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Catalyzing Climate Resilience : Addressing Adoption Barriers to Climate-Smart Agriculture and Food Security in Cameroon's Vulnerable Farming Communities

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Abstract
This study examines the barriers to climate-smart agriculture (CSA) adoption among smallholder farmers in Tiko, Cameroon, and the associated socioeconomic impacts on household food security in the face of environmental change. Despite moderate awareness of CSA practices (60%), adoption remains low (35%) due to limited financial resources, insufficient extension services, restricted access to inputs and infrastructure, and cultural resistance. Using a mixed-methods approach, results identify education, farm size, and particularly access to credit as critical factors influencing CSA uptake, highlighting the intersection of socioeconomic and ecological resilience. Most households report declining food availability attributed to climate variability, leading to coping strategies such as meal reduction and asset sales which threaten long-term adaptive capacity. These findings emphasize the need for integrated interventions combining financial support, capacity-building, improved input supply chains, and culturally sensitive participatory approaches. Additionally, strengthening localized climate information services is essential to aid informed decision-making amid escalating climate risks. Implementing such multidimensional strategies will enhance adaptive capacity, promote sustainable agricultural ecosystems, and improve food security resilience in vulnerable tropical African farming communities.

Keyword: Climate-Smart Agriculture, CSA Adoption Barriers, Smallholder Farmers, Food Security, Climate Variability, Adaptive Capacity, Financial Inclusion, Sustainable Agriculture, Cameroon, Environmental Resilience

1. Introduction

Agriculture in Sub-Saharan Africa remains highly vulnerable to the multifaceted impacts of climate variability and change, threatening the livelihoods and food security of millions of smallholder farmers (FAO, 2018; Niang *et al*., 2024). Climate-smart agriculture (CSA) has emerged as a promising framework to enhance agricultural resilience, boost productivity sustainably, and reduce greenhouse gas emissions (Lipper *et al*., 2014). However, despite growing awareness and global advocacy for CSA practices, actual adoption rates among smallholder farmers in many regions remain low and uneven (Thierfelder *et al*., 2018; Mbuli, Fonjong, & Fletcher, 2023).

Understanding the barriers to CSA adoption is critical for designing effective interventions that address both climatic challenges and socio-economic realities on the ground (Pérez-Escamilla *et al*., 2020). Prior studies have identified a suite of impediments ranging from financial constraints, limited access to knowledge and extension services, infrastructural deficits, to socio-cultural resistance (Tambo & Abdoulaye, 2013; Ericksen *et al*., 2020). These factors intertwine with rural poverty and food insecurity, often reinforcing a cycle of vulnerability that undermines long-term sustainability and resilience (Jones *et al*., 2017).Tiko, a climatically vulnerable region in Cameroon, embodies these global challenges at a local scale. With livelihoods heavily dependent on rainfed agriculture, farmers here face growing threats from changing rainfall patterns, higher temperatures, and frequent extreme weather events, as documented in recent climate impact assessments (Affoh, Zheng, & Dissanin, 2022; Mbuli *et al*., 2023). While evidence points to the necessity and benefits of CSA practices in this context, barriers to adoption remain poorly understood and inadequately addressed in policy frameworks (Tume *et al*., 2020).

This paper investigates the socio-economic and structural obstacles to CSA uptake among farmers in Tiko and explores the broader implications for household food security. Drawing on field surveys, focus group discussions, and key informant interviews conducted in 2024, the study aims to:

(i) identify and quantify key barriers preventing farmers from adopting CSA technologies, (ii) examine how these constraints relate to socio-economic vulnerability and adaptive capacity, and (iii) assess coping strategies employed by households faced with climate-induced food insecurity.By situating these localized insights within the wider literature on climate adaptation, this research aims to inform more context-sensitive and effective policy mechanisms. The findings contribute to the growing discourse emphasizing that CSA adoption is not simply a matter of awareness or technology availability but fundamentally contingent on addressing economic, educational, and institutional challenges within vulnerable farming systems (Lobell *et al*., 2024; Mbuli, Fonjong, & Fletcher, 2023).

2. Literature Review

2.1. Climate-Smart Agriculture: Concepts and Importance

Climate-smart agriculture (CSA) has emerged as a crucial paradigm for enhancing agricultural resilience amid increasing climate variability and change. Defined by the Food and Agriculture Organization (FAO, 2013) as an integrated approach to food security and climate policy, CSA aims to increase productivity sustainably, adapt and build resilience to climate change, and reduce greenhouse gas emissions where possible. CSA encompasses a variety of practices such as improved crop varieties, agroforestry, water harvesting, precision farming, integrated pest management, and soil conservation.

CSA is widely promoted as a solution to the climate-induced challenges facing smallholder farmers in the tropics, whose livelihoods are intricately tied to weather-sensitive agricultural production (Lipper *et al*., 2014; Niang *et al*., 2024). The potential benefits include stabilized yields, diversified income sources, and long-term sustainability under erratic climatic conditions.

2.2. Adoption of Climate-Smart Agriculture: Global and African Perspectives

Despite the clear potential of CSA, adoption rates among smallholder farmers remain highly variable and generally low in many developing countries, including across sub-Saharan Africa (Mbuli, Fonjong, & Fletcher, 2023; Finizola e Silva *et al*., 2024). Empirical studies reveal that adoption is influenced by a complex nexus of factors operating at individual, farm, community, and policy levels (Silva *et al*., 2024; Tambo & Abdoulaye, 2013).

Key determinants of CSA adoption globally include:

- **Education and Awareness:** Higher education levels and climate change awareness positively correlate with adoption, although some studies report mixed effects depending on how education interfaces with local knowledge systems (Finizola e Silva *et al*., 2024; Ado *et al*., 2019).
- **Farm Characteristics:** Larger farm sizes and greater land tenure security often facilitate adoption by reducing risk aversion and increasing resource availability (Van Schoubroeck *et al*., 2024).
- **Access to Information and Extension Services:** Consistent access to extension services, climate information, and technical training strongly enables informed decision-making and uptake of CSA practices (Mbuli *et al*., 2023; Ericksen *et al*., 2020).
- Financial Resources and Credit Access: Economic constraints remain a significant barrier. Limited income and poor access to affordable credit inhibit investment in improved inputs, irrigation, or soil management technologies (Zeleke *et al*., 2023; Mbuli *et al*., 2023).
- **Social Networks and Group Memberships:** Membership in farmer groups or cooperatives can enhance adoption through knowledge sharing, collective action, and improved market access (Lipper *et al*., 2014).

