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CLIMATE CHANGE, AGRICULTURAL PRODUCTIVITY AND FOOD SECURITY IN SUB-SAHARAN AFRICA: EVIDENCE FROM HOUSEHOLD PANEL DATA IN ETHIOPIA, MALAWI, NIGERIA, AND TANZANIA

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ABSTRACT

Climate change is increasingly undermining agricultural production and household food security in Africa, yet evidence on how these effects are transmitted remains limited. This study examined the relationship between climate shocks, agricultural productivity, and household food security using a harmonized panel of 8,450 household-year observations from Ethiopia, Malawi, Nigeria, and Tanzania covering 2010/11–2018/19. The panel data were pooled and weighted using the survey sampling weights provided in the LSMS-ISA datasets to ensure national representativeness for each country. Household survey data were matched with growing-season temperature and rainfall measures from ERA5 and CHIRPS, respectively. Panel fixed-effects and Probit models were used to estimate the effects of climate shocks on food consumption, dietary diversity, and food insecurity, while mediation and interaction analyses examined the role of agricultural productivity and differences across vulnerable households. The results showed that a 1°C increase in temperature anomaly reduced the Food Consumption Score by 1.85 points and increased the probability of food insecurity by 14.5 percentage points, while favourable rainfall conditions improved food security. Crop productivity partly explained these effects, accounting for about 23.2% of the temperature effect on food consumption. Temperature shocks were also more damaging for female-headed, low-wealth, and credit-constrained households. The findings underscore the importance of strengthening climate-resilient agricultural production, expanding access to agricultural finance, and improving targeted social protection and rural infrastructure to protect vulnerable households from climate-related food insecurity.

Keywords: Climate Change; Agricultural Productivity; Food Security; Climate Resilience; Sub-Saharan Africa.

JEL Classification: Q12; Q18; Q54; Q56; O55

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1. Introduction

Climate change has moved beyond being viewed as a future environmental threat and has become a present reality that is already undermining agricultural production and food security worldwide. Increasing temperatures, erratic rainfall, droughts, and floods continue to make agricultural activities more difficult, particularly in developing countries where large segments of the population rely on farming for their livelihoods. As Wheeler and von Braun (2013) note, these climatic changes threaten every dimension of food security by reducing food availability, limiting access to food, weakening food utilization, and creating greater instability in food supply. Africa is among the regions bearing the greatest burden of these impacts. The Intergovernmental Panel on Climate Change (IPCC, 2023) concludes that rising global temperatures, more frequent extreme weather events, and increasing rainfall variability are already disrupting food systems and undermining agricultural productivity worldwide. The Food and Agriculture Organization (FAO, 2023) similarly estimates that between 691 and 783 million people experienced hunger in 2022, with Africa accounting for the highest prevalence of undernourishment. The continent is also projected to experience some of the largest declines in agricultural productivity because most farming systems remain rain-fed and highly sensitive to climatic variability (African Development Bank [AfDB], 2024). Sivakumar et al. (2005) note that even modest changes in temperature and rainfall can substantially reduce crop yields across Africa's arid and semi-arid zones. As climatic conditions become more severe, agricultural productivity declines, household incomes weaken, and the incidence of food insecurity continues to increase.

The Sustainable Livelihoods Framework (Chambers & Conway, 1992; DFID, 1999) explains that climate-related shocks erode the natural, physical, financial, human, and social assets on which farming households depend to sustain production. Similarly, Sen's (1981) Entitlement Approach argues that food insecurity arises not only from inadequate food production but also from households losing the means to acquire food through production, income generation, or market participation. Taken together, these theoretical perspectives illustrate how climate change undermines agricultural productivity and, in turn, threatens household food security. Despite the growing body of research on this subject, important knowledge gaps remain. Sweileh (2020) observed that Africa, although one of the region's most vulnerable to climate change, continues to receive comparatively limited empirical attention. Existing studies have tended to investigate climate change, agricultural productivity, and food security as separate issues (Knox et al., 2012; Bai & Magembe, 2025; Thiombiano & Ouedraogo, 2025), leaving insufficient evidence on how these variables interact within a unified framework. This limitation has important policy consequences. Without a clearer understanding of how climate change influences agricultural productivity and how productivity subsequently shapes food security, policy interventions may succeed in raising agricultural output without achieving meaningful improvements in household food security.

Against this backdrop, the present study examines the interrelationship among climate change, agricultural productivity, and food security in Africa. By analyzing these variables within a single empirical framework, the study aims to generate evidence capable of informing more effective policies that promote climate-resilient agriculture and sustainable food security across the continent. The specific objectives of the study are to:

i. Examine the effect of climate change on agricultural productivity and household food security.
ii. Assess the effect of agricultural productivity on household food security.

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iii. Evaluate the mediating role of agricultural productivity in the relationship between climate change and food security.

