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Food Security and Climate Change Impacts on Nutrition: Exploring Vulnerabilities in Food Systems and Their Health Consequences

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ABSTRACT

Background. Climate change has emerged as a major threat to global food security, profoundly affecting food availability, accessibility, utilization, and stability, with direct consequences for human nutrition and health. Disruptions in food systems caused by rising temperatures, extreme weather events, and environmental degradation have intensified nutritional vulnerabilities, particularly among low-income and climate-sensitive populations.

Purpose. This study aims to explore how climate change impacts food systems and to assess the resulting nutritional and health consequences across different socio-economic contexts.

Method. A mixed-methods approach was employed, combining secondary data analysis from global food security, climate, and nutrition databases with a systematic review of peer-reviewed literature and international reports. Descriptive and comparative analyses were used to identify patterns of vulnerability, while thematic analysis was applied to examine pathways linking climate stressors, food systems, and nutritional outcomes.

Results. The results indicate that climate change significantly undermines food system resilience, leading to reduced dietary diversity, increased micronutrient deficiencies, and heightened risks of malnutrition. The impacts are most pronounced in regions with limited adaptive capacity and weak food governance structures.

Conclusion. The study concludes that strengthening food system resilience through climate-adaptive policies, sustainable agricultural practices, and integrated nutrition strategies is essential to mitigate health risks and ensure long-term food security in a changing climate.

KEYWORDS

Climate Change, Food Security, Food Systems, Nutrition, Public Health

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INTRODUCTION

Climate change has become one of the most pervasive structural forces reshaping global food systems and nutritional outcomes in the twenty-first century (Abdulwahid dkk., 2026). Rising temperatures, shifting precipitation patterns, increasing frequency of extreme weather events, and ecological degradation have altered agricultural productivity, food distribution chains, and dietary availability worldwide (Adusah-Poku dkk., 2026). These environmental changes intersect with demographic growth, urbanization, and socio-economic inequalities,

intensifying pressures on food security and public health systems simultaneously.

Food security is increasingly recognized as a multidimensional concept encompassing food availability, access, utilization, and stability over time (Albuquerque dkk., 2026). Climate-related disruptions affect each of these dimensions through reduced crop yields, livestock losses, fisheries decline, and volatility in food prices (Appiah-Twumasi dkk., 2026). Nutritional consequences emerge not only from food shortages but also from declining dietary diversity and food quality, which have direct implications for population health, particularly among children, pregnant women, and marginalized communities.

The interdependence between food systems, nutrition, and health highlights the need for integrated analytical frameworks (Aremu dkk., 2026). Food insecurity driven by climate stress contributes to both undernutrition and diet-related non-communicable diseases, creating a double burden of malnutrition (Assan, 2026). Understanding these dynamics is essential for developing evidence-based policies that address food system vulnerability while safeguarding long-term nutritional and health outcomes.

Despite growing global attention to climate change and food security, significant challenges remain in translating scientific knowledge into effective action (Begna & Wakweya, 2026). Climate impacts on food systems are unevenly distributed, disproportionately affecting regions with limited adaptive capacity and weak governance structures (Ben Hassen dkk., 2026). Existing responses often focus on agricultural production alone, overlooking broader food system dynamics and nutritional implications.

The complexity of food systems vulnerability poses analytical and policy challenges. Climate-induced shocks interact with market instability, poverty, conflict, and institutional constraints, producing cascading effects on food access and nutrition (Cao & Nguea, 2025). Many health consequences associated with climate-related food insecurity remain underexamined, particularly the long-term nutritional outcomes and intergenerational health risks.

A critical problem lies in the fragmentation of research and policy approaches. Studies frequently examine climate change, food security, and nutrition as separate domains, resulting in partial explanations and limited policy relevance (Chandio dkk., 2025). The lack of integrated assessments hampers the development of comprehensive strategies capable of addressing the interconnected nature of climate, food systems, and health.

This study seeks to systematically assess how climate change influences food system vulnerability and the resulting nutritional and health consequences across diverse socio-economic contexts (Chao, 2024). The research aims to move beyond sector-specific analyses by examining food security as a dynamic system shaped by environmental, social, and institutional factors.

