Do technical and livelihood adaptations mitigate the impact of climate change on food security in rural West Africa?[1]

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Abstract

Climate change poses a growing threat to rural food security in West Africa, where smallholder agricultural systems are vulnerable to extreme weather events. This study examines whether and how agricultural adaptations mitigate drought impacts using a household panel dataset from eight West African countries, integrated with geo-referenced standardized precipitation-evapotranspiration index (SPEI) data. We account for unobserved heterogeneity and adaptation decision endogeneity using fixed-effects instrumental variables and two-stage residual-inclusion Poisson models. The results show that drought reduces food security; however, plot-level technical adjustments—such as improved seeds and intercropping—counteract these negative effects. Moreover, livelihood adaptations through crop diversification, characterized by species richness and spatial equity in land allocation, serve as buffers that stabilize caloric and nutritional intake. This study provides a regional perspective on smallholder climate resilience, showing that targeted technological and portfolio-based strategies can protect rural households from climate shocks.

Keywords: Climate Change Adaptation; Food Security; Smallholder Agriculture; West Africa; Crop Diversification

1. Introduction

Climate change poses a significant risk to food security in rural areas, as agricultural communities become vulnerable to droughts, floods, and temperature variations. West Africa is among the regions most likely to be affected by climate change. Weather changes increase the risks faced by farmers [1]. Smallholder farming systems are vulnerable to climate shocks and are more likely to experience food insecurity. This affects more than 50 million people [2]. With 70% of the population working in agriculture, livelihoods are threatened by continued warming, altered precipitation, and more extreme weather [3]. Research indicates that median yields in West Africa are expected to decrease by 6%, demonstrating the direct impact of climate change on agricultural output [4].

Studies have examined how household agricultural adaptation strategies affect food security in response to climate change [5] [6] [7]. In this context, current agricultural adaptation behaviors serve as a mechanism through which lagged climate shocks affect current food security. However, contemporary adverse climate shocks are most likely to impact current food security, and current agricultural adaptation behaviors are intended to moderate these effects.

This study analyzes how agricultural adaptation strategies affect the impacts of climate change on food security in West African countries. We add to the limited evidence on adaptation's moderating effects within the climate–food security nexus in West Africa, a context of diverse agro-ecological conditions, farming systems, and institutional settings. The existing literature

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using longitudinal data and the standardized precipitation-evapotranspiration index has focused on single-country [8] or aggregated-country-level analyses [9] [11], limiting its broader applicability. Using a harmonized, two-wave panel dataset across eight francophone countries, this study adds to the literature on livelihood adaptations by evaluating crop diversification as a complex portfolio. We assessed how both the intensity (species richness) and spatial equity (land allocation) of crop diversification moderate the effects of drought.
The remainder of this paper is structured as follows. Section 2 outlines the conceptual framework linking climate shocks, adaptation, and food security. Section 3 specifies the econometric models and identification strategy. Section 4 details the data sources and provides descriptive statistics. Section 5 presents and discusses the empirical results, and Section 6 concludes.

2. A conceptual framework

To analyze how climate change and agricultural adaptations affect food security, this study draws from the agricultural household model under risk and uncertainty [10] [11]. In the rural West African Economic and Monetary Union (WAEMU), smallholder households act as both producers and consumers. Due to market imperfections, such as restricted credit and insurance markets, production and consumption decisions are non-separable. Thus, agricultural production shocks directly affect household consumption and dietary intake (Fig. 1).