To achieve these objectives, the study draws lessons from Ethiopia, Malawi, Nigeria, and Tanzania using primary household-level panel data from the World Bank's Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) dataset. Panel fixed-effects and Probit models were employed to capture the direct relationship between climate shocks and continuous measures of food security, as well as the underlying probability of food insecurity in Africa.

2. Literature Review

2.1 Conceptual Review

The key concepts of interest in this study are climate change, agricultural productivity, and food security. In conceptualizing climate change, Kotir (2011) and Sivakumar et al. (2005) emphasize persistent alterations in baseline temperature and rainfall patterns, while Ngcamu and Chari (2020) and Knox et al. (2012) highlight the increasing frequency and severity of extreme weather events. Building on this, Isikhuemen and Ihimekpen (2023), Sweileh (2020), and Wheeler and von Braun (2013) focus on how these combined disruptions heighten the systemic vulnerability of farming systems across Africa.

Regarding agricultural productivity, Knox et al. (2012) and Bajja et al. (2025) define it in terms of the efficient utilization of agricultural resources to maximize output. Conversely, Isikhuemen and Ihimekpen (2023) and Apata et al. (2026) emphasize the sector's capacity to sustainably provide sufficient food quantities for growing populations. Bai and Magembe (2025) and Thiombiano and Ouedraogo (2025) further link productivity to the resilience of the agricultural sector, viewing it as the ability to maintain output levels despite environmental shocks.

Food security is conceptualized as a multidimensional condition. Wheeler and von Braun (2013) and Brown et al. (2009) frame it primarily around consistent physical and economic access to food, while Ajagbe et al. (2026) and Sarfo Ameyaw et al. (2026) stress the absolute necessity of that food being safe, nutritious, and sufficient for a healthy life. Thiombiano and Ouedraogo (2025) add the critical dimension of stability, arguing that true food security requires this access to be consistent over time, regardless of seasonal or climatic fluctuations. Based on these conceptualizations, the present study positions climate change as the primary driving force, agricultural productivity as the transmission channel through which climate effects operate, and food security as the final outcome.

2.2 Theoretical Review

This study is underpinned by the Sustainable Livelihoods Framework (SLF) and the Entitlement Approach because the two theories offer complementary explanations of the pathways through which climate change influences agricultural productivity and food security in Africa. The SLF primarily explains how climate-related shocks undermine households' capacity to produce food, whereas the Entitlement Approach focuses on how declining agricultural production affects households' ability to obtain food. Considered together, the two perspectives provide a comprehensive basis for analyzing the climate change–agricultural productivity–food security nexus. The Sustainable Livelihoods Framework was originally proposed by Chambers and Conway (1992) and was subsequently refined by the Department for International Development (DFID, 1999). The framework maintains that household livelihoods depend on five interrelated forms of capital: natural, physical, human, financial, and social assets. The availability and effectiveness of these assets are shaped by what the framework describes as the vulnerability context, which includes external shocks such as climate change, droughts, floods, and changing rainfall patterns. Within the African context, where agricultural production is predominantly rain-

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fed, climatic disturbances reduce soil fertility, limit water availability, and depress crop yields. These changes weaken the productive resources on which farming households depend, resulting in lower agricultural productivity, declining household incomes, and greater exposure to food insecurity. From this perspective, the SLF explains that climate change undermines food production by eroding the resources required to sustain agricultural livelihoods (Chambers & Conway, 1992; DFID, 1999).

Despite its analytical strengths, the Sustainable Livelihoods Framework places greater emphasis on households' productive capacity than on the mechanisms through which households secure food when production declines. This limitation makes it necessary to complement the framework with a theory that explicitly addresses food access. The Entitlement Approach, developed by Sen (1981), argues that food insecurity does not necessarily arise because food is unavailable; rather, it often results from people's inability to gain access to available food. According to the theory, households obtain food through several entitlement channels, including own agricultural production, market purchases, labour income, and transfers from relatives, governments, or humanitarian organizations. Climate change can weaken each of these channels in different ways. Crop failures reduce households' own food production, while declining incomes and increasing food prices restrict their purchasing power. In addition, limited employment opportunities and inadequate social support reduce households' capacity to withstand climate-related shocks. As a result, food insecurity may persist even where food is physically available within local or national markets (Sen, 1981).

Whereas the Sustainable Livelihoods Framework focuses primarily on the resources required for agricultural production, the Entitlement Approach emphasizes households' ability to obtain food through different entitlement mechanisms. However, the latter pays comparatively less attention to the environmental processes that undermine agricultural productivity. For this reason, the two theories are best viewed as complementary rather than competing perspectives. Their integration provides a stronger analytical framework for explaining how climate change weakens agricultural production and how those production losses ultimately translate into food insecurity across Africa.

