

Climate Change Adaptation Strategies and Food Security of Agricultural Households in Semi-Arid Areas in Cameroon

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Working Paper 079-2026

Bringing Rigour and Evidence to Economic Policy Making in Africa

CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

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AERC Research Paper 079-2026
African Economic Research Consortium,
Nairobi April 2026

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Published by: The African Economic Research Consortium

P.O. Box 62882 - City Square

Nairobi 00200, Kenya

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Abstract:

Like other vulnerable regions of the Sahel, the semi-arid zone of Cameroon plays a crucial role in the local ecosystem but remains highly exposed to the adverse effects of climate change, with significant implications for household food security. Adopting appropriate adaptation strategies, therefore, appears essential to mitigating these negative impacts. This study aims to assess the effect of climate change adaptation strategies on the food security of agricultural households in semi-arid areas of Cameroon. Based on cross-sectional data from 1,000 agricultural households, a multinomial endogenous switching regression model was applied, considering the different possible combinations of coping strategies. The findings reveal that households combining adaptation strategies such as improved seeds and compost, crop diversification, and compost, or the simultaneous adoption of improved seeds, compost, and crop diversification experience significant improvements in both food consumption and dietary diversity. These results suggest that public authorities, through agricultural extension services, should not only facilitate access to improved seeds for the most vulnerable households but also strengthen training and awareness programs on the use of compost and improved seeds. Encouraging households to adopt complementary strategies, rather than relying on a single practice, could substantially enhance food security in semi-arid zones.

Keywords: Climate change; MESR¹; cereal productivity; income; agricultural households.

¹ Multinomial Endogenous Switching Regression

1- Introduction

In recent years, the world has been exposed to several external shocks such as the Covid-19 crisis, the Russia-Ukraine war, and climate change, which are undermining the achievement of Sustainable Development Goal 2 "End hunger, achieve food security and improved nutrition and promote sustainable agriculture". Indeed, climate change is manifested by the multiplication of the scale, duration, and frequency of natural disasters with negative and significant implications on food security, due to the inability of food systems to ensure sufficient production (Musafiri et al., 2022). This vulnerability of the agricultural system is linked to the agricultural sector's strong dependence on climate, in particular, abnormal variations in temperature and rainfall (IPCC, 2014). The inability of the agricultural sector to recover from climate shocks is reflected in the production of food of low quality and in insufficient quantities. Compared to 2019, 152 million more people were facing hunger worldwide and 8.9% to 9.4% of the world's population were undernourished in 2023 (UNICEF, 2024). The same report estimates that about 28.9% of the world's population, or 2.33 billion people, were moderately or severely food insecure in 2023 (UNICEF, 2024). This dismal situation nevertheless hides a strong disparity between the regions.

While progress is being made in other regions of the world, Africa is the region with the highest level of undernourishment, well above the pre-COVID-19 situation. In 2023, 20.4% of the population in this region faced undernourishment, compared to only 8.1% in Asia, 7.3% in Oceania, and 6.2% in Latin America and the Caribbean (UNICEF, 2024). In addition, in Africa, 298.4 million people suffer from hunger, compared to 41 million in Latin America and the Caribbean and 3.3 million in Oceania. The region is also characterized by a high prevalence of moderate or severe food insecurity (58%), which is almost double the global average, while countries in Latin America and the Caribbean, Oceania, and Asia are closer to the global average, at 28.8%, 26.8%, and 24.8%, respectively. In addition, the prevalence of moderate or severe food insecurity was 31.9% in rural areas, compared to 29.9% in peri-urban areas and 25.5% in urban areas (UNICEF, 2024). Accompanied by COVID-19 and the Russia-Ukraine war, food insecurity has been exacerbated by the sustained increase in food prices and climate change. According to updated projections, 582 million people will suffer from chronic undernourishment in 2030 if nothing is done.

While developing countries, particularly those in Africa, are the least responsible for climate change (3.8% of total GHG emissions), they are the most vulnerable. About 1700 natural disasters were reported in Africa between 1970 and 2019, 60% of which were flood-related (ADRIFI, 2022). Sub-Saharan Africa is the only region in the world to have recorded

an increase in flood-related mortality rates since the 1990s. To this end, in 2020, floods affected 8.1 million people and caused 1,273 deaths (IPCC, 2021).² Further to the security risks that climate change poses to economies, it is also an important factor for agricultural production and food security in the sense that African agriculture is highly dependent on rainfall (Affoh et al., 2024; Rahman et al., 2022).

As in many other sub-Saharan African countries, agriculture occupies a central place in the Cameroonian economy. Cameroon, often referred to as “*Africa in miniature*”, is subdivided into five major agro-ecological zones: the Sahelian zone, the Guinean high savannah, the bimodal forest zone, the western highlands, and the monomodal forest zone, each with specific climatic vulnerabilities (Notre Dame Global Adaptation Initiative, 2023). Agriculture in the country is predominantly family-based, with nearly 90% of farms operating on less than 2 hectares (FAO, 2021). It employs over 60% of the working population, supplies more than 50% of raw materials to local industries, and contributes about 22% to the Gross Domestic Product (GDP) (INS, 2017). Despite this importance, agriculture remains highly vulnerable to adverse climatic conditions, particularly rising temperatures, declining rainfall, and the intensification of extreme weather events (ONACC, 2019). Between 1974 and 2020, the average annual temperature increased by 0.86°C, with the rise being most pronounced in the semi-arid zone, while average annual rainfall decreased by 2.9 mm per decade (World Bank, 2022). These trends are projected to worsen: by 2099, temperatures could rise by up to 3.9°C, while rainfall variability may intensify, especially in the northern part of the country (World Bank, 2022).

This climatic fragility has serious implications for food security. According to the latest *Cadre Harmonisé* (CH), more than 3 million Cameroonians (around 11% of the population) were affected by food insecurity (Nugroho et al., 2022). The *Global Report against Food Crises* (2023) revealed that 22% and 10% of the population were in phase 2 and phase 3 of acute food insecurity, respectively, an alarming increase compared to 2022, when only 11% were in phase 2, and to 2021, and 10% in phase 3. Projections indicate that between June and August 2024, an additional 2.5 million people could be exposed to food insecurity. Children are among the most affected: in 2021, about 0.3 million children under 5 years suffered from acute malnutrition, particularly in the semi-arid zone, where nearly one-third of households (32%) had poorly diversified diets (WFP, 2022).

² <https://africacenter.org/spotlight/cyclones-more-frequent-storms-threaten-africa/>

The semi-arid zone, in particular, remains the most climate-vulnerable part of the country. It is regularly affected by high winds, floods, erosion, and prolonged dry spells, with alternating periods of heavy rainfall and dry seasons lasting six to seven months (MINEPDED, 2015). Recent events illustrate the scale of the challenge; nearly 47,000 hectares of cropland were flooded, leading to localized but severe agricultural losses. Agricultural productivity in this region is consistently below the national average, with cereal crops essential for household food needs yielding only 1006.9 kg/ha compared to the national average of 1269.5 kg/ha (MINEPDED, 2015). Cereal production, which covers nearly 90% of household food consumption in the area, remains particularly vulnerable to climate shocks. The availability and accessibility of food are therefore closely tied to households' capacity to adapt to these recurrent risks, making resilience-building a key policy and research priority.

Faced with this dismal situation, several major investments have been made by the Cameroonian government in research and development in the agricultural sector. These include the National Territorial Planning and Sustainable Development Scheme (SNADDT), the Five-Year Action Plan (PAQ), the National Climate Change Adaptation Plan, and the Adaptation Investment Plan (MINEPDED, 2015). However, the results of these programs remain mixed and marked by a lack of awareness of the policy by some actors responsible for its implementation.

With regard to the behavior of agricultural households in the face of climate variability, several adaptation measures have been undertaken, as shown by the statistics. At the farm level, 23% of households diversified their activities, 39% adjusted the agricultural calendar, and 42% practiced fallowing. However, none of the households irrigated their fields or ploughed before transplanting. In addition, 69% relied on rites and prayers, to the detriment of adopting improved varieties (less than 11%) made available to them by the "Institute de Recherche Agricole pour le Developpement" (Oumarou et al., 2017). Despite government support, the low rate of adoption of adaptation strategies among agricultural households is mainly explained by the widespread poverty affecting the majority of them, as well as their attachment to ancestral practices (Tene et al., 2013).

Empirically, several studies show that the adoption of adaptation strategies significantly improves household food security through increased consumer spending, and the likelihood of a household remaining poor decreases (Di Falco et al., 2011; Biru et al., 2020; Tagang et al., 2021; Shita et al., 2021; Zegeye et al., 2022). However, much of this work remains limited. This is the case of the work of Di Falco et al. (2011), Tagang et al. (2021), Etwire et al. (2022), Khanal et al. (2018b), and Zhu et al. (2021), who focused on the impact of adaptation strategies

as a whole or of a single adaptation strategy. In doing so, they fail to consider the multiplicity of adaptation strategies, their complementarity, and possible combinations that can produce different effects. Thus, the literature remains limited on the contribution of climate change adaptation strategies to household food security. Also, among the few studies that consider several adaptation strategies, complementarity and possible combination of strategies are excluded, except for a study by Khonje et al. (2018) and Nonvide (2024). Biru et al. (2020); Khonje et al. (2018), and Nonvide (2024) found that the greatest impact is achieved when farm households combine several complementary coping strategies.

The current study reinforces the literature on the link between climate change adaptation strategies and household food security by moving beyond single-strategy analysis and examining combined adaptation packages within a multinomial endogenous switching regression (MESR) framework. Given the categorical nature of the selection variable, the MESR model is particularly appropriate, as it corrects for selection bias and accounts for unobserved characteristics such as motivation, ability, or risk attitudes that influence adoption decisions (Di Falco et al., 2011; Tagang, 2022; Nonvide, 2023). Unlike commonly used approaches such as instrumental variables (IV) or propensity score matching (PSM), this method allows for the estimation of both ATT and ATU effects, thereby providing more robust causal evidence. Furthermore, by jointly using Food Consumption Score and Dietary Diversity Score indicators, the study offers a multidimensional assessment of food security and reveals heterogeneous, context-specific impacts in semi-arid regions of Cameroon. In line with El Chami et al. (2022), who emphasize the importance of assessing adaptation impacts in vulnerable regions such as Africa and Asia, this research helps fill an important empirical gap and provides timely evidence for Cameroon, where national climate change adaptation plans are currently being developed and implemented.

Against this backdrop, the objective of this research proposal is to analyze the impact of the use of climate change adaptation strategies on household food security in semi-arid areas in Cameroon. Specifically, these are

- To assess the patterns of adaptation strategies used by agricultural households in semi-arid areas of Cameroon.
- To determine the factors that influence the adaptation strategies used by agricultural households in semi-arid areas of Cameroon.
- To assess the impact of adaptation strategies used by agricultural households on food security in semi-arid areas of Cameroon.

2- Literature Review

3.1- Determinants of adaptation to climate change

For several decades, countries in sub-Saharan Africa have been disproportionately vulnerable to climate change due to the increasing frequency and scale of natural disasters (Mahmood et al., 2024). Indeed, this high vulnerability is linked to the fact that climate change negatively affects food security (Musafiri et al., 2022). Faced with the negative implications of climate change on food security, several studies postulate that overcoming this problem requires the implementation of adaptation strategies (Atube et al., 2021; Diallo et al., 2020). To this end, numerous empirical studies have shown that the characteristics of households such as household size, age and education level of the head of household, influence choices in terms of adopting coping strategies (Khanal et al., 2018a). Access to credit, extension services, and climate information also influences by enabling households to move away from traditional adaptation strategies and adopt modern (planned) strategies to better cope with climate change (Bryan et al., 2009; Tagang, 2022). In the face of these changes, socio-economic and institutional characteristics and the type of agro-ecological zone have a positive and overall impact on the adoption of adaptation strategies (Tarfa et al., 2019).

Households use many adaptation strategies in response to the effects of climate change. The main household-level adaptations identified in the literature include the use of soil and water conservation technologies, agroforestry, irrigation, crop diversification, diversification of livelihoods, changes in planting schedules, and high-yielding, drought-tolerant crop varieties (Tagang, 2022; Gebre et al., 2023). Ethiopia is an example of where, due to the shortening of the rainy season, households use biophysical technologies for soil and water conservation; diversification of livelihoods, high-yielding, and drought-tolerant crop varieties (Hilemeleket et al., 2021). In four regions in Niger, households are diversifying crops, diversifying livelihoods, and changing the agricultural calendar in response to lower rainfall (Zakari et al., 2022).

3.2- Impact of climate change adaptation on food security

Some studies have analyzed the impact of climate change adaptation on food security in Cameroon. For example, Molua (2002) observes that the adoption of climate change adaptation strategies, such as changes in soil practices and crop rotation, improves agricultural yields,

which is conducive to strengthening food security in southern Cameroon. Tingem and Rivington (2008) believe that, due to the uncertainty of climate change, changing seed dates is ineffective for agricultural productivity in Cameroon. However, they show that the adoption of late-maturing seeds significantly increases the productivity of maize by 32.1%, sorghum by 17.6%, and groundnuts by 37.1%. This leads to an improvement in the food security of most households that consume their own production. Subsequently, Laux et al. (2010) postulate that changing planting dates in response to climate change improves the productivity and yield of crops such as groundnuts and maize in Cameroon, especially in the drier northern region. This strengthens their food security because of eating habits oriented towards the consumption of groundnuts and maize. Tagang (2022), using propensity score matching and endogenous switching regression on a sample of 721 households, shows that the adoption of adaptation strategies such as diversification of activities, crop association, plant protection, irrigation, and use of early seeds improves sorghum productivity in the semi-arid zone in Cameroon. The adoption of these strategies thus makes it possible to increase sorghum productivity by 1000.40 kg/ha compared to households that have not adopted any strategy. This high productivity thus reinforces the food security of households in the area. Kimengsi et al. (2022) determined through binary logistic regression that the adoption of adaptation strategies such as improved seeds, irrigation, and membership in agricultural groups improves the availability and quality of vegetables in the western highlands of Cameroon. Tsambou and Tagang (2024) show, through the endogenous switching regression method, that the adoption of innovative adaptation strategies improves the productivity of farms in the Sudano-Sahelian zone of Cameroon. This increase in the productivity and yield of agricultural products due to the adoption and use of climate change adaptation strategies is conducive to reducing food insecurity, especially as it provides farmers with socio-economic security.

Outside Cameroon, there are several other studies that have examined the impact of climate change adaptation strategies on food security. Among these studies, Ndiritu and Muricho (2021) analyze the effect of adopting climate change adaptation strategies such as purchasing fodder, water management, shifting livelihoods, and herd management on the food security of 440 agropastoral households in Kenya. Using an endogenous switching regression model, they find that the adoption of these strategies improves food security. Despite the findings, one limitation of the study is that it analyzes adaptation strategies without highlighting the strategies that act more effectively on food security. Vatsa et al. (2023) analyzed the effect of the adoption of climate-smart agricultural innovations on food security in six provinces in China between January and February 2022. Using a conditional mixed process model that

simultaneously estimates ordered probit regression and linear regression, they showed that the adoption of strategies such as soil conservation, improved rice varieties, farm manure, water-saving techniques, and biopesticides reduces food insecurity. Teklu et al. (2024) estimated the effect of adopting climate change adaptation strategies on the food security of 424 smallholder farms using the propensity score matching method and endogenously switching regression. They conclude that agroforestry, crop residue management, and compost use reduce food insecurity through increased household food consumption and dietary diversity in Ethiopia.