2.3. Barriers to CSA Adoption: Evidence from Africa and Similar Contexts

Barriers to CSA adoption are as much socio-economic and institutional as they are technical. A growing literature has documented the following recurrent obstacles:

1. **Financial Constraints:** The cost of adopting climate-resilient seeds, water-saving technologies, and improved inputs remains prohibitive for many smallholders, especially those facing poverty and income volatility (Silva *et al*., 2024; Tambo & Abdoulaye, 2013).
2. **Lack of Knowledge and Training:** Insufficient extension services and inadequate farmer training limit awareness of CSA benefits and reduce confidence in new practices (Mbuli *et al*., 2023; Zeleke *et al*., 2023).
3. **Limited Access to Inputs and Infrastructure:** Poor availability of improved seeds, fertilizers, tools, and inadequate irrigation or drainage infrastructure restrict CSA uptake (Ericksen *et al*., 2020; Tume *et al*., 2020).
4. **Cultural and Behavioral Factors:** Traditional farming practices, risk aversion, and social norms sometimes resist change, particularly among older farmers, though this is less reported compared to economic barriers (Mbuli *et al*., 2023).
5. **Market and Policy Environment:** Inconsistent policies, lack of government support, and unreliable markets for CSA products disincentivize investment in climate-smart technologies (Gilbert *et al*., 2022; Silveira *et al*., 2025).

Studies from regions similar to Tiko, including drought-prone parts of West and Central Africa, stress the compounded effect of these barriers in trapping smallholder farmers in cycles of vulnerability (Finizola e Silva *et al*., 2024; Kumar *et al*., 2024).

2.4. Socioeconomic Implications of Limited CSA Adoption

The limited adoption of CSA practices exacerbates food insecurity and poverty in vulnerable farming systems. Climatic shocks such as droughts, floods, and heatwaves damage staple crop productivity, leading to yield volatility and loss of household income (Mbuli *et al*., 2023; Affoh, Zheng, & Dissanin, 2022). Without adaptive strategies, households resort to negative coping mechanisms meal reduction, asset sales, or distress migration which undermine long-term resilience and nutritional outcomes (Kumar *et al*., 2024; WHO, 2022).Furthermore, disparities in CSA adoption widen gender and socioeconomic inequalities, as marginalized groups often face steeper barriers and exclusion from extension, credit, and markets (Ericksen *et al*., 2020; Lobell *et al*., 2024).

2.5. Knowledge Gaps and Rationale for the Current Study

While overall barriers to CSA adoption are documented broadly, site-specific analyses remain scarce, especially in regions like Tiko where the intersection of climate risk and socio-economic challenges is acute. Existing policy frameworks in Cameroon often overlook local socio-cultural and economic contexts that shape adoption decisions (Tume *et al*., 2020). Furthermore, the linkage between adoption barriers and household food security outcomes requires detailed exploration to inform integrated interventions.This study addresses these gaps by providing empirical evidence from Tiko farmers, identifying key constraints to CSA uptake and their implications for food security, to inform targeted, contextually relevant policy design.

3. Study Area and Methodology

3.1. Study Area

The study was conducted in Tiko, a coastal town located in the South West region of Cameroon (Figure 1). Tiko is characterized by a tropical climate with two distinct seasons: a dry season from November to mid-March and a rainy season from mid-March to November. The region experiences an average annual rainfall ranging between 2,000 to 4,000 mm, with a mean temperature around 26–28 °C (Che *et al*., 2012; Affoh, Zheng, & Dissanin, 2022). Its fertile volcanic soils, coupled with a humid climate, make Tiko a significant hub for agriculture, including large-scale plantations producing bananas, palm oil, and rubber, as well as extensive smallholder farming primarily based on rainfed systems (CDC Head Office, 2022; Mbuli *et al*., 2023).

Tiko's agricultural sector is vulnerable to climatic variability, including erratic rainfall, rising temperatures, and increasing frequency of extreme weather events such as drought and flooding. These changing climate dynamics directly and indirectly affect crop yields and have significant socio-economic implications for smallholder farmers who rely heavily on traditional farming calendars and practices (Niang *et al*., 2024; Tume *et al*., 2020). The mixed rural-urban composition of the area, combined with diverse livelihood strategies, provides a relevant setting to investigate barriers to climate-smart agriculture (CSA) adoption and the resulting food security outcomes.