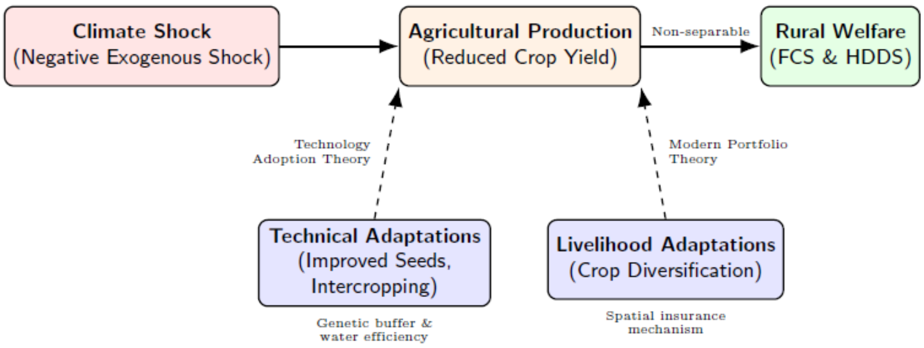

Fig. 1: Pathways of climate shocks and the moderating role of technical and livelihood adaptations.

Following expected utility theory under risk [11], a rural household maximizes utility from food consumption and dietary diversity, subject to constrained agricultural production. Climate shocks act as negative exogenous shocks to production. In a non-separable household model, reduced crop yields directly constrain the household's caloric availability and food variety. Without adaptation or insurance markets to smooth consumption, the household bears the negative effect of climate shocks, leading to food insecurity [12].
Household adaptation behavior encompasses adjustments made to reduce the effects of climate impacts. We conceptualize these adaptations through two theoretical channels. Agricultural adaptations, such as adopting improved seeds or intercropping systems, represent plot-level technological shifts. According to the theory of technology adoption under uncertainty [13] [14], households invest in these inputs to alter the sensitivity of crops to moisture deficits. Improved seeds provide genetic protection, whereas intercropping enhances water efficiency. These systems reduce drought damage to crop yields, protecting household consumption. The decision to diversify crops can also be explained through modern portfolio theory applied to

agriculture [15]. Rather than maximizing returns from a single cash crop, households construct portfolios to minimize aggregate yield variance. Different crop species respond differently to weather shocks; therefore, distributing land across multiple crops provides spatial insurance. If the main cereal crop is impacted by drought, drought-resistant legumes or tubers help the household maintain basic caloric and nutritional diversity.

3. Model and estimation method

We assessed the interaction effects between climate shock and adaptation behavior on food security outcomes through the following model.

$$\mathrm{FS}_{ijgt} = \alpha + \beta_1 \mathrm{Climate}_{gt} + \beta_2 Strategy_{ijgt} + \beta_3 \left(\mathrm{Climate}_{gt} * Strategy_{ijgt}\right)$$

$$+\beta_4 \mathrm{X}_{ijgt} + \beta_5 \mathrm{E}_{ijg} + \gamma_t + \theta_i + \gamma_c + \varepsilon_{\mathrm{ijgt}} \quad (1)$$

Where: FS_{ijgt} is food security outcome for household i living in village j located in grid g at time t, $\mathrm{Climate}_{gt}$ is climate variable at grid g in year t, $Strategy_{ijgt}$ is adaptation behavior measures for household i living in village j located in grid g at time t, X_{ijgt} (E_{ijg}) are control variables, time-varying (invariant) vector of covariates (household and contextual characteristics), γ_t are year fixed effects to control for macroeconomic or aggregate regional shocks common to all households in a given wave, γ_g are location (country fixed effects), and θ_i represents household fixed effects, effectively absorbing all time-invariant unobservable characteristics (e.g., innate farmer ability, long-term soil quality) and $\varepsilon_{\mathrm{ijgt}}$ are unobserved error terms. Standard errors are clustered at the primary sampling unit (grappe) level to account for localized spatial correlation. The parameter of primary interest is β3. A positive and statistically significant estimated coefficient indicates that the adaptation strategy successfully moderates the adverse impact of climate shock.