Furthermore, Kandel et al. (2024) find through logit models that the adoption of adaptation strategies such as irrigation, temporary migration, and agroforestry significantly reduces food insecurity, especially when farmers have a high level of education and easy access to markets, credit, and information. In addition, Gebre et al. (2023) analyze the determinants of the choice of adaptation strategies and their impact on food security in Tanzania. Using a multivariate probit and an endogenous change regression model, the authors estimate that adopting strategies such as growing early maturing crops, changing planting dates, planting more drought-tolerant crops, and diversifying livelihoods reduces food insecurity. However, these studies did not consider the complementarity between adaptation strategies. Existing literature on climate change adaptation remains underdeveloped in its treatment of the differentiated and interactive effects of adaptive strategies implemented by farming households. While some recent studies acknowledge the diversity of adaptation responses, they largely overlook the structural complementarity and potential synergies arising from the combination of multiple strategies. With few exceptions (e.g., Khonje et al., 2018; Biru et al., 2020; Nonvide, 2024), most empirical contributions conceptualize adaptation as a uniform aggregate process, thereby constraining a nuanced understanding of its implications for food security outcomes. This analytical gap is further compounded by the limited availability of robust empirical evidence, particularly in Global South contexts, as noted by El Chami et al. (2022). Addressing this deficiency, the present study empirically investigates how different strategic configurations of adaptation emphasizing complementarities and interaction effects shape food security among agricultural households.

3- Methodology

The methodology is articulated around the conceptual framework, area of study, the data source, specification of the econometric model and description of variables.

3.1 Conceptual framework

Building on prior research, we conceptualize the response of family farms to the perceived risks associated with climate shocks as a functional relationship (Figure 3). The literature shows that agricultural systems in developing countries are highly vulnerable to climate shocks, particularly in Cameroon, a microcosm of Africa where subsistence farming is prevalent. According to Mendelsohn et al. (1994) and Rosenzweig and Parry (1994), variations in temperature and rainfall directly affect agricultural yields, especially in the rainfed systems prevalent in sub-Saharan Africa. Faced with these risks, adaptation decisions are shaped by the socio-economic characteristics of households. According to Rogers et al. (2014), diffusion of innovations theory, the dissemination of information plays a central role in the decision to adopt adaptive strategies. This theory further emphasizes that adaptation choices are influenced by various factors, including a farmer's socioeconomic characteristics (e.g., gender, age, education), farm-specific attributes (e.g., farm size), societal and geographic context (e.g., agroecological zones, urban versus rural settings), perceived risks (economic, environmental, or security-related), and government support (Deressa et al., 2009; Diendéré & Ouedraogo, 2023; Bekuma et al., 2023). To this end, Barrett et al. (2010) emphasize that households adjust their practices to reduce the risk of irreversible losses, while Below et al. (2010) identify a coherent set of strategies used by small-scale producers. Finally, public policies play a crucial role. Government and NGO interventions, documented by Adger et al. (2005), improve adaptive capacity by strengthening access to agricultural services and credit, and by stabilizing food markets.

Then, empirical studies show that adaptation improves agricultural productivity. Kassie et al. (2013) demonstrate the positive effect of crop diversification, improved varieties, and sustainable practices on productivity, while Di Falco and Veronesi (2013) confirm that adaptation reduces climate-related losses. These gains are reflected in household income, in line with the agricultural models of Sadoulet and Janvry (1995) and Barrett's (2008) analyses of the links between production, markets, and rural income. These mechanisms directly influence food security, defined by the FAO around the dimensions of availability, access, utilization, and stability. Income is a central determinant of dietary diversity (Hoddinott, 1999) and nutritional quality (Headey and Ecker, 2013). Furthermore, some adaptation strategies have a direct effect on food security: Abid et al. (2016) show that crop diversification and other adaptive practices strengthen the stability of food consumption in vulnerable areas. Moreover,

studies suggest that the adoption of such practices improves crop yields for adopting households who also raises incomes and promotes dietary diversification. Furthermore, higher agricultural output may contribute to lower food prices, thereby improving affordability and leading to increased food consumption expenditures (Biru et al., 2020; Mveng et al., 2022; Zegeye et al., 2022).

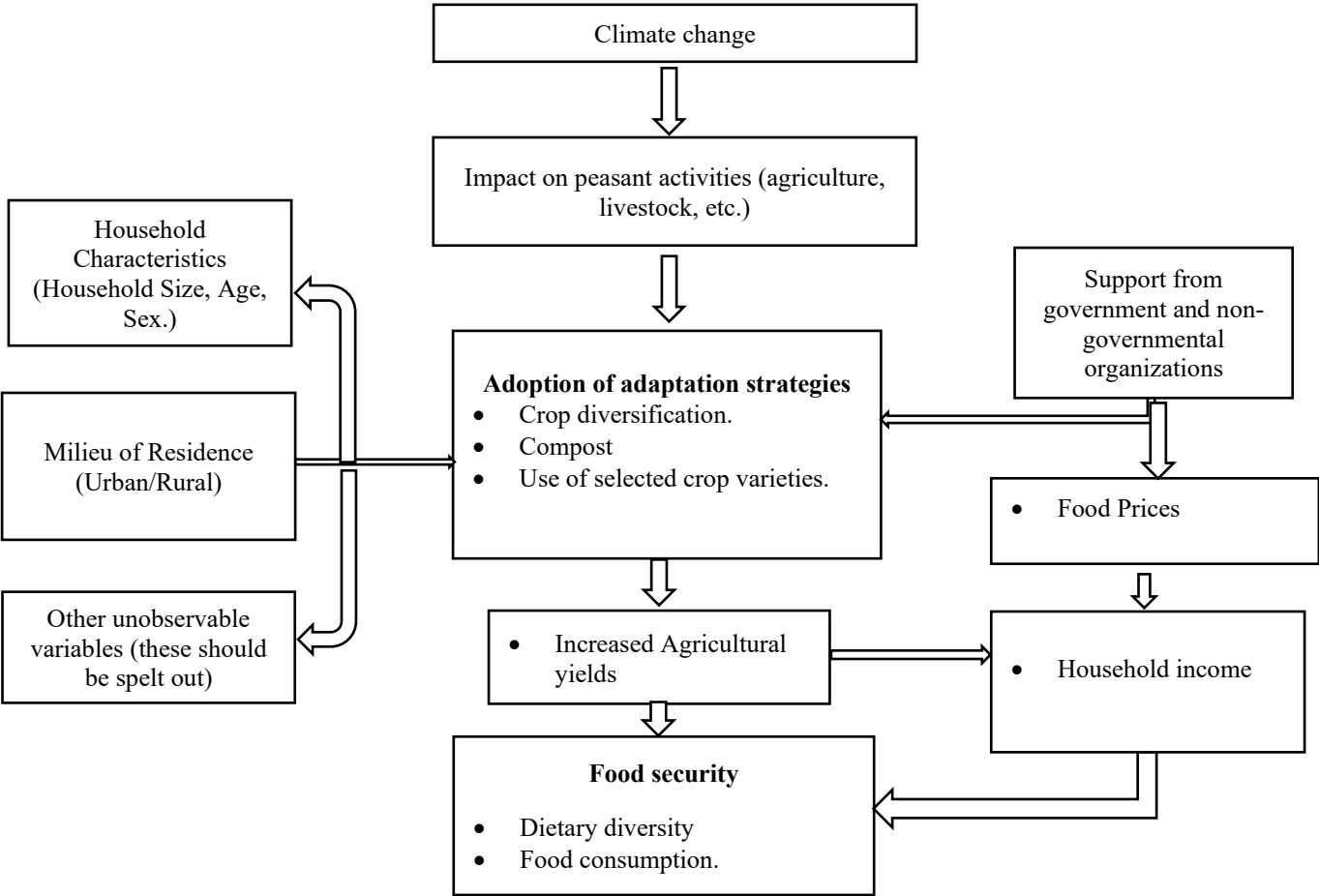


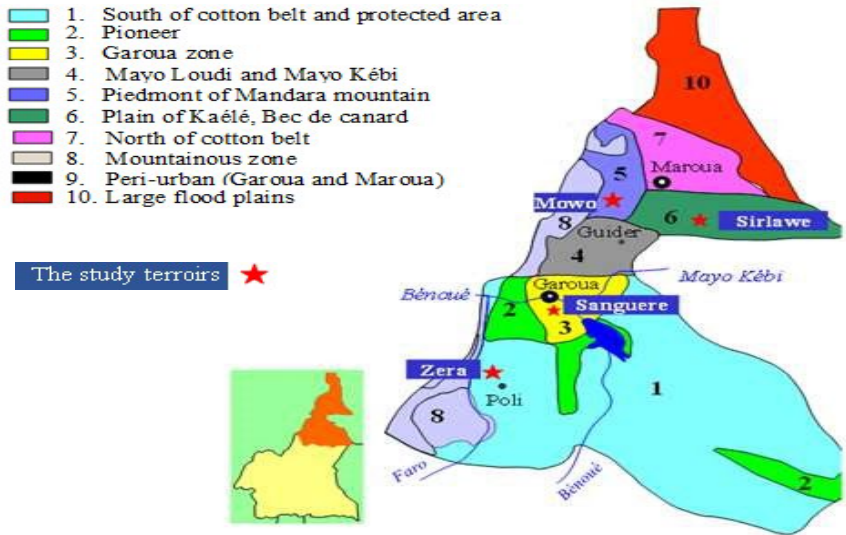
Figure 1: Channels through which climate change impacts food security

3.2 Description of Study Areas

Cameroon has agroecological specificities that represent Africa as a whole. Its poverty rate of 54% is 24 percentage points higher than the average for sub-Saharan Africa (INS, 2017). The country is divided into four major agro-ecological zones: The Southern Rainforests (Eastern, Central, Littoral, and South-West regions), the Western Highlands, the Central Savannah (southern part of the North and Adamawa region), and the semi-arid zone (Far North and North regions) (ONACC, 2019). Agriculture is based on the peasantry, especially the cultivation of cereals (ONACC, 2019). The northern and far northern regions of the semi-arid

zone were chosen because of their history and experience in growing cereals (maize, sorghum, millet, rice, etc.). This zone is in Cameroon's northwestern region. It shares borders with Chad to the north, Nigeria to the west, and the Central African Republic (CAR) to the east. The area is divided into ten departments, encompasses 100,350 km², or 21% of the country's total surface area. Its population is estimated to be around 5,530,643, or 29% of the total population of the country. As shown in Figure 2 on the agro-ecological zoning of Cameroon's North and Far North regions, the region has two distinct seasons: the rainy season, which lasts from June to August, and the dry season, which lasts from September to March.

Figure 2: Agro-ecological Zoning of the semi-arid zone in Cameroon.



Source: Adapted from, Dugué and al. (1994)

3.3 Data Sources

The data used come from secondary sources, collected as part of the project on modelling the impacts of climate change on agriculture in the rural areas of the Extreme North and North regions of Cameroon, led by the National Observatory of Climate Change (ONACC). The survey was conducted during the 2021 agricultural season, on a sample of 1,000 farming households. Using an open-ended questionnaire, it gathers information on the adoption of resilience strategies, the socio-economic and demographic characteristics of farmers, the structure of agricultural production, the socio-institutional environment, and farmers’ perceptions of climate change, and food security.

3.4 Specification of the econometric model.

To analyse the adoption patterns of adaptation strategies, this subsection first reviews the main models used in the literature and highlights their limitations. It then introduces the multinomial logit model, which is applied to examine the determinants of adaptation strategy adoption, and finally presents the multinomial endogenous switching regression model, used to evaluate the impacts of adoption.

Generally, it is difficult to perform an impact analysis on data from non-randomized surveys. The operationalization of this objective requires the consideration of three main biases, namely the bias resulting from self-selection by households, omitted heterogeneities bias and the endogeneity bias. Indeed, households make production decisions about the optimal choice of inputs. These decisions can be modeled based on the expected benefit. A household will adopt one of the coping strategies if the expected benefit of that adoption outweighs the expected benefit of non-adoption (Khonje et al., 2018). This means that the adaptation comes from a decision based on the household's choice. In other words, households in the semi-arid zone adopt one or more simultaneous coping strategies in the hope of improving their food security.

In addition, adaptation to climate change could be endogenous and correlated with disturbances. Beyond observable characteristics, some unobservable characteristics can influence both adaptation and food security. As a result, comparisons between adoptive and non-adoptive households may not provide the causal effects of inclusion and estimation by standard estimation methods such as OLS (Salazar et al. 2016). To overcome these econometric problems, quasi-experimental methods have been adopted in the literature, such as the propensity score matching (PSM). However, the PSM only considers observable characteristics and is limited in correcting for selection bias related to unobservable characteristics (Abdulai et al., 2014; Bourguignon et al., 2007). A related literature postulates that the use of fixed-effect models can overcome this difficulty arising from unobserved heterogeneity by eliminating the effects of constant factors over time. However, this model can be problematic in that it assumes that the model eliminates individuals and explanatory variables, which are also influenced by unobservable factors (Suri, 2011). In addition, the adoption or non-adoption of coping strategies depends on variations in unobservable factors that may affect the sample during the period.

In this study, we use the endogenous switched multinomial model as an impact analysis method, drawing on the work of Di Falco and Veronesi (2013). In robustness, we use the multinomial endogenous processing effect (METE). Unlike the fixed-effect models and the PSM, the MESR and METE models correct for selection and endogeneity bias arising from observable and unobservable factors. These methods have more than one advantage. First, it corrects for selection bias by calculating an inverse Mills ratio (IMR) based on truncated normal distribution theory and latent factor structure (Malikov and Kumbhakar, 2014; Bourguignon et al., 2007). Second, they make it possible to construct counterfactuals based on returns to the characteristics of households that adopt and non-adopt the adaptation strategy (Kassie et al., 2017). Third, they allow an interaction between all climate change adaptation strategies and explanatory variables to capture their effect (Kassie et al., 2017; Di Falco and Veronesi, 2013). Finally, the models identify both the specific impact of each coping strategy on the outcome variables and their possible combination, and allow us to see which strategy has the highest effect on the outcome (Wu and Babcock, 1998).

The Multinomial Endogenous Switching Regression (MESR) is done in two steps. First, a multinomial logistic selection model (MNLS) is used to estimate the adaptation decision through the adoption of one or more simultaneous strategies if this maximizes the utility of the household by considering the unobserved variability. The estimated probabilities used in the MNLS model are used to calculate Mills inverse ratios (RMIs). Then, in the second step, the outcome equation is estimated using ordinary least squares (OLS) to assess each combination of different coping strategies, and RMIs are introduced as additional factors to account for selection bias caused by time-varying unobserved heterogeneity on food security.

