pressures and volatile markets, agricultural innovation is becoming more necessary than ever. According to De Janvry & Sadoulet (2002), agricultural innovations contribute to poverty reduction, increased farm incomes, and lower food prices. They can generate multiplier effects through job creation in processing, local development, and the strengthening of rural markets (Moyo et al., 2007). Seeds, in particular, play a central role in improving yields (McGuire & Sperling, 2016). The adoption of innovations is estimated to have contributed to 40% of the increase in global crop production over the last few decades (Garbero et al., 2018). However, the link between agricultural innovation and food security remains dependent on the context of infrastructure, agricultural policies, technological choices, and producer involvement (Kabunga et al., 2011). However, three main channels help to understand the impact of agricultural innovations on food security (Mucioki et al., 2018 ; McGuire & Sperling, 2011) : (1) direct production for self-consumption, (2) the sale of surpluses to generate income, and (3) reduced food prices through improved access to inputs and financing. Access to innovations remains strongly influenced by the geographical and social proximity of farmers (Mveng et al., 2023 ; Takam-Fongang et al., 2018). In Togo, although efforts have been made to promote innovations, their adoption remains marginal. Challenges include technical expertise, socio-economic behaviors, as well as governance and social cohesion issues (Mugwagwa et al., 2010). In the case of Togo, legislation to improve food security emphasizes product quality. Thus, households that adopt agricultural innovations can take steps to use them within reasonable limits in order to obtain good yields with good quality and contribute to improving the food security of the population without disturbing the natural balance of the environment.

In this context, this research aims to analyze the effect of agricultural innovations on the food security of farming households in Togo. Thus, the main research question is: what is the effect of agricultural innovations on the food security of farming households in Togo? While the literature generally agrees on their positive impact, the results remain mixed depending on the country and the technologies used. For example, Mveng et al., (2023) Studies have shown that improved seeds contribute to improved household food security. Indeed, Shilomboleni et al. (2019) conclude that the widespread adoption of food security innovations in low-income rural settings has often failed to produce substantial and sustainable results, and this poor performance can therefore be attributed to the dominant and linear approaches associated with the diffusion of innovations, which involve research and development of technologies and their subsequent transfer to farmers.

Furthermore, Zhu & Begho (2022) found a positive correlation between agricultural innovations and food security in China. These authors demonstrated that the development of alternative foods is an important aspect of sustainable food security in China, thereby reducing the negative environmental impact of fertilizer use. Bigini et al. (2021) and Abecassis et al. (2018) showed that the use of biotechnology improves cereal disease resistance and increases yield and grain quality (Zhu et al., 2021). Also, according to Pare (2022), the use of fertilizers and improved seeds has a positive effect on agricultural production. These authors argue that the combined effect of improved seeds and chemical fertilizers increases agricultural production and ultimately contributes to improved food security. A weak effect of the use of improved maize seeds and chemical fertilizers was observed by Pare (2022) and the World Bank (2013) in Burkina Faso. However, Koussoubé & Nauges (2015) concluded that the adoption of agricultural innovations such as improved maize seeds and fertilizers has a weak impact on agricultural production and food security. This research aims to contribute to the empirical debate on the effectiveness of agricultural innovations in food security within the Togolese context, which is characterized by significant structural vulnerabilities.

The rest of the research is organized as follows. Section 2 presents a literature review on agricultural innovations and food security. Section 3 is devoted to the methodological approach used. The results and discussions are reported in Section 4, and finally, Section 5 is devoted to the conclusion and policy implications.

II. AGRICULTURAL INNOVATIONS AND FOOD SECURITY: A LITERATURE REVIEW

Despite the crucial importance of food security, which stems from agriculture, most Asian and African countries have failed to implement a comprehensive agricultural revolution. However, in developing countries, agricultural innovations are considered a valuable adaptation strategy for addressing food insecurity. This section presents the concept of food security, the theoretical foundations of the link between agricultural technological innovations and food security, and some empirical studies.

A) The concept of food security and its measurement

The concept of food security is complex and of great concern within the international community. It remains a relevant and highly relevant topic. Food security is a concept that has evolved over time (Robert et al., 2013). Its initial definitions emerged in the 1970s from international organizations and have since been modified by evolving approaches to economic policy (Paolo , 2012). It was initially conceived as a matter of sufficient food availability to meet growing demand and fluctuations in production and prices (Dury & Eve, 2010). According to this understanding of food security, simply increasing global food production would be enough to address the deficit linked to population growth. For Llabrés (2011), food security consists of producing a food supply that, in sufficient quantity and quality, allows rural food producers to feed themselves, sell their surpluses to generate a satisfactory income, encourage their productivity, and meet the effective demand of both rural non-food producers and urban populations. From this definition, the author distinguishes two dimensions of food security: restricted and general. Restricted food security aims to secure the food supply. This involves producing all the basic foodstuffs necessary to meet the food requirements of rural and urban populations, and ensuring the marketing of these products to generate income for the purchase of agricultural inputs. The general dimension, on the one hand, consists of making non-food agricultural production profitable so that rural households can acquire the food they do not produce themselves, and on the other hand, promoting the appropriate conditions so that urban populations in the secondary (industry) and tertiary (trade and services) economic sectors can also acquire the factors of production they need.

Economic literature, beginning with the mercantilists, shows that the state must monitor, regulate, and intervene in markets, if necessary, to guarantee a fair equilibrium price. These food policies are not the sole domain of the mercantilists (Malthus, 1815). These theories were challenged by liberals who proposed that the market is self-regulating and that food products are like any other commodity. For them, the best way to ensure food security is to let the market operate freely. For the physiocrats, agriculture is the sole creator of wealth and must be independent. There is no contradiction between abundance and high prices (Loïc, 1998). Any increase in production can contribute to a reduction in food and nutritional deficiencies. According to Malthus, who developed the first theory of famines in 1798, the arithmetic growth of supply could not ultimately satisfy the needs of a geometrically growing population. Events have refuted this theory. The exceptional growth in food production that the planet has experienced has not, however, ended the problem of famine (Azoulay, 2016). The world continues to fail to feed its inhabitants. These are most often women and children living in sub-Saharan African countries.

Nevertheless, women play a key role in agriculture in sub-Saharan Africa, and their access to land can positively influence income, food supply, the well-being of farming households, health, and food security. Malthus (1815) argued that population growth is geometric and that livelihoods, even under the most favorable conditions for industry, can only grow arithmetically. Because population growth combined with the growth of human activities is likely to deplete natural resources and threaten the future of generations to come, the Malthusian thesis was controversial. Sen (1981) then reopened the theoretical debate on food insecurity and explained that the food availability-to-population ratio, so dear to Malthus, is insufficient to explain food insecurity. Food security is the ability to ensure that everyone, at all times, has physical (distribution networks and infrastructure) and economic (citizens' purchasing power) access to the food they need (Heidhues et al., 2004; FAO, 2010). Clay (2002) and the World Bank (1986) highlighted the temporal dynamics of food insecurity and the distinctions between chronic food insecurity, associated with persistent poverty and low incomes, and transient food insecurity, which is more linked to periods resulting from natural disasters.

Economists disagree on the role of agricultural production in food security. According to orthodox economists, increased cereal and livestock yields improve food security (Vall et al., 2017; Dury et al., 2017). However, according to Agidew & Singh (2018), the determining factors of food insecurity are the scarcity of arable land, recurring drought, climate shocks, lack of rainfall, and land degradation. The complete absence of a literature review on impact studies of agricultural policy in the WAEMU (West African Economic and Monetary Union), which could have revealed whether this agricultural policy has boosted food security in the various member states of the Union or whether it incorporates mechanisms to mitigate the effects of future international food price shocks, was noted (Savadogo, 2009). The concept of food security is multidimensional and complex to define, encompassing four dimensions: availability, accessibility, utilization, and stability or sustainability. In the literature, approximately two hundred indicators have been used to measure food security (Hoddinott et al., 2008). However, despite the implementation of numerous indicators in past decades, no single indicator has yet been chosen that is sufficient on its own to encompass all four dimensions (Dandonougbo et al., 2023). Therefore, this study uses a combination of two frequently used indicators in the context of food security to address at least two of these aspects: the dietary diversity score, which measures utilization, and per capita food expenditure, which takes accessibility into account.

The Household Dietary Diversity Score (HDDS) is a score that encompasses both food frequency and diversity. This indicator measures improvements in food access, food consumption, and dietary quality. This indicator was chosen because it offers advantages and is easy to collect, group, and calculate. It is calculated by grouping sixteen food categories into twelve subgroups and adding their frequencies. For each subgroup, a new variable with two values is created: 1 if the household consumed that food in the subgroup and 0 otherwise. To calculate the values for the dietary diversity variable, all the food categories included in the food consumption score are added together in twelve subgroups. For the dietary diversity score, see the table below. The new variable, "Dietary Diversity Score" (HDDS), takes values from 0 to 12, corresponding to the number of food categories collected (FAO, 2013). Furthermore, other indicators can also be used to measure food security, such as dietary frequency and diversity indicators and dietary behavior indicators (WFP, 2014). In recent years, dietary diversity indicators have become increasingly popular due to their relative cost-effectiveness (Headey & Ecker, 2013).

The most widely used measure of dietary diversity at the household level is the Household The Dietary Diversity Score (HDDS) on a scale of 12, developed by the Food and Nutrition Technical Assistance (FANTA) project of the United States Agency for International Development (USAID), and the Dietary Consumption Score (DCS), which is a frequency-weighted dietary diversity score calculated from a seven-day household food consumption recall, available from the World Food Programme's (WFP) Vulnerability Analysis (SCAVA) (Hidrobo et al., 2018; Sraboni et al., 2014 ; Headey & Ecker , 2013 ; WFP, 2008). Both DCS and HDDS are measures of diet quality (Hidrobo et al., 2014). According to the World Food Programme (WFP, 2008), the Food Security Score (FSS) is based on dietary diversity, meal frequency, and the relative nutritional importance of different food groups. Three food consumption profiles can emerge based on the FSS: (i) poor ($0 \leq FSS \leq 21$), (ii) borderline ($21.5 \leq FSS \leq 35$), and (iii) acceptable ($FSS > 35$). Table 9 summarizes the food groups used to calculate the different food security scores. Furthermore, the share of agricultural innovations used by farming households serves as an indicator of food security.