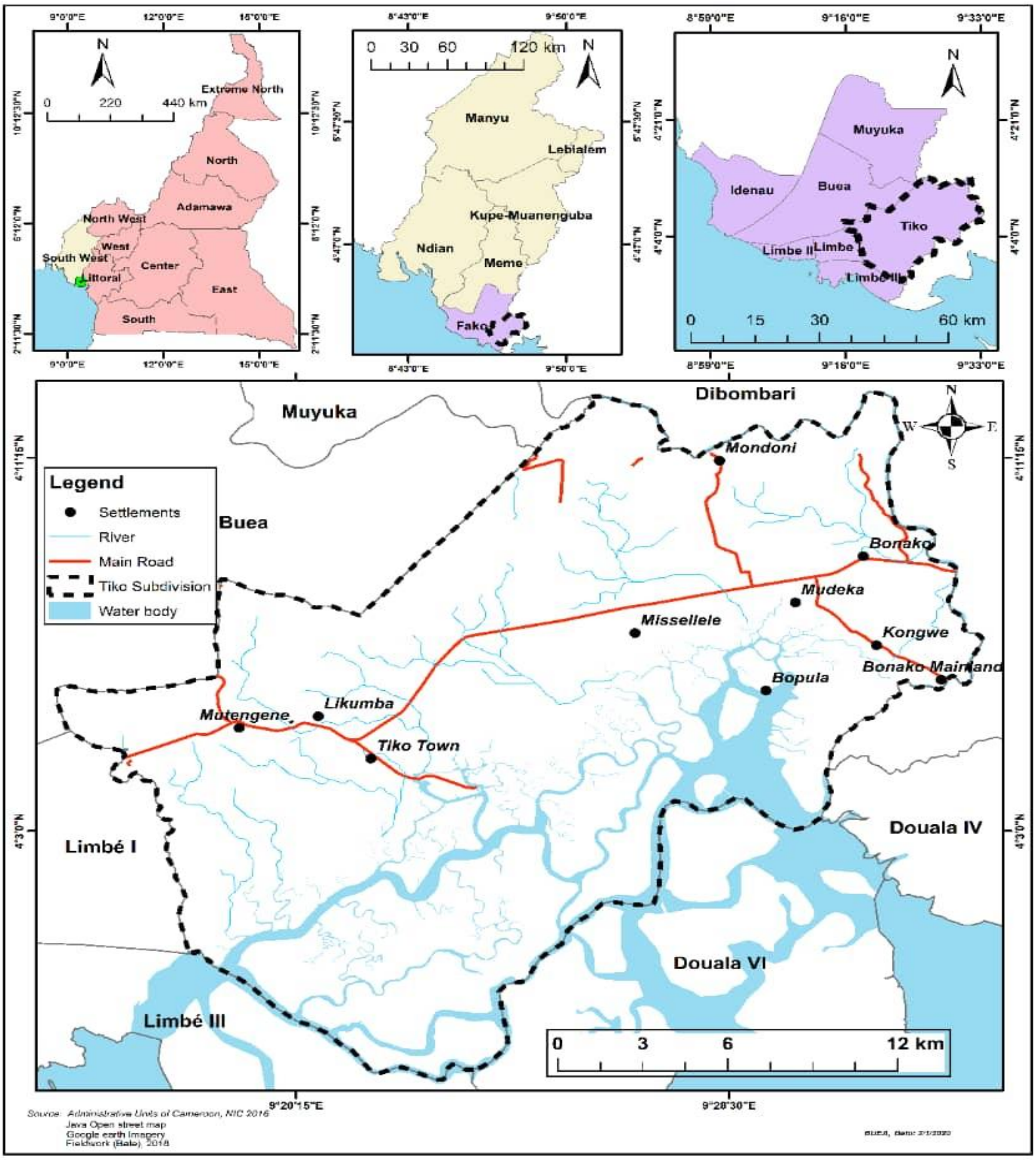

Fig 1: Location Map of Tiko Subdivision, Southwest Region, Cameroon

3.2. Research Design and Methodology
This study employed a mixed-methods approach, integrating quantitative surveys with qualitative data collection to comprehensively assess the socioeconomic barriers to CSA adoption and their implications for household food security in Tiko.

3.2.1. Sampling and Participants
A total of 200 smallholder farming households across diverse neighborhoods of Tiko were surveyed in 2024. Respondents were selected using stratified random sampling to ensure representation of different socio-economic groups and farming systems. Inclusion criteria emphasized households actively engaged in rainfed agriculture and those vulnerable to climatic stresses. Additionally, focus group discussions (FGDs) and key informant interviews (KIIs) were conducted with purposively selected farmers, agricultural extension officers, local government officials, and community leaders. These qualitative components aimed to contextualize survey findings, explore perceptions of climate risks, and identify systemic barriers to CSA uptake.

3.2.2. Data Collection Instruments
- A structured household questionnaire gathered data on demographic characteristics, agricultural practices, CSA adoption status, perceived barriers, and food security indicators.
- Semi-structured FGD guides facilitated discussions around climate impacts, adaptation experiences, knowledge gaps, and social-economic constraints.
- KIIs provided expert insights into institutional, infrastructural, and policy-related challenges affecting climate resilience pathways.

3.2.3. Climate Data Integration
The study incorporated secondary climatic datasets to relate farmer perceptions and practices to observed climate variability
- Historical meteorological records of temperature and precipitation (2000–2024) were obtained from the Cameroon Development Corporation (CDC) meteorological service and regional climate databases.
- These data characterized local climate trends, variability, and extremes, serving as contextual evidence to correlate with agricultural outcomes and behavioral responses documented in fieldwork.

3.2.4. Data Analysis
- Quantitative data from surveys were analyzed using descriptive statistics to identify common barriers, adoption rates, and socio-economic profiles. Cross-tabulations and logistic regression models assessed relationships between socio-demographic variables and CSA adoption likelihood.
- Qualitative data from FGDs and KIIs were transcribed, coded, and thematically analyzed using NVivo software to extract patterns related to barriers, adaptation strategies, and policy shortcomings.
- Triangulation of qualitative and quantitative results ensured comprehensive interpretation and validated findings.

3.3. Ethical Considerations
All participants provided informed consent. The study adhered to ethical guidelines ensuring confidentiality, voluntary participation, and cultural sensitivity during data collection.

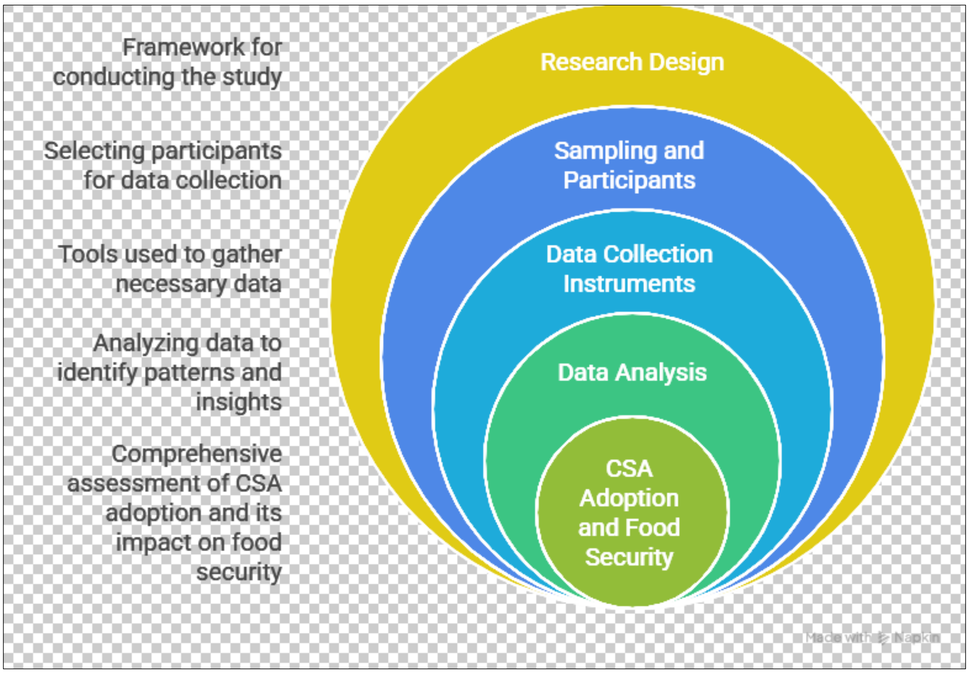

Fig 2: Logical Sequence of Research Methodology for Assessing CSA Adoption and Food Security Impacts

4. Results
This section presents the study's key findings, drawing systematically on quantitative and qualitative evidence to elucidate the factors shaping climate-smart agriculture adoption and food security among smallholder households in Tiko. To provide a comprehensive understanding, we begin by describing the socio-demographic characteristics of respondents, as these underpin both exposure to climatic risk and the capacity for adaptation.