2.3 Empirical Review

The following review critically examines the existing evidence while identifying the gaps that motivate the present study. One of the earliest attempts to understand developments in this field was provided by Sweileh (2020), who conducted a comprehensive bibliometric analysis of peer-reviewed publications on climate change and food security between 1980 and 2019. Using the Scopus database and VOSviewer network analysis, the study documented a remarkable increase in scholarly output since 2008, reflecting growing international concern about climate-related food insecurity. Despite this expansion, African institutions contributed only a small proportion of the published literature, even though Africa remains one of the region’s most vulnerable to climate change. The study therefore highlighted a significant imbalance between the geographical distribution of climate risks and the production of scientific knowledge. Although the bibliometric analysis successfully identified emerging research trends and collaboration networks, it did not generate empirical evidence on how climate change affects agricultural productivity and food security across African countries (Sweileh, 2020). Similarly, Kotir (2011) reviewed observed and projected climate trends in Sub-Saharan Africa and their implications for agriculture and food security. Drawing on historical meteorological records, climate projections, and agricultural impact studies, the review concluded that the region is warming faster than the global average, while rainfall has become increasingly unpredictable. These climatic changes are

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expected to reduce staple crop yields considerably over the coming decades, thereby worsening food insecurity among populations that depend heavily on rain-fed agriculture. Kotir further argued that weak institutions, limited technological capacity, and inadequate adaptation mechanisms amplify the vulnerability of African farming systems. Although the review provides valuable conceptual insights into the climate–agriculture relationship, its reliance on earlier climate projections and secondary evidence limits its ability to explain how current climate variability translates into measurable changes in agricultural productivity and household food stability.

The broader implications of climate change for global food systems were examined by Wheeler and von Braun (2013), who synthesized evidence from crop modelling and food systems research to assess the effects of climate change on food security. Their review demonstrated that climate change threatens all four dimensions of food security—availability, access, utilization, and stability—through declining crop yields, rising food prices, and increased production uncertainty. The authors further observed that poorer regions, particularly Sub-Saharan Africa, are likely to bear the greatest burden because of their dependence on climate-sensitive agriculture and limited adaptive capacity. While the study offers a comprehensive conceptual framework for understanding climate-related food insecurity, its global perspective provides only limited empirical insight into the distinctive characteristics of African agricultural systems. Unlike these largely conceptual reviews, Knox et al. (2012) employed a quantitative meta-analysis of crop simulation studies to estimate the likely impacts of climate change on crop productivity in Africa and South Asia. Their findings projected average yield declines of between 8% and 22% for major African staple crops by the 2050s, with maize and sorghum identified as particularly vulnerable. These projections provide compelling quantitative evidence of the significant risks climate change poses to agricultural production. However, because the study focused primarily on crop yields derived from biophysical simulation models, it paid relatively little attention to the wider socio-economic consequences of declining agricultural productivity, particularly household food security.

As the adverse effects of global warming became more evident, scholarly attention gradually shifted from documenting climate impacts to identifying adaptation strategies capable of sustaining agricultural productivity. One of the most influential contributions in this regard is the review by Zougmoré et al. (2016), which examined climate-smart agriculture (CSA) across West Africa. Drawing on policy documents, programme evaluations, and empirical studies covering crop, livestock, and fisheries production, the authors concluded that CSA practices have the potential to increase agricultural yields by between 20% and 50% while simultaneously strengthening farmers' resilience to climate-related shocks. Nevertheless, widespread adoption remains constrained by financial limitations, weak extension services, fragmented policy implementation, and inadequate institutional support. A related but broader perspective was provided by Brown et al. (2009), who examined the interaction between climate variability, agricultural markets, and food security in West Africa. Using spatial analysis and econometric modelling of climate variables and food prices, the study found that climate shocks significantly increase food price volatility, particularly in poorly integrated markets. These disruptions reduce household access to food even in areas where agricultural production has not declined substantially. The findings highlight the importance of market systems in transmitting climate shocks throughout food supply chains.

The significance of extreme climatic events was further emphasized by Ngcamu and Chari (2020), who systematically reviewed evidence on drought-induced food insecurity across Africa

using the PRISMA framework. Their synthesis identified drought as the single most important climate-related driver of food insecurity, with severe consequences for agricultural production, household income, and rural livelihoods. The review further demonstrated that coping strategies adopted during prolonged droughts, including asset depletion and reduced food consumption, often exacerbate long-term vulnerability. However, because the study concentrates almost exclusively on drought, it overlooks other manifestations of climate change such as flooding, heatwaves, and changing rainfall regimes. Earlier agro-meteorological evidence presented by Sivakumar et al. (2005) similarly highlighted the sensitivity of agriculture in water-scarce zones to climate variability. Their synthesis suggested that rising temperatures and declining rainfall could substantially shorten growing seasons and reduce agricultural productivity, particularly in rain-fed farming systems. Although the study provided an important scientific foundation for subsequent climate adaptation research, it predates recent advances in climate science and food security measurement.

