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How to Farm in the Midst of Climate Change? A Systematic Review of Farmer Adaptation Strategies in Countries with Extreme Climate Change

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Abstract

Climate change is becoming a multidimensional threat to the global agricultural sector, demanding urgent adaptation especially in countries with extreme climates, which has a serious impact on farmers' productivity and livelihoods. This systematic review aimed to analyse how farmers are adapting their farming practices in the midst of extreme climate change, as well as to identify the most common and effective adaptation strategies, including the barriers faced. Using the PRISMA guidelines, the study screened 1,734 articles from the Scopus database, resulting in 52 final review articles that met the eligibility criteria. The results showed that farmers implemented various adaptation strategies grouped into five main themes: agronomy & crops, water resource management, social & economic adaptation, technology & information-based adaptation, and institutional & community-based adaptation. Agronomic and water management strategies are most widely applied. However, the implementation of adaptation is faced with significant obstacles, namely limited access and availability of resources, lack of knowledge, information, and support, as well as social, institutional, and behavioral constraints. Bibliometric visualizations confirm "climate change" and "smallholder farmers" as central focuses, with increasing interest in "climate-smart agriculture". In conclusion, smallholder adaptation is a multidimensional effort that requires integrated and holistic support from government policies as well as all stakeholders to build long-term resilience.

Keywords: *Farmer Adaptation, Climate Change, Agricultural Strategies, Countries with Extreme Climates.*

INTRODUCTION

Agriculture is a very vital sector in realizing the Sustainable Development Goals (SDGs), especially in the 2nd goal related to zero hunger (Adeboa & Anang, 2024). Therefore, the agricultural sector is the government's concern so that crop yields remain maximum so that food availability is maintained for the needs of millions of people (File et al., 2023). However, the future of agriculture is now threatened by climate change which has a significant impact on agricultural productivity. The occurrence of extreme weather such as droughts, floods, and storms has had a significant impact on the decline in agricultural productivity (Mbegalo et al., 2024).. Agricultural activities are very sensitive to rapidly changing weather patterns, this can damage agricultural crops so that crop yields are not optimal (Madamombe et al., 2024).

Millions of people living in rural areas make the agricultural sector their main source of livelihood (Swarnam et al., 2024). Climate change not only threatens global food security, but also impacts the disappearance of many people's incomes (Asare & Forkuor, 2024). The threat of climate change to the agricultural sector is most felt by smallholder farmers in regions with extreme climate change patterns, especially countries in sub-Saharan Africa. About 80% of Africa's workforce depends on the agricultural sector, amid extreme climate change their productivity and income are threatened (Yamba et al., 2019). The occurrence of extreme droughts in Africa has caused rain-fed farmland to decline by about 50%, this shows how climate change has crippled the agricultural sector in countries with extreme climates (Adego et al., 2019).

A study in Ethiopia conducted by (Hussein, 2024), shows that climate change is severely impacting the agriculture and livestock sectors, causing the national food and nutrition supply to be threatened. Then the study conducted by (Bogale & Erena, 2022), in three countries, namely Ethiopia, Somalia, and Kenya, also showed the same conditions, how extreme droughts cause severe economic hardship and pressure on farmers and the local economy, ranging from decreased productivity, population loss, and trauma due to damage to native crops, soils and vegetation. Furthermore in rural Ghana farmers are also feeling the significant impact of climate change, drought and decreased rainfall causing agricultural productivity to be disrupted, this can create vulnerability to the sustainability of their main source of income in the agricultural sector (Osei-Acheampong & Mensah, 2025).

Climate change not only provides vulnerability to farming households in rural areas, but also impacts farming households in the suburbs. Urban fairy farmers use land in the suburbs that is still not used as a residential area. Climate change felt by urban farmers includes increasing temperatures and decreased rainfall. A study of urban fairy farmers on the outskirts of Bulawayo, Zimbabwe shows that farmers are feeling the impact of climate change on their agricultural productivity as a result of reduced rainfall, suboptimal drill yields and drought (Dube et al., 2021). Furthermore, in the suburbs of Ghana, urban farmers are also feeling the impact of climate change, ranging from decreased rainfall and rising temperatures, which greatly impact their crops and incomes. In addition, climate change has caused most urban fairy farming households to have to look for new livelihood alternatives, in order to maintain their income and food availability (Anum et al., 2022).

Climate change has posed a major threat to the sustainability of agricultural activities in many countries in the world, especially countries with extreme climates. To increase agricultural productivity, maintain food security, and protect the main source of people's income, a series of adaptation strategies are needed in an effort to boost productivity even in the midst of an ever-increasing rate of climate change (Habib et al., 2022). Adaptation strategies provide new hope and opportunities for farmers to create smart farming systems that are resilient to climate change (Sewando et al., 2016). Adaptation strategies include processes of adjusting agricultural patterns to climate change, including changing the types of agricultural crops that are suitable for the ongoing climate, the use of technology and information, and the management of irrigation systems (Incoom et al., 2025).