4.1. Socio-Demographic Characteristics of Respondents
To contextualize patterns of CSA adoption and food security outcomes, we begin with the socio-demographic attributes of surveyed households.

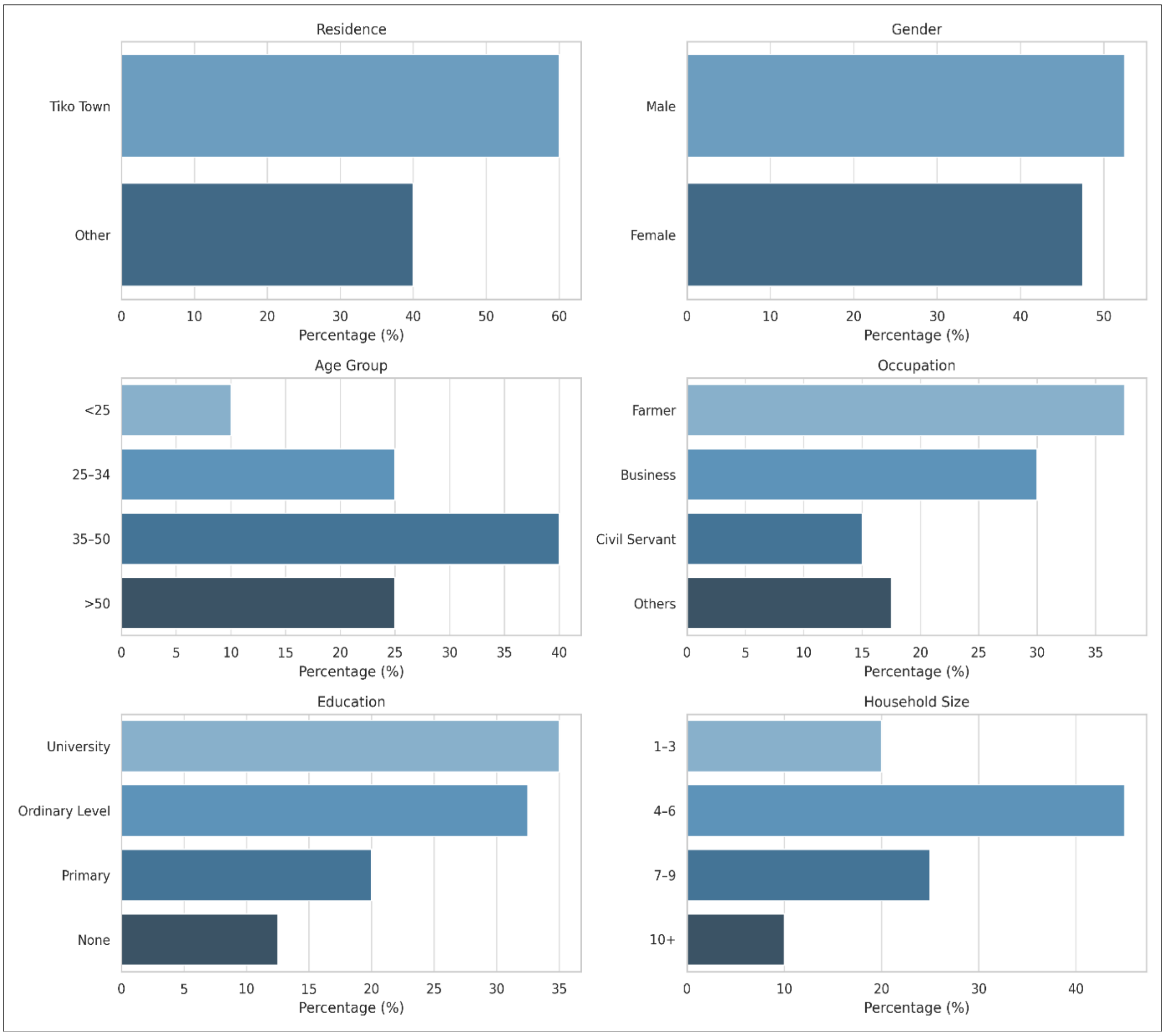

Fig 3: Socio-Demographic Characteristics of Surveyed Households

- **Residence:** 60% of respondents reside in Tiko Town, with 40% from peri-urban and rural zones, highlighting both an urban-proximate core and a substantial rural component.
- **Gender:** Males make up a slight majority (52.5%), with females comprising 47.5%, indicating near-gender parity in agricultural participation.
- **Age Group:** The dominant group is 35–50 years (40%), followed by those 25–34 (25%) and above 50 (25%), with only a small share below 25 years old (10%).
- **Occupation:** Households are primarily headed by farmers (37.5%), but business (30%) and civil service roles (15%) are also significant, reflecting livelihood diversification.
- **Education:** Nearly 68% have Ordinary Level or higher education and 35% are university graduates.
- **Household Size:** 45% of households consist of 4–6 members.

Figure 3 demonstrates a community characterized by relatively high education, a working-age population, and diversified non-farm livelihoods coexisting with a strong agricultural orientation. These characteristics suggest foundational capacity for innovation adoption, but also potential for food security pressures due to medium-to-large household sizes. This configuration is consistent with adaptive potential observed in other African agricultural systems (Affoh, Zheng, & Dissanin, 2022; Mbuli, Fonjong, & Fletcher, 2023).

Table 1: Socio-Demographic Profile of Respondents

Variable	Category	Percentage (%)
Residence	Tiko Town	60
	Other	40
Gender	Male	52.5
	Female	47.5
Age Group	<25	10
	25–34	25
	35–50	40
	>50	25
Occupation	Farmer	37.5
	Business	30
	Civil Servant	15
	Others	17.5
Education	University	35
	Ordinary Level	32.5
	Primary	20
	None	12.5
Household Size	1–3 members	20
	4–6 members	45
	7–9 members	25
	10+ members	10

The table 1 provides quantitative detail underlying Figure 3, further reinforcing the demographic narrative. Notably, relatively high education levels and moderate household sizes are recognized benchmarks for enabling adaptation and innovation dissemination (Mbuli *et al.*, 2023; Van Schoubroeck *et al.*, 2024). However, evidence from comparable contexts warns that these positive features can be offset by systemic economic and informational constraints unless actively addressed (Ado *et al.*, 2019).