Table 1: Analysis of Household Food Security Based on Food Groups

<table>
<tr><th>Food groups</th><th>Food groups</th></tr>
<tr><td>1. Cereals</td><td>1. Cereals</td></tr>
<tr><td>2. Roots and tubers</td><td>2. White roots and tubers</td></tr>
<tr><td>3. Plants rich in vitamin A</td><td rowspan="3">3. Vegetables</td></tr>
<tr><td>4. Dark green leafy vegetables</td></tr>
<tr><td>5. Other vegetables</td></tr>
<tr><td>6. Fruits rich in vitamin A</td><td rowspan="2">4. Fruits</td></tr>
<tr><td>7. Other fruits</td></tr>
<tr><td>8. Meats</td><td rowspan="2">5. Meats</td></tr>
<tr><td>9. Liver, kidneys, heart and/or other organs</td></tr>
<tr><td>10. Eggs</td><td>6. Eggs</td></tr>
<tr><td>11. Fish/Seafood</td><td>7. Fish and Seafood</td></tr>
<tr><td>12. Legumes</td><td>8. Legumes, nuts and seeds</td></tr>
<tr><td>13. Milk and Dairy Products</td><td>9. Milk and Dairy Products</td></tr>
<tr><td>14. Oils/fats/butter</td><td>10. Oils and fats</td></tr>
<tr><td>15. Sugar or sweets</td><td>11. Sweets</td></tr>
<tr><td>16. Spices/condiments</td><td>12. Spices, condiments and beverages</td></tr>
</table>

Source: *FAO, 2013*

B) Theoretical and empirical foundations

a. Theoretical Foundations

The economic literature presents theoretical works on the determining causes of food insecurity and agricultural innovations. Since the Second World War, the concept of innovation has remained largely unused, with technological progress being the dominant focus. For a long time, diffusionist approaches to innovation held sway in research, before the 1980s saw the emergence of critiques of the agricultural development model and a renewed understanding of innovation. By agricultural innovation, we mean anything that utilizes agricultural inputs (improved seeds, fertilizers) and electronic devices such as computers or mobile phones, and that can be exchanged via networks like the internet. Innovation thus constitutes a strategy that can advance and sustain productivity and, consequently, food security. However, the key elements of technological innovation in the agricultural sector are necessarily research and development and commercialization (Yao et al., 2014). The neoclassical theory of expected utility, the dominant approach, analyzes the decisions of farming households to adopt agricultural innovations in their production systems to improve food security (Von Neumann & Morgenstern, 1994). According to this theory, economic agents operating in an environment characterized by risk and uncertainty are so rational.

Empirical studies have shown that the superior performance of a sector, in this case the agricultural sector, is driven by its capacity for technological innovation (Song et al., 2005; Ju et al., 2013; Krasnikov & Jayachandran, 2008). Although research and development capacity is central to technological innovation, the benefits of technological resources are increasingly lacking in the market (Yao et al., 2014). Investment in research and development and marketing capabilities forms the basis for combining the theory of technological innovation and marketing theory (Yao et al., 2014). According to Yang et al. (2009), in the theory of technological innovation, technological innovations emphasize new products and market gains, which are the activities of marketing and technology. In marketing theory, a firm's research and development capacity is its ability to effectively utilize technologies to create new and efficient products and services. In research and development, technological innovations in the agricultural sector are characterized by a lengthy research and development process, strong involvement of agricultural stakeholders, country-specific characteristics, and the promotion of publicity (Yao et al., 2014). Due to the inherent contradiction between the availability of qualified technological innovations and farmers' limited marketing skills, innovative companies are compelled to adopt demonstration and extension strategies to promote the development of new techniques. It has been recognized that innovation enables farmers to produce more efficiently with existing resources and to reduce production costs, while ensuring that more sustainable production methods are implemented to conserve natural resources and guarantee household food security (FAO, 2018).

According to Mutisya et al. (2016), education is considered the determining factor in food security. However, education enables individuals to acquire greater capacity to engage in agricultural activities, contributing to household food security (De Muro & Burchi, 2007)and also providing guarantees of employment opportunities, improved diets and nutrition, thereby promoting health, market access, and decision-making. The economic approach to the effect of human capital by Becker (1962), Psacharopulos (1981), and Schultz (1961) has been widely criticized (Robeyns, 2006; Sen, 1997). In contrast, according to the capabilities approach, human capital (education), through social change, can have an effect on food security. Indeed, the sociodemographic characteristics of the head of household can significantly influence household food security (Bogale & Shimelis, 2009; Babatunde et al., 2008). However, investment in farmer training and agricultural innovations contributes to ensuring food security.

The relationship between agricultural technological innovations and food security demonstrates significant theoretical and practical importance for promoting agricultural and technological development (Gouvéa et al., 2022). According to Gaffney et al. (2019), agricultural technological innovation contributes to solving problems in the food production process and fosters sustainable agriculture. In China, Begho & Zhu (2023) and Zhu & Begho (2022) argue that alternative food development remains a key element in the sustainable development of food security and can contribute to reducing the negative environmental impact of fertilizer use. Agricultural technological innovations can help overcome the challenges associated with the scarcity of arable land and water (Lei et al., 2023). To improve climatic and environmental conditions in sub-Saharan Africa and mitigate the rise in food insecurity in urban areas, (Wakweya, 2023)the use of climate-smart agricultural technological innovations is proposed. It is worth noting that agricultural technological innovations were used in all food production chains (Li et al., 2023), from consumption to distribution, while providing the agricultural sector with a significant contribution to its sustainable development (Adenle et al., 2019) in order to ensure food security (Amorim et al., 2023).

The literature agrees on the key role of agricultural innovations in improving food production and food security. Some authors have concurred that agricultural technological innovations play a crucial role in food production chains to ensure food security (Gui et al., 2022; Tian et al., 2016). The impact of agricultural innovations on food security is primarily manifested through intermediary mechanisms. According to Liu et al. (2023), digital financial inclusion could contribute to food security and lead to increased agricultural yields. To ensure improved efficiency in the food consumption and distribution chain, Wolfert et al. (2023); Mantravadi & Srai (2023) proposed the use of digital technologies, highlighting the importance of developing the Internet of Things (IoT) in food industry supply chains to enhance access to diverse and high-quality food (Wang & Mu, 2022; Alam et al., 2023). However, it is important to note that a low level of experience and skills among farmers in mastering the use of new agricultural technologies could impact productivity and efficiency, and consequently food security, unless these farmers receive support (Dandonougbo et al., 2023). Access to training and technical support for farmers helps overcome the constraints related to their lack of expertise. Several frameworks exist that explain the link between agricultural innovations and the food security of farming households. However, agricultural innovations affect the food security of farming households by increasing productivity, reducing the environmental impact of the agricultural sector, decreasing food losses, creating economic opportunities, facilitating the adaptation of farming practices, and strengthening the resilience of food systems (Djinadou & Mensah, 2024). The socioeconomic characteristics of farmers and farms also influence the adoption and effectiveness of innovations. It should also be noted that institutional factors, such as extension services and access to credit, facilitate the adoption of innovations and optimize their impact on intermediary mechanisms. All of these moderating factors explain why some farms benefit more from innovations than others and justify the inclusion of interaction terms in models to assess the effect of innovations on food security. Figure 1 below illustrates the conceptual framework of the link between agricultural innovations and food security.

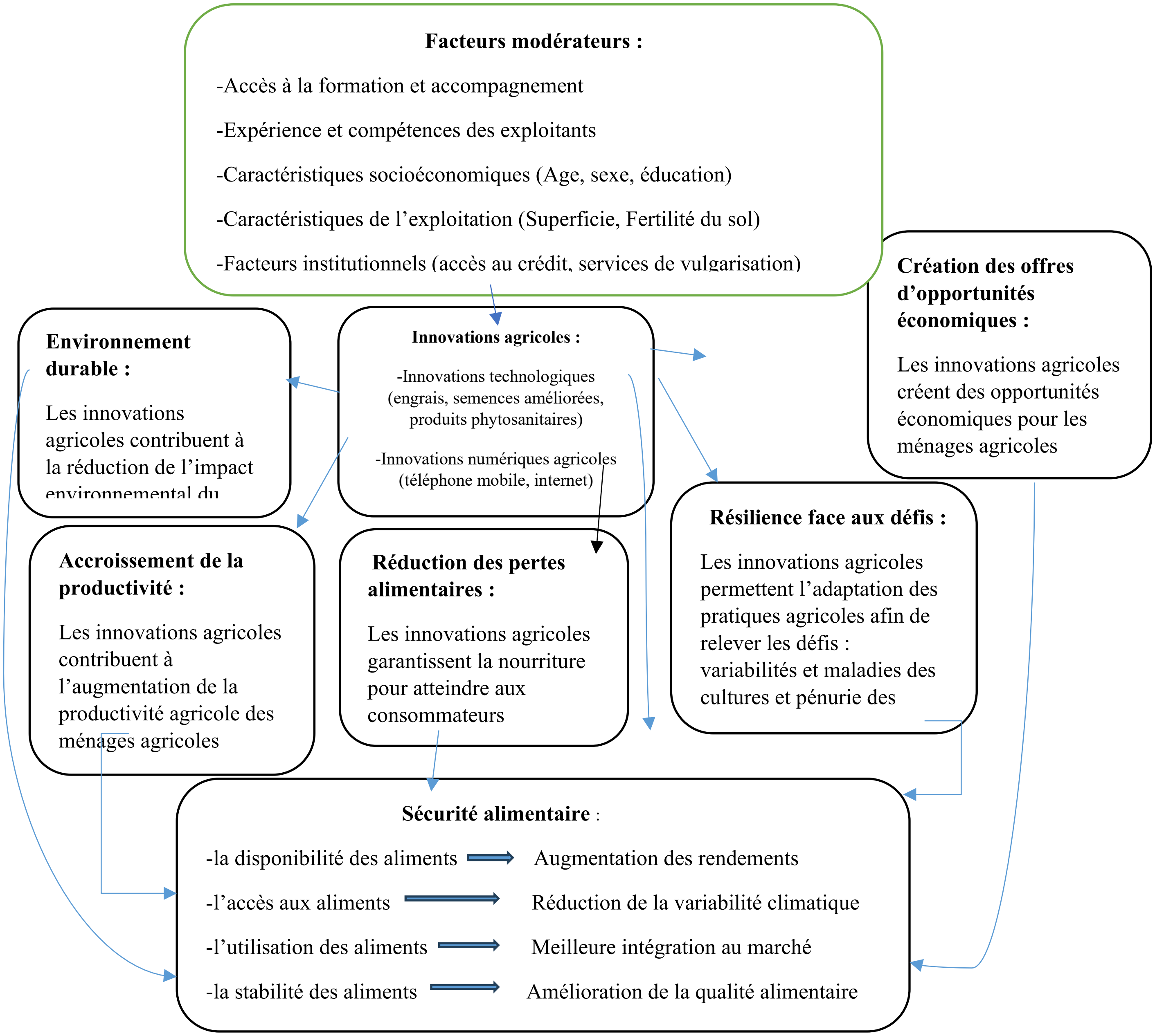

Figure 1. Link between Agricultural Innovations and Food Security

Source: *Author based on literature*

b. Some empirical studies

In the empirical literature, the effect of agricultural technological innovations on food security has been little studied in both developing and developed countries. In Africa in general, and in Togo in particular, many agricultural innovations are either unavailable or poorly adopted by households, which may be due to unfavorable conditions or unsuitable features of the innovations (Kabunga et al., 2011; Smale & Tushemereirwe, 2007; Barrett et al., 2004). Previous studies on adoption and impact are of great importance for better analyzing and understanding which types of agricultural innovations work in which areas. Recent research has analyzed the effect of different agricultural innovations on productivity, income, and poverty (Cunguara & Darnhofer, 2011; Christiaensen et al., 2010). As can be seen, there is a bidirectional, interactive relationship between agricultural innovation and food security. However, there are very few empirical studies linking agricultural innovations to household food security.