Climate change presents unprecedented multidimensional challenges for the agricultural sector, especially in countries experiencing extreme climate change. Phenomena such as prolonged droughts, flash floods, heat waves, and shifting planting patterns drastically affect land productivity and food security. Farmers, as the frontline, must adapt quickly to these uncertain conditions to sustain their livelihoods and ensure food supplies remain stable. The urgency of this research lies in the urgent need to comprehensively understand the adaptation strategies that have been and are being implemented by farmers in the most vulnerable areas. This understanding is crucial to formulate effective policies, targeted support programs, and relevant agricultural innovations so that farmers can continue to produce in the midst of an increasingly intense climate crisis.

Given this urgency, the main research questions that arise are: How are farmers in countries with extreme climate change adapting their farming practices to address the impacts of climate change? More specifically, this question can be elaborated into: What are the most common and effective adaptation strategies used by farmers, be it traditional practice-based strategies, adoption of new technologies, crop diversification, or changes in water management systems? What social, economic, and institutional factors influence the choice and success of the adaptation strategy? Furthermore, how are the success of these strategies measured, and what are the main obstacles that farmers face in the adaptation process? Through a systematic review, this study seeks to identify patterns, knowledge gaps, and policy recommendations to support agricultural resilience in the future.

METHOD

Research Design

Using a systematic review approach, this study focuses on answering key questions related to how farmers in countries with extreme climate change can adapt? What are the adaptation strategies that they apply to still be able to maximize agricultural yields? And what are the main obstacles faced by farmers in implementing their adaptation strategies? To answer this question, this study identifies, analyzes, assesses, and selects critically and systematically previous studies that are relevant to the established theme. This study applies the standards of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to minimize bias so that it can produce more reliable findings in providing answers to

research questions. This research has gone through several stages starting from determining the research design, selecting data sources, determining search strategies by determining keywords, applying eligibility criteria including inclusion and exclusion, study selection, assessing the quality of the review study methodology, and conducting data extraction based on the coding scheme.

Data Sources and Search Strategies

The data in this study is sourced from previous studies taken from the leading electronic database, Scopus. The selection of the Scopus database as the main source of research data aims to cover a wide range of studies from various countries, mainly related to research topics. In addition, the selection of the Scopus database is intended to obtain quality findings covering the disciplines of the social sciences, humanities, environmental studies, policy studies, governance, and welfare and development studies. Then the search strategy in this study includes the determination of search keywords based on two key axes, namely "Climate Change" and "Farmer Adaptation". **Table 1** below will present in detail a list of search words used in the study search process in electronic databases.

Table 1. Search Word Glossary

Search Word Axis		Search Word Combinations
Climate Change	**Farmer Adaptation**	
"Climate change"	"Farmer Adaptation Strategy"	"climate change" AND "farmer adaptation strategies"
"Global Warming"	"Farmer resilience"	"global warming" AND "farmer resilience"
"Climate impact"	"Agricultural adaptation"	"climate impact" AND "agricultural adaptation*"
"drought OR flood"	"Adaptation strategy"	("drought OR flood") AND "adaptation strategies"
"Yield Is Down"	"Farmer Innovation"	"crop yields are falling*" AND "farmer innovation"
"Extreme weather"	"Resilient agriculture"	"extreme weather" AND "resilient agriculture"
"Climate"	"Climate-smart agriculture"	"climate" AND "climate-smart agriculture"
"Environmental change"	"Resistant varieties"	"environmental change" AND "resistant varieties*"
"Climate threats"	"Efficient water management"	"climate threats" AND "efficient water management"
"Mitigation"	"Agroforestry"	"mitigation" AND "agroforestry"
"Climate Vulnerability"	"Farmer Adaptation Capacity"	"climate vulnerability" AND "farmer adaptation capacity"
"Food Security"	"Adaptation Farmer Support"	"food security" AND "adaptation farmer support"
"Livelihood"	"Verified Search"	"Livelihood" AND "Verified Livelihood"

Study Eligibility Criteria

The feasibility criteria for the study include the requirements that must be met by the review article to be suitable as a source of research data. This study uses two eligibility criteria including inclusion and exclusion criteria. Inclusion criteria include the characteristics or conditions that must be met by an article to be eligible for review, while exclusion criteria include characteristics or conditions that cause a review article to be removed from the review list. In Table 2, the following is presented in detail the inclusion and exclusion criteria applied in this study.