4.2. Awareness and Adoption of Climate-Smart Agriculture Practices

We next present patterns of CSA knowledge and uptake, which set the stage for understanding barriers and enablers.

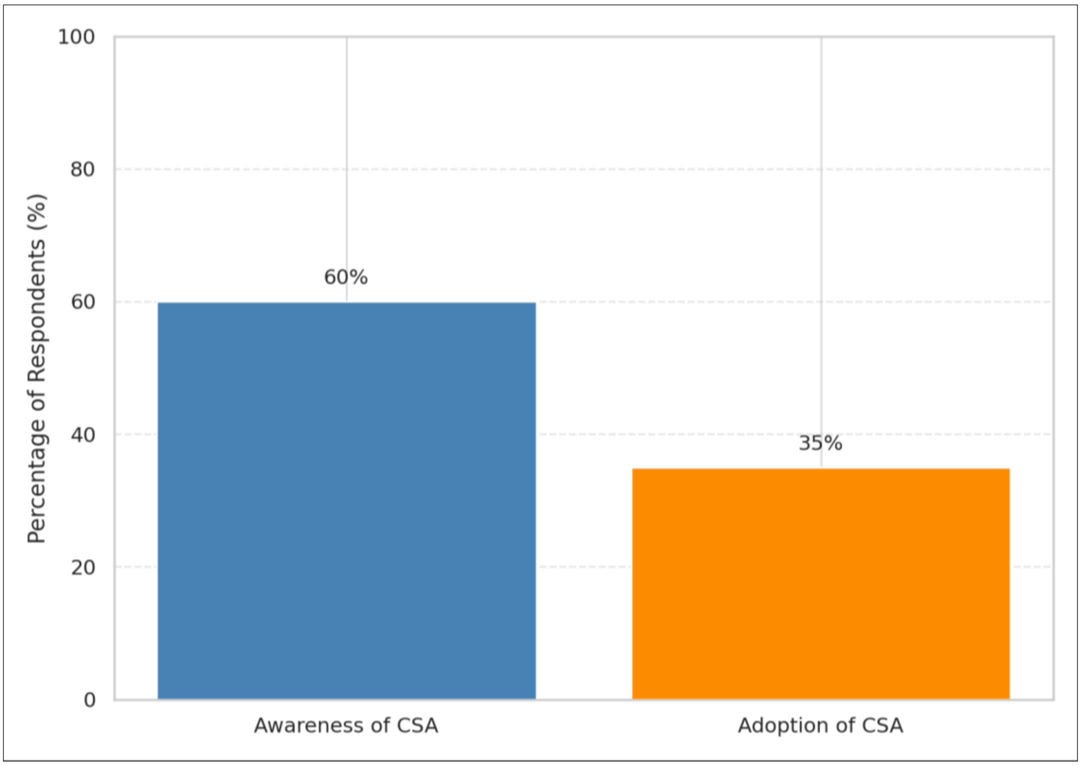

Fig 4: Awareness and Adoption Rates of Climate-Smart Agriculture

- Awareness of CSA practices is relatively high at 60%.
- Adoption lags significantly at only 35%.

The 25 percentage-point gap between awareness and adoption underscores a persistent "know-do" gap, commonly documented in the CSA literature for tropical Africa (Lipper *et al.*, 2014; Mbuli *et al.*, 2023). Despite widespread recognition of techniques like drought-tolerant crops, mulching, and water conservation, substantial bottlenecks prevent actionable uptake. This result, reinforced by Tambo and Abdoulaye (2013), confirms that merely improving awareness without targeted interventions in access, finance, or extension is insufficient for behavior change.

4.3. Barriers to Climate-Smart Agriculture Adoption

This section details the key obstacles limiting CSA implementation.

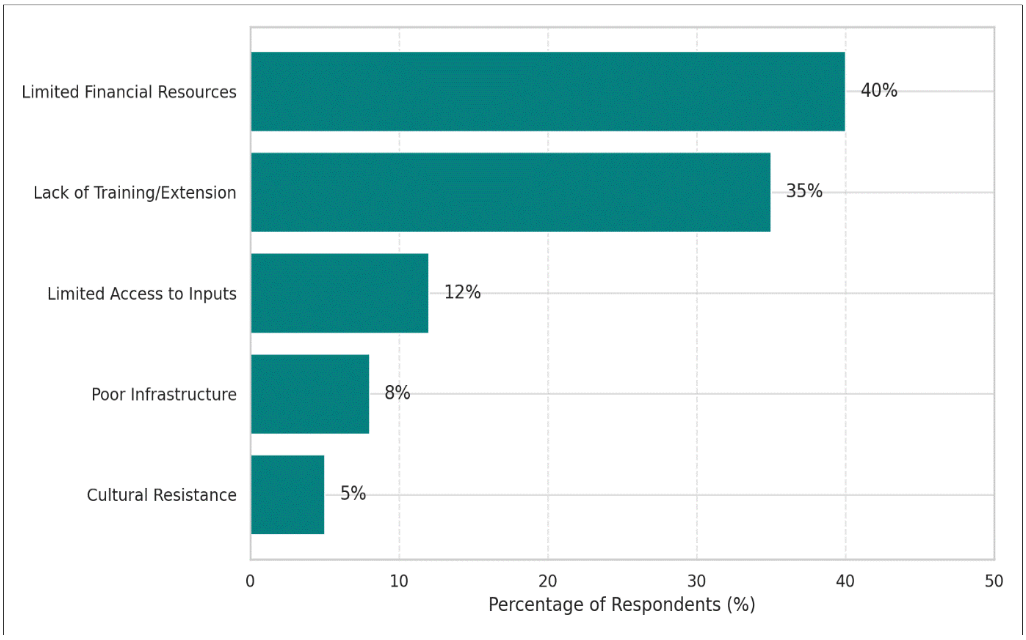

Fig 5: Main Barriers to Climate-Smart Agriculture Adoption

- Limited Financial Resources (40%) are the most frequently cited constraint.
- Lack of Training/Extension (35%) highlights shortfalls in capacity-building infrastructure.
- Limited Access to Inputs (12%) and Poor Infrastructure (8%) document logistical and physical barriers.
- Cultural Resistance (5%) remains present, though limited.