However, empirical results show that agricultural technological innovations and food security exhibit positive trends. Kabunga et al. (2011), in studying the impact of banana tissue culture technology on farm household income and food security in Kenya, used treatment effect models and found that the adoption of tissue culture technology significantly reduces food insecurity and increases farmer and household incomes by 153% and 50%, respectively. Huang et al. (2017), in their study, used the degree of coupling and coordination model to conclude that agricultural technological innovations significantly improve food security in China. However, Liu et al. (2023); Cai et al. (2023), in studying the interaction model between agricultural innovation and food security, used the coupled coordination model in the grain-producing area of China and concluded that the fundamental solution to the food problem lies in technological innovation. This is due to China's recent commitment to implementing basic food self-sufficiency policies and the vigorous promotion of agricultural innovations (Liu et al., 2023).

Zhao et al. (2024) studied the coupling coordination relationship between agricultural technological innovation and food security in provincial areas of China. Using the entropy value implementation method, the coupling coordination model, and the exploratory spatial data analysis method, they showed that the level of agricultural technological innovation and the development of food security in China from 2008 to 2020 generally increased, and that the development of technological innovation outpaced that of food security. Similarly, Affoh et al. (2024), using a multinomial endogenous switching regression approach and a multinomial endogenous treatment effect approach on the decision to adopt climate-smart agricultural practices and their impact on household food security among smallholder farmers in Togo, found a positive effect of agricultural technology adoption on food security. Similarly, other studies have shown that the adoption of technologies has improved crop yields and increased farmers' incomes (Olasehinde et al., 2023; Wekesa et al., 2018).

III. RESEARCH METHODOLOGY

A) Conceptual framework and theoretical foundations

This research falls within the framework of the economic theory of farm households, according to which rural households simultaneously make production and consumption decisions in a context of imperfect factor and product markets (Becker, 1965; Singh et al., 1986). In developing countries, farm households are both producers and consumers of the food they produce, thus justifying a unified approach to production and consumption. Within this framework, decisions regarding the adoption of agricultural innovations (improved seeds, fertilizers, and pesticides), land allocation, and the use of factors of production directly influence production levels, incomes, and ultimately, household food security. According to the agricultural household utility model (Singh et al., 1986; Ogundari, 2017), food security can be understood through the household's food demand, which depends on its socioeconomic characteristics, productive resources, and the adoption of agricultural technological innovations. The household program in the model is as follows:

$$\begin{cases} Max U\left[(C_d, C_n), \phi_{ma}\right], k_i(Z_i) \\ S/C \\ P_n C_n + P_{ma} C_{ma} + P_d C_d + Sk = P_d Q_d + N - SL \end{cases} \quad (1)$$

With U being the twice-differentiable and strictly quasi-concave utility function, C_d domestic or own production, C_n the good purchased on the market, φ_{ma} the non-food good, k_i leisure demand, and Z_i a vector of sociodemographic characteristics including agricultural technological innovation, the constraint represents, respectively, household expenditure and income for equality from left to right: $P_n C_n$ the value of food purchases consumed on the market, $P_{ma} C_{ma}$ the value of non-food expenditure, $P_d C_d$ the purchase value of one's own good produced on the farm, and Sk leisure expenditure. Regarding household income, $P_d Q_d$ the value of agricultural output, N non-agricultural income, and SL the value of labor used.

To obtain the optimal value for household food consumption, the program is solved using the constrained Lagrange method:

$$\varphi_a = \left[P_d, P_{ma}, P_n, S, Y^*(P_d, S, N, A^0, K^0), Z_i\right] \quad (2)$$

Where P_d, P_{ma}, P_n represent respectively the price of food products produced by the household, the price of the non-food good and the price of the food good purchased on the market; S the wage rate in the economy, Y^* the total household income on which consumption decisions are made; A^0 the quantity of fixed land of the household and K^0 the stock of fixed capital.

According to Ogundari, (2017) and cited by Dandonougbo et al., (2023), household food demand (φ_a) can be considered as a measure of food security (FS) and is written as follows:

$$\varphi_a = SA = \left[SCA, SDA, Dep_{a\lim}, IP, I_{sa} .....\right] \quad (3)$$

With SA a vector of various indicators of household food security (Food Consumption Score, Food Diversity Score, Food Expenditure, Production Index or Undernourishment Index (Obayelu , 2012; Lokosang et al., 2011).

B) Empirical specification of the model

The objective of this study is to determine the effect of agricultural technological innovations on household food security in Togo. To do this, we will rewrite the relationship between food security and its determinants using the reduced equation (2) and considering equation (3) as follows:

$$GIS_i = [Y_i^*, P_i, IT_i, X_i/\alpha, \phi] + \varepsilon_i \quad (4)$$

With GIS a categorical composite index derived from the combination of two food security indicators (food consumption score and food diversity score) representing the household food security index, IT_i vectors of agricultural technological innovations, X_i other household characteristics, α and φ the parameters to be estimated and ε_i the error term.

To estimate the parameters of equation (4), it is necessary to choose a particular distribution for the perturbations. Fundamentally, two models are mainly considered, namely the probit model and the logit model, just as in the case of a variable with two modalities.

C) Analysis Methods

In this study, household food security is measured using two complementary indicators. The Food Consumption Score (FCS), which combines the frequency of consumption and the nutritional importance of different food groups, was used to classify households into three levels: low, borderline, and acceptable. The Food Consumption Score (FCS), a proxy used by the World Food Programme (WFP, 2014), is a composite indicator developed to assess food security. It is calculated as follows:

$$\text{SCA}=\sum_{i=1}^{n}(Fi \times Pi)$$

Or

Fi: is the frequency of consumption of the number of days during seven days of food group i.

Pi: is the nutritional weight assigned to food group i.

n : the total number of food groups

In parallel, the Dietary Diversity Score (HDDS), based on the number of food groups consumed per household during the 24-hour reference period, was divided into three categories corresponding to low, medium, and high diversity. It is calculated as follows:

$$\text{SDA}=\sum_{i=1}^{n} Zi$$

Or

Zi = 1 if at least one food from group ia was consumed by the household during 24 hours, otherwise Zi = 0

n : the total number of food groups considered.

To obtain a composite measure, these two indicators were combined using multiple correspondence analysis (MCA), which yielded a factor score reflecting the common dimension of food security. This score was then transformed into a continuous index and grouped into three classes to facilitate comparisons between household groups.

Given the potentially endogenous nature of agricultural innovation adoption, a simple ordered logit / probit model would risk producing biased estimates. To correct this bias, we used a *Conditional Mixed Process (CMP)* simultaneous equations approach, which allows for the joint estimation of the adoption decision (probit) and the effect of this adoption on the food security score (ordered probit). This approach allows for the correlation of error terms between the two equations, thereby capturing endogeneity related to unobserved factors. Thus, joint estimation improves the validity of causal inferences compared to an isolated ordered model (Roodman, 2011; Wooldridge, 2010). The model generally takes the following form:

$$Y_i^* = \beta X_i + \gamma Z_i + \varepsilon_i$$

Or:

Y_i^* : the latent variable of food security intensity (food insecurity, borderline or acceptable security)

β And γ : vectors of the parameters to be estimated

X_i : drivers of agricultural innovations, including plant protection products, fertilizers, and improved seeds

Z_i : vectors of control variables

ε_i : error term

D) Descriptive Data and Statistics

This research uses data from the Harmonized Household Living Conditions Survey (EHCVM) conducted by INSEED in Togo in 2020-2021. Data were collected from 6,171 households and their members across the country. Information on agricultural inputs, access to different food sources, and other characteristics of farming households is used in this research.

Table 2 provides descriptive statistics for the different variables used in this research. It shows that, on average, approximately 1.4% of farming households have a low food consumption score; 9.5% have a borderline food consumption score; and 89.1% have an acceptable consumption score. This would suggest that most farming households in the study sample have acceptable food security, but it should be noted that a minority, nearly 11% of households, remain food insecure, which is a concern in a vulnerability assessment. Regarding the food diversity score, it appears that, on average, 36.9% of farming households have a low score; 32.9% a medium score; and 30.2% a high score. It is clear that, in the study sample, most households have low to medium food diversity, highlighting their vulnerability to food insecurity. In terms of agricultural innovations, in the study sample, on average, over 38.4% of farming households did not adopt any agricultural innovations, while over 61.6% adopted at least one. The table also shows that, in the study sample, farming households used an average of 2 hectares of land. The gap between agricultural innovations and the area cultivated demonstrates significant heterogeneity in agricultural practices in Togo.

The average age of household heads is approximately 40 years, with a minimum of 17 years and a maximum of 99 years. This indicates a predominantly working-age adult population. The average household size is approximately 3 people. Overall, this indicates that households in the study sample are relatively small. The table also shows that agricultural households are primarily headed by women (53.5%) compared to 46.5% headed by men. Furthermore, the majority of household heads live in rural areas (88.2%) and practice agriculture as their main activity (88.1%), but are constrained by very weak land tenure security (6.9%), which remains a vulnerability factor. Overall, average annual expenditures are 8,288 FCFA. The education level of agricultural households in the study sample is relatively low, with a predominance of primary education (52.1%), followed by secondary education (43.3%), and very little access to higher education (2.2%).