The dependent variables exhibited different statistical properties, so we used two distinct estimators. For the continuous outcome, we estimated a linear panel fixed effects (FE) model. For the strictly nonnegative count outcome, we estimated a fixed-effects Poisson model. Estimating the model via fixed effects or Poisson regression assumes that adaptation strategies are strictly exogenous. However, agricultural adaptation is a household choice, making the strategy variable and its interaction with the climate variable endogenous. First, households anticipating food insecurity may be forced into desperate diversification (reverse causality). Second, unobserved time-varying heterogeneity exists. A localized micro-shock may simultaneously destroy a household's crop portfolio and dietary diversity. Failure to account for this endogeneity leads to biased estimates. Our empirical strategy follows two steps: first, establishing baseline panel fixed-effects models; and second, applying instrumental-variables (IV) and control-function techniques to address endogeneity in adaptation decisions.

To account for endogeneity in linear models, we used a fixed-effects instrumental-variables (FE-IV/GMM) estimator. For nonlinear count models, we used the two-stage residual inclusion (2SRI) approach [16]. In the first stage, we estimated linear fixed-effects models for each endogenous regressor and each interaction term, using exogenous covariates and instrumental variables to obtain generalized residuals. These residuals were then included as covariates in the primary fixed effects Poisson model to control for unobserved confounding factors. Significant coefficients on the residuals confirm endogeneity, and their inclusion purges this bias from the structural parameters.

We instrumented for endogenous adaptation using spatial, lagged, and geographic instruments, including regional diversification patterns, distance indicators, and their interactions with climate shock. Valid instruments must satisfy relevance and exclusion restrictions. The relevance condition requires that instruments correlate with household adaptation decisions, given that regional norms and proximity influence seed access and agricultural information. The exclusion restriction requires that spatial/lagged instruments affect food security only through the adaptation strategy, conditional on household fixed effects. We verify instrument validity using the Kleibergen-Paap F-statistic and the Hansen J test.

4. Data and descriptive statistics

Household survey data

The primary household data for this study stemmed from the Harmonized Survey on Households' Living Standards (EHCVM). The EHCVM is a nationally representative household survey conducted in collaboration with the National Statistics Offices of the West African Economic and Monetary Union (WAEMU) member states, the WAEMU Commission, and the World Bank. A key advantage of the EHCVM is its strict harmonization across countries, allowing for robust cross-border comparative analyses within a unified econometric framework. This study used a balanced two-wave rural household panel dataset covering the agricultural seasons of 2018/2019 and 2021/2022. The geographically expansive sample encompasses all eight francophone WAEMU countries: Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal, and Togo. We constructed a final analytical sample of 41,478 observations (20,739 households per wave).

Climate data

Among extreme climate shocks, droughts exert the most detrimental impact on crop production. Specifically, we used the Standardized Precipitation-Evapotranspiration Index (SPEI), sourced from the SPEI Global Drought Monitor. The SPEI is a multiscalar climatic drought index that offers a significant methodological advantage over standard rainfall anomalies by explicitly incorporating the effects of temperature variability on evapotranspiration and water demand [17]. The SPEI data, provided at a 1-degree spatial resolution, were matched to the EHCVM household survey databases using the GPS coordinates of the rural survey clusters. The temporal scale of the SPEI retained aligns with the agricultural seasons specific to each country's grid cell. Following standard meteorological thresholds, we constructed a binary drought-shock variable that takes the value 1 if the localized SPEI falls below -1 (indicating moderate to extreme drought conditions) and 0 otherwise.

Measurement of outcomes and adaptation Strategies

Household food security is evaluated using two indices from the survey's consumption module. The food consumption score (FCS) measures dietary quantity and caloric sufficiency, while the household dietary diversity score (HDDS) captures nutritional variety. Household adaptation behavior encompasses adjustments made by farming households to reduce their vulnerability to climate impacts [18]. We categorized adaptation behavior into two channels aimed at mitigating climate variability. Technical adaptations are captured at the plot level, such as whether households adopted improved seed varieties and used intercropping. We measured livelihood adaptations (crop diversification) using four metrics: a binary indicator of multiple-crop cultivation, the number of crop species cultivated, the Simpson index, and the Shannon-Wiener (modified entropy) index. These latter indices capture both species richness and spatial evenness of land allocation across crops.