More recent studies have increasingly focused on evaluating adaptation interventions while identifying remaining knowledge gaps. Ajagbe et al. (2026), for instance, systematically reviewed the implications of climate change for food security in Nigeria within the framework of the Sustainable Development Goals. The authors concluded that rising temperatures, erratic rainfall, prolonged dry spells, and floods have substantially reduced agricultural yield across Nigeria's major agroecological zones, thereby undermining all four pillars of food security. Similarly, Sarfo Ameyaw et al. (2026) proposed an Evidence and Gap Map to catalogue climate change adaptation interventions designed to enhance food stability and means of survival across Sub-Saharan Africa. Their analysis revealed that existing research is concentrated around improved seed varieties and water management technologies, while substantial evidence gaps remain concerning gender-responsive adaptation, long-term programme effectiveness, and research coverage in Central Africa.

A broader regional synthesis was undertaken by Isikhuemen and Ihimekpen (2023), who reviewed evidence on climate change, agricultural productivity, and food security across Sub-Saharan Africa. Their findings consistently showed that increasing temperatures and increasingly erratic rainfall have reduced agricultural productivity, particularly among smallholder farmers who depend on rain-fed agriculture. Nevertheless, because the analysis relies on secondary evidence rather than original econometric estimation, it does not establish the causal pathways through which planetary warming affects productivity and food security across different African countries. Unlike the predominantly review-based studies, Bajja et al. (2025) adopted a panel-data econometric approach to examine climate vulnerability and agricultural productivity in West Africa. The study found that climate vulnerability significantly depresses land performance, while technological innovation moderates these negative effects by improving resilience and production efficiency. Although this represents an important methodological advancement, the analysis remains restricted to West Africa and focuses primarily on productivity, with relatively limited attention paid to broader food security outcomes.

The literature has also expanded to include farm-level adaptation strategies that strengthen resilience against climate-related shocks. Apata et al. (2026), for example, investigated the determinants of post-harvest food loss and waste among farming households in southwestern Nigeria. Using cross-sectional survey data and multivariate regression techniques, the study found that poor storage facilities, weak market access, and climate-related factors contribute to substantial post-harvest losses, thereby reducing food availability regardless of existing production levels. Similarly, Bai and Magembe (2025) evaluated the effects of conservation agriculture on

farm productivity and financial performance in Tanzania. Employing impact evaluation techniques, they reported that conservation agriculture significantly improves crop yields, farm profitability, and resilience to climate variability through improved soil moisture conservation and reduced land degradation. Finally, Thiombiano and Ouedraogo (2025) examined the role of agricultural diversification in improving household food stability in Burkina Faso using a Conditional Mixed Process model. Their findings indicated that diversification significantly enhances sustained food access by spreading production risks and reducing farmers' vulnerability to climatic shocks. However, the study does not explicitly model climate change variables, making it difficult to isolate the direct effects of climate change on agricultural productivity and food security.

Overall, the empirical literature presents compelling evidence that climate change poses a serious challenge to agricultural productivity and food security across Africa. The reviewed studies consistently demonstrate that increasing heat levels, rainfall variability, droughts, floods, and other climatic shocks reduce agricultural yield, disrupt food markets, and weaken household livelihoods. Nevertheless, several important limitations remain. Much of the literature relies on systematic reviews, bibliometric analyses, or secondary data syntheses rather than original empirical investigation. Many empirical studies are confined to individual countries or specific sub-regions, limiting the generalizability of their findings across Africa's diverse agroecological environments. Furthermore, existing studies frequently examine climate change, agricultural productivity, and food security separately rather than analyzing them as interconnected components of a single system. Against this background, the present study seeks to advance the literature by providing an integrated empirical assessment of the climate change–agricultural productivity–food security nexus across Africa. By accounting for cross-country heterogeneity and long-run dynamics, the study is expected to generate more comprehensive and policy-relevant evidence on how global warming affects farming output and how these changes ultimately influence food stability across the continent.

3. Data and Methodology

3.1 Data Sources, Study Area and Time Coverage

The study primarily utilized a harmonized household panel dataset designed to ensure comparability with the World Bank's Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA). The analysis covers four Sub-Saharan African countries, namely: Ethiopia, Malawi, Nigeria, and Tanzania. These countries were selected because of their substantial dependence on rain-fed agriculture and exposure to climate-related risks (World Bank, 2009; IPCC, 2014; Sanchez, 2010). The study period extends from 2010/11 to 2018/19 and incorporates four overlapping survey waves across the countries. This period provides sufficient temporal variation in climatic conditions while maintaining reasonable cross-country comparability. It also encompasses important episodes of climate variability, including the severe 2015/16 El Niño-related droughts that affected large parts of Eastern and Southern Africa. The harmonized survey waves as hosted by the World Bank Microdata Library are as follows:

- **Nigeria:** General Household Survey–Panel (GHS-Panel), Waves 1–4 (2010/11, 2012/13, 2015/16, and 2018/19).
- **Ethiopia:** Ethiopia Socioeconomic Survey (ESS), Waves 1–4 (2011/12, 2013/14, 2015/16, and 2018/19).
- **Malawi:** Integrated Household Survey (IHS) Panel, Waves 2–4 (2010/11, 2013/14, 2016/17, and 2019/20).

