Review Article

Climate-Smart Agriculture to Enhance Agricultural Production: A Bibliometric Analysis and Systematic Literature Review

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Abstract | Climate change severely threatens global agricultural systems, endangering food security in rural areas. Climate-smart agriculture (CSA) has emerged as a strategy to enhance agricultural productivity, build resilience, and minimize environmental impacts. This study employs a bibliometric analysis and systematic literature review to explore the evolution of CSA research, identifying key trends, supporting and opposing evidence, and research gaps. The dataset comprises 1,169 publications from 499 sources (2012–2025), with an annual growth rate of 7.3%. These studies have accumulated 72,064 citations, averaging 22.76 citations per paper. It also makes a significant contribution to increasing productivity and food security, and to climate change adaptation by the introduction of technologies such as precision farming, agroecology, and climate-resilient crops, with a reduction of GHG emissions and improvement in sustainable NRM. International collaboration has significantly shaped CSA research, with 44% of publications involving authors from multiple countries. China leads CSA research, followed by the U.S., India, and the Netherlands. The most cited paper, Lipper et al. (2014), has received 1,176 citations. Despite advancements, CSA research faces gaps in gender-sensitive approaches, scalability across diverse climates, and the integration of digital technology in smallholder farming. Future studies should bridge these gaps by integrating principles of the green economy, agricultural science, econometrics, and social science. Strengthening CSA's sustainability and inclusivity can drive agricultural transformation. The study's findings provide valuable insights for policymakers, agricultural practitioners, and development organizations to enhance CSA implementation, fostering a climate-resilient agricultural future.

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Introduction

Climate change has become a critical global concern, affecting agricultural systems. Elevated temperatures, unpredictable precipitation patterns, heightened severe weather events, and changing climatic zones jeopardize food security, rural livelihoods, and agricultural sustainability (Onyeaka *et al*., 2024). These detrimental impacts need new and adaptable techniques to maintain agricultural output while reducing environmental damage. Climate-smart agriculture (CSA) has emerged as a comprehensive strategy combining sustainable farming methods to bolster resilience, augment production, and diminish greenhouse gas emissions (Qureshi *et al*., 2022). CSA is a comprehensive framework that includes several methods, such as conservation tillage, integrated soil fertility management, precision farming, agroforestry, and climate-resilient crop varieties, all of which together promote sustainable agricultural growth (Mahedi *et al*., 2025).

The rising significance of CSA has resulted in an expanding corpus of scholarly research examining its efficacy, implementation obstacles, and policy ramifications across various agroecological regions. Nonetheless, due to the extensive and interdisciplinary scope of CSA literature, a thorough evaluation is necessary to delineate the intellectual terrain of study in this domain. A bibliometric analysis coupled with a comprehensive literature review offers a rigorous methodological framework for integrating current knowledge, pinpointing developing research trends, and elucidating significant gaps in the literature (Punj *et al*., 2023). Bibliometric analysis enables a quantitative evaluation of publishing trends, citation networks, keyword co-occurrence, and the most significant works, institutions, and nations involved in CSA research. A thorough literature evaluation facilitates a qualitative synthesis of results, providing profound insights into conceptual breakthroughs, policy implications, and practical implementations of Climate Smart Agriculture across various agricultural systems.

Although the increasing acknowledgment of CSA as a revolutionary methodology exists, several obstacles impede its extensive use. The problems include restricted financial resources, insufficient institutional support, technology obstacles, knowledge deficiencies, and region-specific limitations that hinder smallholder farmers' ability to successfully apply Climate-Smart Agriculture practices (Teklu *et al*., 2022). Moreover, the convergence of CSA with comprehensive policy frameworks, climate adaption techniques, and socio-economic elements necessitates additional investigation to formulate context-specific, scalable, and inclusive solutions (Mabhaudhi *et al*., 2025). Addressing these challenges necessitates a multidisciplinary approach synthesizing agronomy, environmental science, economics, and social sciences ideas to formulate evidence-based policies for climate-resilient agriculture.

This research has considerable academic and practical importance. The authors' thorough literature assessment and research trend mapping offer significant insights into the conceptual evolution of CSA, establishing a basis for future inquiries. Furthermore, the results will guide policymakers, agricultural professionals, and development organizations in the successful large-scale implementation of CSA. Given the ongoing threats of climate change to agricultural productivity, comprehending the scientific dialogue and practical implementations of CSA is essential for securing a sustainable and resilient agrarian future.

Given the complexity and importance of CSA research, this study aims to give a comprehensive assessment of the intellectual landscape of CSA using bibliometric analysis and systematic literature review methodologies. By examining thirteen years' worth of scholarly publications that are indexed in Scopus, this study seeks to solve fundamental research issues.

