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REVIEW ARTICLE

Climate change and food security: Exploring adaptation strategies and regional vulnerabilities through a systematic review

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Abstract

Climate change poses a critical threat to global food security, disrupting agricultural systems and socio-economic resilience. This systematic review synthesizes scholarly research from 2019 to 2024, focusing on the impacts of climate change on food systems, adaptation strategies and regional disparities. The study highlights the vulnerability of developing nations, heavily reliant on rainfed agriculture, to climate-induced challenges like declining crop yields and extreme weather events. Utilizing a systematic literature review methodology guided by PRISMA, 112 articles were selected from the Scopus database. Bibliometric analysis identified thematic trends, collaboration patterns and emerging research areas. Key themes such as "climate change," "food security," and "adaptive management" dominate the discourse, reflecting the growing emphasis on resilience strategies and sustainable practices. Advanced tools, including spatiotemporal analysis and regression models, are increasingly employed to assess climate impacts, although their adoption in resource-constrained regions remains limited. The findings underscore the importance of adaptation strategies such as crop diversification, climate-resilient crops and integrated water resource management. Regional disparities highlight the need for tailored interventions, with sub-Saharan Africa and South Asia facing the most acute vulnerabilities. Policy frameworks promoting access to credit, technology and education are pivotal for enhancing adaptive capacity. In conclusion, addressing the nexus of climate change and food security requires a multi-dimensional approach, integrating socio-economic analyses, innovative technologies and global collaborations. This review provides insights to inform policy and research, emphasizing the need for sustainable and equitable solutions to safeguard food systems in a changing climate.

Keywords: agricultural adaptation; climate change; food security; regional disparities; sustainable practices

Abbreviations

SLR- Systematic Literature Review; PRISMA- Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SCP- Single Country Publications; MCP- Multiple Country Publications

Introduction

Climate change has emerged as one of the most significant challenges facing humanity in the 21st century, impacting ecological stability, economic structures and human livelihoods. Among its many effects, the disruption of global food systems poses a severe threat to food security, which encompasses the availability, access, utilization and stability of food. This intersection between climate change and food security has profound implications for agricultural productivity, socio-economic resilience and global sustainability (1).

The increase in global greenhouse gas emissions has intensified climate variability, leading to phenomena such as rising temperatures, erratic rainfall and extreme weather events like droughts, floods and storms. These changes adversely affect agricultural productivity by reducing crop yields, degrading arable land and disrupting supply chains (2, 3). For example, studies predict that by 2050, global crop yields for maize, wheat and rice could decline by 10-20 %, directly impacting food security and economic stability in many regions (4).

Developing countries are disproportionately affected by climate change due to their high dependence on agriculture, which is often rainfed and less mechanized. Regions such as sub-Saharan Africa and South Asia face severe challenges due to limited adaptive capacities, high poverty levels and weak institutional frameworks (5). Vulnerable communities in these areas are already experiencing declining agricultural outputs and increasing food insecurity, underscoring the urgency for targeted adaptation measures (6, 7).

This study explores the complex relationship between climate change and food security through a systematic synthesis of recent research. The key objectives are as follows:

1. To assess the major trends and patterns in research addressing climate change and its impact on food systems.
2. To identify effective adaptation strategies for mitigating climate risks in agriculture.
3. To examine regional disparities in climate change impacts and adaptive capacities.
4. To highlight technological and methodological advancements in studying climate-food system dynamics.
5. To provide recommendations for policy and institutional frameworks to enhance resilience and sustainability in food systems.

Despite the growing body of research, significant gaps persist in understanding the socio-economic dimensions of climate change. While much of the existing literature focuses on biophysical impacts such as yield reductions, fewer studies address the broader implications for rural livelihoods, migration and social equity (8). Furthermore, the application of advanced tools such as big data analytics and geospatial technologies remains limited in developing regions due to resource constraints (9, 10).

Longitudinal studies to evaluate the long-term effectiveness of adaptation strategies are also sparse, hindering the ability to design scalable and sustainable interventions. These research gaps highlight the need for interdisciplinary approaches to better capture the complexities of climate change and food security dynamics (11, 12).

Adaptation is pivotal in mitigating the adverse effects of climate variability on agricultural systems. Effective strategies include crop diversification, the adoption of drought-resistant crop varieties and integrated water resource management (13, 14). For instance, precision agriculture technologies, which use data-driven insights to optimize farming practices, have shown significant potential to enhance productivity and resilience (15, 16).

However, these solutions require robust policy support and institutional frameworks to ensure widespread adoption. Investments in farmer training, infrastructure development and financial incentives are critical for facilitating the transition to climate-smart agricultural practices (17, 18).

Policies aimed at improving access to agricultural resources, such as credit, markets and technology, play a central role in supporting farmers' adaptive capacities. International collaborations and initiatives, such as the Global Alliance for Climate-Smart Agriculture, demonstrate the importance of coordinated efforts in addressing climate-related food insecurity (19, 20). At the national level, programs focused on building institutional capacity, enhancing education and fostering public-private partnerships are essential for driving resilience (21).

The uneven distribution of climate impacts necessitates region-specific interventions. For example, while sub-Saharan Africa faces recurrent droughts, South Asia grapples with frequent flooding. These disparities call for tailored solutions that address the unique challenges of each region. Localized adaptation measures, such as the introduction of salt-tolerant rice in coastal areas, exemplify the importance of context-specific approaches. Emerging technologies, including satellite remote sensing, machine learning and predictive modeling, offer unprecedented opportunities to study and address the impacts of climate change on food systems. These tools enable precise assessments of climatic effects on crop production, livestock health and resource availability, informing evidence-based policy decisions (22). However, their implementation in resource-poor settings remains a challenge, necessitating capacity-building initiatives to bridge the technological divide (9, 23).

This review examines the intricate relationship between climate change and food security, a nexus of growing global concern with profound implications for sustainable agricultural development. By systematically analyzing peer-reviewed literature indexed in the Scopus database from 2019 to 2024, the study adopts a global perspective to identify prevailing trends, thematic priorities and emerging gaps in research. Key focus areas include the impacts of climate variability on agricultural systems, the effectiveness of adaptation strategies and the role of innovative technologies, such as artificial intelligence, precision farming and digital financial services, in enhancing resilience. The review also highlights critical research gaps, including the need for localized adaptation strategies, comprehensive economic impact assessments and the integration of risk management tools like agricultural insurance and microfinance. The findings underscore the importance of strengthening regional and international collaborations to bridge disparities and promote an inclusive, climate-resilient food system.

Methodology

A Systematic Literature Review (SLR) is a methodical approach to analyzing and synthesizing research on a specific subject, characterized by its transparency and reproducibility. An SLR is a process used to locate, examine and interpret all existing studies pertinent to a specific research question or area of interest (24). The Systematic Literature Review (SLR) was selected for this study due to its structured, transparent and replicable approach to selecting and compiling a database for analysis. The research followed the guidelines of the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Statement (25) (Fig. 1).