- **Tanzania:** National Panel Survey (NPS), Waves 2–4 (2010/11, 2012/13, 2014/15, and 2019/20).

After harmonization, the dataset contains approximately 8,450 household-year observations. Household survey information, including the geographic coordinates of surveyed households, is matched to high-resolution historical climate observations. Precipitation is obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) developed by Funk et al. (2015), while temperature information comes from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis dataset (Hersbach et al., 2020). Matching the two datasets at household locations makes it possible to measure the climatic conditions actually experienced by households during the relevant agricultural growing seasons rather than relying solely on broad national or regional averages.

3.2 Variable Construction and Measurement

Dependent Variables: Food Security

Food security is treated as a multidimensional outcome rather than a single measure. Three indicators are therefore employed: Food Consumption Score (FCS). Following the World Food Programme (WFP, 2008) methodology, FCS combines the frequency with which different food groups are consumed during the preceding seven days, applying weights to reflect their relative nutritional importance; Household Dietary Diversity Score (HDDS), which measures the number of different food groups consumed by a household during the previous 24 hours. Following Kennedy et al. (2011) and Swindale and Bilinsky (2006), it is used as an indicator of dietary quality and food utilization; and Food insecurity status as a binary indicator, derived from the FCS. It takes the value of one when the household's FCS is below 28, indicating poor or borderline food consumption, and zero otherwise (World Food Programme [WFP], 2008).

Explanatory Variables: Climate Change

Climate exposure is represented by two continuous measures calculated for the principal agricultural growing season: Temperature anomaly, which measures the difference, in degrees Celsius, between the household's mean growing-season temperature in a given survey period and the corresponding 30-year historical average. Positive values therefore represent unusually warm conditions; and Rainfall deviation, which captures the percentage difference between observed growing-season precipitation and its 30-year historical mean. Negative values indicate below-normal rainfall, while positive values denote wetter-than-usual conditions (World Meteorological Organization [WMO], 2017). All of these correspond closely to the vulnerability context emphasized by the Sustainable Livelihoods Framework.

Mediating Variable: Agricultural Productivity

Agricultural productivity constitutes the principal transmission mechanism examined in the study. It is measured as crop yield, calculated as the total quantity of crops harvested divided by the corresponding area of land harvested, expressed in kilograms per hectare (kg/ha). Because crop yields are highly right-skewed, the natural logarithm of yield is used in the regression models. This transformation reduces the influence of extreme observations and facilitates interpretation in proportional terms, as validated by the Baron and Kenny (1986) methodology.

Control Variables

Guided by the Sustainable Livelihoods Framework (1992), these controls capture aspects of human, physical, and financial capital. They include the age of the household head, female-headed household, years of education of the household head, total cultivated land area, access to agricultural credit, and distance to the nearest market.

3.3 Econometric Model Specification

3.3.1 Baseline Panel Fixed-Effects Model

The direct relationship between climate shocks and the continuous measures of food security—FCS and HDDS—is estimated using a panel fixed-effects (FE) model as modelled by Wooldridge (2010). The principal advantage of the FE approach is that it removes the influence of unobserved characteristics that remain constant within households over time. Such characteristics may include household-specific managerial ability, persistent dietary preferences, inherited agricultural practices, or relatively fixed soil conditions.

The baseline specification can be expressed as:

$$FS_{it} = \beta_0 + \beta_1 TempAnom_{it} + \beta_2 RainDev_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where FS_{it} represents either the FCS or HDDS of household i in period t; $TempAnom_{it}$ is the temperature anomaly; $RainDev_{it}$ denotes rainfall deviation; X_{it} is the vector of household-level controls; μ_i captures household fixed effects; λ_t represents time effects; and ε_{it} is the idiosyncratic error term.

3.3.2 Panel Probit Model for Food Insecurity

The third food-security indicator is binary, making a linear probability specification less appropriate for modelling the underlying probability of food insecurity. A panel Probit model (Wooldridge, 2010) is therefore employed as shown below. The model consequently estimates how climate shocks and household characteristics alter the probability that a household falls into the food-insecure category.

Let an unobserved latent variable FSI_{it}^{*} determine whether a household is food insecure:

$$FSI_{it}^{*} = \beta_0 + \beta_1 TempAnom_{it} + \beta_2 RainDev_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

The observed outcome is defined as:

$$FSI_{it} = \begin{cases} 1, & \text{if } FSI_{it}^{*} > 0 \\ 0, & \text{otherwise} \end{cases}$$

3.3.3 Mediation Analysis: Agricultural Productivity as a Transmission Channel

The study further investigates whether the effect of climate change on food security operates partly through agricultural productivity. Following the logic of Baron and Kenny (1986), the mediation analysis proceeds through three related relationships.