This barrier profile mirrors regional findings: limited finances remain the dominant impediment to CSA adoption across sub-Saharan Africa (Silva *et al*., 2024); knowledge and training gaps further depress uptake (Ericksen *et al*., 2020). Intertwined supply chain gaps (Tume *et al*., 2020) and infrastructural challenges (Ericksen, Ingram, & Liverman, 2020) compound structural exclusion. Qualitative testimony reaffirms the compounded nature of these constraints, with poverty and lack of extension most cited a pattern echoed by Finizola e Silva *et al*. (2024) and Kumar *et al*. (2024). Culturally rooted resistance, while rare, is not absent, consistent with the nuanced findings of Mbuli *et al*. (2023).

4.4. Socioeconomic Determinants of CSA Adoption

To further illuminate drivers of uptake, we turn to the results of the adoption determinants analysis.

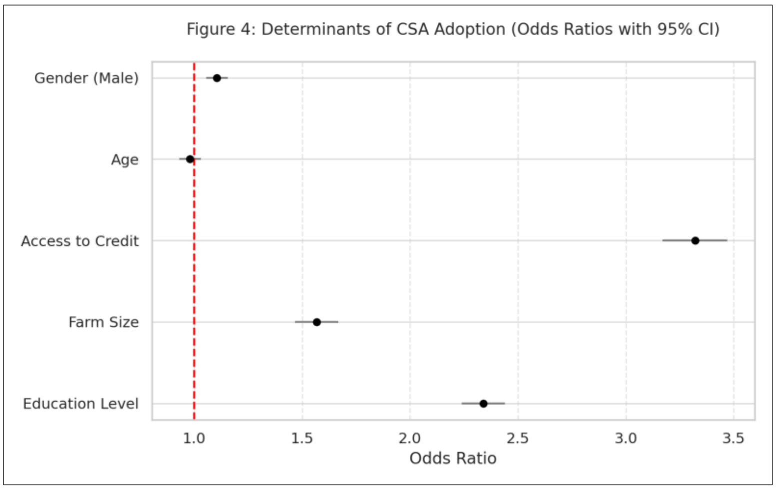

Fig 6: Logistic Regression Results for CSA Adoption Determinants

Figure 6 highlights that investments in education, farm asset enhancement, and especially credit provision are essential to drive up CSA adoption in Tiko. These determinants are strikingly consistent with adoption literature across Sub-Saharan Africa and emphasize the need for multifaceted, targeted interventions that go beyond awareness-raising (Lipper *et al*., 2014; Mbuli *et al*., 2023).

Table 2: Logistic Regression Results for CSA Adoption Determinants

Predictor	Coefficient (β)	Std. Error	p-value
Education Level	+0.65	0.20	0.002 **
Farm Size (ha)	+0.48	0.22	0.031 *
Access to Credit	+0.72	0.18	<0.001 **
Age	–0.05	0.03	0.12
Gender (Male = 1)	+0.10	0.15	0.48

(Note: *p< 0.05, **p< 0.01*)

Regression results show that education level (β = 0.65, OR = 2.34, p = 0.002) and farm size (β = 0.48, OR = 1.57, p = 0.031**)** significantly enhance the likelihood of CSA adoption each added education tier more than doubles the probability, and larger farms are better resourced to implement innovations. Access to credit (β = 0.72, OR = 3.32, p < 0.001) is the strongest predictor, more than tripling adoption odds. These findings are strongly aligned with prior research emphasizing the pivotal role of human capital, farm assets, and financial access (Van Schoubroeck *et al*., 2024; Ado *et al*., 2019; Zeleke *et al*., 2023).Age and gender are statistically nonsignificant, suggesting that in Tiko when resources and information are controlled for, all demographic groups can participate in CSA, though qualitative nuance regarding gendered resource access persists (Mbuli *et al*., 2023; Ericksen *et al*., 2020).

4.5. Implications for Household Food Security

The results below link CSA barriers and adoption patterns to observable food security dynamics.

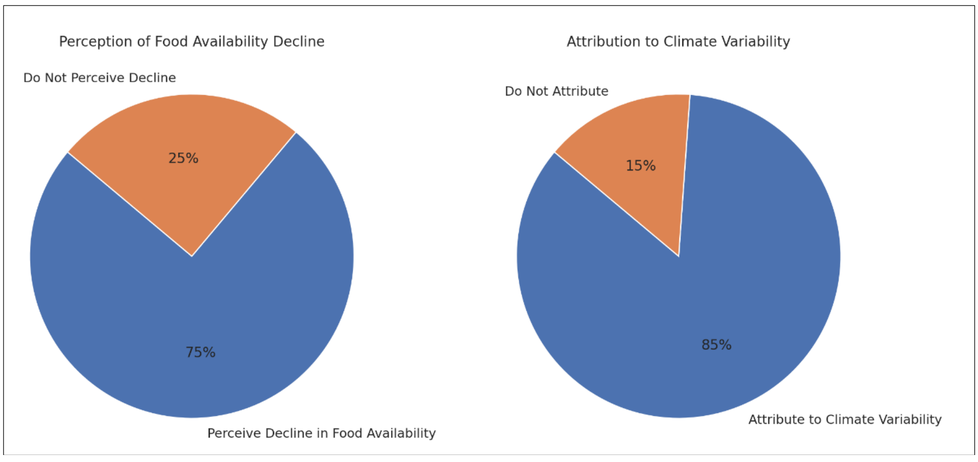

Fig 7: Household Food Security Perceptions and Climate Attribution

- 75% perceive a decline in food availability.
- 85% directly attribute food decline to climate variability.

These findings echo FAO's (2018) and Mbuli *et al.*'s (2023) conclusions that climate shocks are now the dominant trigger for food insecurity in smallholder settings. The high incidence of climate attribution indicates that farmers are acutely aware of the threat posed by erratic rainfall and rising temperatures.