Table 2. Study Eligibility Criteria

Criterion	Inclusions (Included)	Exclusion (Not Included)
Main Topics	Research that clearly analyzes farmers' adaptation strategies to climate change in the context of agriculture	Research that does not make farmers the main subject of adaptation, studies that focus on analyzing climate change mitigation without examining adaptation processes, and research that is not related to agriculture
Geographical Context	Research that focuses on countries or regions that are categorized as experiencing extreme climate change or are highly vulnerable to climate change	Research that focuses on regions or countries that experience mild or no impact on agricultural activities from climate change. Then studies that do not mention specific research areas

Review Study Research Methods	Research that uses empirical approaches (qualitative, quantitative, and mixed mthod), systematic reviews, research reports, theses, and dissertations that have gone through a peer-review process	Book reviews, opinions, news, film reviews, editorials, book chapters that do not include research results or reports that have not gone through the scientific validation process
Research Subject	Research that directly examines farmers as the main actors in the adaptation process	Research that focuses only on macro-level policies or agricultural systems without looking at the adaptation process at the farmer level
Language	Research articles that use English	Research articles that do not use English
Year of Publication	Research articles published in the last 10 years from January 2015 to December 2025	Research articles published under 2015
Document Access	Research articles that can be accessed in full-text	Articles that only provide abstracts or full text are not accessible

Study Selection

The study selection process includes a series of review article screening processes that are carried out to identify the quality and relevance of the content of the article in question. In this screening process, study exclusions refer to the appropriate eligibility criteria (inclusion and exclusion) in Table 2. We conducted two stages of screening in identifying the feasibility of the study, including initial screening which aimed to analyze the title and abstract and the second screening was carried out by identifying the entire content of the article. If an article is found that is not suitable or relevant in providing answers to research questions, we first have a discussion before excluding the article in question. The series of study selection processes we conducted are presented in a flowchart according to the following Figure 1.

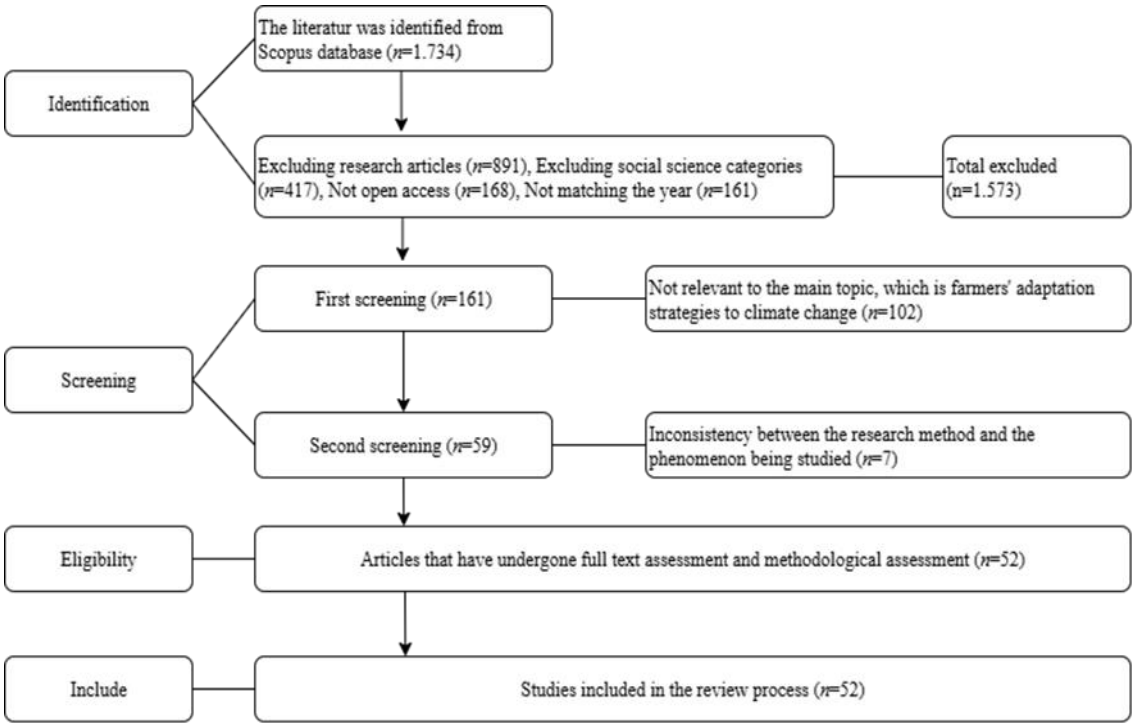


Figure 1. Study Selection Process Flow Diagram

Methodological Quality Assessment

After conducting a series of study selection processes based on inclusion and exclusion eligibility criteria, we then conducted a methodological quality assessment of the reviewed articles. This assessment is intended to ensure the suitability of the phenomenon with the method used. Studies that have such inconsistencies will be excluded. Before making a study exception, we first have a discussion to reconsider it.

Data Extraction

The data extraction process includes a series of stages carried out by distributing the findings of the review article based on the thematic that has been created. To ensure that the key findings of the review article are distributed according to the theme, we have created a coding scheme. There are nine 11 main codes used to distribute research findings according to their themes. **The following table 3** presents in detail the coding scheme used.