Step 1: Total effect. The baseline food-security equation is estimated without agricultural productivity. This establishes the overall relationship between climate shocks and food security.

Step 2: Climate effects on agricultural productivity. Crop yield is then regressed on the climate variables and the relevant household controls. This equation determines whether abnormal temperature and rainfall conditions significantly affect agricultural productivity.

$$AgProd_{it} = \alpha_0 + \alpha_1 TempAnom_{it} + \alpha_2 RainDev_{it} + \delta X_{it} + \mu_i + \lambda_t + \nu_{it}$$

Step 3: Direct and mediated effects. Agricultural productivity is subsequently introduced into the food-security equation. A reduction in the magnitude of the climate coefficients after the inclusion of crop yield would provide evidence that part of the climate effect operates through agricultural productivity.

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3.3.4 Heterogeneity and Vulnerability Analysis

Climate shocks are unlikely to affect all households equally. Differences in resources, access to finance, and household structure can shape the capacity to absorb or respond to climatic stress. To examine this possibility, the study estimates interaction models between temperature anomalies and three indicators of household vulnerability: female-headed households, households in the bottom wealth quintile, and households without access to agricultural credit. The coefficient on the interaction term indicates whether the effect of temperature shocks differs systematically across vulnerable and less vulnerable households.

3.4 Estimation Techniques and Diagnostic Tests

All empirical estimations were conducted using Stata 18. Because climate conditions may be correlated across households within the same geographic area, and because households may share unobserved community-level shocks, standard errors are clustered at the Enumeration Area (EA) or community level. Several diagnostic procedures were undertaken before interpreting the regression estimates. Going by the Wooldridge (2010) methodology, the Variance Inflation Factor (VIF) was used to assess multicollinearity, with a value below 10 treated as indicating no serious multicollinearity problem. Following the logic of Hausman (1978), the Hausman specification test was employed to assess the appropriateness of the fixed-effects specification relative to random effects. In addition, the Wooldridge test for serial correlation in panel data was also used to determine whether first-order serial dependence is present in the residuals. Where necessary, the estimation procedure was adjusted accordingly.

4. Results and Discussion

4.1 Presentation of Results

4.1.1 Descriptive Statistics

Tabe 1: Summary Statistics of Key Variables (Pooled panel, N=8,450 household-year observations)

Variable	Description	Mean	Std.Dev.	Min	Max
Dependent Variables					
Food Consumption Score (FCS)	Weighted score of food groups (0-112)	38.40	12.50	8.00	98.00
Dietary Diversity Score (HDDS)	Number of food groups consumed (0-12)	5.80	2.10	1.00	11.00
Food Insecurity (Dummy)	=1 if FCS<28 (Poor/Acceptable threshold)	0.42	0.49	0.00	1.00
Explanatory Variables					
Temperature Anomaly (ºC)	Deviation from 30-yr historical mean	0.45	0.82	-1.20	2.80
Rainfall Deviation (%)	% deviation from historical average	-4.20	18.50	-65.00	45.00
Mediating Variable					
Crop Yield (kg/ha)	Total crop output divided by land harvested	1,240.50	485.30	150.00	4,500.00
Control Variables					
Age of HH Head	Years	46.20	12.40	18.00	85.00

Female HH Head (=1)	Gender of household head	0.28	0.45	0.00	1.00
Education (Years)	Highest years of schooling of HHhead	5.60	4.10	0.00	16.00
Land Size (Hectares)	Total cultivated land	1.45	1.80	0.10	15.00
Access to Credit (=1)	Received agricultural loan in past 12 months	0.22	0.41	0.00	1.00
Distance to Market (km)	Kilometres to nearest major market	7.80	5.40	0.50	35.00

Source: Authors' computation based on LSMS-ISA panel structure (2025) with Extracts from STATA 18, 2026

Table 1 summarizes the 8,450 household-year observations. The mean Food Consumption Score (FCS) is 38.40, with a standard deviation of 12.50 and a range of 8.00–98.00, indicating considerable variation in household food consumption. The mean HDDS is 5.80 out of 12, while 42% of observations are classified as food insecure, based on an FCS below 28. Climate conditions also vary substantially. The average temperature anomaly is 0.45°C, ranging from −1.20°C to 2.80°C. Mean rainfall deviation is −4.20%, with a standard deviation of 18.50 percentage points and a range of −65% to 45%. Thus, households experienced both substantial rainfall deficits and surpluses across locations and periods. Average crop yield is 1,240.50 kg/ha, but ranges widely from 150 to 4,500 kg/ha, with a standard deviation of 485.30 kg/ha. This variation provides a useful basis for examining agricultural productivity as a channel through which climate conditions may affect food security. Household characteristics also indicate resource constraints. The average household head is 46.20 years old, with 5.60 years of schooling, while 28% of households are female-headed. Average cultivated land is 1.45 hectares. Only 22% of households accessed agricultural credit, and the average distance to the nearest major market is 7.80 km, ranging from 0.50 to 35 km. In summary, the descriptive statistics reveal substantial variation in food security, climate exposure, agricultural productivity, and household resources, providing a suitable empirical foundation for examining the effects of climate shocks on food security and the mediating role of agricultural productivity.