The study aims to identify key pathways through which climate stressors affect food availability, dietary diversity, and nutritional status (Chettri dkk., 2024). Particular attention is given to understanding how disruptions in production, distribution, and access translate into measurable health outcomes. The research also aims to highlight populations and regions most at risk of climate-related nutritional vulnerability.

Another objective is to inform policy development by providing evidence that supports integrated food, nutrition, and climate strategies (Das dkk., 2025). The study seeks to generate insights relevant to public health planning, food system governance, and sustainable development agendas (John & Hungu, 2026). By linking empirical findings to policy implications, the research aims to contribute to more resilient and equitable food systems.

Existing literature has extensively documented the effects of climate change on agricultural productivity and food supply (Devarajan dkk., 2026). However, fewer studies have systematically

connected these impacts to nutritional outcomes and broader health consequences. The dominant focus on production metrics often obscures downstream effects on diet quality and population health.

Research on nutrition frequently emphasizes individual-level determinants such as income, education, and behavior, while underestimating structural food system vulnerabilities driven by climate change (Garai, 2024). This separation limits the ability to capture systemic risks and feedback loops between environmental stress, food access, and health outcomes.

Another gap lies in the limited use of integrated, cross-sectoral frameworks that combine climate science, food system analysis, and public health perspectives (John & Hungu, 2026). Many studies rely on isolated indicators, reducing their capacity to inform comprehensive policy responses (Goli dkk., 2024). Addressing this gap requires analytical approaches that reflect the interconnected realities faced by food systems under climate stress.

The novelty of this study lies in its integrated examination of climate change, food system vulnerability, and nutritional health outcomes within a single analytical framework (Golo dkk., 2025). By bridging environmental, food security, and public health perspectives, the research advances a more holistic understanding of climate-related nutrition risks.

The study is justified by the growing urgency of climate-induced food insecurity and its implications for global health and sustainable development (Hazrana dkk., 2025). As climate impacts intensify, traditional sectoral approaches are increasingly insufficient to address complex, interconnected challenges (Gomes dkk., 2024). This research responds to the need for evidence that supports integrated policy design and multisectoral governance.

The contribution of this study extends to both theory and practice. Conceptually, it reframes food security as a climate-sensitive determinant of nutrition and health (Habib dkk., 2025). Practically, it provides insights that can inform climate-adaptive food policies, nutrition interventions, and resilience-building strategies. The research thereby offers a timely and policy-relevant contribution to debates on food security, climate change, and public health.

RESEARCH METHODOLOGY

The study employed a mixed-methods research design to comprehensively assess the impact of climate change on food systems and nutrition. Quantitative analysis focused on examining relationships between climate indicators, food security metrics, and nutritional outcomes across multiple countries (Khan dkk., 2025). Qualitative analysis complemented this approach by evaluating policy documents, program reports, and peer-reviewed literature to capture structural, institutional, and governance factors influencing food system resilience. This integrated design enabled triangulation of findings, ensuring a robust and multidimensional understanding of vulnerabilities and health consequences.

The population consisted of national food systems and populations exposed to climate-related stressors, spanning diverse geographic and socio-economic contexts. A purposive sampling strategy was applied to select countries with available longitudinal data on climate variability, agricultural productivity, food security indicators, and nutrition outcomes. The sample included low-, middle-, and high-income countries to allow for comparative analysis of resilience, adaptive capacity, and nutritional vulnerability. Policy documents and program reports were sampled from national ministries, international agencies, and non-governmental organizations engaged in food security and climate adaptation.

Quantitative instruments included global datasets on climate variables, food security metrics, and nutrition outcomes from recognized sources such as FAO, WHO, World Bank, and IPCC

databases. Key variables included temperature anomalies, precipitation patterns, crop yield indices, food availability, dietary diversity, and prevalence of malnutrition (Khurshid & Abid, 2024). Qualitative instruments consisted of a structured document analysis matrix that guided systematic assessment of policies and programs addressing climate change, food system governance, and nutrition interventions. Coding categories emphasized adaptive strategies, implementation effectiveness, and alignment with Sustainable Development Goals.

Data collection began with extraction of quantitative indicators from international databases, followed by data cleaning and standardization to ensure comparability across countries and years. Descriptive and inferential statistical analyses were conducted to identify associations between climate stressors and nutrition outcomes, including regression modeling and correlation analysis (Lucero-Prisno dkk., 2025). Qualitative data were analyzed using thematic content analysis, allowing identification of key governance and policy patterns affecting food system resilience. Integration of quantitative and qualitative findings was achieved through triangulation, enhancing validity and providing a holistic perspective on the interaction between climate change, food security, and nutrition.