• Step One: Multinomial Logistic Model (MNLS)

Using a multinomial logistic model, we evaluate the determinants of the choice of the adoption of one or more strategies and their combination. As introduced above, households will decide to adapt to climate change if this adaptation makes it more useful than in the case of non-adaptation. Here, it is assumed that the household chooses a given Y strategy that maximizes its level of food security (dietary diversity and food consumption scores) by comparing the benefits and gains provided by the set of alternative Y coping strategies. To do this, it would be necessary that $Y_{ij} > Y_{iM}$; with $M \neq j$, in other words, the choice of strategy j , would have to offer a higher expected food security (diversity and food consumption) than any other strategy. The selection equation is written as follows:

$$Y_{ij}^* = X_i \beta_j + \varepsilon_{ij} \quad (1)$$

Where Y_{ij}^* is the latent variable, which represents the choice of whether to use a particular adaptation strategy, influenced by the observed characteristics of the household and the plots farmed, the intensity and type of climatic hazards, the location of households, and unobservable characteristics.

X_i , represents exogenous observable factors, assumed to be uncorrelated with the error term ε_{ij} , expressed by $E(\varepsilon_{ij} | X_i) = 0$. ε_{ij} , represents the unobserved factors and is assumed to be distributed identically, in accordance with Grumbel's theory of independent and irrelevant alternatives. The selection model (1) leads to a multinomial logit model where the probability of adopting the strategy $j(P_{ij})$ is established as follows:

$$P_{ij} = P(\varepsilon_{ij} < 0 | X_i) = \frac{\exp(X_i \beta_j)}{\sum_{M=1}^j \exp(X_i \beta_M)} \quad (2)$$

• Step Two: Endogenous Change Multinomial Regression Model (MERS)

Following the work of Ng'ombe et al. (2017), the present study uses MERS to analyze the impact of the use of a particular adaptation strategy on food security (food consumption score and dietary diversity score), by applying the selection bias correction model. Choosing a strategy leads to equations of different outcomes, with treatment effects being a binary comparison of the actual and counterfactual outcomes of strategy adoption and non-adoption. Thus, households face a set of mutually exclusive adaptation strategy choices, where $j=1$ represents the reference (base) category corresponding to non-adoption of any strategy (CD0DTS0OC0), $j=2$ Improved seed and crops diversification (CD1DTS1OC0), $j=3$ Improved seed and use compost (CD1DTS0OC1); $j=4$ crops diversification and use compost; (CD0DTS1OC1) and $j=5$ crops diversification, Improved seed and use compost (CD1DTS1OC1). The diet equation for each possible regime is therefore given by:

$$\begin{aligned} \text{Re gime1: } Q_{i1} &= Z_i \alpha_1 + \mu_{i1} \\ \text{Re gimej: } Q_{ij} &= Z_i \alpha_j + \mu_{ij} \end{aligned} \quad (3) \text{ if } i=1, \dots, j$$

Where Q_{i1} represents the food security status (dietary diversity and/or food consumption scores) in the set of diets, Z_i represents the set of exogenous variables and the i th household in the diet and μ_{ij} represents the error terms that are distributed with $E(\mu_{ij} | x, z) = 0$ and

$\text{var}(\mu_{ij} | x, z) = \delta_j^2$. The MERS model operates only on the linear assumption that consistent estimates of α_j include the choice correction term from equation (2).

$E(\varepsilon_{ij} | \varepsilon_{i1} \dots \varepsilon_{ij} = \delta_j \sum_{m \neq j}^1 r_j (\varepsilon_{im} - E(\varepsilon_{im})))$ The difference between the error terms of equations (2) and (3) is zero.

Based on this statement, equation (3) can be rewritten as follows:

$$\begin{aligned} \text{Re gime1: } Q_{i1} &= Z_i \alpha_1 + \delta_1 \lambda_1 + \omega_{i1} \\ \text{Re gimej: } Q_{ij} &= Z_i \alpha_j + \delta_j \lambda_j + \omega_{ij} \end{aligned} \quad (4) \text{ with } i=1$$

Where δ_j is the covariance between the ε and μ , where λ_j is the inverse Mills ratio calculated from the probabilities in equation (4) as follows:

$$\lambda_j = \sum_{m \neq j}^j \rho_j \left[\frac{P_{im} \ln(P_{im})}{1 - P_{im}} + \ln(P_{ij}) \right] \quad (5)$$

Where ρ represents the correlation coefficient of ε and μ , while ω_{ij} are the error terms whose values are zero. To account for the heteroscedasticity resulting from the regressors produced by λ_j the standard errors of equation (4) were boosted, since in the multinomial situation there were j-1 adaptation strategies. Drawing on the literature, we use access to climate information via radio, perception of climate change and membership in a peasant organization as an identification tool (khanal et al., 2018; Khonje et al., 2018).

Estimated mean treatment effect (ATT)

To estimate the mean effects of treatment (ATT), a contrary analysis was carried out by comparing the expected outcomes of adopters and non-adopters (Asfaw et al., 2012; Heckman and Vytlačil, 2001).

Food security status (dietary diversity and food consumption scores) with adoption

$$E(Q_{i2} | i = 2) = Z_i \alpha_2 + \delta_2 \lambda_2 \quad (6a)$$

$$E(Q_{ij} | i = j) = Z_i \alpha_j + \delta_j \lambda_j \quad (6b)$$

Food security status (dietary diversity and food consumption scores) without adoption

$$E(Q_{i1} | i = 2) = Z_i \alpha_1 + \delta_j \lambda_2 \quad (7a)$$

$$E(Q_{i1} | i = j) = Z_i \alpha_1 + \delta_j \lambda_j \quad (7b)$$

The ATT is therefore the difference between the expected results of the current and counterfactual scenarios given by equations (6) and (7):

$$ATT = E(Q_{i2} | i = 2) - E(Q_{i1} | i = 2) = z_i (\alpha_2 \alpha_1) + \lambda_2 (\delta_2 - \delta_1) \quad (8)$$

The right-hand side of equation (8) indicates the expected outcome in the average food security status (diversity and food consumption) of adopters, if the characteristics of adopters were similar to those of non-adopters, for example, if adopters had the same characteristics as non-adopters, while is λ_j the selection term that captured all the potential effects of the difference in unobserved variables.

3.5 Estimation issues

The second stage can be estimated using Ordinary Least Squares (OLS), that is, through a linear regression. However, OLS estimates may be biased if α_{ij} is correlated with μ_{ij} , which violates the exogeneity assumption of OLS estimators. Indeed, the variable measuring the choice of adaptation strategies (α_{ij}) may potentially suffer from two issues: self-selection and endogeneity. The simultaneous adoption of multiple climate change adaptation strategies is a self-selective process: farming households decide for themselves whether to adopt multiple strategies simultaneously. Some may be more inclined to adapt than others due to differences in skills, motivation, and risk preferences (Di Falco 2011; Heckman 1979). Moreover, if adaptation to climate change can influence food security, it is also possible that the households that adapt are those who are already relatively better off. This likely reverse causality generates an endogeneity problem. In addition, because the endogenous variable is categorical, particular attention must be paid to model specification to avoid inappropriate estimation (Lokonon and Pilo, 2021).

To address these issues, this study uses a Multinomial Endogenous Switching Regression (MESR). This model allows for correcting selection and endogeneity bias related to the choice of adaptation strategies by simultaneously estimating the selection equation (multinomial choice of strategies) and the outcome equations (food consumption and dietary diversity). The MESR thus accounts for the non-random self-selection of farming households in adaptation

strategies. The use of MESR requires the fulfilment of the exclusion restriction assumption: certain variables must influence the choice of adaptation strategy without directly affecting household food consumption and dietary diversity. In this regard, the following variables are used as instruments: Climate information, Perception of climate change, and Membership in a farmers' organization. In practice, these instruments have been applied in the studies by Khanal (2011), Tagang (2022), and Nonvide (2024). It takes the values 2, 3, 4, and 5 if the farming household considers that adaptation minimizes the negative impacts of climate change on food consumption and dietary diversity, and 1 otherwise. Nonvide (2024) argues that some farming households may not adapt to climate change due to a lack of information or appropriate beliefs. These instrumental variables are assumed to influence the probability of simultaneously adopting the combination of adaptation strategies without directly affecting food consumption and dietary diversity, outside the adaptation channel. An instrument validity test (falsification test) is conducted (Appendices 1 and 2) to verify that they satisfy the exclusion restriction condition, in accordance with previous studies (Asante et al., 2024; Nonvide, 2024). The results indicate that these variables significantly increase the probability of simultaneously adopting adaptation strategies without a direct effect on food consumption and dietary diversity, confirming their validity within the MESR framework.

3.6 Econometric Diagnostic Tests

Before model estimation, multicollinearity among explanatory variables was tested using the Variance Inflation Factor (VIF). An auxiliary Ordinary Least Squares (OLS) regression including all covariates used in the multinomial logit and outcome equations was estimated. The results (Appendix 3) show that all VIF values are well below the critical threshold of 10, with a mean VIF of 1.22. This indicates the absence of severe multicollinearity among the explanatory variables.

3.7 Definition of variables

In this subsection, we present the different variables that allow us to understand the impact of the adoption of climate change adaptation strategies on food security in semi-arid areas in Cameroon (See the table in Appendix 4). To do this, we first present the adaptation variables and the outcome variables.

3.7.1 Adaptation to climate change variables

Many are increasingly using the concept of climate change adaptation to study how economic agents respond to climate change. Adaptation can be defined as an adjustment to reduce vulnerability to change in specific communities (IPCC, 2021). Adapting to climate change is about reducing vulnerability to current and future climate risks. This vulnerability is largely determined by the adaptive capacity of family farms. A given climate event does not affect all members of a community or even a household in the same way, with some households having a greater capacity to cope with a crisis than others. Adaptation to climate change, therefore, depends on several factors. For example, the variable "adaptation to climate change" is binary, with 1 indicating that the household is adapting and 0 indicating that it is not adapting.

In this study, we will analyze four adaptation strategies and their combination including (Improved seed and crops diversification tagged Adaptation 1), (Improved seed and use compost tagged Adaptation 2), (crops diversification and use compost tagged Adaptation 3) and (crops diversification, Improved seed and use compost tagged Adaptation 4) in the model to assess their impacts on food security (i.e., dietary diversity and food consumption scores).

✓ Organic compost (OC)

Compost is a soil and water conservation technique, a local technology that combines water and waste collection and nutrient management in West Africa (Fatondji et al., 2011; Roose et al., 1993). It promotes agricultural production on degraded soils and mitigates the negative effects of droughts, which are frequent during the agricultural season in the Sahel region (Fatondji et al., 2006; Roose et al., 1993). This technique of conserving soils for agricultural production could increase agricultural production and food security in the arid zone. The technique could increase soil water content and water and nutrient use efficiency by trapping water and improving its retention and infiltration into the soil for uptake by plants (Kebenei et al., 2021).

✓ Drought-tolerant seed variety (DTS)

The drought-tolerant seed variety, which could help improve the adaptation of food production in the region (Akinseye et al., 2017). Improved varieties are selected based on their breeding history, phenology (maturity and photoperiod sensitivity), and food productivity in terms of food security (Adam et al., 2018).

✓ **Crop diversification (CD)**

Crop diversification consists of combining varieties grown in the same plot. Varieties must coexist for a significant period of their growth, even if they are not necessarily sown and harvested at the same time. This technique reduces soil depletion, strengthens the plants' natural defenses, and saves water.

3.7.2- Outcome Variables

✓ **The Household Dietary Diversity Score (SDAM)**

The Household Dietary Diversity Score (SDAM) is an indicator that measures the variety of foods consumed by a household over a given period (i.e., 24 hours or 7-days period). It is a supplementary measure of the nutritional quality of the diet, which makes it possible to assess the quality of a household's diet by considering different food groups (Ruel, 2003). While this dietary diversity score can be calculated in different ways, the most widely used approach is the calculation of the dietary diversity score based on the number of food groups consumed by a household over a given period (FAO, 2010). To better reflect a quality diet, we calculated the number of different food groups consumed in the last seven days prior to the survey rather than the number of different foods consumed. This calculation technique makes it possible to find out whether the household has a more diversified diet from a macronutrient than a micronutrient perspective. In addition, this technique also allows us to have a more significant indicator, because by considering the number of different foods, a household can consume four foods from the same group, for example. Based on our sample and the approach of the literature, we grouped foods into 12 food groups³ (Cereals, roots and tubers, vegetables, fruits, meat/poultry/organ meats, eggs, fish and seafood, pods/legumes/nuts, milk and dairy products, oil/fat, sugar/honey, spices/condiments) to calculate the SCDM (Swindale & Bilinsky, 2006).

Dietary diversity scores are calculated by counting the number of food groups consumed in the household during the reference period (last 7 days) as shown by the FANTA III project (Swindale & Ohri-Vachaspati, 2005). This involves creating a binary variable that takes 1 if the household consumed the food group and 0 otherwise, and then summing all the food groups included in the score. This gives you a score between 0 and 12. The higher the score, the more

³ This set of food groups is taken from the Food and Agriculture Organization of the United Nations. Table of Food Composition for Africa. Rome, Italy, 1970. To be consulted at the following address: www.fao.org/docrep/003/X6877E/X6877E00.htm

food diversity and food security households have. The mathematical formulation for determining SDAM is as follows:

$$SDAM_i = \sum_{j=1}^{12} \rho_j = \sum (A + B + C + D + E + F + G + H + I + J + K + L) \quad (4)$$

With $SDAM_i$ household dietary diversity scores i and the number of food groups consumed during the reference period (last 7 days) by household members. The values for A to L are either "0" or "1". ρ_j

✓ The Household Food Consumption Score (SCAM)

To construct the household consumption score, we use the World Food Programme's standard method. During the survey, a section of the questionnaire was reserved for food safety. Households surveyed were asked how often they consumed different foods consumed in the previous seven days. We have grouped these foods into 9 food groups (Main Commodities, Legumes, Vegetables, Fruits, Meat/Fish, Milk, Sweets, Oil, Condiments) as shown by the Food Programme (World Food Programme, 2009). We calculated the SCAM by summing the consumption frequencies and multiplying by the standardised weight of the food groups (see Table 2 below). Standard weights are given by the World Food Programme (2009). To do this, we used a multi-step process, as shown in the literature (Wiesmann et al., 2009; Leroy et al., 2015).

- Step 1: Group foods into specified food groups.
- Step 2: Add up all the frequencies of consumption of foods in the same group.
- Step 3. Multiply the value of each food group by its weight (see Table 2).
- Step 4. Add the weighted scores of the food groups to obtain the SCAM.
- Step 5. Determine the household's food consumption status based on the following thresholds: 0-21: Poor; 21.5-35: Limit; >35: Acceptable. These thresholds have been defined by the MAP.

$$SCAM_i = \sum_{j=1}^9 X_{ij} \varphi_{ij} = X_{i1} \varphi_1 + X_{i2} \varphi_2 + X_{i3} \varphi_3 + X_{i4} \varphi_4 + X_{i5} \varphi_5 + X_{i6} \varphi_6 + X_{i7} \varphi_7 + X_{i8} \varphi_8 + X_{i9} \varphi_9 \quad (5)$$

Table (Appendix 6) shows the nutrient weights or densities of food groups according to the World Food Programme (2009). The highest weight was assigned to foods with relatively high energy, good-quality protein, and a wide range of micronutrients that can be easily absorbed. Table (Appendix 6) presents the measures of household food consumption indicators.