Descriptive Statistics

Tables 1 and 2 present the statistics for the outcome variables, adaptation strategies, and household covariates across survey waves. Food security metrics remained stable, suggesting adaptation effects. Most households (85.1%) practiced crop diversification, with an average of 3.35 crop species. Additionally, 48.1% used intercropping, and 18.2% planted improved seeds. The sample reflects typical West African agricultural demographics, with an average of 6.8 household members and 87.4% of households headed by males. Education remains limited: 80.2% of heads have no formal education, and 33.4% are literate. Households manage approximately 2.3 tropical livestock units as buffer assets.

Table 1: Descriptive Statistics - Outcomes and Adaptation Strategies

	2018	2021	Pooled
Food consumption score	13.912	14.928	14.474
	(4.278)	(4.554)	(4.462)
Household Dietary Diversity Score	7.901	8.181	8.056
	(1.610)	(1.664)	(1.646)
Drought =1 if corresponding spei <-1	0.070	0.493	0.304
	(0.255)	(0.500)	(0.460)
Household used improved seed	0.180	0.183	0.182
	(0.384)	(0.387)	(0.386)
Household used intercropping system	0.507	0.461	0.481
	(0.500)	(0.498)	(0.500)
Crop diversification: binary	0.848	0.853	0.851
	(0.359)	(0.354)	(0.356)
Number of crop cultivated	3.349	3.342	3.345
	(2.370)	(2.263)	(2.309)
Simpson index	0.482	0.498	0.491
	(0.266)	(0.266)	(0.266)
Modified Entropy Index	0.865	0.867	0.866
	(0.570)	(0.562)	(0.565)
Observations	20739	20739	41478

Notes: Data from EHCVM. Means are reported with standard deviations in parentheses.

Table 2: Descriptive Statistics - Household Control Variables

	2018	2021	Pooled
Head is a man (1/0)	0.887	0.863	0.874
	(0.317)	(0.344)	(0.332)
Age of head	45.624	48.563	47.249
	(14.430)	(14.215)	(14.386)
Education of head (None)	0.796	0.807	0.802
	(0.403)	(0.395)	(0.398)
Head can read and write (1/0)	0.340	0.329	0.334
	(0.474)	(0.470)	(0.472)
Household size	6.727	6.820	6.778
	(3.981)	(3.947)	(3.963)
Relative Wealth Index (PCA-based)	1.524	1.372	1.440
	(1.903)	(1.953)	(1.932)
Log(land size)	1.363	1.835	1.624
	(0.793)	(2.847)	(2.195)
Total Livestock Holding (TLU)	2.289	2.324	2.308
	(7.478)	(6.366)	(6.885)
Remittances (1/0)	0.358	0.352	0.354
	(0.479)	(0.477)	(0.478)
Distance to nearest city	25.153	24.728	24.918
	(23.109)	(23.147)	(23.131)
Market exist in the community (1/0)	0.221	0.242	0.233
	(0.415)	(0.428)	(0.423)

Observations	20739	20739	41478

Notes: Data from EHCVM. Means are reported with standard deviations in parentheses.

5. Results and discussion

Effects of crop diversification on food security: overall results

Tables 3 and 4 present the baseline and moderated impacts of climate shocks and crop diversification on food security outcomes. To account for unobserved heterogeneity and endogeneity, the results are presented using baseline specifications, fixed-effects instrumental-variables (FE-IV), and two-stage residual inclusion (2SRI) models. Across the models, drought has a significant negative effect on household food security. In the fixed effects specification (Table 3, FE Mod), drought reduces the food consumption score by 0.878 points. The FE Poisson model (Table 4) shows that drought significantly reduces dietary diversity, confirming the vulnerability of rural smallholder farming systems to climate shocks.