Document search

The Scopus scholarly electronic database was utilized to identify relevant studies on the impact of climate change on food security as part of the systematic literature review. Scopus was selected for its reliability as a source of high-

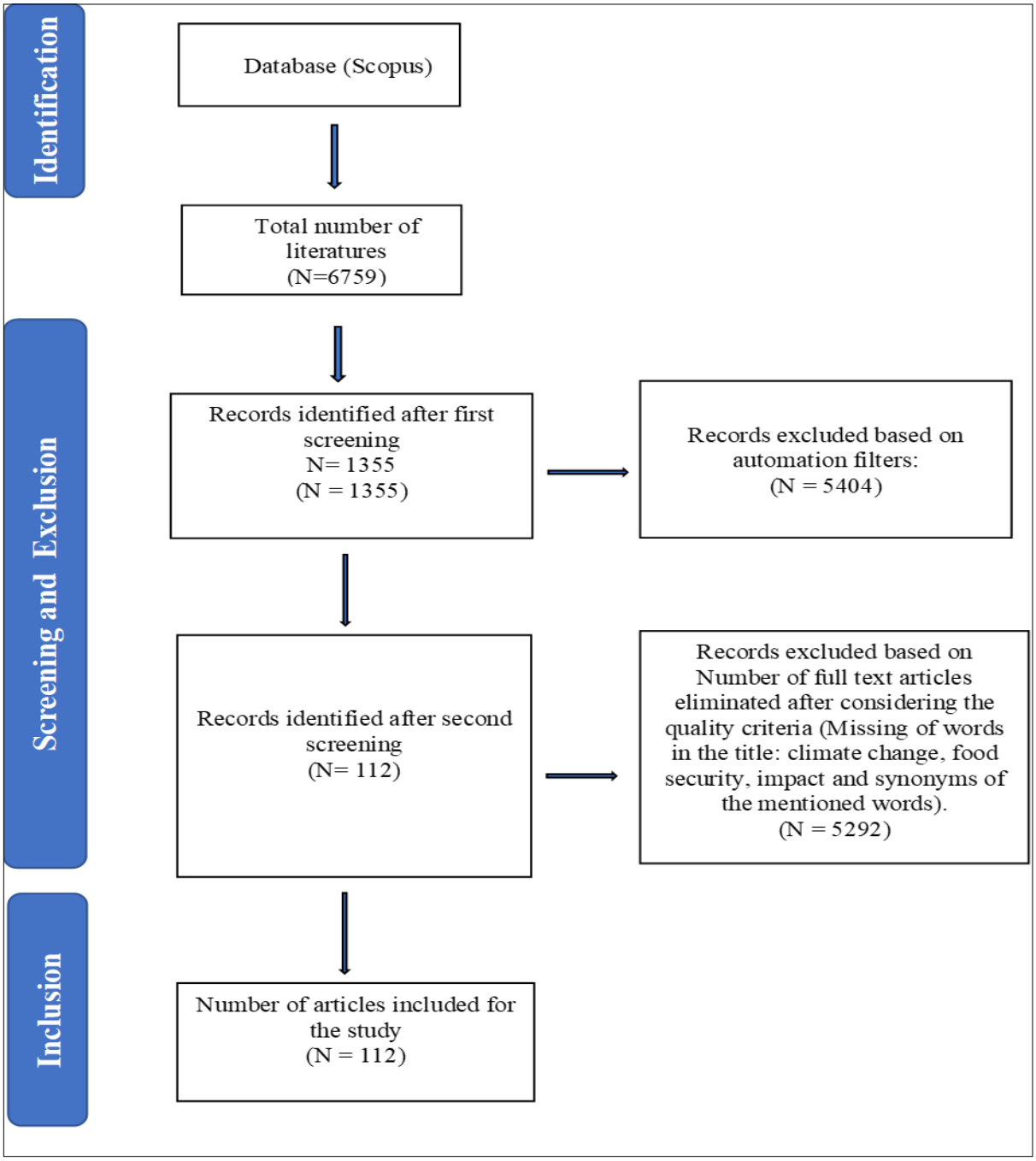

Fig. 1. PRISMA flowchart.

quality academic research, offering extensive coverage, rigorous indexing standards and comprehensive inclusion of peer-reviewed literature across diverse disciplines. While inclusion of additional databases such as Web of Science or PubMed could potentially broaden the scope and reduce publication bias, the exclusive use of Scopus in this review was due to institutional access limitations. Despite this constraint, Scopus remains a widely recognized and robust platform for conducting systematic literature reviews.

Research articles were identified using carefully curated keyword combinations. The final search string was optimized through expert consultation and necessary adjustments to ensure accuracy and relevance (Table 1). To obtain the most recent and comprehensive insights, the search was limited to publications from 2019 to 2024, ensuring a contemporary understanding of climate change's impact on food security while reflecting current trends and developments in the field.

Table 1. Combination of keywords used and total number of articles

Database	Search terms/Keywords	Numbers of Articles
Scopus	"impact" AND "climate change" AND "food security"	6759

Screening articles and constructing the literature review

Articles were initially screened using predefined inclusion and exclusion criteria. Gray literature, conference proceedings, editorial letters and book chapters were excluded, with the review focusing solely on papers published in open-access journals. The articles were further filtered based on their relevance as indicated by the abstracts and adherence to the non-redundancy criterion (Table 2). In addition to this screening process, a critical appraisal of the included articles was conducted to ensure methodological rigor and validity. Standardized quality assessment tools, such as the Critical Appraisal Skills Programme (CASP) checklist, were employed

to evaluate the trustworthiness, relevance and results of each study. This quality assessment step was integral to ensuring that only methodologically sound studies contributed to the synthesis addressing the research question.

Method of data analysis

Recent advancements in bibliometric software have enabled the detailed analysis of specific scientific fields, topics, or areas of interest. The Bibliometric package, an open-source tool developed in the R programming language, provides a comprehensive platform for scientific mapping and analysis. Featuring a wide array of graphical and statistical tools, it offers users flexibility and is regularly updated to ensure its effectiveness (26). The program generates a collaborative network when multiple authors contribute to an article, helping to elucidate the dynamics involved in the creation of such studies (27).

The program generates a network of terms by identifying frequently co-occurring keywords, with high density represented by a network containing numerous such keywords. It then evaluates the connections between this term network and others, categorizing the keywords into subject areas and organizing themes based on their density and centrality (28).

Results

The descriptive analysis for the bibliometric investigation was conducted using the Bibliometrics software in RStudio version 4.3.2 for Windows. The widely used R package, Bibliometric, has been gaining popularity and is increasingly being employed in numerous research studies (29). Bibliometric data from the Scopus database were directly imported into R, a widely recognized platform for statistical analysis and visualization. Within R, the Bibliometrix package was used for conducting the core bibliometric analysis, while its web-based interface, Biblioshiny, facilitated an interactive and user-friendly environment for visual exploration and mapping of research trends (30).

The bibliometric analysis (2019–2024) encompasses 112 documents from 72 scholarly sources, highlighting a dynamic research field with an annual publication growth rate of 36.72 %. The documents are recent, with an average age of 1.45 years, indicating a focus on contemporary issues. On average, each document garners 15.54 citations, reflecting a moderate to high academic impact. A total of 7370 references underlines the extensive research foundation. The dataset features 477 "Keywords Plus" and 367 "Author's Keywords," showcasing broad and focused thematic representation. Authorship analysis reveals significant collaboration, involving 506 contributors, with only 10 single-authored works. The average number of co-authors per document is 4.79 and 46.43 % of the works involve international co-authorship, highlighting a global research effort.

All 112 documents are peer-reviewed articles, demonstrating a strong preference for disseminating findings through academic journals. This dataset illustrates a vibrant and impactful research culture emphasizing contemporary challenges, robust collaboration and international engagement in the studied domain (Table 3).

Fig. 2 visualizes the annual distribution of articles published between 2019 and 2024. It reveals a clear upward trajectory in the number of articles published, demonstrating a significant increase in research output over the given period. In 2019, the number of articles was relatively low, with only a handful published. This trend continued into 2020 and 2021, where the number of publications remained modest, signifying an early phase of growth in the research domain. However, starting from 2022, there was a noticeable rise in the volume of articles, marking a shift towards a more substantial output. The upward trend continued in 2023, albeit at a slightly slower rate compared to the explosive growth observed in 2024. In 2024, the number of published articles reached its peak, with nearly 40 articles being published in that year alone, signifying an accelerating rate of research activity.