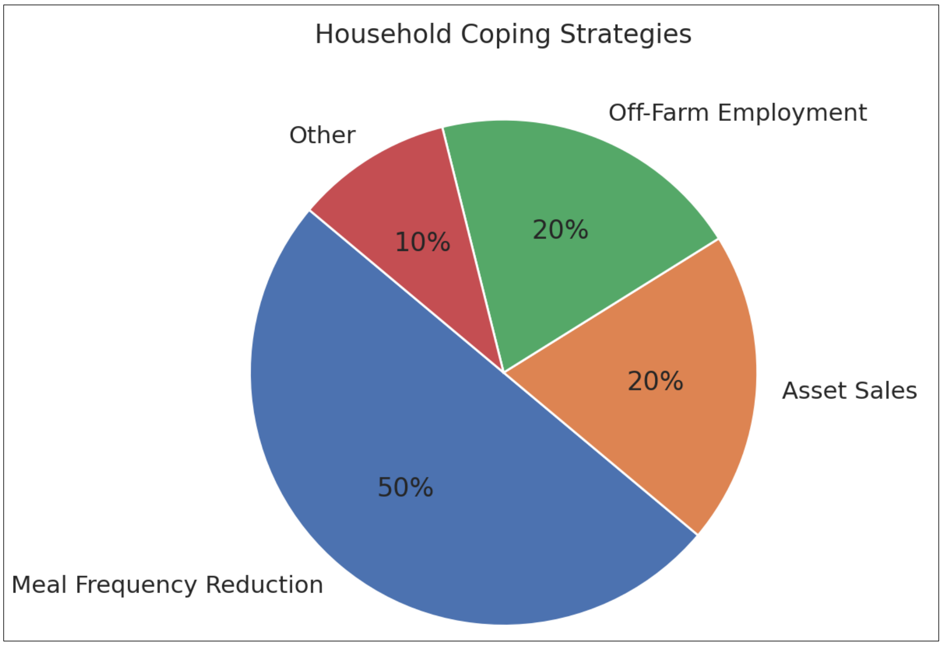

Fig 8: Household Coping Strategies

- Meal reduction (50%) is the most common response.
- Asset sales (20%) and off-farm employment (20%) are also prevalent.
- Other strategies (10%) include borrowing and community support.

Such coping approaches offer only short-term relief but often sow the seeds of negative long-term impacts, such as undernutrition and asset depletion (Tambo & Abdoulaye, 2013; WHO, 2022). The rapid shift to these adaptive responses following food supply disruptions is a well-recorded phenomenon in climate-vulnerable African agricultural systems (Kumar *et al.*, 2024; Mbuli *et al.*, 2023).

4.6. Institutional & Cultural Insights from Qualitative Data

While not visualized as a figure, qualitative material reinforces key quantitative findings:

- Extension services are under-resourced, preventing effective CSA diffusion (Mbuli *et al.*, 2023; Ericksen *et al.*, 2020).
- Policy and market uncertainties reduce incentives (Gilbert *et al.*, 2022; Silveira *et al.*, 2025).
- Cultural inertia, though not dominant, manifests as localized resistance among older cohorts (Mbuli *et al.*, 2023).

Overall, results reveal a demographically favorable but economically and institutionally constrained environment for climate adaptation. High awareness but low adoption of CSA reflects persistent financial, capacity, and input-barrier bottlenecks. The food security implications are clear: without addressing these multi-level structural barriers, household resilience in Tiko will continue to erode under climate stress.

5. Discussion

The findings presented above emphasize the complex interplay of demographic, socioeconomic, and institutional factors influencing climate-smart agriculture adoption and food security. To unpack these themes more thoroughly, we first examine how the socio-demographic characteristics of the community shape their adaptive capacity.

5.1. Socio-Demographic Foundations of Adaptation Potential

The socio-demographic profile of respondents demonstrates a community with considerable adaptive potential, given the predominance of a working-age population (35–50 years, 40%) actively engaged in farming and business, alongside relatively high education levels (67.5% with Ordinary Level or higher and 35% university graduates). Such attributes are generally conducive to innovation uptake and resilience-building in agricultural contexts (Affoh, Zheng, & Dissanin, 2022; Mbuli, Fonjong, & Fletcher, 2023). The near gender parity in participation (52.5% male, 47.5% female) and diversified livelihoods beyond agriculture (30% business, 15% civil service) are further strengths that could support adaptive capacity.

However, the moderate to large household sizes (45% with 4–6 members, 35% larger) suggest elevated food and resource demands that may intensify vulnerability under climatic stress, echoing similar findings in African smallholder settings where labor availability coexists with increased consumption pressures (Kumar, Singh, & Verma, 2024; Ado *et al.*, 2019). Thus, while socio-demographic characteristics provide a favorable baseline, they must be considered alongside systemic constraints which can negate potential benefits (Mbuli *et al.*, 2023; Van Schoubroeck *et al.*, 2024).

5.2. The Awareness Adoption Gap: Structural Barriers to Climate-Smart Agriculture

Despite a relatively high level of CSA awareness (60%), adoption rates lag significantly at 35%, emphasizing a persistent "know-do" gap consistent with extant literature on agricultural innovation in sub-Saharan Africa (Lipper *et al.*, 2014; Mbuli *et al.*, 2023; Tambo & Abdoulaye, 2013). This gap is symptomatic not of a lack of interest or knowledge alone but rather of entrenched structural barriers that impede the translation of awareness into action.

The predominance of limited financial resources (40%) and lack of training/extension services (35%) as chief barriers underscores the dual necessity of economic empowerment alongside accessible, quality capacity-building. This finding aligns with Silva *et al*. (2024) and Ericksen *et al*. (2020), who highlight financial constraints and deficient institutional support as critical limits on CSA adoption. The additional barriers of limited input access and poor infrastructure further compound implementation challenges, consistent with observations by Tume *et al*. (2020) and Ericksen, Ingram, and Liverman (2020). Cultural resistance, while less reported, remains a relevant factor in some community subsets (Mbuli *et al*., 2023).

5.3. Socioeconomic Determinants Predicting CSA Uptake

The logistic regression analysis identifies education, farm size, and credit access as crucial determinants enhancing the likelihood of CSA adoption. The positive and significant association of education level with adoption (OR = 2.34) confirms the role of human capital in facilitating comprehension, acceptance, and effective application of CSA practices (Ado *et al*., 2019; Van Schoubroeck *et al*., 2024). Larger farm size (OR = 1.57) similarly signals resource availability and management flexibility conducive to innovation uptake (Kumar *et al*., 2024).

Most notably, access to credit more than triples the likelihood of adoption (OR = 3.32), reflecting financial liquidity as a key enabler to overcome upfront costs and risks associated with CSA practices (Zeleke, Mekonnen, & Kebebew, 2023; Silva *et al*., 2024). Conversely, age and gender show no significant direct effects when controlling for these factors, indicating that access to education, land, and finance are more decisive than demographic categories per se, although gender-sensitive approaches remain necessary given broader evidence on intra-household dynamics (Mbuli *et al*., 2023; Ericksen *et al*., 2020).