The estimated coefficient of interaction between drought shocks and crop diversification provides empirical evidence of the moderating effect of agricultural adaptation. The results show a significant positive effect across food security indicators. In the FE-IV Mod specification (Table 3), the interaction coefficient of 1.806 ($p < 0.05$) offsets the negative impact of drought, indicating that households with multiple crops maintain food consumption during droughts. The non-linear FE 2SRI Poisson model (Table 4) confirms this protective effect of dietary diversity, as multiple crops help maintain stable caloric intake when primary yields face precipitation deficits.

Given the endogenous nature of crop diversification decisions, we rely on models that account for endogeneity (FE-IV for linear models and FE 2SRI for non-linear models). The endogeneity test (p-value=0.005) rejects the exogeneity of crop diversification, whereas the first-stage control function residuals indicate significant confounding, confirming the need for instrumental-variables approaches. Our instruments perform well in the linear FE-IV model, with a Kleibergen-Paap F-statistic of 114.5, exceeding the threshold of 10, indicating strong identification. The Hansen J-statistic (p-value=0.737) confirms instrument validity and appropriate exclusion from the second-stage equation.

Table 3: Moderating effect of crop diversification on food consumption scores (FCS)

	Shock Only	Shock+Ctrl	OLS Base	OLS Mod	FE Mod	FE IV Mod
Drought (1/0)	-0.453***	-0.312***	-0.414***	-0.959***	-0.878***	-1.472**
	(0.119)	(0.117)	(0.117)	(0.259)	(0.301)	(0.618)
Crop Diversif (1/0)			0.563***	0.008	-0.080	-1.320**
			(0.112)	(0.106)	(0.150)	(0.546)
Drought x Crop Diversif				0.783***	0.978***	1.806**
				(0.254)	(0.297)	(0.711)
Observations	41,478	41,478	41,478	41,478	41,478	22,898
R-squared	0.208	0.236	0.210	0.237	0.036	0.020
Country FE	YES	YES	YES	YES		
Year FE	YES	YES	YES	YES	YES	YES
Number of ID_unique_menage					20,739	11,449
Household FE					YES	YES
Endog P-val						0.00524

Hansen P-val	0.737
K-P F-Stat	114.5

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1

Source: Calculations based on the EHCVM 2018/19 data.

Table 4: Moderating effect of crop diversification on Household Dietary Diversity Score (HDDS)

	Pois Shock Only	Pois Shock+Ctrl	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI oisson
Drought (1/0)	-0.019***	-0.013**	-0.017***	-0.037***	-0.024***	-0.046**
	(0.006)	(0.005)	(0.005)	(0.012)	(0.007)	(0.019)
Crop Diversif (1/0)			0.031***	0.007	0.011***	-0.064***
			(0.005)	(0.005)	(0.004)	(0.017)
Drought x Crop Diversif				0.030***	0.023***	0.070***
				(0.011)	(0.007)	(0.021)
CF Resid (Crop Diversif)						0.073***
						(0.017)
CF Resid (Drought x Crop Diversif)						-0.075***
						(0.023)
Constant	2.150***	2.088***	2.126***	2.087***		
	(0.007)	(0.010)	(0.007)	(0.011)		
Observations	41,478	41,478	41,478	41,478	41,476	22,898
Country FE	YES	YES	YES	YES		
Year FE	YES	YES	YES	YES	YES	YES
Number of ID_unique_menage					20,738	11,449
Household FE					YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1

Source: Calculations based on the EHCVM 2018/19 data.

Effects of adjustments in agricultural practices

The adoption of improved, climate-resilient seed varieties aligns with our hypothesis (Tables 5 and 6). In the FE-IV model, the interaction between drought shock and improved seed adoption is significant at 3.551, showing households using improved seeds offset drought's negative effects on food consumption. For nutrition, the FE 2SRI Poisson specification yields a significant coefficient of 0.141, confirming that improved seeds protect caloric intake and food variety during climate shocks. Model validity is confirmed by diagnostic tests, with a Kleibergen-Paap F-statistic of 96.48 and Hansen J-statistic ($p = 0.964$). Intercropping also provides significant protection against climate shocks, with the FE-IV model showing a positive interaction between drought shock and intercropping (1.510). For dietary diversity, the FE 2SRI Poisson model shows a significant effect (0.050, $p < 0.01$), indicating intercropping supports varied diets during drought. The intercropping models show a Kleibergen-Paap F-statistic of 47.62 and significant CF residuals. Both improved seeds and intercropping effectively mitigate the impacts of climate shocks on West African households.