This growth suggests that the research field has gained significant momentum, particularly in the last two years, likely due to increasing interest and relevance of the topic, higher research collaboration and possible funding or institutional support. The sharp rise in 2024 also points to the possibility of emerging breakthroughs or increasing urgency in the research area, reflecting the field's growing importance in academic discourse. This surge in publication activity underlines the vibrant and rapidly expanding nature of the research within this timespan.

Table 2. Criteria for inclusion and exclusion

Parameter	Inclusion criteria	Exclusion criteria
	Initial identification	
Publishing year	2019-2024	If published below 2019
Document type	Article	Review, conference paper, book chapter, book
Subject Area	Environmental science, agricultural and biological science and social science	Energy, earth and planetary sciences, computer sciences, medicine, biochemistry, genetics and molecular biology, economics, econometrics and finance, engineering, veterinary, immunology and microbiology, decision sciences, arts and humanities, neuroscience, nursing, mathematics, materials science, health professions, psychology, chemistry, pharmacology, toxicology and pharmaceutics, chemical engineering, physics and astronomy, multidisciplinary
Language	English	Spanish, romanian, portuguese, moldovan, moldovian
Source type	Journal	Conference proceedings, book, book series
Publishing stage	Final	Article in press
Access type	Open Access	Gold, hybrid gold, green, bronze
	Screening	
Title and abstract	Existence of predefined keywords in the title, abstract, or keywords part of the paper	
Full text	Included relevant papers which discusses the predefined keywords	

Table 3. Overview of data attributes and key findings

Description	Results
Timespan	2019:2024
Sources (Journals, Books, etc)	72
Documents	112
Annual Growth Rate %	36.72
Document Average Age	1.45
Average citations per doc	15.54
References	7370
Keywords Plus (ID)	477
Author's Keywords (DE)	367
Authors	506
Authors of single-authored docs	10
Single-authored docs	10
Co-Authors per Doc	4.79
International co-authorships %	46.43
Article	112

Fig. 3 illustrates the contributions of the most relevant authors to academic publications, measured by the number of articles produced. The horizontal bar chart provides a clear comparison of the publication output among the listed authors, highlighting their relative significance in the research field. Among the authors, Zhang X, Zhang Y and Zheng H emerge as the most prolific contributors, each with three publications. This indicates their prominent role and active involvement in advancing the research within the domain. The remaining authors, including Feike T, Dangui K, Chen A, Boateng E, Bavorova M, Affoh R and Abdullaye T, have each contributed two articles, reflecting consistent participation in scholarly discourse.

The distribution of contributions suggests a collaborative and balanced authorship structure, with a mix of leading contributors and a supporting group of active researchers. This pattern underscores the importance of key authors in driving the research agenda while maintaining a diverse pool of contributors to enrich the academic landscape with multiple perspectives and insights.

Fig. 4 displays the distribution of corresponding authors by country, divided into Single Country Publications (SCP) and Multiple Country Publications (MCP), providing an overview of geographic research activity and international collaboration. China leads with the highest number of documents, predominantly SCPs, highlighting strong domestic research capacity and institutional support. The USA, ranking second, shows a significant proportion of MCPs, emphasizing its robust tradition of international

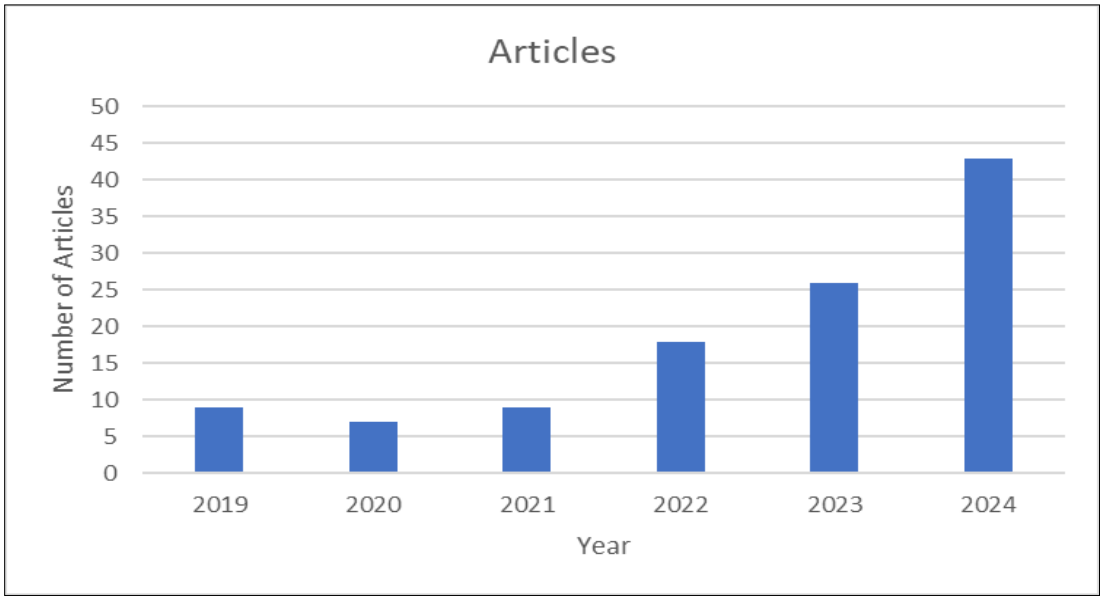

Fig. 2. Annual scientific production for the period of 2019-2024.

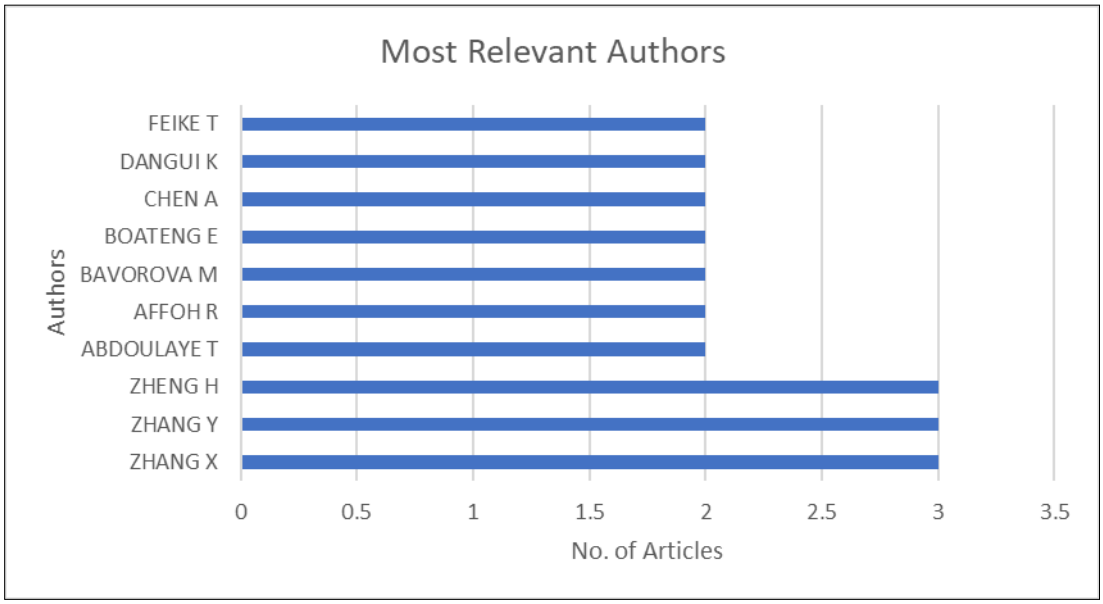

Fig. 3. Most relevant authors in the period of 2019-2024.