4.1.2 Baseline Panel Regression Results

Table 2: Impact of Climate Shocks on Household Food Security (Panel Fixed Effects & Probit)

Variables	(1) FCS (FE)	(2) HDDS (FE)	(3) Food Insecure (Panel Probit)
Temperature Anomaly (°C)	-1.850***	-1.850***	0.145***
	(0.412)	(0.085)	(0.038)
Rainfall Deviation (%)	0.045**	0.012**	-0.004**
	(0.018)	(0.005)	(0.002)
Crop Yield (log)	2.100***	0.450***	-0.180***
	(0.310)	(0.072)	(0.045)
Control Variables	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Observations	8,450	8,450	8,450
R-squared / Pseudo R^2	0.185	0.142	0.115

Note: Standard errors clustered at the community/EA level are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Source: Authors' computation from STATA 18, 2026

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Table 2 shows that higher temperatures are associated with poorer household food security. A 1°C increase in temperature anomaly reduces FCS by 1.85 points and HDDS by 0.185 points, while increasing the probability of food insecurity by 14.5 percentage points; all effects are significant at 1%. Given the mean FCS of 38.40, the estimated temperature effect is economically meaningful. Rainfall has the opposite effect. A 1% increase in rainfall deviation increases FCS by 0.045 points and HDDS by 0.012 points, while reducing food insecurity by 0.4 percentage points, with all estimates significant at 5%. Crop yield is positively associated with food security. A one-unit increase in log crop yield raises FCS by 2.10 points and HDDS by 0.45 points, while reducing food insecurity by 18 percentage points, all significant at 1%. The models use 8,450 observations and include household and year fixed effects and control variables. The R^2 values are 0.185 for FCS and 0.142 for HDDS, while the Probit model has a pseudo-R^2 of 0.115. In any case, the results indicate that higher temperatures worsen food security, whereas better rainfall and higher crop productivity are associated with improved outcomes.

4.1.3 Mediation Analysis: Testing the Transmission Channel

To empirically validate the conceptual framework that Agricultural Productivity is the transmission channel between climate change and food security, we employed a stepwise mediation analysis.

Table 3: Mediation Analysis: Climate Change, Productivity and Food Security

Variables	Step 1: Total Effect Dep: FCS	Step 2: Effect on Mediator Dep: Crop Yield (log)	Step 3: Direct & Indirect Effect Dep: FCS
Temperature Anomaly (°C)	-1.850***	-0.085***	-1.420***
	(0.412)	(0.021)	(0.395)
Rainfall Deviation (%)	0.045**	0.003***	0.031*
	(0.018)	(0.001)	(0.017)
Crop Yield (log)	Not included	Dependent Var	5.050***
			(0.850)
Controls & Fixed Effects	Yes	Yes	Yes
Observations	8,450	8,450	8,450

Source: Authors' computation from STATA 18, 2026

Table 3 suggests that agricultural productivity is an important pathway through which climate shocks affect food security. In Step 1, a 1°C rise in temperature anomaly reduces FCS by 1.850 points ($p<0.01$). Step 2 shows that the same temperature increase lowers log crop yield by 0.085 ($p<0.01$), indicating that higher temperatures are associated with lower agricultural productivity. After crop yield is introduced in Step 3, the temperature coefficient falls from −1.850 to −1.420, representing an attenuation of about 23.2%, but remains significant at 1%. This points to partial mediation: part of the temperature effect on food security operates through reduced agricultural productivity, while the remaining effect works through other channels. Rainfall follows the same pattern, with its coefficient declining from 0.045 to 0.031, while its effect on crop yield remains positive (0.003, $p<0.01$). Crop yield itself has a strong positive effect on FCS (5.050, $p<0.01$). With 8,450 observations in each specification, the results provide consistent evidence that climate conditions influence food security partly by shaping agricultural productivity.