Table 5: Moderating effect of use of cropping systems on household food security

	Food Consumption Scores (FCS)				Household dietary diversity Score (HDDS)			
VARIABLES	OLS Base	OLS Mod	FE Mod	FE IV Mod	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI Poisson
Drought	-0.447***	-0.250	0.122	-0.759**	-0.019***	-0.013**	-0.009**	-0.018*
	(0.119)	(0.153)	(0.212)	(0.340)	(0.006)	(0.007)	(0.004)	(0.010)

Intercrop Sys	0.120	0.194**	0.112	-1.316*	0.009**	0.011***	0.001	-0.065***
	(0.084)	(0.089)	(0.124)	(0.689)	(0.004)	(0.004)	(0.003)	(0.020)
Drought x Intercrop Sys		-0.109	-0.290	1.510**		0.002	0.012**	0.050***
		(0.187)	(0.235)	(0.601)		(0.008)	(0.006)	(0.015)
CF Resid (strategy)								0.071***
								(0.021)
CF Resid (Drought x strategy)								-0.060***
								(0.015)
Observations	41,478	41,478	41,478	22,898	41,478	41,478	41,476	22,898
Number of ID_unique_menage			20,739	11,449			20,738	11,449
R-squared	0.208	0.236	0.034	0.010				
Endog P-val				0.00584				
Hansen P-val				0.504				
K-P F-Stat				47.62				
Country FE	YES	YES			YES	YES		
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Household FE			YES	YES			YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1
Source: Calculations based on the EHCVM 2018/19 data.

Table 6: Moderating effect of improved seed on household food security

	Food Consumption Scores (FCS)				Household dietary diversity Score (HDDS)			
VARIABLES	OLS Base	OLS Mod	FE Mod	FE IV Mod	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI Poisson
Drought	-0.434***	-0.410***	-0.105	-0.518***	-0.019***	-0.016***	-0.005	-0.009
	(0.119)	(0.125)	(0.167)	(0.191)	(0.006)	(0.006)	(0.004)	(0.006)
improved seed	0.421***	0.041	0.372***	-1.260*	0.019***	0.003	0.015***	-0.042*
	(0.080)	(0.095)	(0.144)	(0.759)	(0.003)	(0.004)	(0.004)	(0.024)
Drought x improved seed		0.588***	0.480	3.551***		0.021**	0.009	0.141***
		(0.191)	(0.295)	(0.937)		(0.008)	(0.008)	(0.028)
CF Resid (strategy)								0.047*
								(0.024)
CF Resid (Drought x strategy)								-0.134***
								(0.031)
Observations	41,478	41,478	41,478	22,898	41,478	41,478	41,476	22,898
Number of ID_unique_menage			20,739	11,449			20,738	11,449
R-squared	0.209	0.237	0.036	0.017				
Endog P-val				0.00362				
Hansen P-val				0.964				
K-P F-Stat				96.48				
Country FE	YES	YES			YES	YES		
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Household FE			YES	YES			YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1
Source: Calculations based on the EHCVM 2018/19 data.

Livelihood adaptations

Tables 7-9 evaluate diversification's moderating effects using three metrics: Simpson's Index, Shannon-Weiner Index, and the number of crops cultivated. Using the FE-IV Mod correction, the drought shock's baseline impact remains negative across models, reducing the food consumption score by 1.347 to 1.559 points. The interaction terms between drought and diversification indices are positive and significant, confirming our hypothesis.