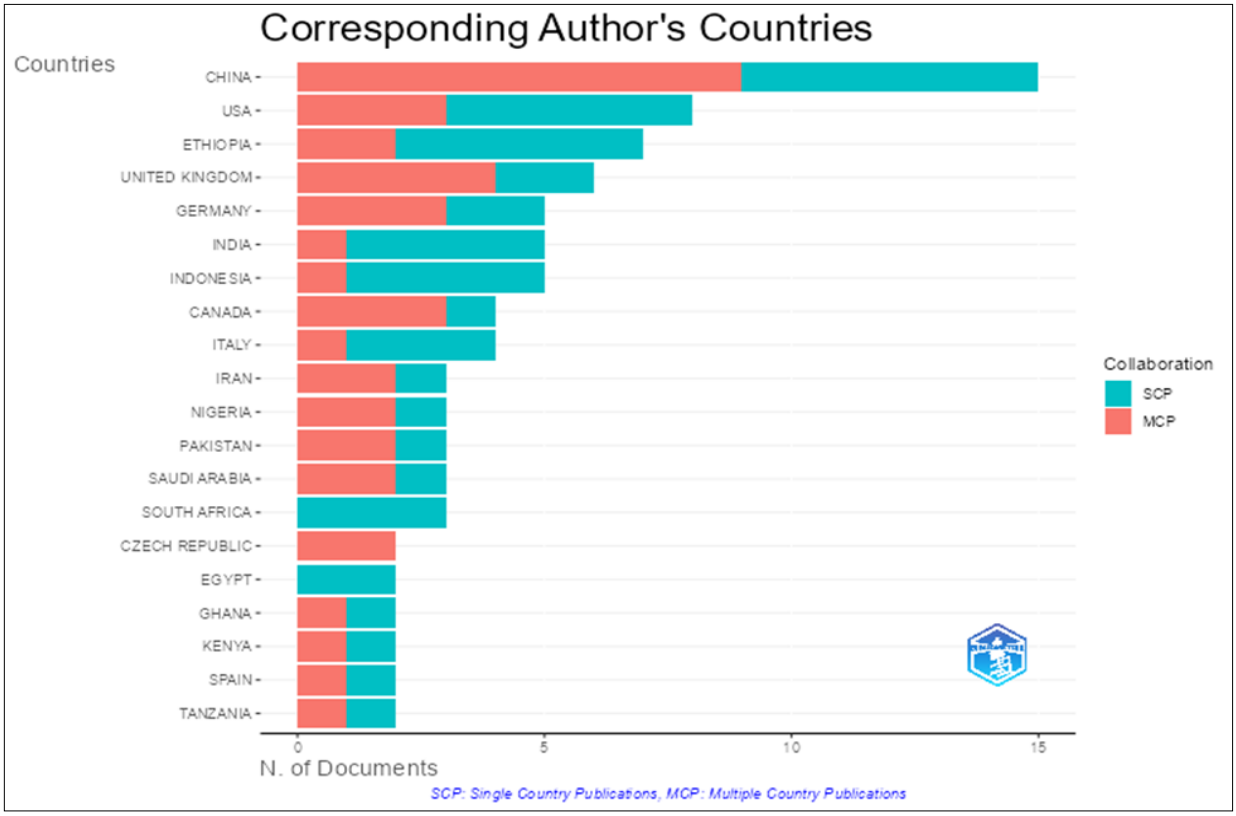

Fig. 4. Distribution of corresponding authors by country and collaboration type.

collaboration and the global relevance of its research.

Countries like Ethiopia, the United Kingdom, Germany and India demonstrate a balanced mix of SCP and MCP contributions, indicating active domestic research while maintaining significant international partnerships. This balance positions them as key players in both national and global academic networks. In contrast, Pakistan, Nigeria, South Africa and Egypt rely more on MCPs, suggesting limited domestic resources and a strategic focus on international collaborations to boost their research output. Countries such as Italy, Iran and Canada contribute moderately, showcasing a blend of national and international research efforts that indicate impactful participation in the global academic sphere.

The data underscores the dominance of developed nations in both independent and collaborative research. At the same time, emerging economies increasingly depend on global partnerships to enhance their research footprint, highlighting the critical role of international academic networks in fostering knowledge exchange and addressing global challenges in the research field.

The Table 4 presents the total citations (TC) and average citations per document (Average A) for various countries, providing insights into the research impact and quality in the domain. The United Kingdom leads with 459 citations and the highest average of 76.5 citations per document, reflecting the exceptional impact and quality of its research, supported by robust academic institutions and influential studies. China follows with 174 total citations but a lower average (11.6), suggesting high productivity with relatively less impact per document. The USA balances productivity and impact with 138 total citations and an average of 17.2 citations per document.

Table 4. Country-wise total citations and average article citations

Country	TC	Average Article Citations
United Kingdom	459	76.5
China	174	11.6
Usa	138	17.2
Italy	123	30.8
Ethiopia	102	14.6
Japan	89	89
Pakistan	83	27.7
Nigeria	78	26
South Africa	75	25
Indonesia	36	7.2
Uganda	34	34
Malaysia	32	32
Saudi Arabia	31	10.3
Kenya	28	14
Egypt	25	12.5
Iran	22	7.3
Senegal	18	18
India	16	3.2
Canada	13	3.2
Sweden	12	12
Lebanon	11	11
Ireland	10	10

Italy and Pakistan stand out with high average citations per document (30.8 and 27.7, respectively), underscoring their impactful contributions to the field. Among African nations, sub-regional analysis reveals notable variation: Ethiopia (102 total citations, 14.6 average), Nigeria (78 total citations, 26 average) and South Africa (75 total citations, 25 average) demonstrate significant research influence within their respective regions, indicating strong academic reception. However, further sub-regional exploration-such as comparisons between East and West Africa-could uncover nuanced vulnerabilities and localized research priorities, thereby enhancing the policy relevance of the findings. In South Asia, while Pakistan shows high citation impact, India (16 total citations, 3.2 average) presents lower

visibility, suggesting the need for greater emphasis on research dissemination and influence. Similarly, countries like Canada (13 total citations, 3.2 average) Germany and Portugal reflect limited citation performance, pointing to either lower research output or challenges in attaining broader global recognition.

This data underscores disparities in research impact, with developed nations like the UK, USA and Italy excelling in both productivity and quality. Emerging economies demonstrate promising potential to enhance academic influence through targeted collaborations and impactful research initiatives.

Table 5 provides an analysis of key terms used in scholarly research, offering insights into dominant themes and focal points in the field. "Climate change" is the most frequently mentioned term, with 74 occurrences, highlighting its central role in the literature, especially regarding its impact on agriculture and food systems. "Food security", appearing 59 times, is the second most common term, emphasizing its critical importance in addressing global challenges related to food availability and stability in a changing climate. Together, these terms reflect a focus on sustainable development and agricultural resilience.

Specific dimensions of the discussion include "crop yield" (22 occurrences), "climate effect" and "food supply", which underline the significance of mitigating climate impacts on food systems. Terms like "crop production", "adaptive management" and "agricultural production" point to strategies for sustainable productivity in challenging environmental conditions. Additionally, terms such as "drought" and "wheat" highlight key stressors and critical crops affected by climate variability. Broader themes are represented by terms like "agriculture", "crops" and "food production" (each with 9 occurrences), emphasizing the interconnectedness of agricultural practices, food systems and environmental sustainability.

Table 5. Frequency of most relevant keywords in the article

Words	Occurrences
climate change	74
food security	59
crop yield	22
climate effect	21
food supply	19
crop production	13
adaptive management	12
agricultural production	10
drought	10
wheat	10
agriculture	9
crops	9
food production	9

In conclusion, the data portrays a research landscape centered on the interplay between climate change, agriculture and food security. It underscores the pressing need for adaptive strategies to mitigate climate risks and ensure the resilience of global food systems.