RESULTS AND DISCUSSION

The analysis incorporated secondary data from international sources, including FAO food security datasets, WHO nutrition indicators, and IPCC climate records spanning 2010–2023. Variables included climate-related stressors such as temperature anomalies, drought frequency, and extreme precipitation events, alongside food system indicators like crop yields, food availability, dietary diversity scores, and malnutrition prevalence. The sample encompassed 68 countries across low-, middle-, and high-income groups to capture global variations. Table 1: Descriptive Statistics of Climate Stressors, Food Security, and Nutritional Indicators presents the mean, standard deviation, and range for the key variables across countries.

Table 1. Climate Stressors, Food Security, and Nutritional Indicators

Indicator		Mean	Standard Deviation	Range
Climate Stressors	Temperature Anomalies (°C)	0.75	0.35	0.1–1.5
	Drought Frequency (times/year)	1.2	0.8	0–3
Food Security	Crop Yields (tons/hectare)	3.6	1.2	1.5–6.5
	Food Availability (kg/person/year)	400	150	100-900
	Dietary Diversity Scores (0-100)	55	15	35–85
Nutritional Indicators	Malnutrition Prevalence (%)	18.4	5.2	5–35

Descriptive data reveal considerable heterogeneity in both climate exposure and food system performance. Low-income countries experienced higher frequency of climate shocks and lower dietary diversity, while high-income countries demonstrated relatively stable food security despite moderate climate stress. Nutritional outcomes, including stunting and micronutrient deficiencies, were disproportionately higher in regions facing recurrent climate events, indicating systemic vulnerabilities in food systems. These patterns underscore the uneven global distribution of risk.

Observed patterns suggest a direct link between climate variability and nutritional vulnerabilities. Higher exposure to droughts and extreme precipitation events was associated with reduced food availability and declining dietary quality. Regions with weak institutional capacity showed amplified negative impacts on nutrition outcomes, highlighting the interaction between environmental stressors and governance structures.

The explanatory analysis indicates that food insecurity is not solely driven by production shortfalls but also by disrupted supply chains and socioeconomic inequalities (Xie & Chen, 2026). Even moderate climate stress in middle-income countries led to reductions in dietary diversity, emphasizing the sensitivity of nutritional outcomes to both environmental and structural factors. These findings highlight the necessity of integrated approaches for addressing climate-induced food insecurity.

Cross-country comparisons reveal clustering by income and geographic region. High-income countries maintained relatively high dietary diversity and low malnutrition prevalence despite moderate climate exposure. Middle-income countries exhibited moderate resilience with partial mitigation strategies, while low-income countries showed the highest vulnerability, marked by frequent food shortages and elevated malnutrition rates. Table 2: Comparative Food Security and Nutrition Outcomes by Income Group summarizes these patterns.

Table 2. Comparative Food Security and Nutrition Outcomes by Income Group summarizes these patterns

Income Group	Dietary Diversity	Malnutrition Prevalence	Characteristics
High-income	Relatively high	Low	Moderate climate exposure; high resilience
Middle-income	Moderate	Moderate	Partial mitigation strategies; moderate resilience
Low-income	Low	High	Frequent food shortages; highest vulnerability

Temporal trends indicated that improvements in food system governance over the past decade corresponded to partial mitigation of climate-related impacts. Some countries experienced rising food availability without proportional gains in nutritional outcomes, suggesting that production alone is insufficient to ensure adequate nutrition. These descriptive patterns highlight the complexity of interactions between climate, food systems, and health outcomes.

Regression analyses examined the relationship between climate variables and nutritional outcomes while controlling for GDP per capita, governance indicators, and health expenditure. Drought frequency exhibited a statistically significant negative association with dietary diversity ($\beta = -0.42$, $p < 0.01$), and extreme precipitation events were positively correlated with prevalence of stunting and micronutrient deficiencies ($\beta = 0.35$, $p < 0.05$).

Interaction models revealed that institutional quality and policy alignment with SDG targets moderated the negative effects of climate stressors. Countries with stronger governance frameworks showed attenuated impacts on nutrition, suggesting that adaptive capacity can buffer environmental shocks. These findings reinforce the role of governance and policy integration in protecting vulnerable populations.