Table 3. Coding Scheme

Code	Information	Code	Information
AS	Adaptation Strategies	AS5	Institutional & Community-Based Adaptation
HA	Factors Hindering Adaptation	HA1	Access and Availability of Resources
AS1	Agronomy & Crops	HA2	Knowledge, Information & Support
AS2	Water Resource Management	HA3	Social, Institutional & Behavioral
AS3	Social & Economic Adaptation	HA4	Direct Impacts & Climate Consequences
AS4	Technology & Information-Based Adaptation	A	Article Code

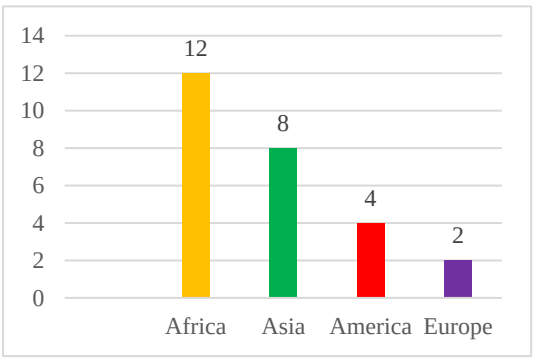
RESULT AND DISCUSSION

Result

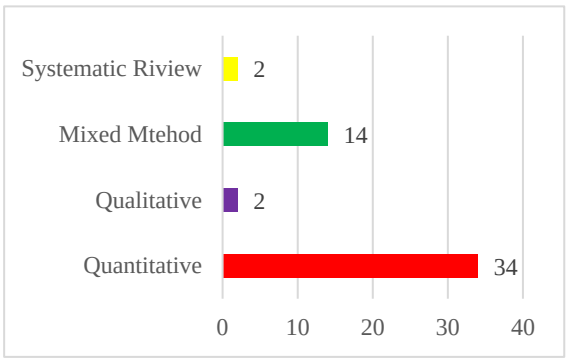
An article search from the Scopus electronic database yielded 1,734 search results, which were then rigorously assessed the feasibility of the articles to assess the quality, relevance, and suitability of the methodology through pre-established inclusion and exclusion criteria. A series of feasibility and quality assessment studies resulted in 52 final articles which were then identified to extract key findings that fit into the coding scheme.

1. Characteristics of Review Articles

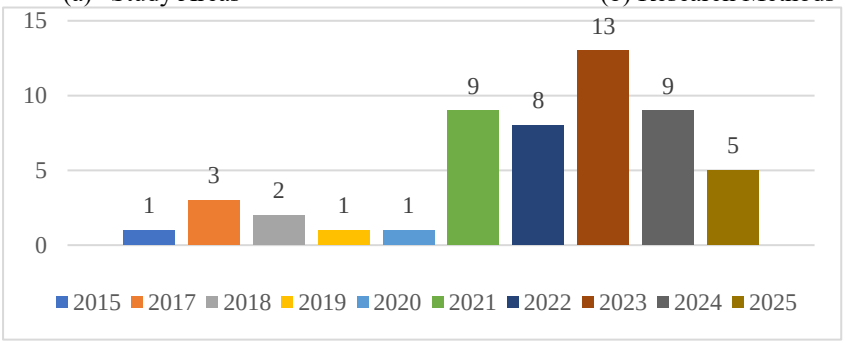
The article characteristics section presents basic information from the review study, this includes information related to the region or country of the research conducted, then information about the research methods used in conducting the research, and information related to the year of publication of the article. Figure 2 below presents a visualization of the characteristics of the study reviewed using a graph.



(a) Study Areas



(b) Research Methods



(c) Year of Publication of the Article

Figure 2. Visualization of Review Article Characteristics

The most dominant research approach applied in the review study was quantitative as many as 34 studies. Then the mixed method was ranked second with 14 studies, and the qualitative approach and systematic review were 2 studies each. Furthermore, Figure 2 (b) also presents information related to the year of publication where the dominance of articles was published in 2023 as many as 13 studies, then in 2021 and 2024 as many as 9 studies each, in 2022 as many as 8 studies, in 2025 with 5 studies, in 2017 as many as 3 studies, in 2018 as many as 2 studies, and in 2015, 2019, and 2020 1 study each. In addition, Figure 2 (a) also presents a visualization related to the study area where the African continent dominates with 12 countries, Asia 8 countries, America 4 countries, and Europe 2 countries.

2. Key Findings

The key findings section presents the distribution of the main results of the review articles that have been grouped according to their theme. Two key findings from the review article include the forms of adaptation strategies implemented by farmers in countries with extreme climate change and the factors that hinder farmers' adaptation strategies.

a. Farmer Adaptation Strategy

Climate change has posed a major threat to agricultural productivity around the world, especially for countries with extreme climate change. This phenomenon has required many farmers to adapt in order to realize food security and still maintain their main source of income. There are many forms of adaptation strategies that are then implemented by many farmers according to the results of 52 review articles ranging from combining local knowledge and scientific knowledge, choosing drought-resistant crops, managing irrigation, utilizing technology and many more. All forms of adaptation strategies found in the 52 review articles are grouped into five main themes: Agronomy & Crops, Water Resource Management, Social & Economic Adaptation, Technology & Information-Based Adaptation, and Institutional & Community-Based Adaptation. The following table 4 specifically presents the forms of adaptation that farmers apply according to the findings in the review article.