4- Result

In this section, we will present the descriptive statistics, the results of the assessment of adaptation strategies, the determinants of adaptation, and finally the results of the impact of adaptation strategies on food security.

4.1- Descriptive Statistics

Table 1 presents the significant differences between households that do not use adaptation strategies and those using all climate change adaptation strategies (Adaptation 4). In this study, four adaptation strategies were identified based on the combination of practices adopted by households. Adaptation 1 corresponds to the use of improved seeds jointly with crop diversification. Adaptation 2 combines improved seeds and the use of compost, while Adaptation 3 involves crop diversification together with the use of compost. Finally, Adaptation 4 represents the most comprehensive strategy, combining improved seeds, crop diversification, and compost use simultaneously. This typology allows for a clearer understanding of how different levels of adaptation practices influence household outcomes and their capacity to cope with climate variability.

The results show that the adoption of certain strategies, including the use of improved seeds, crop diversification, or combinations of all adaptation strategies (Adaptation 2 and Adaptation 4), is associated with improved diversity and food consumption scores. Thus, adoptive households generally have better food security than those that do not use any adaptation strategy. In addition, informational and institutional factors appear to be decisive. Households with climate information, a clear perception of the effects of climate change, and belonging to a farmer organization will significantly utilize any and all of the adaptation strategies relative to the non-users. On the socio-economic level, education plays a positive role, while lack of education is more common among the maladjusted. Similarly, the results indicate that larger farms with more government support are more likely to use adaptation measures.

Finally, the difference test comparing households without a strategy and those using all strategies (Adaptation 4) confirms the existence of statistically significant differences in access to information, perception of climate change, organizational affiliation, rainfall received, and farm size. These results highlight that the use of adaptation strategies is conditioned not only by biophysical and climatic factors, but also by socio-economic and institutional dimensions.

Table 1: Descriptive statistics according to the different strategies adopted

Variables	Climate Change Adaptation Strategies								Test t (No Adaptation and Adaptation 4)
	No strategy	Improved seeds	Crop diversification	Use of compost	Adaptation1	Adaptation2	Adaptation3	Adaptation 4	
Dependent variables									
Dietary Diversity Score	7.76	9.57	7.43	8.41	7.87	9.58	7.90	8	0.14
Food Consumption Score	39.35	46.15	39.14	41.11	40.06	42.74	38.45	41.59	3.66
Instrumental variables									
Climate information (%)	18.75	23.14	45.09	19.90	39.65	13.40	31.50	40.30	25.19***
Perception of climate change (%)	78.4	85.18	94.01	86.06	98.27	82.68	89.04	97.40	20.89***
Membership in a farmers' organisation (%)	18.75	36.11	30.02	29.35	29.31	31.28	28.76	42.80	30.20***
Socioeconomic variables									
Gender of head of household (males) (%)	73.29	72.22	90.04	58.70	93.10	63.12	75.34	87	23.15**
Age (%)	55	61	62.06	67.4	58.7	67.5	64.7	56.50	-4.5
Marital status (Married) (%)	80.11	80.37	94.09	68.15	87.93	70.94	79.45	84.40	4.12**
Sahelian zone (%)	76.70	57.40	94.07	33.33	89.65	13.96	57.53	81.80	20.9**
Savannah area (%)	23.29	42.59	6.01	66.67	10.34	86.03	42.46	18.20	-4.97**
Christian religion (%)	53.40	49.07	57.08	59.20	58.62	73.74	58.90	57.10	4.1
Muslim religion (%)	44.88	45.37	41.07	28.35	39.65	20.11	27.39	32.50	-12.7*
Uneducated (%)	48.86	19.44	45.05	15.92	3448	12.84	23.28	33.80	-15.9
Primary education (%)	28.97	45.37	43	28.35	43.10	27.93	41.09	40.30	14.35*
Secondary education (%)	18.18	21.29	12	38.30	13.79	42.45	23.28	22.10	3.2
Household size	7.37	7.54	9.21	7.09	8.40	6.24	7.65	8.38	1.31*
Farming experience (%)	92.61	87.96	80.04	90.04	67.24	86.03	79.45	75.30	-16.84**
Average income (%)	44.88	30.84	32.02	45	27.58	51.95	41.09	33.80	-8.6
Landowners (%)	55.11	57.4	72.05	46.26	62.06	37.43	64.38	67.50	14.5*
Government assistance (%)	15.90	25.92	36.02	21.39	22.41	10.05	21.91	33.8	21.71***
Precipitation 2020	113.01	121.91	110.05	111.22	118.95	118.46	103.96	106.35	6.65**
Precipitation 2021	116.08	124.54	113.53	113.95	121.33	121.53	106.55	109..30	6.78**
Farm size (hectare)	1.78	1.98	3.21	2.51	2.61	2.26	4.11	3.76	-1.97***

Figure 3 presents the food diversification score according to the different coping strategies adopted. Thus, households that use improved seeds and simultaneously use improved seeds and diversified crops (Adaptation 2) had the highest dietary diversity scores of 9.57 and 9.58, respectively.

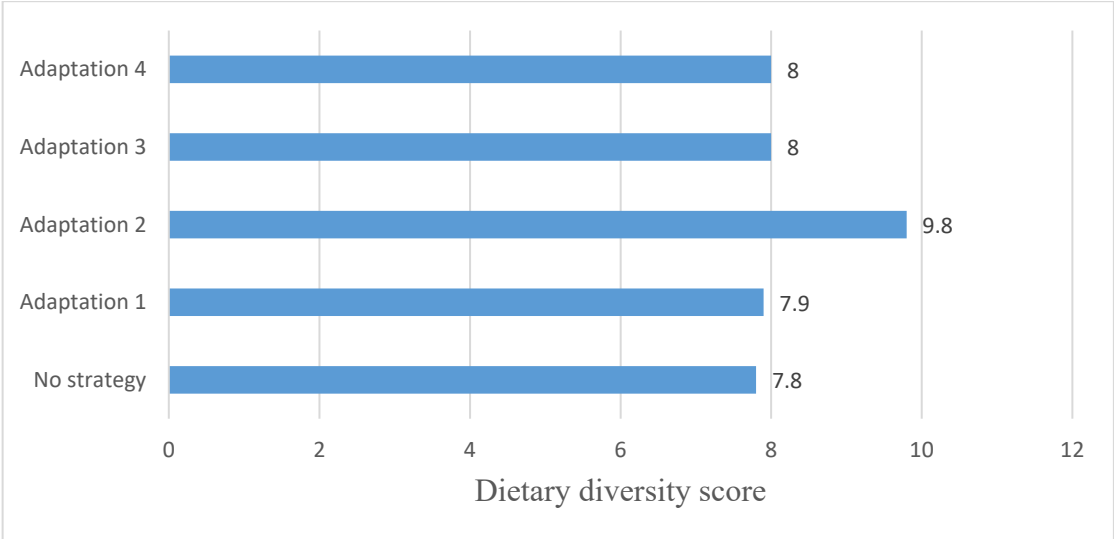


Figure 3: Dietary diversity score by adoption status

Figure 4 presents the food consumption score according to the different coping strategies used. Thus, households that used improved seeds and simultaneously used improved seeds and diversified crops had the highest food consumption scores of 46.15 and 42.74, respectively.

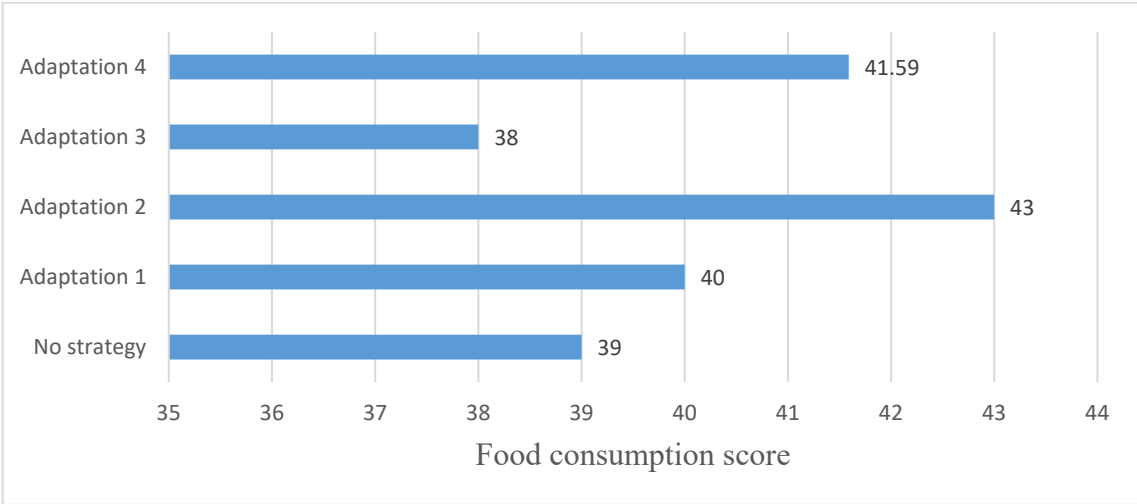


Figure 4: Food Consumption Score by Adoption Status

4.2- Evaluation of adaptation strategies

According to Fabre (2010) and Jouve (2010), rural households mainly use three types of adaptation strategies: the use of improved seeds, crop diversification, and composting. These practices are widely recognized in the literature for their positive effects. Indeed, improved seeds, especially drought-tolerant varieties, strengthen agricultural adaptation by securing harvests in the face of climatic hazards (Hellin et al., 2012). Crop diversification helps stabilize production systems and improve dietary diversity (Sibhatu et al., 2015). Finally, composting helps to restore soil fertility, improve water retention, and reduce dependence on chemical fertilizers (Palm et al., 2001). These strategies can be seen either as proactive, when they aim to limit climate-related risks, or as reactive, when they address them. However, in the Cameroonian context, survey results show that households do not limit themselves to a single strategy but frequently combine several practices. To account for this reality and to ensure a statistically robust analysis, the study focuses only on five modalities: non-adaptation and four combined forms of adaptation. More specifically, these are Adaptation 1: improved seeds + diversification (6.47% of households), Adaptation 2: improved seeds + compost (19.96%), Adaptation 3: diversification + compost (8.14%), and Adaptation 4: improved seeds + diversification + compost (8.25%) as shown in Figure 5.

The choice to retain these modalities is based on three main arguments. First, they correspond to the prevailing practices observed in the field and reflect the actual behaviour of households in the face of climate change. Second, their statistical weight is sufficient to allow a reliable econometric estimate, unlike other marginal strategies whose representativeness is low. Finally, these combinations are in line with the conclusions of several studies (Deressa et al., 2009), according to which vulnerable households tend to multiply responses in order to simultaneously reduce several types of climate and economic risks. Ultimately, the empirical analysis therefore focuses on the comparison between non-adaptation and the four combined forms of adaptation (Adaptation 1 to 4), which offer a relevant analytical framework for understanding the determinants and effects of adaptation strategies in the semi-arid areas of Cameroon.

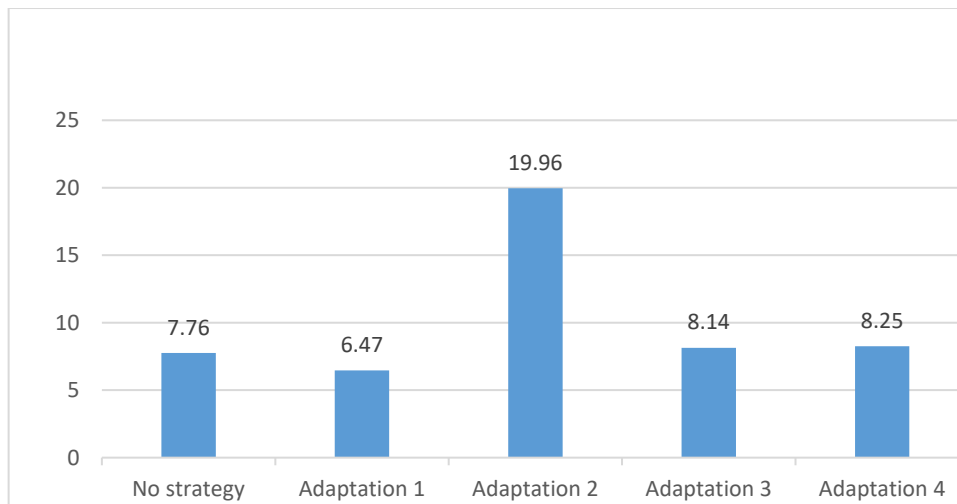


Figure 5: Percentages of households by adaptation strategies adopted

In analyzing adaptation strategies across the different agro-ecological zones, it should be noted that households in the Sahel zone are the ones that have used the most adaptation strategies. On the other hand, 89.66% simultaneously used drought-tolerant improved seeds and diversified crops (i.e., adaptation 1), 57.53% used diversified crops and compost (i.e., adaptation 3), while 53.30% used all three ranges of adaptation strategies (i.e., adaptation 4). Households in the savannah zone used compost most frequently, and simultaneously used a combination of improved drought-tolerant seeds and compost (86.03%), known as adaptation 2, as shown in Figure 6.

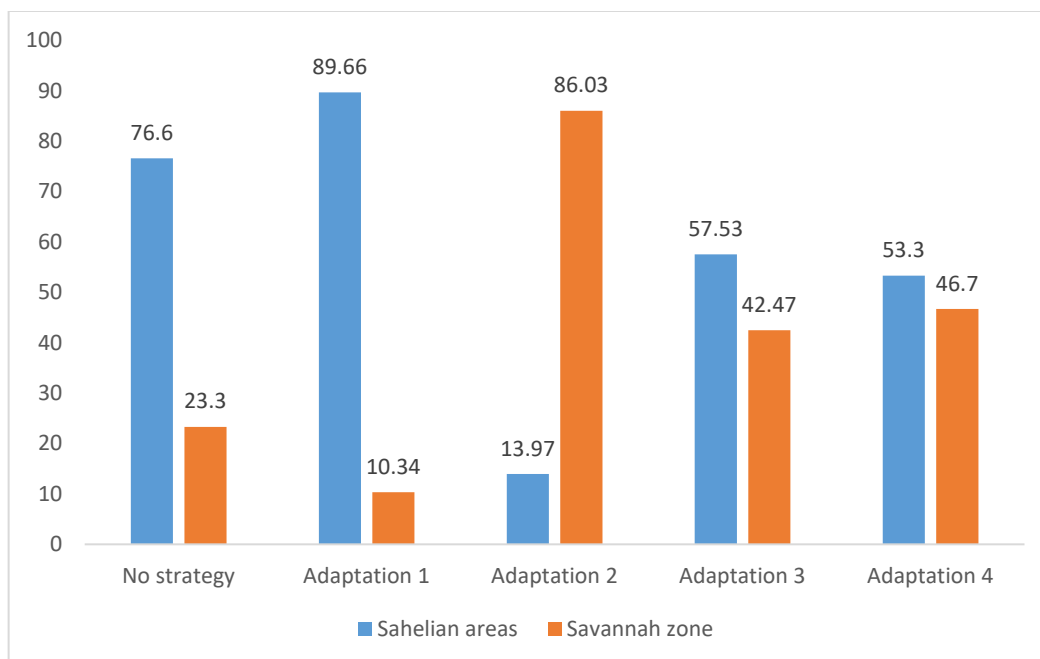


Figure 6: Percentage of households by adaptation strategies and by agro-ecological zone

This disparity in the use of adaptation strategies at the level of agro-ecological zones is justified by several constraints (see Figure 7). First, there is a lack of information (risks, effectiveness) on strategies. Secondly, the lack of financial means and high prices of agricultural inputs on the market, and finally, a strong preference for mystical beliefs to the detriment of the use of climate change adaptation strategies.