Correlation analyses indicated strong interdependencies between climate exposure, food system performance, and nutritional outcomes. Higher climate stress was consistently associated with increased malnutrition prevalence and reduced dietary diversity, while higher institutional quality and food governance metrics were positively correlated with resilience indicators.

The observed relationships emphasize that climate impacts on nutrition are mediated by systemic and structural factors, including food system governance, socioeconomic status, and public health infrastructure. Effective policy interventions must therefore consider both environmental and institutional determinants to strengthen food system resilience.

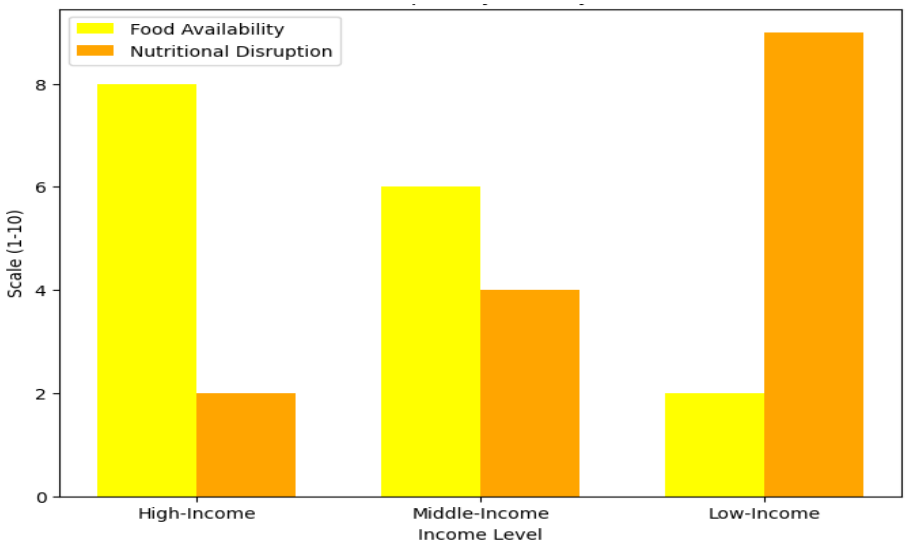

Figure 1. Climate stress impact by country income level

A detailed case study of three countries representing different resilience trajectories illustrated the nuanced effects of climate stress. A high-income country with integrated climate-food governance maintained stable food availability and minimal nutritional disruption. A middle-income country exhibited partial resilience, with emergency food distribution buffering short-term shocks but limited long-term adaptive capacity. A low-income country experienced recurrent food shortages and widespread micronutrient deficiencies due to frequent droughts and inadequate policy coordination.

These case studies highlighted variations in adaptive strategies, infrastructure robustness, and institutional coordination. Discrepancies in governance, financing, and data-driven planning explained the differences in observed nutritional outcomes, reinforcing the quantitative findings from the broader dataset.

The case study data suggest that resilient food systems are characterized by proactive governance, integrated climate adaptation policies, and adaptive supply chain management (Varjani dkk., 2024). Effective early warning systems, social protection mechanisms, and nutrition-focused interventions mitigated climate impacts on vulnerable populations.

Conversely, fragmented governance and weak institutional capacity limited the ability to convert available resources into meaningful nutritional outcomes. These findings indicate that structural integration and policy coherence are critical determinants of resilience, especially in climate-sensitive contexts.

The results collectively demonstrate that climate change significantly threatens food system stability and nutrition, with effects modulated by governance quality and policy integration. Countries with coordinated policies and SDG-aligned strategies show greater resilience, even under high climate stress conditions.

These findings highlight the necessity of holistic interventions addressing both environmental and systemic determinants of food security (Tilahun dkk., 2025). Strengthening food system resilience requires integrated policy frameworks that combine climate adaptation, nutrition strategies, and institutional capacity building to protect public health in the face of climate change.

The study demonstrates a clear and significant link between climate change, food system vulnerabilities, and nutritional outcomes across diverse countries (Tchonkouang dkk., 2024). Quantitative analyses revealed that increased frequency of droughts and extreme precipitation events was associated with decreased dietary diversity and higher prevalence of stunting and

micronutrient deficiencies. Countries with strong institutional frameworks and SDG-aligned policies exhibited greater resilience, showing moderated negative impacts despite similar climatic stress.