The Simpson index, which captures species richness and evenness, shows a coefficient of 2.273 ($p < 0.05$). Households with even crop portfolios are better protected against consumption declines caused by drought. This aligns with Shannon–Wiener index and crop-count results, showing that the magnitude of diversification and spatial equity protect rural food security. Drought reduces dietary diversity; however, higher levels of livelihood adaptation mitigate this effect. The interaction terms for the Simpson index (0.081, $p < 0.01$), the Shannon-Wiener index (0.040, $p < 0.01$), and the crop count (0.012, $p < 0.01$) indicate that broader agricultural bases support greater nutritional diversity under climate shocks. Econometric specifications are validated across all livelihood adaptation tables.

Table 6: Moderating effect of livelihood adaptations (Simpson index) on household food security

	Food Consumption Scores (FCS)				Household Dietary Diversity Score (HDDS)			
	OLS Base	OLS Mod	FE Mod	FE IV Mod	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI Poisson
Drought	-0.712***	-1.248***	-1.353***	-1.461**	-0.029***	-0.054***	-0.049***	-0.041**
	(0.139)	(0.258)	(0.351)	(0.587)	(0.006)	(0.012)	(0.008)	(0.016)
Simpson index	1.816***	0.925***	1.059***	-2.755**	0.091***	0.049***	0.040***	-0.135***
	(0.188)	(0.190)	(0.345)	(1.169)	(0.009)	(0.009)	(0.009)	(0.036)
Drought x Simpson index		1.324***	1.684***	2.273**		0.061***	0.051***	0.081***
		(0.398)	(0.535)	(1.068)		(0.018)	(0.013)	(0.029)
CF Resid (strategy)								0.172***
								(0.038)
CF Resid (Drought x strategy)								-0.085**
								(0.034)
Observations	25,772	25,772	25,772	9,724	25,772	25,772	21,202	9,724
Number of ID_unique_menage			15,170	4,862			10,601	4,862
R-squared	0.248	0.273	0.045	0.006				
Endog P-val				0.00907				
Hansen P-val				0.0233				
K-P F-Stat				59.23				
Country FE	YES	YES			YES	YES		
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Household FE			YES	YES			YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1

Source: Calculations based on the EHCVM 2018/19 data.

Table 7: Moderating effect of livelihood adaptations (Shannon-Wiener Index) on household food security

	Food Consumption Scores (FCS)				Household dietary diversity Score (HDDS)			
	OLS Base	OLS Mod	FE Mod	FE IV Mod	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI Poisson
Drought	-0.707***	-1.166***	-1.195***	-1.347**	-0.029***	-0.052***	-0.049***	-0.034**
	(0.139)	(0.231)	(0.330)	(0.525)	(0.006)	(0.010)	(0.007)	(0.014)
Entropy Index	0.968***	0.496***	0.425***	-1.483**	0.051***	0.028***	0.022***	-0.074***
	(0.088)	(0.094)	(0.161)	(0.669)	(0.004)	(0.005)	(0.004)	(0.020)
Drought x Entropy Index		0.655***	0.756***	1.128**		0.032***	0.028***	0.040***
		(0.189)	(0.253)	(0.526)		(0.009)	(0.006)	(0.014)
CF Resid (strategy)								0.097***
								(0.021)
CF Resid (Drought x strategy)								-0.038**

								(0.016)
Observations	25,772	25,772	25,772	9,724	25,772	25,772	21,202	9,724
Number of ID_unique_menage			15,170	4,862			10,601	4,862
R-squared	0.251	0.274	0.043	-0.000				
Endog P-val				0.0117				
Hansen P-val				0.0244				
K-P F-Stat				54.10				
Country FE	YES	YES			YES	YES		
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Household FE			YES	YES			YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1
Source: Calculations based on the EHCVM 2018/19 data.