Table 2: Descriptive Profile of Agricultural Households: Food Security, Adoption of Innovations and Socio-Demographic Characteristics

Variables	Observation	Mean	Std. Dev.	Minimum	Maximum
SCA					
Weak	9,115	0.014	0.119	0	1
Limit	9,115	0.095	0.293	0	1
Acceptable	9,115	0.891	0.312	0	1
HDDS					
Low diversity	9,115	0.369	0.483	0	1
Average diversity	9,115	0.329	0.470	0	1
High diversity	9,115	0.302	0.459	0	1
Education level					
None	2,781	0.024	0.153	0	1
Primary	2,781	0.521	0.500	0	1
Secondary	2,781	0.433	0.496	0	1
Superior	2,781	0.022	0.148	0	1
Agricultural innovations No adoption	9,115	0.384	0.486	0	1
Adoption	9,115	0.616	0.486	0	1
Marital Status					
Bachelor	8,670	0.210	0.407	0	1
Married or in a common-law relationship	8,670	0.656	0.475	0	1
Separated/Divorced/Widower	8,670	0.134	0.341	0	1
Region					

Maritime	9,115	0.124	0.329	0	1
Plateaux	9,115	0.225	0.418	0	1
Central	9,115	0.158	0.365	0	1
Kara	9,115	0.257	0.437	0	1
Savannas	9,115	0.231	0.421	0	1
Greater Lomé	9,115	0.006	0.075	0	1
Religion					
Muslim	9,115	0.177	0.381	0	1
Christian	9,115	0.442	0.497	0	1
Animist	9,115	0.309	0.462	0	1
Other/Non-religious	9,115	0.073	0.260	0	1
Sex					
Male	9,115	0.465	0.499	0	1
Female	9,115	0.535	0.499	0	1
Age	7,436	40.178	16,266	17	99
Household size	9,115	2.752	2.498	1	24
Living environment					
Rural	9,115	0.882	0.323	0	1
Urban	9,115	0.118	0.323	0	1
Area	9,037	2.083	2.775	0	8.923
Credit					
Yes	258	0.895	0.307	0	1
No	258	0.105	0.307	0	1
Member of a group					
Yes	5,442	0.157	0.364	0	1
No	5,442	0.843	0.364	0	1
Spent	9,115	8.288	1.546	3.912	14,947
Non-agricultural activity					
Yes	9,115	0.119	0.324	0	1
No	9,115	0.881	0.324	0	1
Land security					
None	5,226	0.931	0.254	0	1
Legal document	5,226	0.069	0.254	0	1

Source: *Author Based On EHCVM, 2020-2021 (Togo)*

IV. RESULTS AND DISCUSSION

A) Effect Of Agricultural Innovations on the Food Consumption Score

Table 3 below shows the distribution of households according to their food consumption score. An examination of the food consumption score (FCS) reveals that the vast majority of households (89.1%) fall into the "acceptable" category, indicating relatively sufficient and regular food consumption. However, nearly 9.5% of households are in the "borderline" category and 1.5% in the "low" category. While these proportions may seem small, they remain concerning as they refle ct situations of overt or latent food insecurity.

These results suggest that, despite an overall favorable situation, a significant proportion of households remain exposed to food insecurity, particularly in the event of seasonal or economic shocks. This underscores the need for targeted policies to improve the resilience of these vulnerable households, through interventions focusing on production diversification, improved access to inputs, and social protection.

Table 3: Distribution of households by levels of food consumption score (FCS)

FCS Category	Number of employees (N)	Percentage (%)
Weak	132	1.5
Limit	865	9.5
Acceptable	8,118	89.1
Total	9,115	100.0

Source: *Author, Based on EHCVM 2021*

Table 4: Results of the Estimation of the Effect of the Adoption of Agricultural Innovations on the Food Consumption Score

Food Consumption Score (FCS)			
	Ordered probit	**Extended Probit**	
Variables		Equation 1	Equation 2
Agricultural innovation	0.272** (0.094)		0.276** (0.128)
Age	-0.002 (0.004)	-0.013*** (0.004)	-0.002 (0.004)
Member of a group		0.306* (0.163)	
In surface area		-0.630*** (0.067)	
Women	0.241** (0.097)	0.072 (0.113)	0.241** (0.099)
Education level (Reference=None)			
Primary	0.604** (0.267)	-0.121 (0.460)	0.604** (0.250)
Secondary	0.552** (.0270)	-0.027 (.462)	0.552** (0.251)
Superior	0.748 (0.463)	-0.569 (0.623)	0.749 (0.431)
Marital status (Reference = Bachelor)			
Married or in a common-law relationship	0.101 (0.140)	0.498*** (0.159)	0.101 (0.144)
Widowed/divorced/separated	-0.332* (0.197)	0.400* (0.230)	-0.333* (0.200)
Place of residence (Reference=Urban)			
Rural	-0.282* (0.145)	0.462*** (0.151)	-0.283* (0.148)
Land security (Reference = None)			
Legal document	-0.559*** (0.157)	-0.247 (0.221)	-0.559*** (0.158)
Constant		0.911* (0.500)	
cut 1	-1.610*** (0.323)		
cut 2	-0.662** (0.320)		
rho _12 (correlation)			-0.006(0.112)
Number of observations	=1.187		
Wald chi2(21)	=143,260		
Prob > chi2	=0.000		

*Significance rating of standard errors in parentheses: (*p<0.1; **p<0.05; ***p<0.01)*
Source: *Author, based on EHCVM 2021*

Table 4 presents the results of the joint estimation of agricultural innovation adoption and the household food consumption score (FCS). These results do not reveal a significant correlation between the error terms of the two equations (ρ_{12} = -0.006; p > 0.1), as the correlation parameter rho_12 is not significant and indicates weak endogeneity between the equations. Nevertheless, the extended probit confirms the robustness of the results, showing that the determinants of adoption and food security, while related, are not entirely interdependent. In other words, the unobserved factors that influence the probability of adopting agricultural innovations do not significantly affect household food consumption. This lack of endogeneity suggests that the adoption of agricultural innovations influences the food consumption score primarily through direct and observable effects, rather than through unobservable determinants common to both phenomena. Thus, the observed effect of adoption on food consumption can be interpreted more robustly as a structural effect, rather than simply reflecting selection bias related to unobserved household characteristics. The results of the ordered probit model show that the adoption of agricultural innovations has a positive and significant effect on the food consumption score, confirming that adopting households improve their food diversity and quality. This result corroborates, to some extent, those of Wainaina et al. (2016) and Kassie et al. (2015), who showed that the adoption of improved seeds and modern inputs strengthens the food security of rural households.

The age of the household head is negatively and significantly associated with the adoption of agricultural innovations, but does not influence the food consumption score. Households headed by older heads are less likely to adopt innovations, but their food security does not appear to be directly penalized by age. This result is consistent with those of Mwangi & Kariuki (2015), who showed that younger people are often more open to change and risk-taking than older people. However, the age of the head of household does not directly influence the food consumption score, suggesting that older households compensate with their experience, accumulated assets, and diversified income (Genius et al., 2014; Barrett, 2010). Indeed, while youth fosters innovation, seniority does not necessarily compromise food security.

Regarding gender, the results show that having a female head of household significantly improves food consumption scores. This highlights the important role of women in food and nutrition decisions and resource allocation within the household. This finding is similar to that of Sraboni et al. (2014), who emphasize that female-headed households tend to prioritize food expenditures and diversify their diets. However, gender does not appear to be a significant determinant of the adoption of agricultural innovations. This lack of a direct link may be due to structural constraints that limit women's access to inputs, credit, land, and extension services (Peterman et al., 2014). Despite the essential role of agricultural innovations in food production and management, these constraints reduce households' capacity to adopt and experiment with new agricultural technologies.

The results show that the level The education of the head of household has a positive and significant effect on the food consumption score. This result is consistent with the work of Asfaw et al. (2012), who emphasize that education increases households' capacity to understand and apply nutritional information, diversify their diets, and improve food security. Similarly, Burchi & De Muro (2016) These findings confirm that education strengthens autonomy in food choices and promotes the adoption of healthy nutritional practices. However, the level of education does not appear to be a significant factor in the adoption of agricultural innovations. This paradox can be explained by several factors. On the one hand, institutional barriers (limited access to credit, lack of appropriate extension services) reduce the capacity of educated households to translate their knowledge into the effective adoption of innovations (Feder et al., 1985). On the other hand, financial and land constraints can hinder investment in new technologies, even when human capital is relatively high (Doss, 2018). The results indicate that marital status influences the adoption of agricultural innovations. Married households are more likely to adopt innovations, which can be explained by a greater availability of family labor and more efficient organization of agricultural tasks. This finding aligns with the analyses of Abdulai & Huffman (2014), which show that married households have comparative advantages in terms of family labor and collective resource management. Conversely, widowed or divorced households appear more vulnerable in terms of food security, reflecting the impact of social and family shocks on food security, as already observed in other African contexts (FAO, 2011).

Regarding place of residence, rural households are more likely to adopt innovations but have a lower food consumption score. This duality suggests that, although rural areas are the primary location for the diffusion of innovations, structural constraints on access to markets, infrastructure, and food diversity limit the translation of these innovations into nutritional improvements. These results confirm the findings of Barrett (2010), who highlights the persistence of food insecurity in rural areas despite agricultural technological advances. Finally, land tenure security, measured by possession of a legal document, is negatively associated with the food consumption score. This seemingly counterintuitive result can be interpreted by the fact that households that have invested in land formalization dedicate a significant portion of their financial resources to securing their rights, at the expense of immediate food expenditures. This observation is supported by the work of Fenske, (2011), who emphasizes that land tenure security can generate substitution effects between land investment and short-term consumption.

B) Effect Of Agricultural Innovations on the Food Diversity Score (HDDS)

Table 5: Distribution of Households by Levels of the Food Diversity Score (HDDS)

Category HDDS	Number of employees (N)	Percentage (%)
Weak	3,363	36.9
Average	3003	33.0
High	2,749	30.1
Total	9,115	100.0

Source: *Author, based on EHCVM 2021*

Analysis of the Household Dietary Diversity Score (HDDS) reveals that more than a third (36.9%) have low dietary diversity, while 33.0% have medium diversity and only 30.1% have high diversity. This finding highlights that, despite the apparent availability of food (as suggested by the FCS), a significant proportion of households are unable to access a varied and balanced diet.