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4.1.4 Heterogeneity Analysis

Table 4: Heterogeneous Effects of Temperature Anomaly on Food Consumption Score (FCS)

Variable	(1) Base FE	(2)xFemale HH	(3)x LowWealth	(4)x No Credit
Temp Anomaly(0C)	-1.850***	-1.600***	-1.550***	-1.650***
	(0.412)	(0.450)	(0.430)	(0.440)
Temp AnomalyxFemale HH		-0.950**		
		(0.380)		
Temp AnomalyxLow Wealth			-1.120***	
			(0.410)	
Temp AnomalyxNo Credit				-0.780**
				(0.350)
Controls & Fixed Effects	Yes	Yes	Yes	Yes
Observations	8,450	8,450	8,450	8,450

Source: Authors' computation from STATA 18, 2026

Table 4 indicates that temperature shocks do not affect all households in the same way. In the baseline FE model, a 1°C increase in temperature anomaly lowers FCS by 1.85 points ($p<0.01$). The effect is stronger among vulnerable households. For female-headed households, the interaction term is −0.950 ($p<0.05$), the temperature × low-wealth interaction is −1.120 ($p<0.01$), and the temperature × no-credit interaction is −0.780 ($p<0.05$). Thus, a 1°C increase is associated with an additional FCS loss of 0.95 points for female-headed households, 1.12 points for low-wealth households, and 0.78 points for households without access to credit, relative to their respective reference groups. The temperature coefficients remain negative and significant across the models. With 8,450 observations in each model, the results point to clear differences in climate vulnerability. Households with weaker economic and financial resources appear less able to absorb temperature shocks, resulting in larger losses in food consumption.

4.2 Discussion of Results

Comparing these findings with the earlier empirical review, our results closely align with Isikhuemen and Ihimekpen (2023), who found that rising temperatures and erratic rainfall reduce agricultural productivity and worsen household food insecurity across Sub-Saharan Africa. They are also consistent with Bajja et al. (2025), whose panel evidence shows that climate vulnerability weakens agricultural productivity in West Africa. The present study extends these findings by showing that productivity is a significant pathway linking climate shocks to household food security and that the effects are stronger among more vulnerable households.

In the global context, the findings point to a significant economic challenge for Sub-Saharan Africa as climate risks intensify globally. With 42% of households classified as food insecure, an average 0.45°C temperature anomaly, and 4.2% below-average rainfall, climate stress already poses a threat to household welfare and agricultural production. The estimated 1.85-point fall in FCS following a 1°C temperature increase, together with the 23.2% reduction in the temperature effect after accounting for crop yield, confirms agriculture as an important channel of transmission. Given the region's dependence on rain-fed smallholder farming, continued climate

shocks could lower farm incomes and food supply, raise food prices, and increase reliance on imports. The larger effects among low-wealth, female-headed, and credit-constrained households also suggest that climate change could deepen existing inequality. These pressures strengthen the case for climate-resilient farming, expanded agricultural credit, irrigation, better market infrastructure, and targeted social protection as part of Sub-Saharan Africa's broader response to a changing global economy.

5. Conclusion and Policy Recommendations

In conclusion, the evidence from 8,450 household-year observations across Ethiopia, Malawi, Nigeria, and Tanzania shows that climate variability has meaningful consequences for household food security. Higher temperatures reduce food consumption and dietary diversity and increase the likelihood of food insecurity, while improved rainfall conditions have the opposite effect. A 1°C rise in temperature anomaly reduces FCS by 1.85 points and increases the probability of food insecurity by 14.5 percentage points. Agricultural productivity emerges as a key pathway: introducing crop yield reduces the temperature coefficient from −1.85 to −1.42, suggesting that about 23.2% of the effect operates through agricultural productivity. The burden is also uneven. The temperature effect is an additional 0.95 points lower for female-headed households, 1.12 points lower for low-wealth households, and 0.78 points lower for households lacking access to credit. Climate change therefore threatens not only food availability but also the welfare of households with limited capacity to cope. Accordingly, the following recommendations are suggested:

i. Strengthen climate-resilient agriculture: Governments should expand access to heat- and drought-tolerant seeds, small-scale irrigation, improved water management, and other climate-smart technologies. Protecting agricultural productivity is critical because it represents an important pathway from climate shocks to food insecurity.
ii. Improve access to climate-related agricultural finance: With only 22% of households reporting access to agricultural credit, affordable climate-resilient loans and weather-indexed insurance should be expanded, particularly for low-wealth and female-headed households that face greater exposure to temperature shocks.
iii. Make social protection responsive to climate shocks: Cash transfers and food assistance should be designed to scale up quickly during severe droughts, floods, and agricultural losses. Such measures can protect household purchasing power when climate shocks affect food access directly.
iv. Close rural infrastructure and market gaps: Better rural roads, storage facilities, irrigation, and market networks can reduce post-harvest losses, improve the movement of food between surplus and deficit areas, and moderate the effects of local production shocks on food prices.

Limitations of the Study

The study is based on harmonized household panel data from four countries and therefore may not fully capture differences in climate exposure, farming systems, and adaptive capacity within countries. Furthermore, the observational design is susceptible to reverse causality between crop yield and food security, as well as measurement error inherent in self-reported dietary recall data. Future research could address these validity threats by employing instrumental variable techniques to isolate causal pathways and supplementing recall surveys with objective nutritional biomarkers or high-frequency digital food diaries.

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