Table 8: Moderating effect of livelihood adaptations (Number of crops cultivated) on household food security

	Food Consumption Scores (FCS)				Household dietary diversity Score (HDDS)			
	OLS Base	OLS Mod	FE Mod	FE IV Mod	Poisson Base	Poisson Mod	FE Poisson	FE 2SRI Poisson
Drought	-0.690***	-1.207***	-1.062***	-1.559**	-0.028***	-0.055***	-0.050***	-0.038**
	(0.139)	(0.218)	(0.309)	(0.609)	(0.006)	(0.010)	(0.007)	(0.016)
Count index	0.246***	0.130***	0.171***	-0.567**	0.012***	0.006***	0.009***	-0.027***
	(0.020)	(0.023)	(0.037)	(0.268)	(0.001)	(0.001)	(0.001)	(0.008)
Drought x Count index		0.188***	0.167***	0.347**		0.010***	0.008***	0.012***
		(0.045)	(0.063)	(0.172)		(0.002)	(0.002)	(0.004)
CF Resid (strategy)								0.032***
								(0.008)
CF Resid (Drought x strategy)								-0.011**
								(0.005)
Observations	25,772	25,772	25,772	9,724	25,772	25,772	21,202	9,724
Number of ID_unique_menage			15,170	4,862			10,601	4,862
R-squared	0.252	0.276	0.047	-0.047				
Endog P-val				0.0190				
Hansen P-val				0.0262				
K-P F-Stat				36.90				
Country FE	YES	YES			YES	YES		
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Household FE			YES	YES			YES	YES

Standard errors in parentheses are clustered at the "grappe" level. All regressions include control variables. *** p<0.01, ** p<0.05, * p<0.1
Source: Calculations based on EHCVM 2018/19 data.

The empirical results show that while climate shocks threaten rural welfare, both technical and livelihood agricultural adaptations act as buffers. Using multi-country panel data with fixed-effects instrumental-variables models, these findings provide robust evidence that advances the climate resilience literature in West Africa. Our baseline estimates confirm that drought exposure affects household food consumption in quantity and diversity. The negative coefficients on the SPEI drought indicator align with [19], showing extreme droughts drive crop production volatility. In WAEMU's rain-fed smallholder systems, this vulnerability translates climate shocks into nutritional deficits. Our models show that technical adaptations—improved seeds and intercropping systems—mitigate drought's adverse nutritional impacts. Improved seed varieties provide physiological protection against erratic rainfall [13]. Intercropping demonstrates agro-ecological resilience by maximizing water efficiency and creating favorable microclimates. This finding aligns with [6], who showed that traditional agronomic adjustments remain effective risk-mitigation strategies for resource-constrained West African households.

This study evaluates the intensity and evenness of livelihood adaptation beyond binary adoption indicators. The Simpson and Shannon-Wiener indices indicate that the protective power of crop diversification depends on equitable land distribution among species. Following portfolio theory [15], diverse crops reduce risk, as different crops respond differently to moisture deficits. The FE 2SRI Poisson results confirm that this portfolio effect protects household dietary diversity during weather events.

6. Conclusion

This study examined the moderating role of agricultural adaptations in climate–food security relationships in rural West Africa. Using panel data from the EHCVM across eight WAEMU countries and the standardized precipitation–evapotranspiration index, we analyzed smallholder resilience to climate shocks. To address endogeneity in adaptation decisions, we used a fixed-effects instrumental-variables estimator and a two-stage residual-inclusion model. Our empirical results show that droughts significantly impact the quantity and nutritional variety of rural diets. However, households implementing agricultural adaptations can mitigate these effects. Technical adjustments, such as improved seeds and intercropping systems, help protect food consumption from precipitation deficits. Additionally, crop diversification serves as a risk mitigation strategy. Given the moderating effect of improved seeds, agricultural ministries should expand access to drought-tolerant varieties. Reducing financial barriers to these inputs helps ensure food consumption remains secure against climate shocks. Extension programs should emphasize spatial crop diversification and the benefits of intercropping. Farmers need support to build multi-species portfolios that spread risk.

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