Low dietary diversity is generally associated with monotonous diets, often dominated by grains and starches, with limited intake of animal protein, fruits, and vegetables. This increases the risk of nutritional deficiencies, particularly in essential micronutrients. Thus, even if households consume sufficient quantities, nutritional quality remains inadequate for a significant portion of the population.

Table 1: Results of the Estimation of the Effect of the Adoption of Agricultural Innovations on Household Dietary Diversity Scores

Dietary Diversity Score (HDDS)			
	Ordered probit	**Extended Probit**	
Variables		Equation 1	Equation 2
Agricultural innovation	0.309***(0.068)		0.289*** (0.090)
Age	0.004 (0.003)	-0.013***(0.004)	0.004(.003)
Member of a group		0.302 (0.163)	
Lnsurface -0.633(0.067)			
Sex (Reference=Male)			
Women	0.109 (0.068)	0.072(0.113)	0.108(0.069)
Education level (Reference=None)			
Primary	0.100(0.224)	-0.122(0.459)	0.100 (0.211)
Secondary	0.088 (0.226)	-0.027(0.461)	0.089(0.213)
Superior	0.493 (0.329)	-0.561 (0.620)	0.491 (0.330)
Marital status (Reference = Single)			
Married or in a common-law relationship	-0.146 (0.099)	0.498 ***(0.159)	-0.145(0.099)
Widowed/divorced/separated	-0.342** (0.146)	0.397 (0.229)	-0.340**(0.143)
Residential environment (Reference=Urban)			
Rural	-0.089 (0.095)	0.462***(0.150)	-0.087 (0.095)
Land security (Reference = None)			
Legal document	-.0023(0.132)	-0.242 (0.218)	-0.004 (0.145)
Constant		0.917(0.495)	
cut 1	-0.050(0.254)		
cut 2	0.873(0.254)		
rho _12 (correlation)			0.028(0.080)
Number of observations	=1.187		
Wald chi2(21)	=117,930		
Prob > chi2	=0.000		

*Significance rating of standard errors in parentheses: (*p<0.1; **p<0.05; ***p<0.01)*
Source: *Author, based on EHCVM 2021*

Table 6 presents the results of the joint estimation of agricultural innovation adoption and household dietary diversity score (HDDS). These results do not reveal a significant correlation between the error terms of the two equations ($\rho_{12} = -0.28$; $p > 0.7$), as the correlation parameter rho_12 is not significant and indicates weak endogeneity between the equations. The absence of a significant correlation between the equations means that the endogeneity bias related to unobserved factors is limited. Thus, the positive effect of innovation on the dietary diversity score can be interpreted more causally. The results show that the adoption of agricultural innovations is positively and significantly correlated with the dietary diversity score. This result confirms that the integration of innovations (improved seeds, inputs, production technologies) improves not only productivity but also the diversity of food consumed by the household. Indeed, innovations increase agricultural incomes and facilitate access to a wider variety of food products, either directly through self-production or indirectly via the market (Kassie et al., 2015; Snapp & Fisher, 2015). These results are consistent with the work of Jones et al. (2014), who showed that the adoption of innovations in sub-Saharan Africa promotes improved food quality.

Age significantly reduces the likelihood of adopting innovations, but it does not directly affect the dietary diversity score. This dual finding suggests that younger households are more inclined to experiment with and adopt new technologies (Mwangi & Kariuki, 2015), while older households can compensate through experience, income diversification, and asset accumulation (Barrett, 2010; Genius et al., 2014). This compensation would explain the lack of a direct effect on dietary diversity despite lower adoption of innovations. Being a female head of household significantly improves the dietary diversity score, although this effect is less pronounced on the adoption of innovations. This result confirms that women allocate a larger share of their resources to the household's food and nutritional needs (Doss, 2018 ; Sraboni et al., 2014). However, the lack of effect on technology adoption reflects the structural constraints they face, particularly limited access to productive resources (land, credit, inputs) (Peterman et al., 2014). The household head's education level is positively associated with the dietary diversity score, demonstrating that education increases households' capacity to value innovations and diversify their diets

(Asfaw et al., 2012; Babatunde & Qaim, 2010). Conversely, education does not appear to be a determining factor in adoption, which may be linked to persistent institutional and financial barriers (Feder et al., 1985). Thus, while education promotes better resource use, it does not necessarily guarantee increased adoption of agricultural technologies.

Married households adopt more innovations, likely due to the increased availability of family labor and spousal support (Abdulai & Huffman, 2014). In contrast, widowed or divorced households have lower dietary diversity scores, reflecting increased vulnerability. This finding is consistent with studies showing that single parenthood or the absence of a spouse reduces household food security (Quisumbing et al., 2015). Rural households adopt innovations more frequently but have lower dietary diversity scores than urban households. This paradox suggests that, despite the production gains associated with adoption, constraints on access to markets, infrastructure, and diverse food products persist in rural areas (Barrett, 2010 ; Sibhatu et al., 2015). These results highlight that technological adoption alone is insufficient to improve the quality of diets without better market access. Surprisingly, possessing a legal land tenure security document does not improve dietary diversity scores and even appears negatively correlated in some models. A plausible explanation is that households investing in land tenure security allocate some of their financial resources to formalizing their rights, thereby reducing their food expenditures (Fenske, 2011). This finding highlights the need for land policies accompanied by economic support measures to avoid an adverse short-term substitution effect on food consumption.

C) Effect of agricultural innovations on the food security index

Table 7: Categorization of Households According to the Food Security Index

Food security index category	Number of employees (N)	Percentage (%)
Weak	5,743	63.0
AVERAGE	2,375	26.1
Pupil	997	10.9
Total	9,115	100.0

Source: *Author, based on EHCVM, 2021*

Analysis of the food security index distribution reveals that the majority of households (63.0%) fall into the "low" category, reflecting a situation of high food vulnerability. A significant proportion of 26.1% are in the intermediate ("medium") category, suggesting unstable food security and exposure to economic or climate shocks. Only 10.9% of households achieve a "high" level of food security, indicating limited and unequal access to a diverse and sufficient diet. These results highlight the persistence of significant difficulties in accessing food resources for a large proportion of households, despite the existence of pockets of resilience. They also underscore the importance of targeted investments in agricultural productivity, income diversification, and improved market access to reduce the proportion of households experiencing chronic food insecurity. Figure 1 below illustrates the distribution of households according to the food security index.

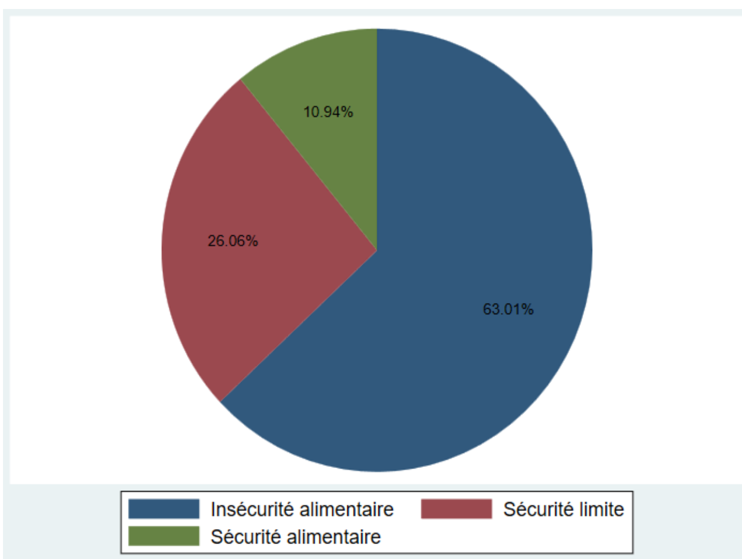

Figure 2. Distribution of households according to food security index categories

Source: *Author, based on EHCVM, 2021*

Table 2: Results of the estimation of the effect of agricultural innovations on the food security index

Explanatory variables	Adoption of innovations (Probit)	Food safety (Ordered) Probit)
Cultivated area	-0.628*** (0.067)	–
Age of the head of household	-0.013*** (0.004)	0.001 (0.003)
Sex (1 = Female)	0.072 (0.113)	-0.152** (0.073)
Education level (Ref. = none)		
Primary	-0.114 (0.462)	-0.278 (0.278)
Secondary	-0.016 (0.463)	-0.195 (0.279)
Superior	-0.559 (0.624)	-0.481 (0.371)
Marital status (Ref. = single)		
Married/Common-law partner	0.507*** (0.159)	-0.016 (0.107)
Widowed/Divorced/Separated	0.403* (0.230)	0.209 (0.159)
Place of residence (Rural=1)	0.464*** (0.150)	0.201* (0.105)
Land security (legal title)	-0.262 (0.218)	0.276* (0.143)
Group affiliation	0.311* (0.162)	–
Innovation adoption	–	-0.385*** (0.089)
rho _12 (correlation)		0.066(0.081)
Number of observations	= 1,187	
Wald chi2(21)	= 138.47	
Prob > chi2	= 0.000	

*Significance rating of standard errors in parentheses: (*p<0.1; **p<0.05; ***p<0.01)*
Source: *Author, based on EHCVM, 2021*

Analysis of the results highlights distinct determinants of agricultural innovation adoption and food security. Regarding adoption, cultivated area and the age of the household head have a significant negative effect. This suggests that farmers with large landholdings and older farmers are less inclined to integrate new practices, preferring traditional methods perceived as safer. The negative link between land area and adoption corroborates the analyses of Feder and Umali (1993), which show that large farms are more risk-averse. The adverse effect of age aligns with the findings of Mwangi and Kariuki (2015), who found that younger people are more willing to adopt new technologies. Conversely, membership in a farmers' group, marital status (married or in a common-law relationship), and rural residence promote adoption, confirming the role of social networks, community organization, and family stability in the diffusion of agricultural technologies. The importance of peasant groups and social networks is confirmed by Doss (2006) and Wollni & Andersson (2014), who emphasize the central role of social structures in the diffusion of innovations.

Regarding food security, as measured by an index combining food diversity and consumption, the results show that the adoption of innovations has a significant negative impact. This can be attributed to the initial costs of acquiring inputs (improved seeds, fertilizers, pesticides), which temporarily reduce the resources available for household food. This paradoxical effect of adoption is consistent with Marenya & Barrett (2009), who explain that the benefits of innovations often appear in the long term, while the immediate costs weaken households. The gender of the household head also appears to be a determining factor : female-headed households are more vulnerable in terms of food security, reflecting persistent inequalities in access to productive resources. The disadvantage faced by female-headed households confirms the analyses of the FAO (2011), which highlights the significant impact of gender inequalities on food production and security. Furthermore, land tenure security has a significant positive effect, highlighting that legal title strengthens investment and household economic stability, with a favorable impact on their food security. The positive contribution of land tenure security aligns with the findings of Place (2009), which emphasizes that secure land rights promote agricultural investment and improve food resilience.