Table 4. Forms of Adaptation Strategies Implemented by Farmers

Adaptation Strategy	Specific Shape	Related Articles
Agronomic & Crop Adaptation Strategies	Growing drought-resistant varieties	A1, A2, A17, A18, A21, A25, A33, A38, A50
	Diversifying plant types / Diversifying crops	A2, A3, A12, A13, A17, A18, A24, A25, A33, A35, A44, A51
	Using short-lived / mature plants	A2, A18, A33
	Intercropping planting	A17, A33, A37, A42, A45, A50
	Planting time adjustment / Changing planting date / Planting seeds early	A9, A15, A16, A17, A23, A24, A25, A32, A42, A44
	Mulification	A12, A17, A42
	Fertilizer use (general/manure/inorganic)	A8, A12, A13, A34, A36, A44
	Pest	A48
	Tree planting (general / shade / lemongrass)	A3, A20, A23, A29, A32
	Cultivation of legume plants	A49
	Use of the shade house	A29
	Growing exotic plants	A34
	Integrated soil fertility management	A6, A18
	Switch to new plants	A25, A44
	Mixed farming (crops and livestock)	A13, A49
	Crop rotation	A37, A49, A50
	Minimal/zero tillage	A4, A51
	Agro-silvo-pastoral system	A29
	Irrigation (general/better/efficient)	A3, A6, A15, A18, A24, A35, A45, A46, A48

Water Resource Management	Water harvesting/irrigation	A24, A26, A33, A42, A45
	Soil and water conservation	A10, A13, A23, A33, A42, A45
	Terraces	A33
	Ditch	A33
	Drainage	A12, A17, A42
	Pumping and storing water	A46
	Strengthening water management at the community level	A46
	Creating a water channel	A16
Social & Economic Adaptation	Diversify sources of income (non-farm work)	A2, A9, A13, A24, A26, A32
	Selling assets/livestock	A9, A13, A24, A26
	Reduce food consumption	A13, A26
	Buying crop insurance	A52
	Expense management	A19
	Reducing social and religious rituals	A13
	Participation in Watershed Management Activities	A9
	Land fragmentation	A15
	Migration / Seasonal migration	A15, A32
	Participate in associations/cooperatives (as PPP adoption/institutional strengthening)	A3, A11, A30, A46, A47, A51
Technology & Information-Based Adaptation	Use of agro-advisory applications	A6
	Utilization of digital agricultural devices/services (DAT)	A39, A45
	Use of TV, radio, smart phone for information	A39
	Seeking guidance from the agriculture/extension service	A48, A34
	Depends on the weather forecast	A48
	Using weather and climate forecasts from Indigenous Knowledge (IK) and Local Knowledge (LK)	A14, A40, A41
	Early warning system	A20
	Knowledge sharing	A20
	Improve access to timely and accurate climate information	A35
Institutional & Community-Based Adaptation	Crop management, risk management, soil/land management, water management, and livestock management (as broad adaptation strategy categories)	A4
	Adoption of Climate-Smart Agriculture Technology (CSAT/CSAP) combination	A7, A18, A50, A51
	Climate risk management (CRM) training and Digital agricultural extension and communication services (DAEC)	A22
	Public-Private Partnership (PPP) Mechanism	A46
	Livestock-plant integration	A37, A50
	Integrated land rehabilitation	A23
	Implementation of social protection measures	A35

Agronomic and crop adaptation strategies are most widely applied by farmers in increasing agricultural productivity in the midst of climate change. There are 18 forms of agronomic adaptation strategies and these plants include planting drought-resistant varieties, using short-lived plants, and implementing an agro-silvo-pastoral system.

b. Factors Inhibiting Farmers' Adaptation

The implementation of adaptation strategies by farmers is inseparable from several factors that hinder it. Based on 52 review articles, there are four main factors that hinder farmers, ranging from access to and availability of resources, knowledge, information and support, social, institutional & behavioural, and direct impacts and climate consequences. Figure 3 below presents a visualization of inhibiting factors based on 52 review articles.