The word cloud (Fig. 5) visualization captures the central themes and key terms prevalent in the analyzed research. The relative size of each word reflects its frequency, indicating its significance within the domain. Dominating the word cloud are "climate change" and "food security", underscoring their critical importance in addressing the challenges posed by climate impacts on global food systems. These terms highlight the urgency of ensuring food availability and stability amidst environmental disruptions.

Notable terms such as "crop yield", "climate effect" and "food supply" emphasize the research focus on agricultural productivity and the impacts of climatic variability. These terms suggest efforts to understand and mitigate adverse effects on yields and supply chains. The presence of terms like "adaptive management", "drought" and "wheat" indicates attention to resilience strategies and adaptation measures, particularly for staple crops crucial to food security. Broader discussions on sustainable agriculture and resource management are evident through terms like "agricultural production", "crop production" and "food production".

Overall, the word cloud reflects a research landscape centered on the interplay between climate change, agriculture and food security. It underscores the need for adaptive strategies, resilience-building and sustainable practices to address these interconnected challenges in a rapidly changing environment.

The strategic thematic map (Fig. 6) provides a visual representation of the research landscape by plotting themes according to two key dimensions: density and centrality. Density measures the internal development of a theme, reflecting how cohesive and well-structured it is. Centrality, on the other hand, indicates the degree of interaction a theme has with other themes, thereby representing its importance and relevance within the broader field. This framework divides the map into four quadrants: motor themes, basic themes, niche themes and emerging or declining themes-each offering insights into the status and evolution of specific research areas.

Motor themes, located in the upper-right quadrant, are both well-developed and central, making them essential pillars of the research domain-such as those on climate

Fig. 5. Word cloud representation of most relevant keywords.

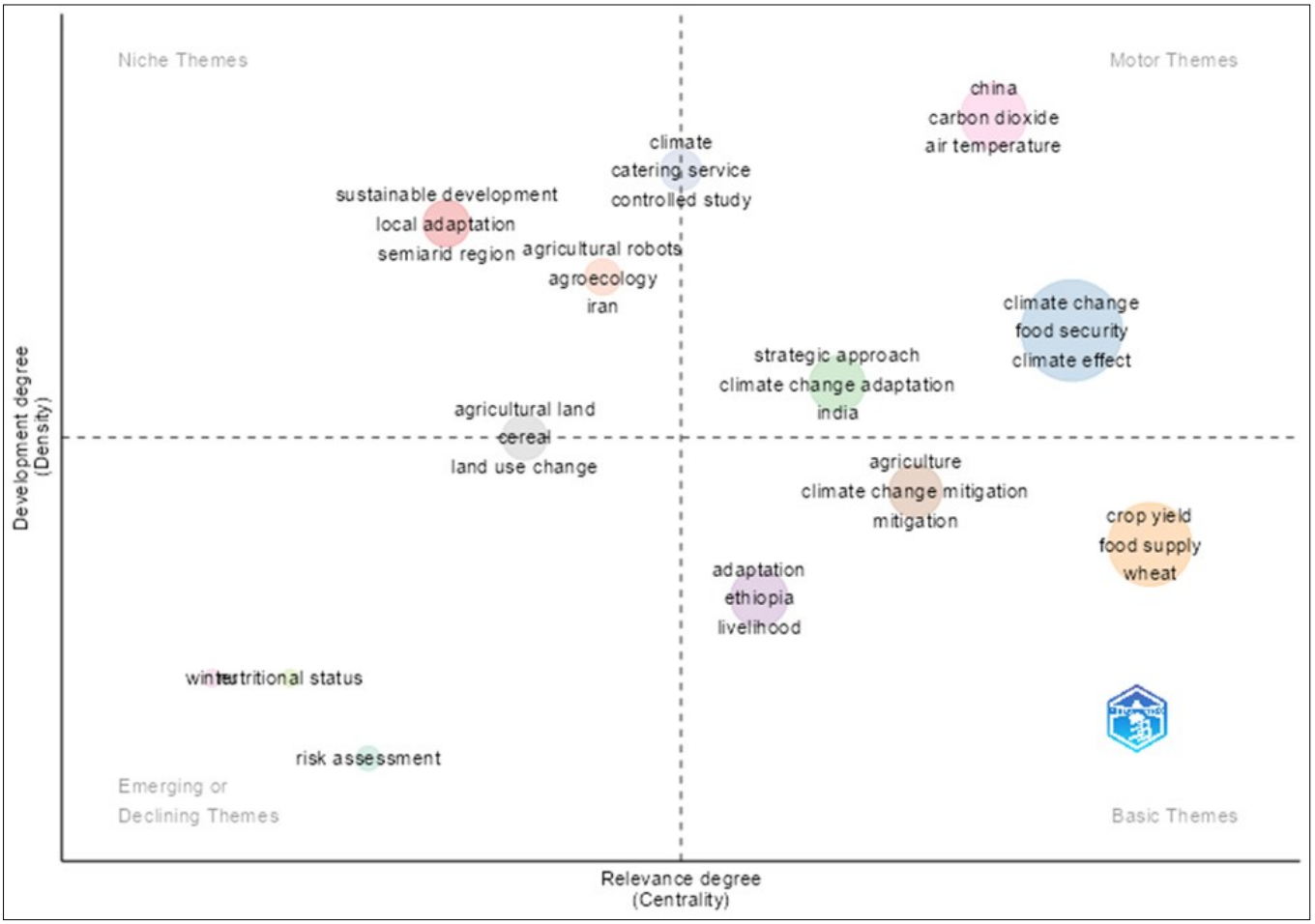

Fig. 6. Thematic evolution.

change, food security and agricultural sustainability. Basic themes, in the lower-right quadrant, are central but underdeveloped, signifying foundational areas that require further exploration, such as agricultural productivity and food systems. Niche themes, found in the upper-left quadrant, are highly developed but have limited external links, often representing specialized research like regional adaptation techniques or precision agriculture. Lastly, emerging or declining themes, in the lower-left quadrant, are weak in both development and relevance, indicating nascent or fading research interests. The map thus underscores the dynamic and multidimensional nature of research in climate change and food security, offering direction for future scholarly focus.

Discussion

The findings from this systematic literature review highlight the intricate and multi-dimensional relationship between climate change and food security. The analysis highlights the growing need to address the adverse impacts of climate variability on agricultural systems and global food supply chains. This discussion explores key insights and implications derived from the study while contextualizing them within broader academic and policy frameworks.

Centrality of climate change and food security

The frequent occurrence of "climate change" and "food security" within the analyzed literature reflects their pivotal roles as global challenges. Food security has become increasingly vulnerable due to climate change. Hence, it is crucial to engage in discussions and implement measures that reduce the environmental impacts on family farming, which is directly or indirectly influenced by climatic events (31). The role of agriculture in greenhouse gas (GHG) emissions and the impact of climate change on food production are global concerns drawing significant attention (32).

Changes in climate trends and patterns are expected to significantly influence agricultural production, disrupt livelihoods and hinder efforts to achieve food security (33). Climate change exacerbates risks to food security by disrupting crop yields, reducing agricultural productivity and increasing the frequency of extreme weather events such as droughts, floods and heatwaves. Climate change, particularly extreme temperature variations, significantly undermines food security and disrupts food production (34). Weather extremes driven by climate change pose significant challenges to cereal production, food security and climate change mitigation in agriculture. This underscores the need to prioritize high-yielding locations, select appropriate crop varieties and adopt resource-efficient management practices to support mitigation efforts (35). Short-term climate fluctuations can substantially disrupt the stability of food resource prices, posing a threat to food security, even when crop production systems are well-adapted to climate change and demonstrate increasing average yields over time (36). These challenges disproportionately affect vulnerable populations, especially those in regions with limited adaptive capacity, emphasizing the need for targeted mitigation and adaptation strategies.