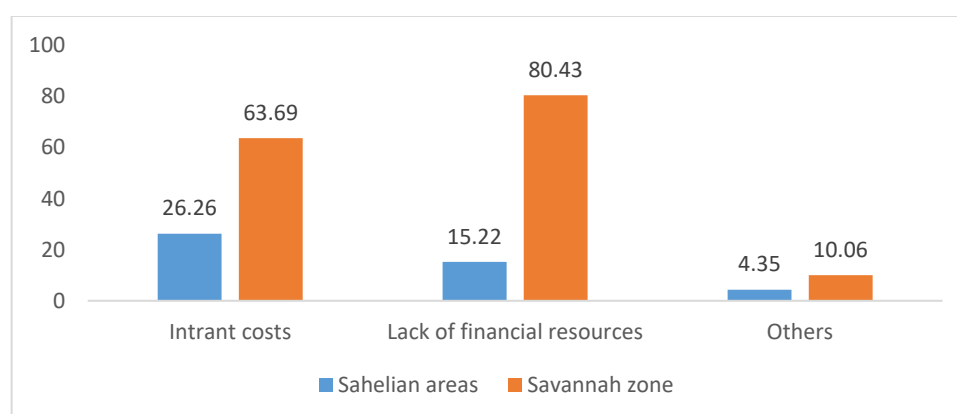


Figure 7: Percentage of households by barriers to adaptation and by agro-ecological zones

4.3- Determinants of the choice of adaptation strategies by households in the semi-arid zone of Cameroon

This section examines the factors influencing the simultaneous adoption of climate change adaptation strategies and evaluates their impact on food security. The multinomial logit model was estimated using 634 observations, with “no adaptation” defined as the base outcome. Accordingly, lack of adoption serves as the reference category against which the six mutually exclusive adaptation strategies are compared, leading to six sets of estimated parameters. The overall model is statistically significant, as confirmed by the Wald $\chi^2(119) = 434.47$ ($p < 0.000$), indicating that the explanatory variables jointly influence households’ decisions to adopt different adaptation strategies. This result rejects the null hypothesis that all regression coefficients are jointly equal to zero. In addition, the pseudo R^2 value of 0.1667 reflects a satisfactory explanatory power, acceptable for multinomial models where relatively low R^2 values are common. The log pseudolikelihood of -1062.3193 further provides an indication of

the model's goodness of fit and supports the reliability of the estimated parameters for subsequent interpretation.

The results in Table 2 indicate that several socioeconomic, climatic, and farm-related factors significantly influence the adoption of adaptation strategies by farm households. The age of the head of household appears to be an important determinant. Although older household heads have more experience, they are less likely to adopt the full range of coping strategies, suggesting a lower willingness to take risks or change their farming practices. Consistently, age negatively affects the adoption of the combined strategy, with older households being 5.2% less likely to adopt it. Education plays a critical role in shaping adaptation choices. Households with no or only primary education are less likely to adopt crop diversification combined with improved seeds, with adoption probabilities reduced by 5.3% and 23.9%, respectively, whereas secondary education increases the likelihood of adopting improved seeds with compost by 8.1%. These results show that the knowledge and skills acquired through education facilitate the use of more complex or combined agricultural practices. Farming experience, while generally considered an asset, has mixed effects on the adoption of adaptation strategies. It can reduce the use of some combinations, such as improved seed with compost or diversification with compost, suggesting that experienced farmers may favor traditional practices. Specifically, it slightly decreases the probability of adopting crop diversification with improved seeds (6.6%) but substantially increases the likelihood of using the combined strategy of improved seeds, crop diversification, and compost (7.4%). Average income has a negative effect on some strategy combinations. Specifically, higher-income households are about 6.4% less likely to adopt the improved seed and compost strategy, suggesting that wealthier farmers may prefer alternative practices or consider this combination less suitable for their needs. Religious affiliation has a limited impact; for instance, Christian households are slightly more likely to adopt the improved seed and compost combination (7.4%). Climatic variables strongly influence the adoption of adaptation strategies. Precipitation in 2020 reduced the use of improved seeds with compost by 8% but increased the adoption of crop diversification with compost by 4.1%, reflecting households' adjustments to adverse conditions that year. In contrast, higher rainfall in 2021 increased the likelihood of adopting improved seeds with compost by 8.2% while slightly reducing the adoption of crop diversification with compost by 4%, indicating that households adjusted their strategies in response to annual climate variations. Location in the Sahelian zone also affects the use of adaptation strategies. Some households were less inclined to adopt certain combinations, likely due to agroecological constraints specific to this zone, while other strategies were used more frequently, reflecting contextual

adaptation to local conditions. In particular, households in the Sahel zone are substantially less likely to adopt improved seeds with compost, with adoption reduced by 23%.

Farm size has a positive and significant effect on the simultaneous use of several adaptation strategies, reflecting a greater capacity to invest in and experiment with different practices on larger areas. Specifically, each additional hectare slightly increases the adoption of improved seeds with compost by 1.1%, crop diversification with compost by 1.2%, and the combined strategy by 0.8%. In contrast, landowner status does not significantly influence strategy use, suggesting that formal land tenure is not a determining factor in the studied context. Overall, these results indicate that both household characteristics and environmental conditions shape the adoption of agricultural adaptation strategies, with the magnitude and direction of effects varying according to the specific combination of practices.

Overall, the results show that the use of adaptation strategies is highly dependent on the mix of practices considered. Socio-economic factors such as age, education, experience, and income, annual climatic conditions, and geographical location, as well as farm size, are the main determinants. These observations underscore the importance of considering both the individual and environmental context of households in order to understand their choices and guide policy to support agricultural adaptation.

The analysis of the results highlights several important lessons concerning the use of adaptation strategies by farm households. The negative effect of age suggests that older farmers, although experienced, are less willing to take risks and invest in new practices, while younger farmers are not. This finding contrasts with those of Onyeneke (2020) and Khanal et al. (2018b), who indicated a positive but not significant effect of age on the simultaneous use of strategies. The unexpected effect of education, which is negative on certain combinations, also deviates from the results of Tagang (2022), which showed that education promotes adoption in the Sudano-Sahelian zone. This indicates that, in the context studied, education does not automatically guarantee better integration of coping strategies. In addition, agricultural experience has a negative effect on certain combinations, which can be explained by a preference for traditional practices or an increased confidence in endogenous knowledge, limiting the simultaneous use of new practices. Average income also had a negative effect on some combinations, suggesting that households with financial resources may diversify their activities away from rainfed agriculture and invest less simultaneously in several agricultural strategies. Rainfall strongly influences household choices. Favourable rains stimulate the use of improved seeds, while rainfall anomalies reduce some combined strategies, such as diversification and compost use. These results confirm that farmers adjust their decisions

according to annual climatic conditions, which is in line with the findings of Deressa et al. (2009) and Alam et al. (2016), who showed that climate variability is a key factor in the use of adaptive agricultural practices. The location in the Sahel zone also plays an important role: increased exposure to climatic hazards encourages households to diversify and combine their practices to secure yields in the face of uncertainty. Furthermore, the size of the farm positively influences the simultaneous use of several strategies. Large farms have greater resources and investment capacities, allowing them to implement more complex combinations of practices, which is in line with the findings of Aryal et al. (2018) and Maguza-Tembo et al. (2017). In contrast, landowner status has no significant effect, suggesting that formally securing of land rights is not a key determinant of concurrent use of adaptation strategy in the context studied.

Overall, these results underscore the fact that the use of adaptation strategies depends on socio-economic characteristics, climatic conditions, and available resources. Younger farmers and those with larger farms are more likely to combine multiple practices, while experience and income influence differently depending on the combination. The analysis thus highlights the importance of adaptation strategy interventions to household specificities and local agroclimatic conditions to improve the effectiveness of the strategies.

Table 2: determinants of households' choice of coping strategies

Variables:	Adapted households								
	Non-Adapter Households	Crop diversification & improved seeds (Adaptation 1)		Improved seed & compost (adaptation 2)		Crop Diversification & Use of Compost (Adaptation 3)		Improved seeds + Crop diversification & compost (Adaptation 4)	
	Coef	dy/dx	Coef	dy/dx	Coef	dy/dx	Coef	dy/dx	Coef
Socioeconomic variables									
Gender (male)	-2.480	0.027	1.144(0.023)	-0.006	0.210(0.030)	0.051	1.160(0.044)	0.006	0.660(0.037)
Age	-1.890	-0.005	0.292(0.019)	-0.007	0.240(0.029)	0.036	1.360(0.027)	-0.052**	-0.150**(0.024)
Married (1)	0.180	-0.033	-0.562(0.024)	0.028	-0.880(0.038)	0.045	0.860(0.052)	-0.006	-0.140(0.040)
Christian	0.354	-0.055	-1.140(0.396)	-0.074*	0.107*(0.330)	0.117	-0.383(0.767)	0.133	-1.433(0.750)
Muslim	0.904	-0.045	-1.145(0.770)	0.045	0.057(0.568)	-0.345	-0.688(0.787)	-0.654	-2.055(0.758)
No education	2.830	-0.053*	1.680*(0.031)	-0.029	-1.180(0.037)	-0.015	-0.530(0.028)	-0.007	-0.250(0.027)
Primary education	0.543	-0.239*	1.439*(0.641)	0.087	0.543(0.546)	0.323	1.226(1.190)	0.087	1.566(1.203)
Secondary education	2.230	-0.020	-0.870(0.023)	-0.081**	0.050**(0.035)	0.051	1.340(0.038)	0.020	0.610(0.032)
Household size	-0.420	0.003	1.260(0.002)	0.004	-0.640(0.003)	-0.002	-0.760(0.003)	-0.002	-0.750(0.003)
Average income	0.710	-0.007	-0.320(0.020)	-0.064**	-0.200**(0.029)	0.028	1.050(0.027)	-0.016	-0.690(0.023)
Landowners	0.350	-0.016	-0.800(0.020)	-0.032	-0.130(0.028)	-0.011	-0.380(0.028)	0.022	0.820(0.027)
Agricultural experience	2.450	0.035	-0.210(0.032)	-0.066*	-1.870*(0.035)	-0.044	-1.510(0.029)	-0.074***	0.770***(0.03)
Climate variables									
Précipitation_2020	-0.240	0.016	0.880(0.018)	-0.08***	-0.510***(0.018)	0.041**	2.480**(0.016)	-0.016	-1.490(0.011)
Précipitation_20211	0.240	-0.017	-0.990(0.018)	0.082***	0.570***(0.017)	-0.04***	2.710***(0.02)	0.014	1.330(0.011)
Government assistance	-2.200	0.055	1.300(0.042)	-0.000	0.710(0.039)	-0.012	-0.310(0.037)	0.002	0.060(0.032)
Sahel Zone	1.240	-0.088	-2.570(0.056)	-0.23***	-2.530***(0.073)	0.063	1.540(0.041)	0.026	0.870(0.029)
Farm size (hectare)	-3.740	0.000	0.268(0.008)	0.011*	0.322*(0.007)	0.012*	0.950*(0.006)	0.008*	1.880*(0.004)
Constant	-2.876		-12.75		-3.80		2.94		-0.78

Note: The numbers in brackets give the corrected standard deviations of heteroscedasticity. Significance *** p<0.01; ** p<0.005; * p<0.05.

4.4- Determinants of food security (FOC) and dietary diversity (DDS) by Adaptation strategy

After identifying the factors for the adoption of adaptation strategies, the analysis focused on their impact on household food security, as measured by the food consumption score (Table 3). The cut-off coefficients m_1 to m_5 reveal that some strategies move households between food score categories. For example, m_1 is strongly negative and significant for Adaptation 1, indicating a shift to lower score categories, while m_2 and m_4 are also significant for some strategies. The correlations of ρ_1 to ρ_5 errors show that unobserved factors influence food security. ρ_1 is positive and significant for Adaptation 1, while ρ_2 is significant and negative for the no-strategy score and Adaptation 3. Finally, the residual σ^2 variance is significant for several strategies, confirming that unobserved factors play an important role in determining food security. The cut-off coefficients m_1 to m_5 indicate that certain strategies are effective in improving the position of households in the distribution of food scores. Error correlations (ρ) suggest that unobserved factors, such as market access or local social networks, influence food security and interact with certain strategies (Tsambou and Tagang, 2024). The significance of σ^2 confirms that elements not captured by the model contribute to the variability of food scores.

Prior to discussing the effects of individual variables on food security, we first examine the diagnostics of the multivariate model, including the parameters $_m_1$ to $_m_5$, ρ_1 to ρ_5 , and σ^2 . The latent utility parameters ($_m_1$ - $_m_5$) represent the baseline effects of each adaptation strategy. Their significance indicates that the model captures a meaningful portion of the variation in food security associated with each strategy. For instance, $_m_1$ for Adaptation 1 is negative and highly significant, reflecting a lower baseline impact of this strategy on the Food Consumption Score relative to households that did not adopt any strategy. Other significant $_m$ -values confirm that each strategy contributes distinctly to explaining variation in food security outcomes.

The residual correlations (ρ_1 - ρ_5) measure the interdependence of adoption decisions across strategies. Positive and significant values, such as ρ_1 for Adaptation 1, suggest that unobserved factors increase the likelihood of adopting multiple strategies simultaneously, whereas significant negative values, like ρ_2 for Adaptation 1, indicate that unobserved factors reduce the probability of concurrent adoption. These results validate the use of a multivariate approach, as strategy choices are interrelated.

Finally, σ^2 represents the residual variance for each strategy equation. High and

significant σ^2 values, for example, for Adaptation 2, indicate that although the covariates explain a substantial part of the variation in food security, there remains unexplained heterogeneity across households and local conditions.

Overall, these diagnostics confirm that the model is statistically appropriate and robust for analyzing the effects of climate change adaptation strategies on household food security.