V. CONCLUSION AND IMPLICATIONS OF ECONOMIC POLICIES

Food security remains a major challenge globally, and particularly in sub-Saharan Africa, where rural households face significant vulnerability due to climate variability, low agricultural incomes, and limited access to productive resources. In this context, the adoption of agricultural innovations is often presented as a strategic pathway to increase productivity, improve incomes, and ultimately enhance food availability and quality. However, the effects of these innovations on food security are not automatic and vary according to socio-economic, institutional, and territorial contexts. In Togo, a country heavily reliant on agriculture, food security is central to public policy, yet households continue to face persistent insecurity. This research is situated within this context. The objective of this study was to analyze the effect of adopting agricultural innovations on household food security in Togo, using data from the Harmonized Survey on Household Living Conditions (EHCVM, 2021). To achieve this objective, several indicators were constructed, including the Food Consumption Score (FCS), the Dietary Diversity Score (HDDS), and a composite food security index. Econometric estimation was performed using ordered and extended probit models, allowing for consideration of the specific characteristics of the data and testing the robustness of the results. The main findings show that adopting agricultural innovations has a positive and significant effect on food consumption and diversity, reflecting an improvement in the quality and variety of diets among adopting households. However, the analysis of the overall food security index reveals a more concerning situation: a large majority of households remain in the low food security category.

Furthermore, the effect of adoption on this overall index appears paradoxically negative in the short term, likely due to the initial investment costs associated with acquiring inputs and technologies. These results suggest that while agricultural innovations contribute to improving certain aspects of nutrition, they are not sufficient on their own to guarantee sustainable and equitable food security. Several policy lessons emerge. First, it is essential to accompany the diffusion of agricultural innovations with social protection measures (targeted subsidies, cash transfer programs, safety nets) to mitigate the short-term negative effects on the consumption of vulnerable households. Second, the implementation of more inclusive gender policies is crucial to strengthen women's participation in the adoption of innovations, while capitalizing on their central role in household food management. Third, while land tenure security is associated with a positive impact on food security, it must be accompanied by financial and institutional mechanisms to prevent formalization costs from negatively affecting food expenditures. Finally, improving rural infrastructure and market access remains essential to translating gains in agricultural productivity into genuine nutritional improvements. Ultimately, this study highlights that promoting agricultural innovations is a necessary but not sufficient condition for sustainably strengthening food security. It must be linked to appropriate social, land, and nutrition policies capable of reducing structural vulnerabilities and building household resilience to economic and climate shocks.

Conflicts of interest

Authors 1 and 2 declare that they have no conflict of interest.

Funding statement

This research did not receive any specific funding from public, private or non-profit organizations.

VI. REFERENCES

[1] Abecassis, J., Cuq, B., Escudier, J.-L., J. -L., Garric, G., Kondjoyan, A., Planchot, V., . . . de Vries, H. (2018). Food chains; the cradle for scientific ideas and the target for technological innovations. Innov. Food Sci. Emerg. Technol. 46, 7–17.

[2] Adenle, A. A., Wedig, K., & Azadi, H. (2019). Sustainable agriculture and food security in Africa: The role of innovative technologies and international organizations. Technol. Soc., 58, 101143. [CrossRef].

[3] Affoh, R., Zheng, H., Zhang, X., Wang, X., Dangui, K., & Zhang, L. (2024). Climate-Smart Agriculture as an Adaptation Measure to Climate Change in Togo: Determinants of Choices and Its Impact on Rural Households' Food Security. Agronomy, 14, 1540. .

[4] Agidew, A., & Singh, K. N. (2018). Determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia: The case of the Teleyayen sub-watershed. Agricultural and Food Economics, 6, 10.

[5] Aidoo, R., Mensah, J. O., & Tuffour, T. (2013). Determinants of household food security in the Sekyere-Afram plains district of Ghana. European Scientific Journal.

[6] Alam, M. B., Tushar, S. R., Zaman, S. M., Gonzalez, E. R., Bari, A. M., & Karmaker, C. L. (2023). Analysis of the drivers of Agriculture 4.0 implementation in the emerging economies: Implications towards sustainability and food security. Green Technol. Sustain., 1, 100021. [CrossRef].

[7] Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. . Climate Risk Management, 16, https://doi.org/10.1016/j.crm.2016.12.001,, 183-194.

[8] Alyahya, S., Khan, W. U., Ahmed, S., Marwat, S. N., & Habib, S. (2022). Cyber Secure Framework for Smart Agriculture: Robust and Tamper-Resistant Authentication Scheme for IoT Devices. Electronics, 11, 963. .

[9] Amorim, A., Silva, V. L., & Sobral, P.J.d.A., P. d. (2023). Food Processing: An overview on links between safety, security, supply chains, and NOVA classification. Clean. Circ. Bioeconomy, 5, 100047. [CrossRef].

[10] Asghar, Z., & Muhammad, A. (2013). Socio-economic Determinants of Household Food Insecurity in Pakistan. Munich personal Repec Archive.

[11] Babatunde, R. O., Omotesho, O. A., Olorunsanya, E. O., & Owotokoit, G. M. (2008). Determinants of vulnerability to food insecurity: A gender-based analysis of farming households in Nigeria. Indian Journal of Agricultural Economics, 63(1), 116–125.

[12] Banque Mondiale. (2013). « Burkina-Faso : Indicateurs de l'Agrobusiness Washington, DC.

[13] Barrett, C., Moser, C., McHugh, O., & Barison, J. (2004). Better Technology, Better Plots, or Better Farmers? Identifying Changes in Productivity and Risk among Malagasy Rice Farmers. American Journal of Agricultural Economics 86(4), 869-888.

[14] Becker, G. S. (1962). Investment in human capital: A theoretical analysis. Journal of Political Economy, 70(5), 9–49.

[15] Becker, G. S. (1965). Une théorie de l'allocation du temps.

[16] Begho, T., & Zhu, Y. (2023). Determinants of consumer acceptance of meat analogues: Exploring measures of risk preferences in predicting consumption. J. Agric. Food Res, 11, 100509. [CrossRef].

[17] Bigini, V., Camerlengo, F., Botticella, E., Sestili, F., & Savatin, D. V. (2021). Biotechnological Resources to Increase Disease-Resistance by Improving Plant Immunity: A Sustainable Approach to Save Cereal Crop Production. Plants, 10, 1146.

[18] Bogale, A., & Shimelis, A. (2009). Household level determinants of food insecurity in rural areas of Dire Dawa, Eastern Ethiopia. African Journal of Food, Agriculture, Nutrition and Development, 9(9), 1–13.

[19] Bouzid, A., Boudedja, K., Cheriet, F., Bouchetara, M., & Mellal, A. (2020). Facteurs influençant l'adoption de l'innovation en agriculture en Algérie. Cas de deux cultures stratégiques : le blé dur et la pomme de terre. Cahier Agriculture. 2020, 29, 15.

[20] Bragdon Chelsea Smith, S. H. (2015). L'innovation des petits exploitants agricoles. Bureau Quaker auprès des Nations Unies (QUNO).

[21] Braham, F., & Seghir, S. (2022). Changement climatique : Clivages théoriques et enjeux pratiques, cas de la Tunisie. . Revue Internationale du Chercheur, 3(1), Article 1. https://www.revuechercheur.com/index.php/home/article/view/394.

[22] Cai, J., Ma, S., Li, X., & Li, N. (2023). Study on the coupling and coordinated development of grain production capacity and cultivated land use intensity. Resour. Dev. Mark. 39, 400–407,416.