Emerging adaptation strategies and farming systems

The thematic analysis highlights "adaptive management" and "sustainable development" as critical emerging areas. Adaptive management refers to a structured, iterative process of decision-making in agriculture and natural resource management, which allows for continuous learning and adjustment in response to climate variability. Raising awareness about the impacts of climate change on farmers and encouraging the adoption of appropriate resilience strategies-defined as targeted actions that enhance the capacity of households to anticipate, absorb and recover from climatic shocks-are critical to improving overall household resilience (37). Within this context, climate-smart agriculture (CSA) has gained prominence as an integrated approach that aims to sustainably increase agricultural productivity, build resilience to climate change (adaptation) and reduce greenhouse gas emissions where possible (38).

Adaptation measures such as crop diversification, climate-resilient farming practices and advancements in agroecological techniques have demonstrated potential in enhancing agricultural resilience. Climate change adaptation measures have enabled farming households to enhance their food security despite challenging climatic conditions (39). Climate change adaptation plays a crucial role in enhancing food security among pastoralists. Pastoralists who have not adapted are 7 percentage points more likely to achieve food security if they had adopted adaptation measures. Conversely, those who have adapted are 27 percentage points more likely to face food insecurity if they had not implemented adaptation strategies (40). Farming systems that include food or cash crops and livestock, which are typically among the most food-secure, are likely to be replaced by other systems across all climate scenarios. In contrast, mixed farming systems (combining food and livestock) and livestock-dominated systems, which are often less food-secure and prevalent in arid regions, are expected to expand as a result of climate change (41). Climate change poses a significant threat to food security and hinders Turkey's progress toward sustainable development goals, especially in achieving no poverty and zero hunger (42). However, the relatively low density of these themes suggests that they require deeper exploration and wider application to achieve impactful results.

Regional disparities and sub-regional vulnerabilities

The geographical distribution of publications indicates that countries such as China and the USA lead in research productivity, while developing nations often rely on international collaborations. This imbalance reflects disparities in resources, infrastructure and research capacity. Countries heavily reliant on rainfed subsistence agriculture experience severe impacts of climate change and variability on agriculture and food security (43). Developing countries are highly vulnerable to climate change due to their socioeconomic conditions, characterized by high poverty levels and their heavy reliance on natural resources for livelihoods (41).

Vietnamese farmers have adjusted to climate change by selecting alternative crops and climate unpredictability and extreme weather events heavily affect Saudi Arabia's fragile food system, which is already under strain (44, 45). By the end of the century (2086-2095), global yield impacts without the CO2 fertilization effect (CFE) are projected to be -2 % for maize, -19 % for rice, -14 % for soybeans and -1 % for wheat, with similar global trends observed when considering the CFE (46).

Moreover, regional variations in climate impacts-such as droughts in sub-Saharan Africa or floods in South Asia-necessitate localized studies and tailored interventions to address unique vulnerabilities. Climate variability and change present a significant challenge to food security in Africa (47). Projects like "AfriCultuReS" support food security by providing integrated monitoring and early warning systems for Africa, covering climate, drought, livestock, crops, water and weather. Such initiatives are vital for combating climate change's impact on food security (48). Afghanistan has experienced severe climatic challenges, including drought, rising temperatures and limited precipitation, which are expected to intensify in the future. Declining crop yields could jeopardize food security in a country where agriculture is the backbone of both the economy and the livelihoods of most of the population (49). Policy recommendations and adaptation strategies are essential for addressing the adverse effects of climate change on agricultural production and food security in Ethiopia and other similar agro-based economies (50).

Technological and analytical innovations

The analysis reveals increasing reliance on advanced tools such as "spatiotemporal analysis" and "regression models" to quantify and predict the impacts of climate change on agriculture. A previous study utilized the Tobit model to analyze adaptation options for climate change and variability, while ordered logistic regression was applied to assess the impact of these adaptations on household food security status, focusing on the food consumption dimension (43). The study's insights into the spatial distribution of selected variables will guide organizations like the World Health Organization and the World Meteorological Organization in providing health and medical support and formulating climate change policy recommendations for specific countries (51). These methods enable precise assessments of climatic effects on specific crops, regions and timeframes, supporting evidence-based policy formulation. However, their adoption in resource-poor regions remains limited, highlighting a critical area for capacity building.

Policy and institutional dimensions

The significant focus on "sustainability" and "adaptive management" in the literature indicates a growing recognition of the need for supportive policies and institutional frameworks. Effective governance approaches must consider household livelihood strategies to ensure that support against the impacts of climate change is appropriate and relevant (52). Enhancing institutional factors like access to credit and markets, extension services and the adoption of drought-resilient crop varieties is crucial for boosting agricultural productivity (37).

Food security is a critical concern amidst climate change and a localized understanding of community vulnerabilities to its effects is essential for effective management and policy development (53). Policies supporting smallholder farmers in

adopting climate change coping measures should be promoted to enhance their adaptive capacity. Government investment plans and regulations should prioritize providing knowledge on climate change, access to credit and education (54). Policy initiatives, such as climate-smart agriculture, integrated water resource management and carbon credit schemes, have shown promise in reducing emissions and enhancing resilience. African governments and non-governmental organizations assist farmers in adapting to climate change by implementing policies that emphasize capacity building and ensuring that extension officers actively and extensively engage with farmers (55). Enhancing climate change awareness, promoting the involvement of female-led households in income generation and strengthening existing adaptation measures all contribute positively to food security (56). The government should prioritize initiatives such as large-scale tree planting to improve agriculture and the environment, food security intervention programs, poverty reduction strategies and the provision of adaptive capacity indicators (57).

However, challenges such as financing, technology access and institutional coordination persist as barriers to widespread adoption. Improving access to drought-tolerant and early-maturing crop varieties, disseminating crop-related and weather information through extension services and empowering farmers with better access to credit would significantly enhance the adoption of climate risk adaptation strategies, thereby boosting food security (58). Future farming policies could focus on targeted irrigation and nutrient application strategies to reduce the adverse effects of extreme weather on crop yields, as these practices have been shown to moderately alleviate the impact of drought and excessive rainfall on agricultural productivity (59). Investing in mitigation efforts, such as clean energy technologies and land-use changes, particularly transitioning to bioenergy production, can help prevent or minimize agricultural production losses due to climate change (60).

Future directions and research gaps

The study identifies key research gaps that require immediate attention:

- Enhanced focus on socio-economic dimensions, including the impacts of climate change on rural livelihoods and migration.
- Development of low-cost, scalable adaptive technologies suitable for smallholder farmers.
- Longitudinal studies to assess the effectiveness of adaptation strategies over time.
- Integration of interdisciplinary approaches to capture the complexities of climate-food systems.