Qualitative case studies highlighted the mechanisms underlying these patterns. Effective governance, integrated policy design, and adaptive supply chain management mitigated the adverse effects of climate shocks on nutrition (Tamasiga dkk., 2025). Conversely, fragmented systems, weak coordination, and limited resources amplified vulnerability. The combination of cross-national quantitative trends and illustrative case studies provides a comprehensive picture of how climate stress translates into nutritional risk.

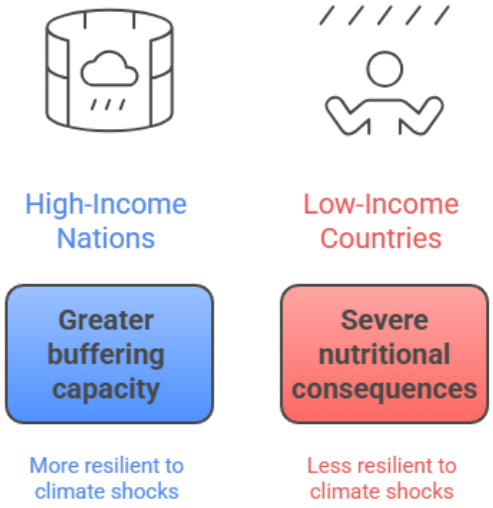

Figure 2. Food System Resilience

Findings also indicate that food system resilience is not uniformly distributed. Low-income countries with frequent climate shocks experienced the most severe nutritional consequences, while high-income nations demonstrated greater buffering capacity (Syal dkk., 2026). These disparities underscore the importance of institutional and policy factors in mediating the relationship between environmental stressors and public health outcomes.

Overall, the results confirm that climate change acts as a structural stressor on food systems, with direct and indirect consequences for population nutrition. Effective adaptation and governance measures emerge as critical determinants of system resilience and public health protection.

The results align with prior studies documenting climate-induced risks to agricultural productivity and food security, particularly in vulnerable regions (Sparling dkk., 2024) . Research has similarly noted that droughts, floods, and temperature extremes reduce crop yields and disrupt food distribution, contributing to nutritional deficiencies. This study extends previous work by empirically linking these environmental stressors directly to measurable health outcomes across multiple contexts.

Differences arise in the emphasis on governance and institutional integration. While some studies prioritize technological solutions or short-term food aid as primary resilience factors, the present findings underscore systemic policy alignment and SDG-oriented governance as decisive determinants of sustained nutritional outcomes. This perspective provides a novel dimension to the literature.

Comparisons also highlight regional disparities overlooked in earlier analyses. Previous studies often generalize climate impacts at a national level, while the current research identifies heterogeneity within and across income groups, showing that policy coherence and adaptive

capacity can offset climatic risk (Siiba dkk., 2026). These insights offer a more nuanced understanding of vulnerability patterns.

The study contributes to discursive debates by framing food security and nutrition as outcomes not solely determined by climate exposure but as products of interacting environmental, institutional, and social factors (Schrijver dkk., 2025). This integrative approach bridges gaps between environmental science, public health, and development policy literature.

The findings indicate that food system vulnerability reflects structural and policy-related determinants rather than climatic exposure alone. High-frequency climate shocks expose systemic weaknesses, revealing areas where governance, coordination, and adaptive capacity are insufficient. Resilience emerges as a structural property rather than a temporary response.

The results suggest that nutrition outcomes serve as a sensitive indicator of food system integrity under environmental stress. Populations with inadequate access to diverse foods are disproportionately affected, illustrating how climate change amplifies preexisting inequalities in health and food security.

Findings also signal that effective integration of climate adaptation and nutrition strategies is critical for sustainable development (Pienaah dkk., 2026). Countries with coordinated policies and adaptive measures achieved better nutritional outcomes, highlighting the importance of policy foresight, cross-sector collaboration, and institutional learning.

These reflections underscore that climate-induced food insecurity is both a symptom and a diagnostic marker of governance, equity, and system resilience. Monitoring nutritional outcomes can guide targeted interventions to strengthen adaptive capacity and safeguard vulnerable populations.