RQ1: In what ways has CSA research progressed?
RQ2: What are the prevailing themes, developing trends, and research clusters in the literature on CSA?
RQ3: Which nations and scholars have significantly contributed to CSA research?
RQ4: What are the principal deficiencies in current research, and which domains need more exploration?

Objectives of the study

The primary aim is to do a bibliometric analysis and thorough literature evaluation of climate-friendly agriculture (CSA) research to comprehend its history, trends, and principal obstacles. The following particular objectives direct the research:

- To Analyze the Evolution and Trends in CSA Research.
- To Assess the Geographical Distribution and Institutional Contributions.
- To Identify the Emerging Research Clusters.
- To Highlight Key Research Gaps and Future Directions.

Systematic literature review

This systematic literature review integrates results of a bibliometric analysis of relevant research on climate-smart agriculture, climate change, and agricultural productivity. The purpose of this systematic review was to synthesize themes, methods, and findings, providing a comprehensive overview of the research in this area. Although these results are synthesized in this review, it identifies the trends, methods, and main conclusions of the process, as well as some limitations of the literature.

The review qualitatively highlights many significant issues. Numerous studies underscore the significance of good irrigation practices and different agricultural systems. Sharma *et al.* (2019) demonstrate that integrating diversified planting and precision irrigation has enhanced water consumption efficiency by over 25%, bolstering resilience under fluctuating rainfall conditions (Bhagat *et al.*, 2025). Gupta and Kumar (2022) demonstrate that integrating digital decision-support tools into agricultural systems has led to a 30% boost in crop yields, even in regions characterized by significant climatic unpredictability (Gupta *et al.*, 2022).

Another common subject is the transformative potential of digital technology. Patel *et al.* (2020) examined remote sensing and Geographic Information Systems (GIS) for monitoring soil moisture and crop health, revealing that these technologies might reduce input costs by 15% while concurrently enhancing output. Qualitative insights complementing this quantitative data indicate that farmers get significant satisfaction from technology-driven solutions, noting that the availability of real-time data substantially improves their decision-making process.

Furthermore, several studies (e.g., Reddy and Singh, 2017) have statistically linked CSA adoption to economic benefits. Their analysis indicates that households using CSA practices had a 20% increase in net income compared to those relying only on traditional farming methods. Chatterjee *et al.* (2021) assert that expanding CSA techniques relies on robust policy frameworks and targeted extension services, supporting economic enhancement, fostering rural development, and reducing poverty rates by 18% (Kassaye *et al.*, 2022).

The literature identifies areas for improvement. Mehta and Rao (2020) observe that whereas several studies focus on short-term benefits, longitudinal research examining the enduring impacts of CSA approaches is lacking. Moreover, gender-specific outcomes and the sociocultural determinants of CSA acceptability remain little examined; hence, future research should include these aspects to provide a more comprehensive understanding.

The thorough literature assessment underscores that CSA enhances agricultural productivity and rural development while addressing climate change. CSA research predominantly focuses on the incorporation of advanced technologies, enhanced resource management, and robust policy support, substantiated by compelling quantitative data demonstrating its economic and environmental advantages (Kassaye *et al.*, 2022). Future research should address the identified shortcomings via gender-focused and longitudinal studies.

Materials and Methods

This study adopts a mixed-methods approach that integrates Bibliometric Analysis with a Systematic Literature Review to examine the evolution, trends, and research gaps in CSA under the influence of climate change. Data were primarily sourced from the Scopus database, chosen for its comprehensive coverage and robust indexing of high-impact journals. The methodology encompasses four major components: data collection, bibliometric analysis, systematic literature review, and data visualization.

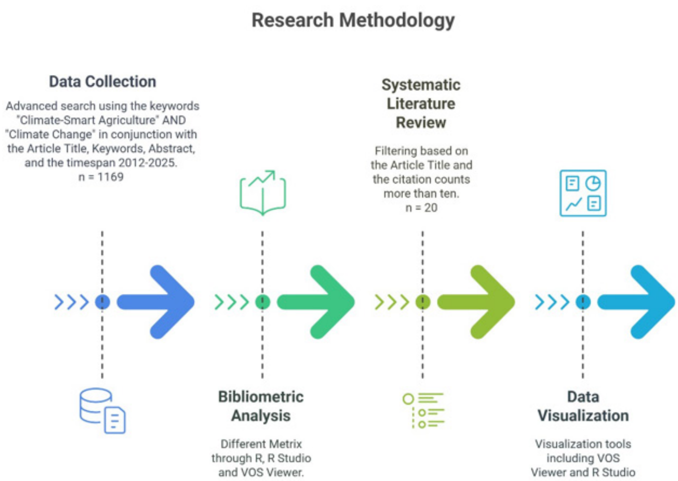

Figure 1: *Methodology of the CSA studies.*

Data collection

A well-crafted search technique was employed to obtain data from the Scopus database. On 17 December 2024, an initial dataset of 1,169 results was obtained by conducting an advanced search using the keywords *"Climate-Smart Agriculture"* and *"Climate Change"* in conjunction with the Article Title, Keywords, Abstract, and the timespan 2012-2025. The final list of 20 important articles was obtained by modifying the selection procedure to filter based on the Article Title and the citation counts (>10).