Conclusion

This systematic review has underscored the profound and multifaceted impact of climate change on global food security, emphasizing the disruptions to agricultural productivity and the socio-economic resilience of vulnerable populations, particularly in developing nations reliant on subsistence farming. While the review reiterates well-established findings on the role of climate change in destabilizing food supply chains and exacerbating extreme weather events, it also contributes novel insights into the socio-economic dimensions of food security. Specifically, the review highlights the critical importance of adaptive strategies such as crop diversification, climate-resilient farming practices and integrated water resource management, but it also reveals significant gaps in the adoption of technological innovations in resource-limited regions. Unlike previous studies, this review places a strong emphasis on the unequal access to these innovations, particularly in rural and marginalized communities, which has been a critical barrier to effective adaptation. Furthermore, the analysis identifies the need for more inclusive policy frameworks that address both technological and socio-economic factors, including farmers' access to credit, markets and education on climate-resilient practices. The findings suggest that while there has been progress, a more interdisciplinary approach is needed to fully address the complexities of the climate-food security nexus. Future research should prioritize evaluating the long-term effectiveness of adaptation measures and developing cost-effective solutions that can be implemented in vulnerable regions. Ultimately, the review emphasizes that achieving sustainable and resilient food systems in the face of climate change requires not only technological innovation but also inclusive policies, international collaboration and a deep understanding of socio-economic vulnerabilities.

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Authors' contributions

MA conducted an extensive literature review, synthesized key concepts and drafted the manuscript. PP provided guidance on the conceptual framework, ensured the integrity of the review process and approved the final manuscript. MS contributed to refining ideas, critically reviewed the manuscript, facilitated access to relevant resources and also played a key role in proofreading and enhancing the overall readability of the manuscript. MC assisted in organizing content, revising the manuscript and ensuring clarity and coherence. GV conducted statistical analyses of secondary data, contributed to summarizing findings and enhanced the quality of the manuscript through revisions. AJ assisted in data collection, conducted preliminary analysis and contributed to the interpretation of results. GA supported the development of tables and figures, contributed to methodological design, ensured the manuscript adhered to journal guidelines and provided critical feedback during the final review process. All authors read and approved the final manuscript.

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References

1. Wheeler T, Von Braun J. Climate change impacts on global food security. Science. 2013;341(6145):508–13. https://doi.org/10.1126/science.1239402
2. Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. Prioritizing climate change adaptation needs for food security in 2030. Science. 2008;319(5863):607–10. https://doi.org/10.1126/science.1152339
3. Arneth A, Barbosa H, Benton T, Calvin K, Calvo E, Connors S, et al. IPCC special report on climate change and land. Intergovernmental Panel on Climate Change (IPCC). 2019.
4. Neupane D, Adhikari P, Bhattarai D, Rana B, Ahmed Z, Sharma U, et al. Does climate change affect the yield of the top three cereals and food security in the world? Earth. 2022;3(1):45–71. https://doi.org/10.3390/earth3010004
5. Mekouar MA. Food and agriculture organization of the United Nations (FAO). Yearbook of International Environmental Law. 2018;29:448–68. https://doi.org/10.1093/yiel/yvz057
6. Thornton PK, Ericksen PJ, Herrero M, Challinor AJ. Climate variability and vulnerability to climate change: A review. Glob Change Biol. 201;20(11):3313–28. https://doi.org/10.1111/gcb.12581
7. Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M. Analysis of the determinants of farmers' choice of adaptation methods and perceptions of climate change in the Nile Basin of Ethiopia [in Amharic]. Washington (DC): International Food Policy Research Institute (IFPRI); 2008. https://doi.org/10.1016/j.gloenvcha.2009.01.002
8. Adger WN, Huq S, Brown K, Conway D, Hulme M. Adaptation to climate change in the developing world. Prog Dev Stud. 2003;3(3):179–95. https://doi.org/10.1191/1464993403ps060oa
9. Leal Filho W, Modesto F, Nagy GJ, Saroar M, Yannick Toamukum N, Ha'apio M. Fostering coastal resilience to climate change vulnerability in Bangladesh, Brazil, Cameroon and Uruguay: a cross-country comparison. Mitig Adapt Strateg Glob Change. 2018;23:579–602. https://doi.org/10.1007/s11027-017-9750-3
10. Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. A meta-analysis of crop yield under climate change and adaptation. Nat Clim Change. 2014;4(4):287–91. https://doi.org/10.1038/nclimate2153
11. Ericksen PJ. Conceptualizing food systems for global environmental change research. Glob Environ Change. 2008;18(1):234–45. https://doi.org/10.1016/j.gloenvcha.2007.09.002
12. Nelson G, Cai Z, Hassan R, Godfray C, Santos M, Swaminathan H. Food security and climate change: A report by the high-level panel of experts on food security and nutrition. Rome: FAO; 2012.
13. Schlenker W, Lobell DB. Robust negative impacts of climate change on African agriculture. Environ Res Lett. 2010;5(1):014010. https://doi.org/10.1088/1748-9326/5/1/014010
14. FAO, IFAD, UNICEF, WFP and WHO The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets, FAO, 2020, p. 320. https://doi.org/10.1111/padr.12418
15. Basso B, Cammarano D, Carfagna E. Review of crop yield forecasting methods and early warning systems. In: Proceedings of the first meeting of the scientific advisory committee of the global strategy to improve agricultural and rural statistics, FAO Headquarters, Rome, Italy, 2013. p. 241.
16. Harvey CA, Chacon M, Donatti CI, Garen E, Hannah L Andrade A, et al. Climate-smart landscapes: Opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. Conserv Lett. 2014;7(2):77–90. https://doi.org/10.1111/conl.12066
17. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, et al. Climate-smart agriculture for food security. Nat Clim Change. 2014;4(12):1068–72. https://doi.org/10.1038/nclimate2437
18. Campbell BM, Thornton P, Zougmoré R, Van Asten P, Lipper L. Sustainable intensification: What is its role in climate-smart agriculture? Curr Opin Environ Sustain. 2014;8:39–43. https://doi.org/10.1016/j.cosust.2014.07.002
19. Nelson V, Morton J. CGIAR Research Program 2020 Reviews: Climate Change, Agriculture and Food Security. Rome: CGIAR Advisory Services Evaluation Function. 2020 Oct 30.
20. Pretty J, Bharucha ZP. Sustainable intensification in agricultural systems. Ann Bot. 2014;114(8):1571–96. https://doi.org/10.1093/aob/mcu205
21. Tubiello FN, Rosenzweig C. Developing climate change impact metrics for agriculture. Integr Assess J. 2008 Jun 2;8(1).
22. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, et al. Solutions for a cultivated planet. Nature. 2011;478(7369):337–42. https://doi.org/10.1038/nature10452
23. Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: The challenge of feeding 9 billion people. Science. 2010;327(5967):812–18. https://doi.org/10.1126/science.1185383
24. Keele S. Guidelines for performing systematic literature reviews in software engineering. Version 2.3. EBSE Technical Report. Durham, UK: EBSE; 2007 Jul 9.
25. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group* T. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 2009;151(4):264–69. https://doi.org/10.1136/bmj.b2535
26. Aria M, Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J Informetr. 2017;11(4):959–75. https://doi.org/10.1016/j.joi.2017.08.007
27. Mühl DD, de Oliveira L. A bibliometric and thematic approach to agriculture 4.0. Heliyon. 2022;8(5). https://doi.org/10.1016/j.heliyon.2022.e09369.
28. Cobo MJ, Martínez MA, Gutiérrez-Salcedo M, Fujita H, Herrera-Viedma E. 25 years at knowledge-based systems: A bibliometric analysis. Knowl Based Syst. 2015 May 1;80:3–13. https://doi.org/10.1016/j.knosys.2014.12.035
29. Majiwala H, Kant R. A bibliometric review of a decade'research on industry 4.0 & supply chain management. Mater Today Proc. 2023;72:824–33. https://doi.org/10.1016/j.matpr.2022.09.058.
30. Buyamin B, Rahayu B, Suradi S, Herawaty I, Suryadi S, Syaifullah DH, et al. The influence of war and global economy on article publication: bibliometric analysis using biblioshiny-R). [preprint]. Res Sq [Internet]. [cited 2023 Jun 21]. https://doi.org/10.21203/rs.3.rs-2680363/v1
31. Silva LL, Fernandes GS, Lima ED, Lopes JR, Moura AD, Silva RD. Potential impacts of climate change on food crops in the state of Piauí, Brazil. Rev Ceres. 2024;71:e71042. https://doi.org/10.1590/0034-737x2024710042
32. DAVIES WJ. Developing a new agenda for increased food and climate security. Front Agr Sci Eng. 2024;11(1). https://doi.org/10.15302/J-FASE-2023514
33. Mugabe P, Kipkulei H, Sieber S, Mhache E, Löhr K. Examining climate trends and patterns and their implications for agricultural productivity in Bagamoyo District, Tanzania. Front Clim. 2024;6:1346677. https://doi.org/10.3389/fclim.2024.1346677