Results from Table 3 indicate that certain socioeconomic variables significantly influence the food score. The results indicate that the impact of climate change adaptation strategies on food security varies according to the type of adaptation strategy and household characteristics. For Adaptation 1, the Food Consumption Score is significantly lower for households located in the Sahelian zone, for Christian households, for those with only primary education, for landowners, and for households not receiving instructions on the adaptation strategy. These findings suggest that Adaptation 1 is less effective in arid or vulnerable areas, among certain religious groups, and for less-educated households, highlighting the importance of guidance and training for effective implementation. For Adaptation 2, average household income is positively and significantly associated with the Food Consumption Score, indicating that wealthier households benefit more from this adaptation. This suggests that Adaptation 2 may require financial resources or investment to enhance food security. Regarding Adaptation 3, household size has a significant negative effect on the Food Consumption Score, suggesting that larger households gain less from this Adaptation strategy, likely due to limited resource distribution or difficulties in applying the Adaptation strategy at a larger scale. Finally, for households adopting no adaptation strategy, average income is positively associated with the Food Consumption Score, while precipitation exhibits contrasting effects: rainfall in 2020 increases the score, whereas rainfall in 2021 decreases it, highlighting the direct influence of climatic conditions on food security even in the absence of adaptation strategies.

The significant effects of household income and education indicate that households with greater financial resources and higher levels of education benefit more from climate change adaptation strategies, which aligns with the findings of Etwire et al. (2022) and Tagang et al. (2021). Specifically, for Adaptation 1, the Food Consumption Score is significantly lower for households located in the Sahelian zone, for Christian households, for those with only primary education, for landowners, and for households not receiving instructions on the strategy. These results suggest that Adaptation 1 is less effective in arid or vulnerable areas, among certain social groups, and for less-educated households, highlighting the critical role of guidance and training for successful implementation.

For Adaptation 2, average household income is positively and significantly associated

with the Food Consumption Score, indicating that wealthier households gain more from this strategy. This suggests that Adaptation 2 may require financial resources or investments to enhance food security effectively. In the case of Adaptation 3, household size has a significant negative effect, implying that larger households may benefit less from this strategy, likely due to challenges in resource distribution or scaling the adaptation effectively.

For households using no adaptation strategy, average income is positively associated with the Food Consumption Score, while precipitation has contrasting effects: rainfall in 2020 increases the score, whereas rainfall in 2021 decreases it. These findings underscore the direct influence of climatic conditions on food security even in the absence of adaptation strategies.

Overall, these results indicate that the use of adaptation strategies improves household food security, but their effectiveness depends on household characteristics, local context, and guidance for implementation. Rainfall directly affects food security outcomes, but strategies can reduce vulnerability to climatic variations, in line with the observations of Deressa et al. (2009) and Alam et al. (2016). While the use of adaptation strategies generally enhances food consumption and household well-being, consistent with Nonvide (2024) and Diallo et al. (2020), in some contexts, such as Lebanon, combined strategies do not always improve food security (Al Dirani et al., 2021), emphasizing the importance of local context and careful management of trade-offs between strategies.

Table 3: Parameter estimates of food security by climate change adaptation strategies use

	Food Consumption Score (No Strategy)	Food Consumption Score (Adaptation 1)	Food Consumption Score (Adaptation 2)	Food Consumption Score (Adaptation 3)	Food Consumption Score (Adaptation 4)
Gender (male)	-8.200(5.563)	41.854(34.312)	22.675(41.464)	0.564(27.726)	15.952(70.990)
Age	1.295(9.935)	0.408(16.017)	3.652(39.782)	-8.168(18.262)	27.037(253.396)
Marital	-18.74(11.827)	29.846(26.349)	6.176(12.076)	7.711(15.752)	24.657(57.226)
Sahelian zone	28.219(26.710)	-65.785*(38.456)	32.234(21.33)	36.149(23.641)	117.284(156.052)
Christian	-13.693(23.625)	-82.646*** (30.045)	24.985(275.255)	-1.557(20.160)	23.616(232.022)
Muslim	-26.304(34.277)	-51.199(46.927)	30.267(223.963)	-10.157(21.042)	66.379(323.701)
No instructions	18.841(21.523)	-100.754*** (35.805)	-26.961(186.836)	34.305(36.562)	26.113(831.365)
Primary education	15.538(19.512)	-68.499*(37.098)	-45.435(159.927)	25.238(24.443)	10.624(689.412)
Secondary education	0.571(1.108)	-17.769(30.776)	-13.388(71.269)	35.829(22.954)	20.260(388.112)
Household size	0.056(0.653)	0.331(0.716)	0.455(0.671)	-1.364*** (0.500)	-2.125(4.670)
Agricultural experience	-7.788(8.280)	-2.934(15.382)	38.798(40.690)	8.698(8.225)	-2.433(369.177)
Average income	6.662** (2.629)	-2.388(10.044)	32.817*** (7.750)	3.752(10.027)	11.591(152.182)
Landowner	-2.520(2.425)	-15.613* (8.012)	-13.449(112.229)	6.508(5.041)	6.829(8.117)
Government assistance	6.465(18.383)	-6.431(29.414)	-46.437(63.717)	-17.635(14.541)	-45.828(396.323)
Precipitation_2020	10.843** (5.114)	-22.001(18.222)	0.196(83.485)	3.245(12.645)	-9.750(65.558)
Precipitation_2021	-11.180** (4.535)	21.297(19.071)	-0.786(93.600)	-3.832(12.899)	15.366(62.790)
Area	5.390(4.973)	0.861(5.412)	-0.801(8596)	0.450(4.798)	2.285(9.933)
_m1	86.0541(80.447)	-103.342*** (29.458)	113.701(240.031)	-24.34(15.4)	-47.100(31.159)
_m2	16.596(18.720)	-35.842** (6.138)	161.608(596.170)	-82.452* (22.48)	-16.392(31.534)
_m3	-48.158** (14.574)	18.138(33.069)	-112.022(219.885)	-61.30(40.258)	4.569(52.432)
_m4	-65.971** (20.009)	-118.89** (51.679)	-109.105(477.853)	12.46(7.64)	13.879(10.500)
_m5	21.092(46.936)	14.738(60.489)	-26.682(151.067)	103.156** (47.357)	89.781*** (22.809)
Constant	134934** (62.115)	30.500(175.009)	140.330(151.925)	26.54(20.52)	38.309(27.034)
Sigma2	3783 965* (194 269)	11088.6** (8069.96)	38524.3*** (3267.59)	12874.6*** (4788.4)	6830.2** (3203.5)
rho1	-0.750(0.593)	0.589** (0.009)	1.138* (0.004)	0.813(0.469)	-0.731(0.574)
rho2	-0.734** (0.371)	0.108(0.620)	-0.647*** (0.133)	-0.197* (0.002)	-0.254(0.648)
rho3	0.204(0.381)	0.221(0.262)	-0.032(1.014)	-0.709* (0.038)	0.071(0.986)
rho4	1.133(0.797)	-1.448** (0.669)	-0.274(0.484)	0.45*** (0.168)	0.215(0.329)
rho5	-0.291(0.672)	0.180(0.790)	-0.053(0.259)	1.140*** (0.508)	1.393*** (0.582)

Note: The numbers in brackets give the corrected standard deviations of heteroscedasticity. Significance *** p<0.01; ** p<0.005; * p<0.1

The analysis of the factors that determine dietary diversity (Food Diversity Score) by each adaptation strategy results in Table 4, show that the cut-off coefficients m_1 to m_5 indicate certain strategies modify the position of households in the distribution of dietary diversity scores. For example, m_1 , which is strongly positive and significant for Adaptation 1, indicates a shift to higher score categories, while m_2 and m_4 are significant for some strategies. The correlations of the ρ_1 to ρ_5 errors indicate that unobserved factors influence dietary diversity. ρ_2 is positive and significant for households without a strategy, while ρ_4 is significant for Adaptation 1. Finally, the residual σ_2 variance is significant for several strategies, confirming that elements not captured by the model contribute to the variation in dietary diversity. Cut-off coefficients m_1 to m_5 confirm the effectiveness of some strategies in improving household food diversity rankings, while error correlations (ρ) indicate the existence of unobserved factors, such as access to markets or inputs, that interact with the effectiveness of strategies (Tsambou and Tagang, 2024). The significance of σ_2 underlines the presence of unmeasured factors influencing dietary diversity.

Table 4 also reveals that certain socioeconomic and climatic variables influence household dietary diversity. The results show that the determinants of the Dietary Diversity Score vary according to the adaptation strategy. For households adopting no adaptation strategy, being located in the Sahelian zone is associated with a higher score, while higher average income and greater precipitation in 2020 also increase dietary diversity. In contrast, precipitation in 2021 reduced the score, highlighting the sensitivity of households to annual climatic conditions even without adaptation measures. These findings suggest that, in the absence of strategies, dietary diversity largely depends on household resources and local climate conditions.

For households using Adaptation 1, several variables significantly influence the Dietary Diversity Score. Lack of instructions strongly reduces the score, emphasizing the importance of guidance and training. Households with primary or secondary education have lower scores, indicating that educational level affects the ability to implement the strategy effectively. Household size is positively associated with dietary diversity, while greater agricultural experience and higher income are negatively associated, suggesting that larger households may better distribute resources, whereas wealthier or more experienced farmers do not necessarily translate these advantages into improved dietary diversity. Precipitation also has contrasting effects: rainfall in 2020 decreases the score, while rainfall in 2021 increases it, indicating that the effectiveness of Adaptation 1 is sensitive to annual climatic variability.

For Adaptation 2 and Adaptation 3, no variables were statistically significant, suggesting

that other unobserved factors may determine dietary diversity under these strategies.

For Adaptation 4, dietary diversity is significantly affected by precipitation: rainfall in 2020 reduces the score, while rainfall in 2021 increases it. This indicates that the success of Adaptation 4 is primarily driven by climatic conditions, highlighting the vulnerability of dietary diversity to year-to-year variability even when a strategy is implemented.

Overall, these results demonstrate that the impact of adaptation strategies on dietary diversity is highly context-specific, depending on household characteristics, access to guidance, and climatic conditions.

The results indicate that the adoption of climate change adaptation strategies has a significant impact on both household food security and dietary diversity, but the effect varies according to the type of strategy and household characteristics. For Adaptation 1, the negative effect of low education and lack of instructions highlights that education and guidance are key determinants of the effective implementation of adaptation strategies, consistent with the findings of Etwire et al. (2022) and Tagang et al. (2021). Household size also positively influences dietary diversity under this strategy, suggesting that larger households may better distribute resources, whereas higher income and greater agricultural experience do not necessarily translate into improved dietary diversity, reflecting strategy-specific limitations.

For households adopting no strategy, the results show that higher income and favorable climatic conditions, such as precipitation in 2020, improve both the Food Consumption Score and Dietary Diversity Score, while adverse climatic conditions, such as rainfall in 2021, reduce these outcomes. This indicates that, in the absence of adaptation strategies, household resources and local climatic conditions are critical determinants of food security and dietary diversity.

For Adaptation 4, dietary diversity is primarily influenced by climatic factors, with precipitation in 2020 reducing the score and precipitation in 2021 increasing it, underscoring the sensitivity of this strategy to year-to-year climatic variability. Adaptations 2 and 3 showed no significant effects on dietary diversity, suggesting that other unobserved factors may play a more important role for these strategies.

Overall, these findings demonstrate that the adoption of adaptation strategies, either individually or in combination, can enhance dietary diversity and food security, particularly for households with adequate education or financial resources. The results also highlight that precipitation and climatic variability influence food security outcomes, but the use of strategies can reduce household vulnerability to these variations, corroborating the work of Deressa et al. (2009) and Alam et al. (2016). Nevertheless, as observed in some contexts such as Al Dirani et al. (2021), the combined adoption of strategies does not always guarantee improved food

security, emphasizing the importance of local context and careful management of trade-offs between strategies.

Some results appear counter-intuitive, particularly the negative impact of Adaptation 1 and the negative association between income, education, and dietary diversity. These findings may reflect short-term adjustment costs, investment constraints, strategy complexity, and heterogeneous effects across households. In semi-arid areas, adaptation strategies may require financial capacity, technical knowledge, and time before benefits materialize. Therefore, the effectiveness of adaptation depends not only on adoption but also on household characteristics and implementation capacity.

Table 4: Parameter estimates of dietary diversity score by climate change adaptation strategies use

	Dietary Diversity Score (No Strategy)	Dietary Diversity Score (Adaptation 1)	Dietary Diversity Score (Adaptation 2)	Dietary Diversity Score (Adaptation 3)	Dietary Diversity Score (Adaptation 4)
Gender (male)	0.491(1.044)	4.054(3.312)	0.195(1.464)	-1.564(2.726)	-0.952(2.990)
Age	1.432(1.935)	3.408(1.017)	-0.652(2.782)	-0.168(1.262)	-2.037(3.396)
Marital	-2.104(1.167)	-9.846(3.349)	-0.176(5.076)	-0.211(4.752)	1.657(2.226)
Sahelian zone	6.219**(2.710)	-9.785(3.456)	-2.827(3.623)	-0.419(7.641)	-0.535(1.622)
Christian	1.693(5.625)	-8.646(5.045)	-0.985(27.255)	1.557(5.160)	-5.616(5.022)
Muslim	0.322(6.277)	-5.199(3.927)	-3.267(25.963)	0.667(3.042)	-5.379(6.701)
No instructions	1.841(3.523)	-14.754**(6.805)	4.961(34.836)	1.705(1.562)	0.613(3.365)
Primary education	-0.538(2.512)	-11.499**(4.098)	2.435(28.927)	0.658(1.443)	2.624(3.412)
Secondary education	-0.571(2.108)	-4.769**(2.776)	1.388(27.269)	-0.829(1.954)	3.260(4.112)
Household size	0.056(0.653)	0.531*** (0.126)	-0.455(0.671)	-0.364(0.500)	0.125(0.670)
Agricultural experience	1.088(2.280)	-2.934**(1.382)	0.798(5.690)	-0.698(1.225)	-2.433(4.177)
Average income	2.662**(0.629)	-2.388**(1.044)	2.817(2.750)	-0.752(1.027)	-3.591(1.182)
Landowner	-1.520(1.425)	-0.113(1.012)	0.249(10.229)	0.508(1.441)	1.829(3.117)
Government assistance	-0.465(2.383)	-0.431(2.414)	-0.137(12.717)	-0.335(2.541)	-0.028(3.323)
Precipitation_2020	2.843*** (0.114)	-3.651*** (1.222)	0.641(1.485)	-1.845(2.645)	-3.750*** (0.958)
Precipitation_2021	-1.180** (0.535)	3.297*** (1.071)	0.786(2.600)	1.832(2.899)	4.366*** (0.790)
Area	0.390(0.973)	-0.861*** (0.412)	-1.801(1.096)	-0.350(0.798)	-0.285(0.933)
_m1	-3.0541(9.447)	13.342*** (8.458)	-1.701(25.031)	2.34(7.476)	-24.100(17.159)
_m2	3.596(11.720)	-23.842* (13.138)	3.608(24.170)	0.972(8.48)2	-2.392(14.534)
_m3	24.158*** (5.574)	-42.138** (8.069)	14.022(36.885)	4.820(4.258)	10.569(7.432)
_m4	-0.971** (0.009)	19.89* (10.679)	-15.105(86.853)	-2.461(6.64)	-1.879(4.500)
_m5	-11.092*** (3.936)	5.738(4.489)	-9.682(36.067)	-0.156(6.357)	-31.781(15.809)
Constant	-2.123(62.115)	-12.500(26.009)	13.330(47.925)	-13.534(20.52)	-31.309(15.034)
Sigma2	546* (108.269)	1916.6** (193.96)	432.3(3267.59)	62.786(297.73)	577.2** (103.5)
rho1	-0.750(0.811)	0.589(0.399)	-0.098(0.874)	0.413(0.469)	-0.0831(0.574)
rho2	0.234** (0.071)	-0.108(0.620)	0.217(0.133)	0.157*** (0.029)	-1.254** (0.648)
rho3	-0.504(0.381)	-1.221(0.262)	0.882(1.014)	0.709* (0.088)	-0.071(0.986)
rho4	-0.133(0.797)	0.448** (0.069)	-0.944** (0.484)	-0.45** (0.168)	0.215(0.329)
rho5	-0.291(0.672)	0.180(0.790)	-0.953*** (0.259)	-1.140*** (0.508)	-0.393(0.582)

Note: The numbers in brackets give the corrected standard deviations of heteroscedasticity. Significance *** p<0.01; ** p<0.005; * p<0.1

4.5- Evaluation of the impact of adaptation strategies use on food security in semi-arid areas in Cameroon

After identifying the factors determining food security by each adaptation strategy, the next step was to measure their impact on household food security, based on both food consumption and dietary diversity scores. Table 5 presents the impact assessment results for different combinations of adaptation strategies as treatment distinguished against the counterfactual, that is, the non-users of adaptation strategy with respect to the food consumption score.