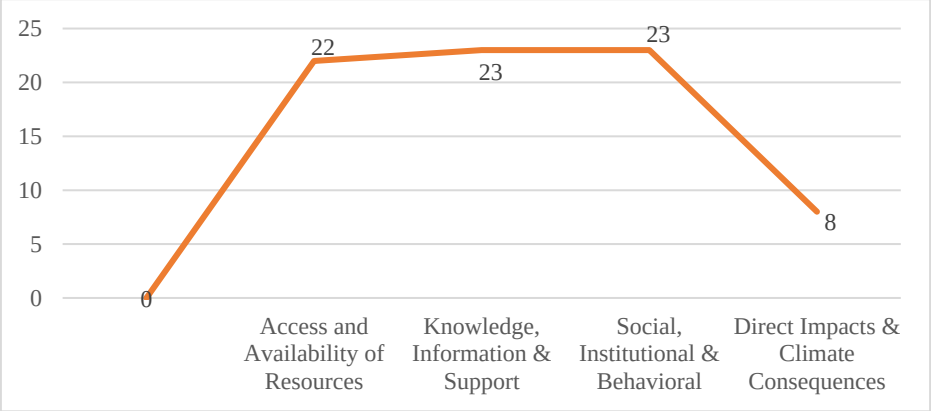
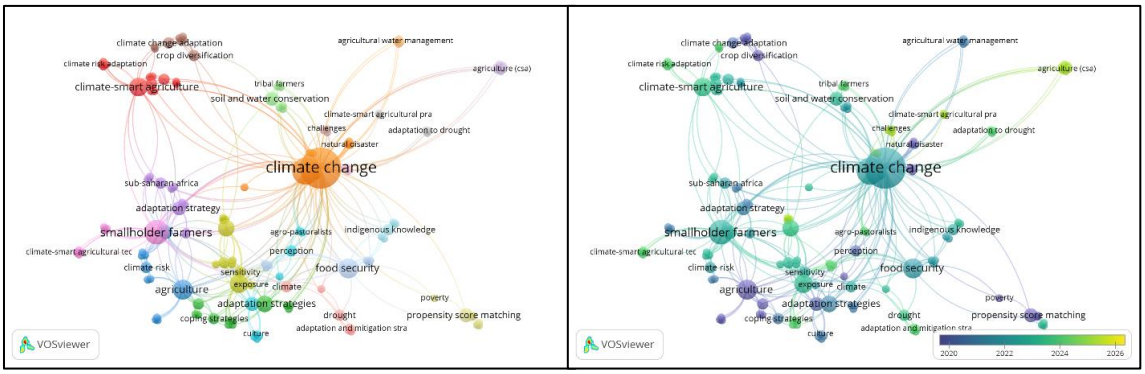


Figure 3. Visualization of Factors Inhibiting Farmers' Adaptation

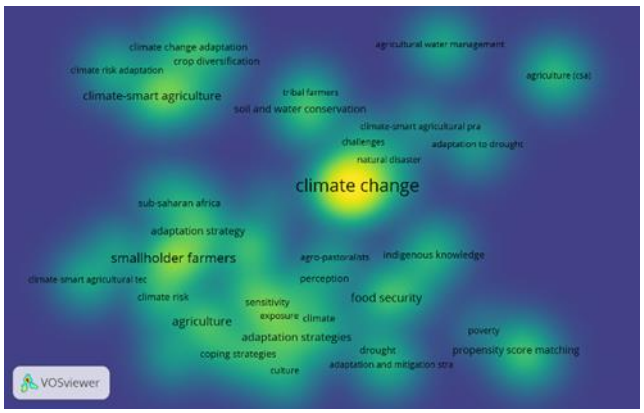
The graph in Figure 3 shows that knowledge, information & support and social, institutional & behavioural factors were most discussed in the 52 review articles with 23 studies each. Furthermore, factors related to access and availability of resources are also obstacles for farmers in implementing their adaptation strategies with 22 studies that discuss them. Finally, as many as 8 studies discuss the direct impact and consequences of climate as one of the factors that also provide obstacles for farmers to adapt in increasing agricultural productivity in the midst of climate change.

3. Bibliometric Visualization of Keywords Review Articles

In an effort to understand the rich and complex research landscape on farmers' adaptation strategies in the face of climate change challenges, a bibliometric visualization analysis of keywords was conducted on 52 comprehensive review articles. These visualizations are specifically designed to identify and map the most dominant themes, uncover the close interconnectedness between research concepts, and track study focus trends that have evolved over the time period reviewed. Through this approach, a deeper understanding can be gained of which areas have been extensively explored, research gaps that may still exist, and potential future research directions related to how the global agricultural community is adapting to increasingly uncertain climatic conditions.



(a) Visualization of Relationships Between Keyword (b) Visualization of the Year of Publication



(c) Keyword Density Visualization

Figure 4. Bibliometric Visualization of Keywords Review Articles

The three bibliometric visualizations (density, overlay, and network) in **Figure 4** collectively present a comprehensive picture of the structure and dynamics of research related to farmers' adaptation to climate change. The density visualization highlights "climate change" as the core of the discussion, with "smallholder farmers" and "climate-smart agriculture" as the other main focuses, indicating the crucial relevance of these topics. The time dimension shown by the overlay visualization shows the consistency of the relevance of the core concepts, while highlighting the increasing trend of attention to "climate-smart agriculture" and aspects of water management in more recent publications. Finally, the visualization of the network with clustering elaborated on the relationships between keywords, grouping the discussion into themes such as innovative agricultural practices, smallholder survival strategies in vulnerable areas, challenges and direct responses to climate impacts, and the socio-economic dimensions of adaptation involving local knowledge and food security. Overall, these findings confirm that farmers' adaptation to climate change is a multidimensional and dynamic research area, with a strong focus on integrated and sustainable solutions.