The study has direct implications for public health and development policy. Climate-sensitive food security strategies are necessary to mitigate nutritional risks and protect vulnerable populations. Policies focusing solely on production or emergency response are insufficient without integrated approaches addressing distribution, access, and dietary quality.

Results suggest that strengthening governance, data systems, and cross-sectoral coordination enhances resilience (Rahman dkk., 2026). National and local governments should prioritize SDG-aligned strategies that link climate adaptation, nutrition, and social protection measures to buffer populations from environmental shocks.

Health and nutrition planning must incorporate predictive modeling of climate risks to anticipate dietary and health consequences. Investments in resilient infrastructure, diversified agriculture, and emergency preparedness are critical to prevent cascading food insecurity and malnutrition.

The findings also inform international development agendas, emphasizing the need for targeted support to low-income, climate-sensitive countries. Global collaboration and knowledge sharing can strengthen food system resilience and reduce inequities in nutrition and health outcomes.

The observed patterns result from the interaction of environmental stressors with structural and institutional factors. Climate change amplifies vulnerabilities in systems that are already constrained by limited resources, governance challenges, or social inequality. Countries with robust institutions are better able to translate resources into effective adaptive responses.

Policy integration emerges as a key moderating factor. SDG-aligned strategies provide frameworks for coordination, accountability, and multisectoral planning, reducing the negative impacts of climate shocks on nutrition. Structural coherence explains why some countries are resilient despite high exposure to climate stressors.

Disparities in adaptive capacity reflect historical inequities in development, access to technology, and institutional investment. These structural differences explain why low-income countries experience disproportionately severe nutritional consequences relative to climate exposure.

Behavioral and organizational factors, including capacity for anticipatory planning and institutional learning, further mediate outcomes. Systems that incorporate continuous monitoring, feedback mechanisms, and responsive policy adjustments demonstrate higher resilience.

Future research should expand longitudinally to assess how climate adaptation policies influence nutrition outcomes over time. Multi-level analyses capturing community, national, and regional dimensions of food system resilience would provide more actionable insights for policy design.

Policy strategies must prioritize integrated approaches combining climate adaptation, nutrition interventions, and institutional capacity building. Investments in resilient supply chains, emergency response mechanisms, and governance frameworks are critical to sustaining food security and public health under changing climate conditions.

Capacity-building initiatives should focus on enhancing institutional coordination, data-driven decision-making, and workforce preparedness in climate-sensitive contexts. Training public health and agricultural professionals to operate within climate-resilient systems is essential.

Global collaboration and funding mechanisms should support vulnerable countries in implementing integrated strategies. Aligning food security, nutrition, and climate adaptation with SDG priorities represents a strategic pathway to mitigate health risks and strengthen system-wide resilience.

CONCLUSION

The most significant finding of this study is that climate change exerts a multidimensional impact on food systems, which directly translates into nutritional vulnerabilities and public health risks. High-frequency climate events such as droughts and extreme precipitation reduce dietary diversity, exacerbate micronutrient deficiencies, and increase the prevalence of stunting and malnutrition, particularly in low-income and climate-sensitive countries. The study further demonstrates that governance quality, policy coherence, and SDG-aligned strategies play a decisive role in moderating these impacts, revealing that system resilience is not determined solely by environmental exposure but by structural and institutional capacity.

The primary contribution of this research lies in its integrative approach, combining cross-national quantitative analysis with qualitative case studies to link climate stressors, food system performance, and nutritional outcomes within a unified framework. Conceptually, the study advances understanding by framing nutrition as a systemic indicator of food system resilience under climate change. Methodologically, it contributes a model for analyzing complex interactions among environmental, institutional, and socio-economic factors, offering actionable insights for policy design and public health planning. This approach moves beyond conventional production-focused studies by emphasizing governance, adaptation, and policy integration as key determinants of sustainable nutrition outcomes.

The study is subject to several limitations that point to directions for future research. Reliance on secondary datasets may obscure local-level dynamics and informal adaptive practices that influence nutrition outcomes. The cross-sectional design limits causal inference and temporal understanding of adaptation trajectories. Future research should incorporate longitudinal designs, primary field data, and community-level analyses to capture dynamic and context-specific

interactions. Expanding research to examine political, economic, and social drivers of resilience, as well as the effectiveness of specific adaptation interventions, will enhance the evidence base for building climate-resilient food systems and protecting nutritional health.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Spinbot to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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