For Adaptation 1 (crop diversification and improved seeds), households that use this strategy have an average food consumption score of 38.00, compared to 43.26 for non-adaptive households. The effect of treatment on users of the strategy is therefore negative (-5.25), indicating that the use of this combination leads to a reduction in food consumption compared to the counterfactual situation. The estimated effect for non-adopters is negative (-10.63), indicating that these households are actually better off by not using Adaptation 1, as their food security score would decrease by 10.63 if they decided to adopt this strategy. The negative impact of Adaptation 1 may reflect short-term adjustment costs, investment constraints, or limited technical knowledge, particularly among poorer households. For Adaptation 2 (compost use and improved seeds) strategy, the impact results show an increase in the food consumption score of 3.08 for the households using the strategy, while the effect for non-users is positive 13.16, which is also significant. These results indicate a positive impact on food security, particularly for households that use the adaptation 3 strategy, and if the non-users of the strategy decide to use their food security would increase by 13.16. In the case of Adaptation 3 (crop diversification and compost use) strategy, the treatment effect is small but positive (0.54), but not significant, while the impact for non-users is more pronounced at 4.52 and significant, suggesting that non-adaptor households would also have benefited from a slight improvement in their food consumption if they had adopted this strategy. Finally, for Adaptation 4 (simultaneous combination of improved seeds, diversification, and compost) strategy, the effect of treatment on treated households is positive (1.62) but not significant, and that of the non-users is also positive (7.77) and significant, suggesting that if the non-users decide to use the Adaptation 4 strategy, their food security would increase by 7.77. These results show that the simultaneous adoption of the three strategies tends to improve household food consumption, although this effect is not statistically significant. The positive but non-significant effect of Adaptation 4 may reflect implementation complexity, initial investment costs, and limited

household capacity to effectively combine multiple practices. The benefits of this comprehensive strategy may require time and adequate support to translate into measurable food security improvements

Analysis of the results shows that the impact of adaptation strategies on food security varies depending on the combination of practices adopted. The simultaneous use of improved seeds and diversified crops appears to deteriorate the food consumption of adopter households, which may be explained by the high upfront costs or the time it takes for the benefits to translate into food security (Etwire et al., 2022). On the other hand, the use of compost combined with improved seeds significantly improves food consumption, confirming that organic inputs increase productivity and yields, thus contributing to food security (Tagang et al., 2021; Nonvide, 2024). The positive effect of diversifying crops with compost, although small, shows that the adoption of combined practices makes it possible to stabilize the diet by reducing vulnerability to climatic hazards, which is consistent with the work of Diallo and Donkor (2020). The combination of the three strategies, while having a positive effect, does not reach statistical significance, suggesting that the simultaneous integration of several practices may require more resources, technical knowledge or time to produce a measurable impact on food consumption (Al Dirani et al., 2021). Overall, these results confirm that the use of adaptation strategies, whether individual or combined, influences household food security, and that the benefits depend on the nature of the strategy, the capacity of households to invest, and their mastery of agricultural techniques adapted to Cameroon's semi-arid context.

The TH results reveal heterogeneity in the impact of adaptation strategies on food security. For Adaptation 1, adopters with higher baseline food security benefit more from the strategy, while non-adopters would experience a decrease in food security if they adopted it, indicating they are better off not adopting. Adaptation 2 shows the opposite pattern: adopters may see a reduction in food security, whereas non-adopters would gain from adoption. Adaptation 3 has a modest positive effect for non-adopters, with little impact on adopters. Finally, for Adaptation 4, adopters with higher baseline consumption experience a slight decrease in food security, while non-adopters benefit from adoption. These results underscore that the effectiveness of adaptation strategies varies across households depending on their baseline status, highlighting the importance of considering heterogeneity in policy and program design.

Table 5: Impact of adaptation strategies on Food security (Food consumption score)

Sub-sample	Decision stage		
	Adapter	Non-Adapter	Treatment effect
Improved Seed* Crop Diversification (Adaptation 1)	38.00 (1.80)	43.26 (0.85)	ATT=-5.25** (1.99)
	28.33(1.74)	38.96(0.54)	ATU=-10.63***(1.82)
	BH1=9.67(3.18)	BH0=4.30(1.06)	TH=5.37*(3.12)
Improved Seed* Use of Compost (Adaptation 2)	40.97 (0.97)	37.89 (0.74)	ATT=3.08** (1.17)
	52.13(1.15)	38.96(0.54)	ATU=13.16***(1.27)
	BH1=-11.15(1.66)	BH0=-1.06(0.91)	TH=-10.08***(2.03)
Crop diversification* Use of compost (Adaptation 3)	38.71 (1.49)	38.17 (1.08)	ATT=0.54 (1.85)
	43.49(1.03)	38.96(0.54)	ATU=4.52**(0.59)
	BH1=-4.77(1.99)	BH0=-0.79(1.13)	TH=-3.97(2.38)
Improved seed* Crop diversification* Use of compost (Adaptation 4)	41.13 (1.56)	39.50 (1.68)	ATT=1.62(1.85)
	46.74(0.87)	38.96(0.54)	ATU=7.77***(1.02)
	BH1=-5.60(1.74)	BH0=0.54(1.09)	TH=-6.14**(1.97)

Note: The numbers in brackets give the corrected standard deviations of heteroscedasticity. Significance *** p<0.01; ** p<0.005; * p<0.1

Table 6 displays the impact results for the different combinations of coping strategies on household food security, as measured by the dietary diversity score. The results reveal contrasting effects depending on the combination of strategies adopted.

For Adaptation 1 (crop diversification and improved seeds), the dietary diversity score of the treated household is slightly lower than that of the non-treated (7.56 vs. 7.66), resulting in a non-significant effect on households that actually use the strategy of -0.09. On the other hand, the effect on households that did not use the strategy is negative and significant (-1.34), indicating that these households would benefit less in terms of dietary diversity if they had adopted this strategy. In the case of Adaptation 2 (improved seeds and compost) strategy, it significantly improved the dietary diversity of the treated households: the dietary diversity score for households using this strategy gave an average of 9.45 compared to 8.78 for non-strategy users, with a positive and significant effect of 0.067. The effect on non-users is also positive and significant (0.85), confirming that for the non-users, the combination strategy could promote better dietary diversity, should they decide to use the strategy.

For Adaptation 3 (crop diversification and compost) strategy users, the impact was positive and significant, with a value of 0.55. The impact on non-users of the strategy is even higher (1.55) and positively significant, demonstrating that should this group of households decide to use the strategy, their dietary diversity would increase by 1.55. Finally, Adaptation 4 (simultaneous adoption of: improved seeds, diversification, and compost) strategy had a positive and significant effect of 0.58 for the users of the strategy, indicating an improvement in dietary diversity. However, the impact on non-users, though significant, was negative (-0.51), suggesting that if this set of households decides to use this adaptation strategy, it would result in a decline in dietary diversity from what they presently have. Hence, they should remain in their current system rather than adopting this combination.

Interpretation of the results shows that the effect of adaptation strategies on dietary diversity is not uniform. The combination of improved seeds and diversified crops (Adaptation 1) does not provide a significant benefit and may even reduce dietary diversity, probably due to specialization or reduction in crop variety in favor of improved seeds (Al Dirani et al., 2021).

On the other hand, the use of compost combined with improved seeds (Adaptation 2) has a very positive impact on dietary diversity. This can be explained by improved soil fertility and yields, which allow households to produce a wider variety of food and secure their food supply (Nonvide, 2024; Tagang et al., 2021). The combination of crop diversification and compost (Adaptation 3) also shows a significant and positive effect. This synergy helps to strengthen food resilience by ensuring better availability and variety of food products, which corroborates

the work of Diallo et al. (2020) and Etwire et al. (2022), who highlight the importance of diversification in adapting to climate shocks. Finally, the simultaneous adoption of the three strategies (Adaptation 4) tends to improve the dietary diversity of adopters, but its effect remains contrasted for non-adopters. This ambivalence can be explained by the high costs, technical complexity, and need for additional resources required to adopt multiple practices together, which limits its immediate benefits (Al Dirani et al., 2021). The results reveal significant heterogeneity in the impact of adaptation strategies on food security. For some strategies, such as Adaptation 1, non-adopters are better off not adopting, while adopters with higher baseline consumption may gain. Other strategies, like Adaptation 2, show the opposite pattern, where non-adopters would benefit more than adopters. Adaptations 3 and 4 demonstrate mixed effects, with gains or losses depending on households' baseline status. Overall, these findings highlight that the effectiveness of adaptation strategies varies across households, underscoring the importance of considering heterogeneity in policy and program design.

Table 6: Impact of adaptation strategies on Food security (Dietary diversity score)

Sub-sample	Decision stage		
	Adapter	Non-Adapter	Treatment effect
Improved Seed* Crop Diversification (Adaptation 1)	7.56 (0.31)	7.66 (0.18)	ATT=-0.09 (0.37)
	9.05(0.19)	7.71(0.10)	ATU=-1.34*** (0.22)
	BH1=-1.49(0.38)	BH0=-0.05(0.21)	TH=-1.44*** (0.34)
Improved Seed* Use of Compost (Adaptation 2)	9.45 (0.09)	8.78(0.12)	ATT=0.067*** (0.16)
	8.56(0.11)	7.71(0.10)	ATU=0.85*** (0.15)
	BH1=0.89(0.17)	BH0=1.06(0.16)	TH=-0.17(0.20)
Crop diversification* Use of compost (Adaptation 3)	7.92 (0.26)	7.36 (0.20)	ATT=0.55*** (0.33)
	9.27(0.20)	7.71(0.10)	ATU=1.55*** (0.22)
	BH1=-1.34(0.38)	BH0=-0.34(0.21)	TH=-1.00*** (0.31)
Improved seed* Crop diversification* Use of compost (Adaptation 4)	8.83 (0.22)	8.25 (0.21)	ATT=0.58* (0.30)
	7.19(0.16)	7.71(0.10)	ATU=-0.51* (0.19)
	BH1=-1.63(0.30)	BH0=0.53(0.21)	TH=1.09*** (0.23)

Note: The numbers in brackets give the corrected standard deviations of heteroscedasticity. Significance *** p<0.01; ** p<0.005; * p<0.1

Overall, the results suggest that strategies combining compost and other practices (improved seeds or diversification) are the most effective in improving dietary diversity. This confirms that agricultural adaptation, when well-integrated into production systems, can play a central role in improving food security in Cameroon's semi-arid areas.

After identifying the factors influencing the adoption of adaptation strategies, the analysis focused on their impact on household food security. The results show that the combinations of practices adopted significantly influence food consumption and dietary diversity.

Households adopting crop diversification and improved seeds (Adaptation 1) have lower food consumption than non-adaptors, with slightly reduced dietary diversity, suggesting that this combination can sometimes limit food security.

The adoption of improved seeds and compost (Adaptation 2) significantly improves food consumption and dietary diversity, showing that this combination enhances food security.

Households combining crop diversification and compost (Adaptation 3) also see positive gains, with slightly higher food consumption and increased food diversification, confirming the effectiveness of this strategy for food resilience.

Finally, the simultaneous adoption of the three strategies (Adaptation 4: Improved Seeds, Diversification, and Compost) benefits adaptor households, with a moderate increase in consumption and dietary diversity, while non-adaptors benefit less from this combination, likely due to costs and associated complexity.

Overall, the results indicate that adaptation strategies, particularly those incorporating compost and improved seeds, improve household food security in Cameroon's semi-arid areas. These observations are consistent with the work of Etwire et al. (2022), Tsambou and Tagang (2024), and Nonvide (2024), which show that the adoption of combined strategies enhances farmers' well-being. However, some combinations may have limited or negative effects, in agreement with Al Dirani et al. (2021), due to knowledge or investment capacity constraints (Diallo et al., 2020; Tagang et al., 2021).

5. Conclusion

To build resilience to the effects of climate change, farm households are adopting a variety of adaptation strategies to mitigate negative impacts on production and food security. This study, based on a sample of 1,000 households in semi-arid areas of Cameroon, explored the effect of combined coping strategies on food security, as measured by food consumption and dietary diversity. The analysis used a multinomial regression model with endogenous change, allowing to evaluate the different possible combinations of strategies. The results show that combinations of strategies are particularly effective in improving food security: (1) improved seeds and compost, (2) crop diversification and compost, and (3) improved seeds, crop diversification, and compost. Conversely, the combination of improved seeds and crop diversification, without compost, tends to reduce food security. These findings have important implications for policymakers and agricultural extension services. The results indicate that adaptation strategies have heterogeneous effects on food security, depending on households' baseline food security and dietary diversity. Therefore, rather than promoting a uniform approach, interventions should be targeted to household conditions. For example, strategies such as Improved Seed * Crop Diversification may benefit households with lower baseline food security, while for those already food secure, adoption may not improve outcomes. Similarly, compost use appears more advantageous for non-adopters, suggesting that households with lower baseline consumption could gain more from adoption. Combined strategies should be recommended selectively, taking into account households' initial food security and dietary diversity to maximize positive impacts. Overall, government and development programs should assess household conditions before recommending adaptation strategies, ensuring that interventions produce meaningful improvements without unintended negative effects.