[23] Christiaensen, L., Demery, L., & Kuhl, J. (2010). The (Evolving) Role of Agriculture in Poverty Reduction--an Empirical Perspective. Journal of Development Economics In Press.
[24] Clay, E. (2002). Food security: concepts and measurement. Trade reforms and food securityconceptualizing the linkages. Rome, UN Food and Agriculture Organization, 25-34.
[25] Cordero-Ahiman, O. V., Vanegas, J. L., Beltrán-Romero, P., & Quinde-Lituma, M. E. (2020). Determinants of food insecurity in rural households: The case of the Paute River Basin of Azuay Province, Ecuador. Sustainability, 12(3),946.
[26] Cunguara, B., & Darnhofer, I. (2011). Assessing the Impact of Improved Agricultural Technologies on Household Income in Rural Mozambique. Food Policy 36(3), 378-390.
[27] Dandonougbo, Y., Johnson, A. A., & Gnedeka, K. T. (2023). Capital humain et sécurité alimentaire des ménages au Togo, Revue internationnale des économistes de langue Française. https://doi.org/10.18559/RIELF.2023.2.7.
[28] De Haen, H., & Hemrich, G. (2007). The economics of natural disasters: Implications and challenges for food security. Agricultural Economics 37(s1):31-45.
[29] De Janvry, A., & Sadoulet, E. (2002). World Poverty and the Role ofAgricultural Technology: Direct and Indirect Effects. The Journal of Development Studies, 1-26.
[30] De Muro, P., & Burchi, F. (2007). Education for rural people and food security. A cross country analysis. FAO.
[31] Djinadou, A. A., & Mensah, G. A. (2024). Valorisation des technologies et innovations agricoles: Quelle approche pour une meilleure implication du secteur privé?
[32] Dury , S., Vall, E., & Imbernon, J. (2017). Production agricole et sécurité alimentaire en Afrique de l'Ouest. Cahier de l'Agricuture, 26 (6) : 61001.4p. .
[33] Dury, S., & Eve, F. (2010). la construction des politiques de sécurité alimentaire: institutions, discours, statistique.
[34] El Bilali , H., Bassole, I. N., Dambo, L., & Berjan, S. (2020). Climate change and food security. Poljoprivreda i Sumarstvo, 66 (3), 197-210.
[35] Ellis , F. (2000). The determinants of rural livelihood diversification in developing countries, Journal of Agricultural Economics, 51(2), 289-302.
[36] FAO. (2010). L'état de l'insécurité alimentaire dans le monde le monde. rome.
[37] FAO. (2013). Guide pour mesurer la diversité alimentaire au niveau du ménage et de l'individu. Organisation des Nations Unies pour l'alimentation et l'agriculture. Rome, p.53.
[38] FAO. (2016b). Statistiques sur la sécurité alimentaire.
[39] FAO. (2018). Symposium international sur l'innovation agricole au service des agriculteurs familiaux: libérer le potentiel de l'innovation agricole pour atteindre les objectifs de développement durable. Rome: Italie.
[40] FAO. (2020). La situation de l'alimentation et de l'agriculture 2020 (SOFA 2020), s'intitule « L'eau en agriculture : la clé d'une transformation durable des systèmes alimentaires ».
[41] FAO, FIDA, OMS, & PAM. (2023). Résumé de L'État de la sécurité alimentaire et de la nutrition dans le monde: Urbanisation, transformation des systèmes agroalimentaires et accès à une alimentation saine le long du continuum rural-urbain. ONU.
[42] Faridi, R., & Wadood, S. N. (2010). An econometric assessment of household food security in Bangladesh. The Bangladesh Development Studies, 33(3), 97–111.
[43] Feleke, S., Kilmer, R. L., & Gladwin, C. (2003). Determinants of food security in Southern Ethiopia. International Institute of Tropical Agriculture, 1–30.
[44] Fotso, J. (2007). Urban-rural differentials in child malnutrition: Trends and socioeconomic correlates in sunsaharan Africa. Health & Place, 13,205-223.
[45] Gaffney, J., Bing, J., Byrne, P., Cassman, K., Ciampitti, I., Delmer, D., . . . et coll. (2019). Agriculture intensive fondée sur la science : durabilité, sécurité alimentaire et rôle de la technologie. Glob. Sécurité alimentaire, 23, [Référence croisée], 236-244.
[46] Garbero , A., Marion , P., & Brailovskaya, V. (2018). The impact of the adoption of CGIAR's improved varieties on poverty and welfare outcomes: A systematic review. IFAD Research Series 33, IFAD, Rome.
[47] Gouvéa, R., Kapelianis, D., Li, S., & Terra, B. (2022). Innovation, TIC et sécurité alimentaire. Glob. Sécurité alimentaire. 35, 100653.
[48] Gui, J. -F., Zhou, L., & Li, X. -Y. (2022). Rethinking fish biology and biotechnologies in the challenge era for burgeoning genome resources and strengthening food security. Water Biol. Secur., 1, 100002. [CrossRef].
[49] Haile , B., Azzarri , C., Roberts , C., & Spielman , D. (2017). Ciblage, biais et impact attendu des innovations complexes sur l'agriculture des pays en développement : données probantes du Malawi. Agricultural Economics (Royaume-Uni), 48(3) :317-326.
[50] Halam, K., Dywili, M., & Nwokolo, E. E. (2017). The role of education, income in determining standard of living and food security amongst the residents of Mhlontlo Local Municipality Eastern Cape, South Africa. Journal of Human Ecology, 60(1),, 18–28.
[51] Headey, D., & Ecker, O. (2013). Rethinking the measurement of food security: From first principles to best practice. Food Security, 327-343.
[52] Heidhues, F. A., Atsain , H. N., Padilla, M., G. Ghersi, J. C., & Vallée, L. E. (2004). Development Strategies and Food and Nutrition Security in Africa: An Assessment,2020. Discussion Paper, n°. 38. IFPRI, Washington, D.C.
[53] Hidrobo , M., Hoddinott , J., Peterman , A., Margolies , A., & Moreira, V. (2014). Cash, food, or vouchers? Evidence from a randomized experiment in northern Ecuador. Journal of Development Economics.
[54] Hoddinott, J., Maluccio, J. A., Behrman, J. R., Flores, R., & Martorell, R. (2008). Effect of a nutrition intervention during early childhood on economic productivity in Guatemalan adults. The Lancet, 371(9610), 411–416.
[55] Huang , J., Pray , C., & Rozelle , S. (2002). Enhancing the crops to feed the poor. Nature 418(6898) : 678–84. https://doi.org/10.1038/nature01015.
[56] Huang, J. -K., Wei, W., Cui, Q., & Xie, W. (2017). The prospects for China's food security and imports: Will China starve the world via imports? J. Integr. Agric. 16, 2933–2944.
[57] INSEED. (2020). Indicateurs socio-démographiques. https://inseed.tg.
[58] Jones , R. L., Guha-Sapir, D., & Tubeuf, S. (2022). Human and economic impacts of natural disasters : Can we trust the global data? Scientific Data, 9(1),. Article 1. https://doi.org/10.1038/s41597-022-01667-x.
[59] Ju, M., Zhou, K. Z., Gao, G. Y., & Lu, J. Y. (2013). Technological Capability Growth and Performance Outcome: Foreign Versus Local Firms in China. Journal of International Marketing, 21, 1-16. http://dx.doi.org/10.1509/jim.12.0171.
[60] Kabunga, N. S., Dubois, T., & Qaim, M. (2011). Impact of Tissue Culture Banana Technology on Farm Household Income and Food Security in Kenya, DiscussionPapers, No. 89, Georg-August-Universität Göttingen, Courant Research Centre - Poverty, Equity and Growth (CRC-PEG), Göttingen.
[61] Kara, A. M., & Kithu, L. M. (2020). Education attainment of head of household and household food security: A case for Yatta sub-county, Kenya. American Journal of Educational Research, 8(8), , 558–566.
[62] Kotu, B. H., Alene, A., Manyong, V. M., & Hoeschle-Zeledon, I. (2017). Adoption and impacts of sustainable intensification practices in Ghana. International Journal of Agricultural Sustainability. 15(1):1-16.
[63] Koussoubé, E., & Nauges , C. (2015). « Returns to fertilizer use: does it pay enough? Some new evidence from sub-Saharan Africa ». Tech. rep., DIAL Working Paper DT 07.

[64] Krasnikov, A., & Jayachandran, S. (2008). The Relative Impact of Marketing, Research-and-Development, and Operations Capabilities on Firm Performance. Journal of Marketing, 72, 1-11. http://dx.doi.org/10.1509/jmkg.72.4.1.
[65] Lawrence , G., & Mc Michael , P. (2012). The question of Food security. Int. J. Soc. Agr. Food 19, 135-142.
[66] Lei, S., Yang, X., & Qin, J. (2023). Does agricultural factor misallocation hinder agricultural green production efficiency? Evidence from China. Sci. Total Environ, 891, 164466. [CrossRef] [PubMed].
[67] Li, F., Liu, X., & Qin, Z. (2023). Grain production space reconstruction: Connotation, mechanism and enlightenment. Environ. Dev. , 45, 100818.
[68] Liu, J., & Ren, Y. (2023). Can digital inclusive finance ensure food security while achieving low-carbon transformation in agricultural development? Evidence from China. J. Clean. Prod. 418, 138016.
[69] Liu, L., Ross, H., & Ariyawardana, A. (2023). Building rural resilience through agri-food value chains and community interactions: A vegetable case study in wuhan, China. J. Rural Stud. 101, 103047.
[70] Liu, L., Wang, X., Meng, X., & Cai, Y. (2023). The coupling and coordination between food production security and agricultural ecological protection in main food-producing areas of China. Ecol. Indic. 154, 110785.
[71] Liu, Y., & Zhou, Y. (2021). Reflections on China's food security and land use policy under rapid urbanization. Land Use Policy , 109, 105699.
[72] Llabrés, J.-P. (2011). Théorie de la Sécurité Alimentaire Restreinte & Générale.
[73] Loïc, C. (1998). Théorie des prix et liberté d'exportation du blé chez Quesnay : une interprétation. Cahiers d'Économie Politique, 41-65.
[74] Lokosang, L. B., Ramroop, S., & Hendriks, S. (2011). Establishing a robust technique for monitoring and early warning of food insecurity in post-conflict South Sudan using ordinal logistic regression. Agrekon: Agricultural Economics Research, Policy and Practice in Southern Africa, 50(4), 101–130.
[75] Malthus, T. R. (1815). Nature and Progress of Rent. Sur www.d.umn.edu, 1815.
[76] Mantravadi, S., & Srai, J. S. (2023). How Important are Digital Technologies for Urban Food Security? A Framework for Supply Chain Integration using IoT. Procedia Comput. Sci. 217, 1678–1687.
[77] Maredia, M., Shupp, R., & Mishili, F. J. (2019). Farmer perception and valuation of seed quality: Evidence from bean and cowpea seed auctions in Tanzania and Ghana. Agricultural Economics 50(4).
[78] McGuire , S., & Sperling , L. (2016). Seed systems smallholder farmers use. Food Security 8(1) : 179–95., https://doi.org/10.1007/s12571-015-0528-8.
[79] McGuire, S., & Sperling , L. (2011). The links between food security and seed security: Facts and fiction that guide response. Development in Practice 21(4–5): 493–508 https://doi.org/10.1080/09614524.2011.562485.
[80] Moodi, M., Salehiniya, H., Mohtashaminia, S., Amininasab, Z., & Arab-Zozani, M. (2023). Prevalence of household food insecurity in the marginal area of Birjand, Iran. Front. Sustain. Food Syst. 7, 951698.
[81] Mounirou, I., & Lokonon, B. K. (2022). Can micro-credit improve food security? Evidence from Benin-West Africa. The journal of Development A reas. Volume 56, No.2 Spring.
[82] Mucioki , M., Pelletier , B., Johns , T., Muhammad, L., & Hickey, G. (2018). On developing a scale to measure chronic household seed insecurity in semi-arid Kenya and the implications for food security policy. Food Security 10(3) : 571–87. https://doi.org/10.1007/s12571-018-0807-2.
[83] Mugwagwa, J. T., Wamae, W., & Outram, S. M. (2010). Agricultural innovation and food security in Sub-saharan Africa: Tracing connections and missing links. Journal of International Development.
[84] Mutenje , M., Kankwamba, H., Mangisonib , J., & Kassie , M. (2016). Innovations agricoles et sécurité alimentaire au Malawi : dynamique de genre, institutions et implications sur le marché. Prévisions technologiques et changement social 103 , 240–248.
[85] Mutisya, M., Ngware, M. W., Kabiru, C. W., & Kandala, N. (2016). The effect of education on household food security in two informal urban settlements in Kenya: A longitudinal analysis. Food Security, 8(4), 743–756.
[86] Mveng, W. D.-P., Ningaye, P., & Nzouessah Feunkeu, Q. L. (2023). Impact économique de l'utilisation de semences améliorées sur la sécurité alimentaire des ménages ruraux au Cameroun. African Journal of Agricultural and Resource Economics Volume 18, Number 2 (2023), pp 127–141.
[87] N'ghalkpa , T., & Abbey, A. G. (2022). « Dépendance spatiale et adoption des variétés améliorées au Togo » , African Scientific Journal « Volume 03, Numéro 14 » pp: 383-406.
[88] Nations Unies (2018). The World ' s Cities in 2018—Data Booklet. United Nations Digital Library.
[89] Ndiaye, M., & Diallo, T. M. (2024). Impact des chocs agro-climatiques sur la sécurité alimentaire des ménages ruraux au Sénégal. African Journal of Agricultural and Resource Economics Volume 19, Number 1, pp 99–110.
[90] Njuki, J., Waithanji, E., Lyimo-Macha, J., Kariuki, J., & Mburu, S. (2013). Women, Livestock Ownership and Markets. Bridging the Gender Gap in Eastern and Southern Africa.
[91] Obayelu, A. E. (2012). Households ' food security status and its determinants in the North-Central Nigeria. Food Economics, 9(4), 241–256.
[92] Ogundari, K. (2017). Categorizing households into different food security states in Nigeria: the socio-economic and demographic determinants. Agricultural and Food Economics, 5(1), 1–20.
[93] Olasehinde, T. S., Jin, Y., Qiao, F., & Mao, S. (2023). Marginal returns on Chinese agricultural technology transfer in Nigeria: Who benefits more? China Econ. Rev., 78, 101935.
[94] Osei Mensah , J., Aidoo , R., & Tuffour , T. (2013). Determinants of household food security in the Sekyere-Afram plains district of Ghana. Global Advanced Research Journal of Agricultural Science 2(1): 347–53.
[95] Otunaiya , A., & Ibidunni , O. (2014). Determinants of food security among rural farming households in Ogun State, Nigeria. Journal of Sustainable Development in Africa 16: 33–44.
[96] PAM. (2022). Plan stratégique de pays – Togo (2022–2026). (https://executiveboard.wfp.org/fr).
[97] Paolo , P. (2012). Sélection et formulation d'indicateurs spécifiques de la sécurité alimentaire durable(Sustainable food security). HAL Id: hal-01189999.
[98] Pardey, P. G., & Pingali, P. L. (2010). "Reassessing International Agricultural Research for Food and Agriculture." Report prepared for the Global Conference on Agricultural Research for Development (GCARD). Montpellier, France, 28–31 .
[99] Pare , B. M. (2022). Complémentarité des décisions d'adoption des semences améliorées et des engrais chimiques chez les producteurs de maïs au Burkina Faso. REVUE CEDRES-ETUDES - N°73 Séries économie.
[100] PARI. (2016). Potentiels d'innovation pour la sécurité alimentaire et la croissance agricole durable en Afrique Subsaharienne. Orientations stratégiques pour la collaboration en matière de développement.
[101] PNUD. (2003). Rapport mondial sur le développement humain. Economica.
[102] Psacharopulos, G. (1981). Returns to education: An updated international comparison. Comparative Education, 17(3), 321–341.
[103] Quirós, R. R. (2017). Seguridad Alimentaria: Evolución conceptual y relación con el cambio climático. Revista de Extensión, 7(2). Universidad en Diálogo.
[104] Renkow, M., & Byerlee, D. (2010). The Impacts of Cgiar Research: A Review of Recent Evidence. Food Policy 35(5), 391-402.