Discussion

Climate change has become an existential threat to the global agricultural sector, demanding urgent adaptation, especially in countries experiencing extreme climatic conditions (Aryal et al., 2017; Shannon & Motha, 2015; Tabe-Ojong et al., 2023). This systematic review highlights that farmers, as the frontline, have implemented various adaptation strategies to ensure food security and the sustainability of their livelihoods. Data from 52 review articles confirm that these adaptations are multidimensional, encompassing agronomic adjustments, water resource management, socio-economic diversification, technology and information utilization, and institutional and community-based initiatives (BelayBelay et al., 2022; Dohale et al., 2024; Savari et al., 2024; Tessema et al., 2019; Yeleliere et al., 2022; Zhang et al., 2018). However, the crucial question that arises is the extent to which these individual strategies are sustainable and adequate without strong structural support.

The dominance of agronomic and crop adaptation strategies, such as planting drought-tolerant varieties or diversifying crop types, does indicate the adaptive initiatives of farmers at the local level (Mekonnen et al., 2021; Mubiru et al., 2018; Ruzol et al., 2021; Sabzevar et al., 2021). However, it should be criticized that the effectiveness of these strategies is often partial and limited to the micro scale. For example, drought-tolerant varieties may succeed to a certain extent, but if extreme droughts persist and spread, their capabilities will be exceeded (KPENEKUU et al., 2025; Tetteh Quarshie et al., 2023). Reliance on agronomic adaptation alone, without external support, risks leading to 'maladaptation' if it is not accompanied by a deep understanding of long-term climate projections and greater adaptability.

Similarly, efficient water management strategies at the farmer level, such as rainwater harvesting or drip irrigation, while important, will not be able to address systemic water scarcity in the absence of comprehensive water resources management policies at the regional or national level (Musafiri et al., 2023; Ogada et al., 2020; Touch et al., 2024). The challenges faced by farmers, especially in regions with extreme climate change, are not only technical issues on the land, but also macro issues related to overall water availability that require major infrastructure investments and strict regulations from the government (Ngetich et al., 2022; RankoanaRankoana, 2022). This highlights the existence of an 'implementation gap' between knowledge of best practices and the ability of farmers to adopt them widely and sustainably.

Although farmers show diverse adaptation capacities, their implementation cannot be separated from various significant obstacles that require policy intervention. This analysis critically finds that lack of access and availability of resources, limitations of accurate knowledge and information, and social, institutional, and behavioral aspects are the main obstacles (Alam et al., 2017; Gannon et al., 2023; Le Goff et al., 2022). These obstacles are often not just the result of negligence, but a reflection of structural failures and inadequate policies in providing a supporting ecosystem for farmers.

Limited access to capital, superior seeds, fertilizers, and reliable infrastructure, as shown by 22 studies, is a reflection of market failures or a lack of government investment in the vulnerable agricultural sector (Ahmed et al., 2021; Chisale et al., 2024; Etongo et al., 2022). Meanwhile, the factors of knowledge, information, and support that were barriers in 23 studies, indicated that existing agricultural extension systems may not be adaptive or do not reach farmers who need them most, especially in remote or marginalized areas (Ali & Erenstein, 2017; Wichern et al., 2023). This suggests that information dissemination and training should be more targeted and contextual, going beyond a 'one size fits all' approach.

Social, institutional, and behavioral aspects, which were also dominant barriers in 23 studies, highlight the complex non-technical dimensions of adaptation (Aboye et al., 2022; Assefa Tofu & Wolka, 2023). Social norms, weak institutional structures, unsupportive policies, or even different risk perceptions among farmers can hinder the adoption of effective adaptation strategies. Governments have a crucial role to play in rebuilding institutional trust, strengthening farmer organizations, and designing policies that are responsive to the social and cultural dynamics of agricultural communities, rather than simply imposing 'top-down' solutions.

The bibliometric visualization of keywords further enriches the understanding of the landscape of this research and implicitly criticizes a focus that may be unbalanced. The centrality of "climate change" and "smallholder farmers" is natural, but the linkages with "poverty" and "food security" suggest that these adaptation issues are closely linked to broader development issues and require a cross-sectoral approach from governments (Madaki et al., 2024; Mahmood et al., 2021). It's not just about productivity, but about the well-being and survival of millions of people. The increased attention to "climate-smart agriculture" in recent studies, as seen in the overlay visualization, is a positive signal. However, the government must ensure that the implementation of this concept is not just a slogan, but actually translated into concrete programs that can be accessed and implemented by smallholders. Investment in the research and development of climate-smart agriculture technologies, including variety adaptation and cultivation practices, should be a national and regional priority (Tham-Agyekum et al., 2023).