Bibliometric analysis

A bibliometric study was performed to statistically evaluate publication trends and research impact in the domain of CSA. Fundamental metrics, including the Main Information of the Data, Publication Trend Analysis, Most Relevant Sources and Authors, Top Countries and Manuscripts by Citation, Keyword Analysis, Three-Field Plot Analysis, Co-occurrence by Keywords, and Nation Collaboration Networks, were calculated using bibliometric programs like R, RStudio and VOS Viewer (Khanam *et al*., 2023; Mahedi *et al*., 2025b). This quantitative assessment delineated the progression of research in CSA while identifying the most prolific research clusters and geographical hotspots of activity. The bibliometric indicators functioned as a reliable metric of academic impact and offered insights into the discipline's conceptual development.

Systematic literature review

The final 20 articles were subject to a comprehensive full-text evaluation to ascertain their relevance, quality, and contribution to CSA research. The systematic literature review was designed to extract significant topics, methodologies, and conclusions, comprehensively examining current research. This method assisted in identifying gaps in previous research and establishing a connection between the bibliometric data and relevant insights.

Data visualization

Data visualization was vital for assessing both the bibliometric and qualitative results. Visualization tools, including VOS Viewer and R Studio, generated network maps depicting co-authorship, keyword co-occurrence, and citation trends (Kabir *et al*., 2025; Mahed *et al*., 2025a). Time-series graphs were created to depict publishing patterns and the development of significant research issues throughout time. These visual tools improved the interpretability of complicated information and offered clear graphical representations of the links among different study components. The visualizations substantially enhanced the narrative by concisely presenting and emphasizing the patterns and interrelations in CSA research.

Findings of the bibliometric analysis

Main information of the data

Table 1 summarizes the bibliometric properties of the dataset from 2012 to 2025. During this period, 499 sources (books, journals, and other academic outlets) produced 1,169 articles authored by 4,039 authors. According to the dataset, the selected years show a continuing increase in academic production with a growth rate of 7.3% per year. In our example, a 3.9-year document (average age) shows a moderate citation effect, which is also demonstrated by 22.76 citations. One hundred six corresponding authors are associated with 109 single-authored papers, an average of 4.54 co-authors per paper, indicating a high level of collaborative research. Over 44.57% of all articles have been co-authored with international scholars, thus, a relatively deep level of cross-border intellectual collaborative exchange. These and the preceding section are a summary of the resulting term-based metadata (2,548 Keywords Plus (ID) and 2,576 Author's Keywords (DE) in this dataset, 65,780 all-time terms, 49 total terms) that gives us a holistic view of the terms we need to pay attention to in this corpus. The 72,064 citations attest to the wealth of literature that has influenced and supported the work included in this collection.

Table 1: *Information summary on retrieved CSA studies (2012–2025).*

Description	**Results**
Timespan	2012:2025
Sources (Journals, Books, etc.)	499
Number of published articles	1169
Authors	4039
Annual growth rate %	7.3
Document average age	3.9
Average citations per doc	22.76
Authors of single-authored docs	105
Single-authored docs	109
Co-Authors per doc	4.54
International co-authorships %	44.57
Keywords plus (ID)	2548
Author's keywords (DE)	2576
References	72064

Publication trend analysis

Figure 2 depicts the yearly trend of publications in the field between 2012 and 2025. Four papers were published in 2012 and this had dropped to three by 2013. Starting in 2014 with 13 articles, then 17 in 2015, 40 in 2016, and 47 in 2017; 2018: 74; 2019: 91; 2020: 111. That is quite a jump up from 2018. Starting with 163 articles in 2021, 180 in 2022, and 199 in 2023, and continuing to grow, reaching a peak of 217 in 2024. Since the data you access goes only up to the end of October 2023, you have only disabled light in the interior of the 2025 grid. As can be seen from the following Figure 2, along with a consistent and significant increase in scientific productivity with time, there is also an obvious increase in the volume of research both quantitatively and qualitatively.