[105] Robert , A., James , O., & Thomas , T. (2013). Determinants of household food security in the Sekyere –Afram plains districts of Ghana.
[106] Robeyns, I. (2006). The capability approach in practice. The Journal of Political Philosophy, 14(3), 351–376.
[107] Saboori, B., Alhattali, N. A., & Gibreel, T. (2023). Agricultural products diversification-food security nexus in the GCC countries; introducing a new index. J. Agric. Food Res. 12, 100592.
[108] Savadogo, K. (2009). La politique agricole de l'UEMOA : Etat de mise en œuvre et défis, Université de Ouagadougou.
[109] Schultz, T. W. (1961). American Economic Association investment in human capital. The American Economic Review, 51(1), 1–17.
[110] Sen. (1981). Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford, Clarendon Press.
[111] Sen, A. K. (1997). From income inequality to economic inequality. Southern Economic Journal, 64(2), 384–401.
[112] Shilombolenia, H., Owaygen, M., De Plaen, R., Manchur, W., & Husak, L. (2019). Scaling up innovations in smallholder agriculture: Lessons from the Canadian international food security research fund. Agricultural Systems 175, 58-65.
[113] Singh, I., Squire, L., & Strauss, J. (1986). A survey of agricultural household models: Recent findings and policy implications. The World Bank Economic Review, 1(1), 149–179.
[114] Smale, M., & Tushemereirwe, W. (2007). An Economic Assessment of Banana Genetic Improvement and Innovation in the Lake Victoria Region of Uganda and Tanzania. International Food Policy Research Insitute, Washington DC.
[115] Smith, L. C., & Haddad, L. (2000). Explaining Child Malnutrition in Deloping countries. A Cross- Country Analysis. Research in Agricultural & Applied Economics.
[116] Smith, L. C., & Subandoro, A. (2007). Measuring food security using household expenditure surveys (vol. 3). International Food Policy Research Institute.
[117] Song, M., Cornelia, D., Sangphet, H., & Calantone, R. (2005). Marketing and Technology Resource Complementarity: An Analysis of Their Interaction Effect in Two Environmental Contexts. Strategic Management Journal, 26, 259-276. http://dx.doi.org/10.1002/smj.450.
[118] Sraboni, E., Malapit, H. J., Quisumbing, A. R., & Ahmed, A. U. (2014). Women's empowerment in agriculture: What role for food security in Bangladesh? World Development.
[119] Takam-Fongang , G., Kamdem , C., & Kane , G. (2018). Adoption and impact of improved maize varieties on maize yields: Evidence from central Cameroon. Review of Development Economics 23(1): 172–88. https://doi.org/10.1111/rode.12561.
[120] Temple , L., Touzard , J. M., Kwa, M., Boyer, J., & Desjardins, D. R. (2015). Comparaison des trajectoires d'innovation pour la sécurisation alimentaire des pays du Sud.Biotechnol. Agron. Soc. Environ. 19(1), 53-61.
[121] Tian, J., Bryksa, B. C., & Yada, R. Y. (2016). Feeding the world into the future—Food and nutrition security: The role of food science and technology†. Front. Life Sci., 9, 155–166. [CrossRef].
[122] Tokhayeva, Z., Almukhambetova, B., Keneshbayev, B., & Akhmetova, K. (2020). Gestion des processus innovants en agriculture et sécurité alimentaire : opportunités de développement. Questions d'entrepreneuriat et de durabilité, 7(3),1565-1579. https://doi.org/10.9770/jesi.2020.7.3(10).
[123] Vall , E., Blanchard , M., Koutou , M., Coulibaly , K., Diallo , A. M., Chia , E., . . . Autfray , P. (2013). Recherche-action en partenariat et innovations face aux changements globaux en Afrique subsaharienne, Agronomie Africaine Numéro spécial (6) sur les changements climatiques : pp. 57 – 66.
[124] Vall, E., Marre-Cast , L., & Kamgang, H. J. (2017). Chemins d'intensification et durabilité des exploitations de polyculture-élevage en Afrique subsaharienne : contribution de l'association agriculture-élevage. Cahiers Agricultures, 26(2) : 25006.
[125] Von Neumann, J., & Morgenstern, O. (1994). "Theory of Games and Economic Behavior", Princeton University Press.
[126] Wakweya, R. B. (2023). Challenges and prospects of adopting climate-smart agricultural practices and technologies: Implications for food security. J. Agric. Food Res, 14, 100698. [CrossRef].
[127] Wang, Q., & Mu, Z. (2022). Risk monitoring model of intelligent agriculture Internet of Things based on big data. Sustain. Energy Technol. Assess., 53, 102654. [CrossRef].
[128] Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: Micro-level evidence from Kenya. Agric. Food Secur., 7, 1–14.
[129] 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.
[130] Wolfert, S., Verdouw, C., Van Wassenaer, L., Dolfsma, W., & Klerkx, L. (2023). Digital innovation ecosystems in agri-food: Design principles and organizational framework. Agric. Syst. 204, 103558.
[131] Wooldridge, M. (2010). Econometric Analysis of Cross Section and Panel Data. Second edition, MIT Press, Cambridge MA.
[132] Xu, Y., Zhang, X., Li, H., Zheng, H., Zhang, J., Olsen, M. S., . . . Qian, Q. (2022). Smart breeding driven by big data, artificial intelligence, and integrated genomic-enviromic prediction. Mol. Plant 15, 1664–1695.
[133] Yan, W., Liu, X., Cao, S., Yu, J., Zhang, J., Yao, G., . . . Wu, Y. (2023). Molecular basis of Pogostemon cablin responding to continuous cropping obstacles revealed by integrated transcriptomic, miRNA and metabolomic analyses. Ind. Crops Prod. 200, 116862.
[134] Yang, P. P., Liu, Y., & Hou, J. G. (2009). The Analysis of the Degree of the Influence from Factors That Promote the New Product Development—Technological Innovativeness as a Moderator. Scientific Management Research, 7, 13-16.
[135] Yao, Q., Xu, M. S., Jiang, W. F., & Zhang, Y. (2014). An Exploratory Study on Technological Innovation of Agricultural Science and Technology Enterprises in China. iBusiness, 6, 101-108. http://dx.doi.org/10.4236/ib.2014.63011.
[136] Zhang, Z., Shi, K., Tang, L., Su, K., Zhu, Z., & Yang, Q. (2022). Exploring the spatiotemporal evolution and coordination of agricultural green efficiency and food security in China using ESTDA and CCD models. J. Clean. Prod. 374, 133967.
[137] Zhao , C., Geng, R., Chi, T., Khiewngamdee , C., & Liu, J. (2024). Agricultural Technology Innovation and Food Security in China: An Empirical Study on Coupling Coordination and Its Influencing Factors Agronomy, 14, 123. https://doi.org/10.3390/agronomy14010123.
[138] Zhu, K., Tan, X., Gu, B., & Lin, J. (2021). Evaluation of potential amounts of crop straw available for bioenergy production and biotechnology spatial distribution in China under ecological and cost constraints. J. Clean. Prod. 292, 125958.
[139] Zhu, Y., & Begho, T. (2022). Towards responsible production, consumption and food security in China: A review of the role of novel alternatives to meat protein. Future Foods 2022, 6, 100186. [CrossRef].