5.4. Climate Variability and Food Security: Perceptions and Coping Strategies

The majority of households (75%) perceive recent declines in food availability, and 85% attribute these declines directly to climate variability, indicating strong local awareness of changing environmental conditions impacting food systems (FAO, 2018; Mbuli *et al*., 2023). These perceptions are consistent with broader empirical patterns linking increased climate shocks to food insecurity in Sub-Saharan Africa (Kumar *et al*., 2024).Coping strategies such as meal reduction (50%), asset sales (20%), and off-farm employment (20%) are indicative of households navigating acute food shortages but also reveal pathways to longer-term vulnerability by eroding nutritional status and productive assets (Tambo & Abdoulaye, 2013; WHO, 2022). These patterns underscore the necessity of bolstering proactive adaptation rather than reactive coping, which risks deepening cycles of poverty and malnutrition especially for vulnerable groups.

5.5. Institutional, Market, and Cultural Constraints

Qualitative findings accentuate institutional factors limiting CSA adoption, including poorly resourced extension services and inconsistent policy and market support (Gilbert, Silveira, & Mbuli, 2022; Mbuli *et al*., 2023). These systemic weaknesses hinder knowledge transfer and reduce incentives for investment in climate-smart technologies.While cultural resistance was less prominent quantitatively, localized inertia particularly among older farmers remains relevant and suggests that climate adaptation strategies should be culturally sensitive and include participatory approaches that balance respect for tradition with innovation promotion (Mbuli *et al*., 2023).

5.6. Synthesis and Implications for Policy and Practice

Collectively, these findings reveal a smallholder farming system in Tiko characterized by considerable intrinsic potential to adopt CSA, rooted in favorable socio-demographic features, but held back by persistent financial, informational, and institutional constraints. The strong effect of credit access points to the vital role of financial inclusion and subsidy mechanisms, while education and extension emerge as indispensable components of any adaptation strategy.

Addressing these multi-dimensional barriers requires coordinated interventions that integrate:

- Financial support schemes such as targeted subsidies and microcredit facilities (Mbuli *et al*., 2023; Silva *et al*., 2024);
- Strengthened extension services and farmer training programs focusing on climatic risks and CSA techniques (Ericksen *et al*., 2020; Tambo & Abdoulaye, 2013);
- Infrastructure improvements to enhance inputs distribution and market connectivity (Tume *et al*., 2020; Ericksen, Ingram, & Liverman, 2020);
- Participatory approaches that engage diverse community members, including culturally sensitive messaging to overcome resistance (Mbuli *et al*., 2023).

Such integrated efforts are essential to amplify CSA adoption, improve food security resilience, and break the cycle of climate vulnerability evidenced in this study.

6. Conclusion and Recommendations

Building on the synthesis of results and discussion, the following section distills the core conclusions of this study, highlighting the key challenges and opportunities for advancing climate-smart agriculture and food security in Tiko.

6.1. Conclusion

This study provides important insights into the multifaceted barriers hindering the adoption of climate-smart agriculture (CSA) among smallholder farmers in Tiko, Cameroon, and the consequent implications for household food security. Although the community exhibits promising socio-demographic features such as a substantial working-age population, diversified livelihoods, and relatively high education levels these enabling factors are insufficient to overcome significant structural constraints.

The key impediments identified include limited financial resources, inadequate training and extension services, lack of access to agricultural inputs, and infrastructural bottlenecks. These barriers contribute to a marked gap between CSA awareness and actual uptake. Importantly, access to credit emerged as the strongest predictor of CSA adoption, highlighting the critical role of financial inclusion. The study further reveals that the majority of households perceive declines in food availability and attribute this to climate variability, with many resorting to coping strategies that have adverse long-term effects on nutrition and livelihood resilience.These findings underscore that solving the climate adaptation challenge requires more than information dissemination; it demands integrated interventions addressing economic, technical, and institutional hurdles to enable sustainable and equitable uptake of CSA practices. Without such investments, food security in Tiko remains highly vulnerable to ongoing climate-induced stresses.

6.2. Recommendations
In light of the evidence, the following recommendations are proposed to enhance CSA adoption and improve food security resilience in Tiko and comparable contexts:

6.2.1. Enhance Financial Access and Support
- Develop targeted credit schemes, microfinance programs, and input subsidies tailored for smallholder farmers to alleviate upfront costs associated with CSA adoption.
- Foster partnerships with financial institutions to create farmer-friendly loan products that reduce risk and improve accessibility.

6.2.2. Strengthen Agricultural Extension and Capacity Building
- Expand extension networks with adequately trained personnel focusing on CSA technologies, climate risk management, and good agronomic practices.
- Implement farmer field schools and peer-to-peer learning platforms to facilitate knowledge exchange and practical skills development.

6.2.3. Improve Access to Quality Agricultural Inputs and Infrastructure
- Invest in reliable supply chains for improved seeds, fertilizers, tools, and disease management products.
- Upgrade rural infrastructure, including roads and storage facilities, to enhance market access and reduce post-harvest losses.

6.2.4. Promote Participatory and Inclusive Approaches
- Engage farmers of all genders and age groups in the co-development of adaptation programs to ensure cultural relevance and local ownership.
- Address cultural resistance through awareness campaigns that respect traditional knowledge while demonstrating the benefits of CSA.

6.2.5. Develop Early Warning and Climate Information Services
- Establish localized climate monitoring and dissemination systems providing timely advisory services to support informed decision-making by farmers.
- Integrate pest and disease forecasting tools tailored to the changing climatic conditions observed in Tiko.

6.2.6. Implement Social Protection and Nutrition Support Programs
- Support safety nets such as cash transfers, food aid, and school feeding during climate shocks to protect vulnerable households and prevent the erosion of assets.
- Promote nutrition-sensitive agriculture interventions to mitigate climate-related malnutrition, particularly among children and pregnant women.

By addressing both the socio-economic and institutional barriers simultaneously, stakeholders can catalyze the effective adoption of climate-smart agriculture, thereby enhancing food security and sustainable livelihoods amidst intensifying climate variability. The insights from Tiko underscore the necessity of integrating financial empowerment, education, infrastructure, and participatory governance to forge resilient agricultural landscapes in tropical Africa.

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