34. Wang H, Liu H, Wang D. Agricultural insurance, climate change and food security: Evidence from Chinese farmers. Sustainability. 2022;14(15):9493. https://doi.org/10.3390/su14159493

35. Riedesel L, Ma D, Piepho HP, Laidig F, Möller M, Golla B, et al. Climate change-induced heat and drought stress hamper climate change mitigation in German cereal production. Field Crops Res. 2024;317:109551. https://doi.org/10.1016/j.fcr.2024.109551

36. Guerriero V, Scorzini AR, Di Lena B, Di Bacco M, Tallini M. Measuring variation of crop production vulnerability to climate fluctuations over time, illustrated by the case study of wheat from the Abruzzo region (Italy). Sustainability. 2024;16(15):6462. https://doi.org/10.3390/su16156462

37. Zakari S, Ibro G, Moussa B, Abdoulaye T. Adaptation strategies to climate change and impacts on household income and food security: Evidence from Sahelian region of Niger. Sustainability. 2022;14(5):2847. https://doi.org/10.3390/su14052847

38. Murniati K. The impact of climate change on the household food security of upland rice farmers in Sidomulyo, Lampung Province, Indonesia. Biodiversitas. 2020;21(8). https://doi.org/10.13057/biodiv/d210809

39. Ogunpaimo OR, Oyetunde-Usman Z, Surajudeen J. Impact of climate change adaptation on household food security in Nigeria-a difference-in-difference approach. Sustainability. 2021;13 (3):1444. https://doi.org/10.3390/su13031444

40. Ndiritu SW, Muricho G. Impact of climate change adaptation on food security: Evidence from semi-arid lands, Kenya. Clim Change. 2021;167(1):24. https://doi.org/10.21203/rs.3.rs-174615/v1

41. Abbas M, Ribeiro PF, Santos JL. Farming system change under different climate scenarios and its impact on food security: An analytical framework to inform adaptation policy in developing countries. Mitig Adapt Strateg Glob Change. 202;28(8):43. https://doi.org/10.1007/s11027-023-10082-5

42. Ahmed N, Areche FO, Cotrina Cabello GG, Córdova Trujillo PD, Sheikh AA, Abiad MG. Intensifying effects of climate change in food loss: A threat to food security in Turkey. Sustainability. 2022;15(1):350. https://doi.org/10.3390/su15010350

43. Hilemelekot F, Ayal DY, Ture K, Zeleke TT. Climate change and variability adaptation strategies and their implications for household food Security: The case of Basona Worena District, North Shewa zone, Ethiopia. Clim Serv. 2021;24:100269. https://doi.org/10.1016/j.cliser.2021.100269

44. Nguyen Chau T, Scrimgeour F. Will climate change jeopardize the Vietnamese target of maintaining farmland for food security? A fractional multinomial logit analysis of land use choice. Agric Econ. 2023;54(4):570–87. https://doi.org/10.1111/agec.12787

45. Rahman MM, Akter R, Abdul Bari JB, Hasan MA, Rahman MS, Abu Shoaib S, et al. Analysis of climate change impacts on the food system security of Saudi Arabia. Sustainability. 2022;14(21):14482. https://doi.org/10.3390/su142114482

46. Waldhoff ST, Wing IS, Edmonds J, Leng G, Zhang X. Future climate impacts on global agricultural yields over the 21st century. Environ Res Lett. 2020;15(11):114010. https://doi.org/10.1088/1748-9326/abadcb

47. Lolaso T, Assef E, Woldeamanuel T. Impact of climate change on food security of smallholder farmers in Shashogo district, central Ethiopia. Clim Serv. 2024;34:100465. https://doi.org/10.1016/j.cliser.2024.100465

48. Affoh R, Zheng H, Dangui K, Dissani BM. The impact of climate variability and change on food security in sub-Saharan Africa: Perspective from panel data analysis. Sustainability. 2022;14 (2):759. https://doi.org/10.3390/su14020759

49. Raoufi H, Jafari H, Sarhadi WA, Salehi E. Assessing the impact of climate change on agricultural production in central Afghanistan. Regul Sustain. 2024;5(3):100156. https://doi.org/10.1016/j.regsus.2024.100156

50. Bouteska A, Sharif T, Bhuiyan F, Abedin MZ. Impacts of the changing climate on agricultural productivity and food security: Evidence from Ethiopia. J Clean Prod. 2024;449:141793. https://doi.org/10.1016/j.jclepro.2024.141793

51. Yao P, Fan H, Wu Q, Ouyang J, Li K. Compound impact of COVID-19, economy and climate on the spatial distribution of global agriculture and food security. Sci Total Environ. 2023;880:163105. https://doi.org/10.1016/j.scitotenv.2023.163105

52. Leonard L. Climate change impacts and challenges of combating food insecurity in rural Somkhele, KwaZulu-Natal, South Africa. Sustainability. 2022;14(23):16023. https://doi.org/10.3390/su142316023

53. Brodie LP, Caballero SV, Ojea E, Taylor SF, Roberts M, Vianello P, et al. A new framework on climate-induced food-security risk for small-scale fishing communities in Tanzania. Food Sec. 2024:1-21. https://doi.org/10.1007/s12571-024-01472-x

54. Ojo TO, Ogundeji AA, Emenike CU. Does the adoption of a climate change adaptation strategy improve food security? A case of rice farmers in Ogun State, Nigeria. Land. 2022 Oct 22;11(11):1875. https://doi.org/10.3390/land11111875

55. Pickson RB, Boateng E, Gui P, Chen A. The impacts of climatic conditions on cereal production: Implications for food security in Africa. Environ Dev Sustain. 2024;26(7):18333–60. https://doi.org/10.1007/s10668-023-03391-x

56. Mekonnen A, Tessema A, Ganewo Z, Haile A. Climate change impacts on household food security and adaptation strategies in southern Ethiopia. Food Energy Sec. 2021;10(1):e266. https://doi.org/10.1002/fes3.266

57. Ceesay EK, Ndiaye MB. Climate change, food security and economic growth nexus in the Gambia: Evidence from an econometrics analysis. Res Globalization. 2022;5:100089. https://doi.org/10.1016/j.resglo.2022.100089

58. Madaki MY, Bavorova M, Zhllima E, Imami D. Effect of climate risk adaptation on food security among farming households: The case of Nigeria. Clim Risk Manag. 2024;44:100600. https://doi.org/10.1016/j.crm.2024.100600

59. van der Veer S, Hamed R, Karabiyik H, Roskam JL. Mitigating the effects of extreme weather on crop yields: Insights from farm management strategies in the Netherlands. Environ Res Lett. 2024;19(10):104042. https://doi.org/10.1088/1748-9326/ad7308

60. Suryanto S, Trinugroho I, Susilowati F, Aboyitungiye JB, Hapsari Y. The Impact of Climate Change, Economic Growth and Population Growth on Food Security in Central Java, Indonesia. Nat Environ Pollut Technol. 2023;22(2). https://doi.org/10.46488/nept.2023.v22i02.048

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