The role of the government and the policy framework are inseparable from the success of farmers' adaptation. Governments need to formulate climate-responsive agricultural policies, allocate adequate budgets for the development of adaptation infrastructure such as resilient irrigation systems and water storage facilities, and strengthen accurate and accessible early warning systems (Aliyar et al., 2024; Anning et al., 2022; Erekalo & Yadda, 2023; Owusu & Yiridomoh, 2021). Affordable agricultural insurance policies and social protection mechanisms are also essential to mitigate the economic risks faced by farmers due to extreme climate events.

Ultimately, this systematic review unequivocally recommends that the sustainability of smallholder adaptation in the midst of extreme climate change is highly dependent on policy frameworks and the active role of governments. Without coordinated policy support, adequate investments, effective extension systems, and active participation of farmers in decision-making processes, individual adaptation strategies, while innovative, will face significant limitations in building long-term resilience to the ever-increasing threat of climate change. An integrated approach involving all stakeholders is key to realizing resilient and sustainable agriculture in the future.

The research findings described are very much in line with Everett M. Rogers' Diffusion of Innovation Theory, which explains how new ideas or technologies spread in a social system. In this case, innovation is the various climate adaptation strategies that farmers implement, from planting drought-tolerant varieties to the use of drip irrigation. These findings identify that while these innovations exist, their adoption process is hampered by a variety of factors. Limited access to resources, information, and weak institutional support are the main obstacles that hinder the widespread diffusion of this strategy. This suggests the existence of an "implementation gap," where knowledge of best practices cannot be effectively disseminated and adopted sustainably due to a lack of structural support, which is an important element in diffusion theory.

Furthermore, this theory also emphasizes the role of communication channels and social systems in the process of diffusion. Analysis of findings has suggested that existing agricultural extension systems may not reach farmers in remote areas or are not adaptive to their specific needs. This is a reflection of the failure of communication channels in disseminating innovative information. In addition, the social, institutional, and behavioral aspects that have been identified as the main barriers suggest that diffusion is not only technical, but also strongly influenced by existing social norms and structures. Without supportive policies, infrastructure investment, and strengthening of farmer institutions, individually adopted innovations will be limited and unable to build long-term resilience. Therefore, the conclusion that adaptation sustainability is highly dependent on the role of governments and policy frameworks underscores the importance of structural support in fostering the effective diffusion of innovation among smallholder communities.

Although the findings show similarities in adaptation patterns among farmers around the world—where they universally rely on agronomic strategies and water management on their land—significant differences emerge in the inhibiting factors and available structural supports. On continents such as Africa and Asia, farmers face fundamental barriers such as limited access to capital, superior seeds, and inadequate infrastructure. In addition, ineffective extension systems often fail to reach smallholders, hindering the dissemination of the critical information they need.

On the other hand, in some parts of America, the challenges tend to shift. While resource access issues remain, key barriers can be more complex, such as difficulties in navigating complex policies, limited access to agricultural insurance, or a lack of accurate and relevant climate information. This highlights that the issue of "access" is universal, but its manifestations are very different on each continent. This difference shows that adaptation solutions cannot be equalized; Instead, policy interventions must be tailored specifically to the economic, social, and institutional contexts of each region to be truly effective.

This comparison reinforces the argument that there is no "one size fits all" solution. Policy responses should be contextual. In Africa and Asia, the top priority is basic capacity building and strengthening of extension systems, while in some other regions, the focus may be on the development of financial instruments (such as insurance) and the improvement of climate information services. This comparative analysis not only adds scientific depth, but also provides a more nuanced roadmap for policymakers, allowing them to design interventions that are truly effective and relevant to the realities of farmers in their respective regions.

CONCLUSION

Climate change is a significant threat to the global agricultural sector, particularly in countries with extreme climates, impacting farmers' productivity and livelihoods. Farmers have implemented various multidimensional adaptation strategies to deal with the impacts of climate change and maintain food security and incomes. Adaptation strategies can be grouped into five main themes: Agronomy & Crops, Water Resources Management, Social & Economic Adaptation, Technology & Information-Based Adaptation, and Institutional & Community-Based Adaptation. Agronomic and crop adaptation strategies, such as the use of drought-resistant varieties and crop diversification, are the most widely applied forms of adaptation by farmers. The implementation of adaptation strategies is inseparable from several main inhibiting factors, namely: access and availability of resources; knowledge, information & support; and social, institutional and behavioral factors.

Bibliometric visualizations show that "climate change" is at the heart of the discussion, with "smallholder farmers" and "climate-smart agriculture" as the main focus of the research, indicating the crucial relevance of these topics. There is a growing trend of attention to "climate-smart agriculture" and aspects of water management in newer publications. Farmer adaptation is a multidimensional and dynamic field of research, with a strong focus on integrated and sustainable solutions.

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