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Appendix

Appendix 1: Food Consumption (Climate Information and Government Support)

Table: Tamper Testing

Variables	Food consumption
Climate Information	4.285(2.684)

⁴ The following were listed as references but not cited in-text; reference no: 2,3,5,6,14,17,18,23,29,34,39,41,46,57,59, 62, 69,72,73,87,91,94,95,96

Perception of the climate	-2.359(3.23)
Variation in precipitation	6.923**(2.725)
Climate information via radio	-7.735**(3.235)
Government assistance	-12.488***(4.065)
Précipitation_2020	1.456(1.132)
Précipitation_2021	-1.7(1.19)
Sex (Male=1)	1.217(2.762)
Household size	.262(.278)
Average income	-1.032(2.575)
Constant	68.97***(19.89)
<hr/>	
Comments	135
R-2	0.284
F-test	4.929
Prob > F	0.000

$p < .01$, ** $p < .05$, * $p < .1$

Appendix 2: Food diversification (Climate information, climate change perception, radio climate information and government support)

Variables:	Food diversification
Climate Information	.738*(.408)
Perception of the climate	.523(.473)
Variation in precipitation	.54(.404)
Climate information via radio	-1.475***(.47)
Government assistance	-1.652***(.595)
Précipitation_2020	-.524***(.167)
Précipitation_2021	.62***(.176)
Sex (Male=1)	.04(.406)
Age (30-45)	-.117(.359)
Marital status (married=1)	.442(.431)
Secondary education	-1.18**(.46)
Household size	.047(.043)
Average income	.437(.379)
Constant	-6.139**(3.019)
<hr/>	
Comments	135
R-2	0.394
F-test	6.044
Prob > F	0.000

$p < .01$, ** $p < .05$, * $p < .1$

Appendix 3: Multicollinearity test

Vif (food consumption)

Variable	VIF	1/VIF
-----+-----		
rev_moyen	1.73	0.578565
rev_sup	1.66	0.601789
taille_men~e	1.23	0.813091
percep_cli~t	1.21	0.827912
Homme	1.20	0.834523

marie	1.18	0.844595
second	1.15	0.872304
info_climat	1.14	0.874381
chretien	1.14	0.875491
Adaptation	1.12	0.895279
gov_support	1.11	0.903882
proprietaire	1.09	0.914547
age30_45	1.07	0.931393
var_precip~n	1.07	0.938302
-----+-----		
Mean VIF	1.22	

Vif (food diversity)

Variable	VIF	1/VIF
-----+-----		
rev_moyen	1.72	0.582376
rev_sup	1.66	0.602972
taille_men~e	1.23	0.811692
Homme	1.21	0.828438
percep_cli~t	1.20	0.832931
marie	1.19	0.843300
second	1.15	0.870720
chretien	1.15	0.873069
info_climat	1.14	0.876857
Adaptation	1.12	0.895786
gov_support	1.11	0.904675
proprietaire	1.09	0.913745
age30_45	1.07	0.930941
var_precip~n	1.07	0.938739
-----+-----		
Mean VIF	1.22	

Appendix 4: Factors Influencing the Choice of Adaptation Strategies

Variables	(1) Improved Seed	(2) Crop diversificatio n	(3) Use of compost	(4) Adapt1	(5) Adapt2	(6) Adapt3	(7) Adapt4
Man	0.598(0.378)	0.039(0.474)	0.449(0.375)	0.978(0.710)	0.984(0.373)	0.372(0.460)	0.872** (0.434)
Age (30-45)	-0.022(0.311)	0.416(0.335)	-0.111(0.318)	-0.426(0.378)	0.446(0.340)	0.226(0.360)	-0.184(0.365)
Marital Status (Married=1)	0.067(0.432)	0.027(0.595)	-0.464(0.374)	-0.434(0.595)	0.129(0.439)	-0.471(0.514)	-0.498(0.466)
Not educated	-1.424(0.384)	-0.387(0.350)	-0.630* (0.361)	-1.093(0.391)	-0.320(0.460)	1.036** (0.430)	-0.787* (0.477)
Secondary education	1.063** (0.433)	-0.354(0.516)	-0.203(0.418)	-0.547(0.558)	-0.281(0.413)	-0.203(0.476)	-0.351(0.465)
Household size	0.041(0.034)	0.030(0.033)	0.062(0.045)	0.016(0.035)	0.076* (0.045)	0.018(0.045)	0.072(0.044)
Average income	0.655** (0.327)	-0.239(0.341)	-0.378(0.309)	0.820** (0.406)	-0.467(0.340)	0.212(0.366)	-0.025(0.358)
Owner	0.254(0.310)	0.134(0.335)	0.186(0.326)	-0.036(0.384)	-0.183(0.359)	0.617(0.396)	0.268(0.364)
Farmer	-0.338(0.535)	-1.461(0.475)	-0.496(0.488)	-2.038(0.500)	1.204** (0.510)	-0.893* (0.541)	0.509(0.736)
Access to finance	0.662(0.428)	0.113(0.433)	0.694(0.430)	1.702(0.484)	1,880(0,367)	0.895** (0.434)	1.220(0.442)
Farmers' organisation	0.801** (0.380)	0.155(0.433)	0.952** (0.430)	-0.722(0.589)	0.196(0.459)	0.411(0.457)	0.737(0.504)
Climate variables							
Climate Information	0.102(0.359)	1.184(0.428)	-0.115(0.405)	1,146** (0,535)	-0.047(0.395)	0.489(0.539)	1,611** (0,793)
Perception of the climate	1,285** (0,515)	1.148(0.804)	-0.386(0.378)	15.521(0.499)	0.316(0.426)	0.263(0.574)	2,511** (1,058)
Variation in precipitation	-0.988(0.348)	0.621* (0.348)	0.189(0.346)	0.009(0.397)	0.166(0.376)	-0.384(0.399)	-0.417(0.375)
Precipitation_2020	0.394* (0.208)	0.107(0.197)	0.436* (0.227)	-0.259(0.211)	-0.409* (0.246)	0.414* (0.228)	0.175(0.262)
Précipitation_2021	0.438** (0.194)	-0.115(0.186)	-0.378* (0.221)	0.244(0.201)	0.497** (0.242)	-0.409* (0.222)	-0.139(0.252)

Government assistance	0.297(0.381)	0.573(0.472)	-0.296(0.523)	0.155(0.598)	0.564(0.553)	0.770(0.499)	1.118*(0.595)
Sahelian zone area	-0.898(1.047)	0.703(0.936)	0.643(0.920)	0.116(0.899)	2,285** ⁻ (1,124)	-0.141(0.895)	-1.522(1.047)
	0.054(0.075)	0.217(0.080)	-0.186*(0.110)	0.210(0.080)	0.150** ⁻ (0.074)	0.093(0.086)	0.053(0.114)
Constant	7,595* ⁻ (4,356)	-2.004(3.924)	-5.888(4.163)	-15.439(3.834)	12,513** ⁻ (5,274)	-1.027(4.097)	-9.361*(5.208)

Number of observations =634; Pseudo R2 = 0.185; LR chi2(22) = 4239.373; Prob> chi2 = 0.000

Note: * p < 0.10, ** p < 0.05, *** p < 0.01. Standard deviations are in parentheses.

Appendix 5: Definition of variables

Variables	Defining Variables	expected signs	comments by the authors
Dependent variables			
Dietary Diversity Score	A continuous variable obtained as scores taking values between 0 and 12.	/	-
Food Consumption Score	A continuous variable obtained as scores, taking values from 0 and above.	/	-
Explanatory variables			
Adaptation 1 no adopted	Take the value 0	?	
Adaptation 2 (Improved drought-resistant seeds +, Compost use)	A binary variable that takes the value 1 if the household has adopted it and 0 otherwise.	?	
Adaptation 3 (Crop diversification+ Use of compost)	A binary variable that takes the value 1 if the household has adopted it and 0 otherwise.	?	
Adaptation 4 (Improved Drought Resistant Seeds+ Crop Diversification+ Compost Use)	A binary variable that takes the value 1 if the household has adopted it and 0 otherwise.	+	Wekesa et al. (2018) increase food security in Kenya
Instrumental variables			

Access to climate information via radio	A binary variable that takes the value 1 if the household has had access to climate information and 0 otherwise.	+/-	Khanal et al., (2018b) access to climate information improved adoption of of climate change adaptation strategies
Perception of climate change	A binary variable that takes the value 1 if the household has perceived climate change and 0 otherwise.	+/-	Abegunde et al. (2019) increase adoption of climate change adaptation strategies
Membership of a Farmers' Organization	A binary variable that takes the value 1 if the household belongs to a farmers' organization and 0 otherwise.	+	Abegunde et al. (2019) increase adoption of climate change adaptation strategies
Socio-economic variables			
Gender of Head of Household (Male)	A binary variable that takes the value 1 if the head of household is a man and 0 otherwise.	+/-	Di Falco et al., (2011), Issoufou et al., (2017), Nchu et al., (2019) and Onyeneke et al., (2020)
Age	Binary variable that takes the value 1 if the head of household is over 55 years old and 0 otherwise.	+	Tagang et al., (2025) Decisions to Adapt Family Farms to Climate Change in Cameroon
Marital status (Married)	A binary variable that takes the value 1 if the head of household is married and 0 otherwise.	+/-	Bishwajit and Yaya (2024) find that marital status affects food security in Cameroon
Sahelian zone	Binary variable that takes the value 1 if the household is from the Sahelian zone and 0 otherwise.	+/-	Chabejong (2016) postulates that unlike other zones, the Sahelian zone in Cameroon is more affected by food insecurity and malnutrition.
Savannah area	Binary variable that takes the value 1 if the household is from the savannah zone and 0 otherwise.	+/-	
Christian religion	A binary variable that takes the value 1 if the head of the household is Christian and 0 otherwise.	+	Kevin Ngangni (2021) shows that compared to non-Muslims, Muslims suffer more from food insecurity in Cameroon
Muslim religion	A binary variable that takes the value 1 if the head of household is Muslim and 0 otherwise.	-	
Without education	A binary variable that takes the value 1 if the head of household is uneducated and 0 otherwise.	-	Oyet et al (2025) find that having at least secondary or tertiary education (as opposed

Primary education	A binary variable that takes the value of 1 if the head of household has a primary education and 0 otherwise.	+/-	to primary education or no formal education) increase food security in Uganda.
Secondary Education	A binary variable that takes the value of 1 if the head of household has a secondary education and 0 otherwise.	+/-	Abegunde et al. (2019) increase adoption of climate change adaptation strategies Ngema et al. (2018) the size of household increase food security in South Africa
Household size	Continuous variable, which is between 1 and 40	+/-	Aryal et al., (2018) and Maguza-Tembo et al., (2017) who found that farm size increases the likelihood of adopting adaptation strategies
Agriculture experience	A binary variable that takes the value 1 if the household with experience in agriculture and 0 otherwise.	+/-	Khonje et al., (2018) and Wainaina et al. (2016) find that land ownership encourages landowners to adopt adaptation strategies
Landowners	A binary variable that takes the value of 1 if the household owns land and 0 otherwise.	+/-	
Average Income	A binary variable that takes the value 1 if the head of household has an average income and 0 otherwise.	- - +	Khonje et al., (2018) show that income level increases the adoption of adaptation strategies against climate change. The higher the income, the more likely the household is to adopt adaptation strategies and diversify its food consumption.
Government support	A binary variable that takes the value of 1 if the household has received government support and 0 otherwise.	+/-	Drammeh et al (2020) believe that poor access to financial and nature assistance can reduce food security.

Appendix 6: Household food consumption indicators

Food groups	Weight	Foods in the database	MAP Rationale, 2008
X1 Main commodities (Cereals, Eggs, Roots and Tubers)	2	- Local Broken Rice, Whole Local Rice, Imported Broken Rice, Whole Imported Rice, Kernel Maize, Millet, Sorghum, Fonio, Local or Imported Wheat Flour, Pasta, Modern Bread, Traditional Bread, Croissant, Biscuits, Cakes, Donuts, Pancakes, Corn Flour, Millet Flour, Other Cereal Flour, Other Cereals. - Eggs. - Cassava, yam, plantain, potato, taro, sweet potato, other tubers, cassava flour, garis or tapioca, attiéké.	Energy density, usually consumed in larger quantities. Lower protein content and lower quality than legumes.
X2 Legumes or Pulses	3	- Tomato paste, Small canned weight, Small dry weight, other pulses, Cowpeas/Dried beans, Fresh peanuts in shells, Dried peanuts in shells, Shelled or pounded peanuts, Roasted peanuts, Peanut paste, Sesame, Cashew black.	Energy density, high amounts of protein but of lower quality than meats, micro-nutrients, low fat content.
X3 Vegetables	1	- Salad (lettuce), Cabbage, Carrot, Green bean, Cucumber, Eggplant, Fresh pepper, Squash/Zucchini, Fresh tomato, Sundried tomato, Fresh okra, Dried okra, Fresh onion, Garlic, Sorrel leaf or bissab, Baobab leaf, Bean or cowpea leaf, Moringa leaf, Cassava leaf, Other fresh vegetables.	Low energy, low protein, no fat, micronutrients
X4 Fruit	1	- Mangoes, Pineapples, Oranges, Sweet bananas, Lemons, Watermelon, Melon, Avocados, Dates, Coconut black, Sugar cane, Other citrus fruits, other fruits (apples, grapes, etc.).	Low in energy, protein, fat and micronutrients
X5 Meat/fish	4	- Beef, Camel meat, Sheep meat, Goat meat, Live chicken, Chicken meat, Offal and trips (liver, kidney, etc.), Pork meat, other domestic poultry, Cold meats (ham, sausage, etc.), Game, Other meat. - Fresh fish (sardinella), Fresh fish (baracouda), Fresh fish wass, other fish (sea bream, youfouf, red mullet, siket, mollette, etc.), Smoked fish (sardinella), Other smoked fish (smoked kong, yaboy or smoked obo), Dried fish (crab and shrimp, etc.), Canned fish.	Highest quality protein, easily absorbable micronutrients, energy density, fat. Even when consumed in small quantities, they significantly improve the quality of the diet.
X6 Milk, dairy products	4	- Fresh milk, Curd, yoghurt, sweetened or unsweetened condensed milk, Powdered milk, Cheese, Baobab milk and flour, Other dairy products.	High-quality protein, micronutrients, vitamin A, energy. However, milk can only be consumed in very small amounts.
X7 Sweeties	0.5	- Powdered or chunky sugar, Honey, Chocolate spread, Chocolate powder, caramel or confectionery, Coffee, tea, Other herbal teas, Fruit juices, Mineral water, soft drinks, Powdered juices, Traditional beer and wine, Industrial beer, Refined palm wine, Peanut wine (saogal).	Empty calories. Usually consumed in small quantities.
X8 Oil & Grease	0.5	- Butter, Charity Butter, Red Palm Oil, Refined Arachin Oil, Cottonseed Oil, Soybean/Vegetable Oil, Refined Palm Oil, Other Oils.	Energy density, but usually no other micronutrients, usually consumed in small amounts.
X9 Condiments (Seasonings?)	0	- Salt, Chili, Ginger, Food Cube (Maggi, Jumbo, etc.), soum bala, mayonnaise, vinegar, other condiments, black cola, other condiments	These foods are consumed in very small amounts and are not considered to have a significant impact on the overall diet.



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