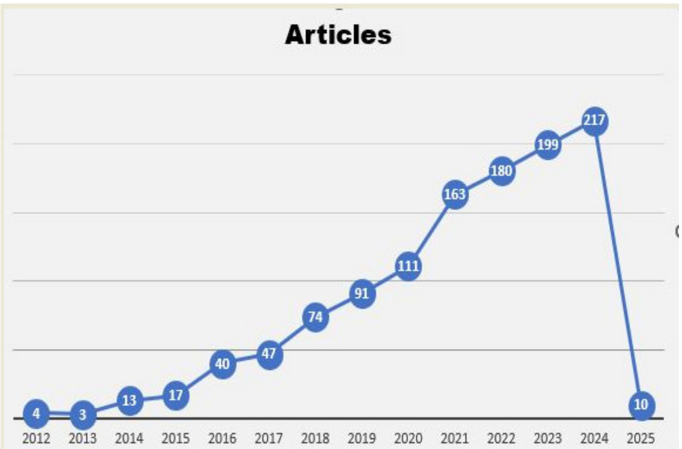

Figure 2: *Yearly scientific production of the CSA studies.*

Most relevant sources

It reflects CSA development as a research field and actualizes major platforms for CSA literature dissemination. The distribution of CSA articles in major academic journals is summarized in Figure 3. The data suggests that Sustainability (Switzerland) (54) and Frontiers in Sustainable Food Systems (52) are responsible for the most publications relating to CSAs, indicating the pivotal role these journals play in facilitating interdisciplinary discourse in sustainable agriculture. Behind these scientific leaders, Agricultural Systems detaches 32 articles, highlighting its orientation to agricultural systems resilience, Heliyon, and Mitigation and Adaptation Strategies for Global Change, with 19 articles and 17 articles corresponding to and illustrating that they deal more closely with climate adaptation and climate-smart technology. Journals like Climate Change Management (16 articles), Agriculture (Switzerland), Agronomy, and the Journal of Cleaner Production (13 articles each) also make this diversity of CSA-focused research perceptible across their domains, with publications touching on aspects ranging from agroecological practices to low-carbon production. Climate (12 articles) underlines the convergence between meteorological and agricultural sciences in dealing with climate challenges. These journals form essential centers for CSA scholarship, connecting policy, technology, and field experience and indicating the broad interdisciplinary breadth and increasing relevance of CSA in global sustainability conversations.

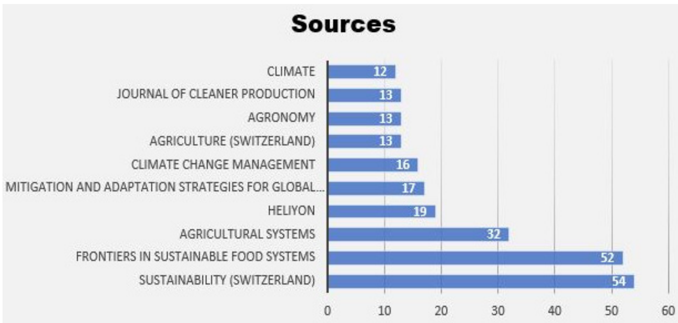

Figure 3: *Most relevant sources of CSA studies.*

Most relevant authors

Figure 4 details the top authors, reporting total articles, and fractional article counts (implying

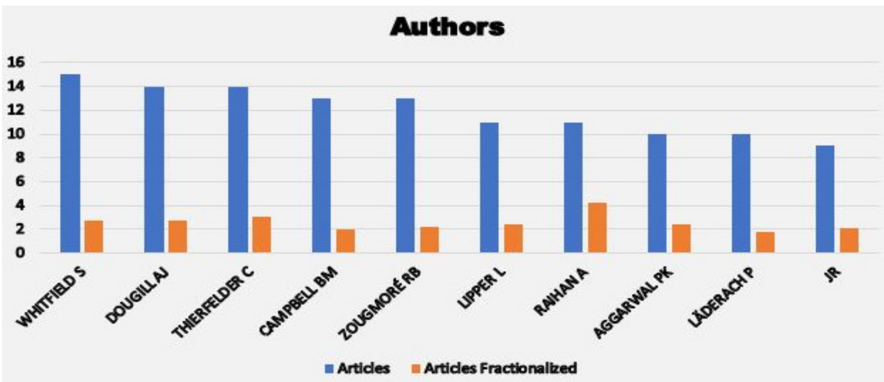

Figure 4: *Relevant authors and articles fractionalization*

dividing authorship credit proportionately). Whitfield S has the most publications, appearing 15 times, but has a fractionalized count of only 2.70, indicating no table collaborative input across the studies. Most notably, Dougill AJ and Thierfelder C tied for third place with 14 articles each; however, Thierfelder's higher fractionalized score (3.11 vs. 2.78) suggests he led to more individual contribution per publication. While Raihan A is a dominant position in authored articles (5.60) with 11 articles written, he has a very high fractionalized count (4.20), which indicates a very dominant role in authored works (i.e., he was the lead or sole author on all articles to their name). Research veterans Such as Zougmoré RB (13 articles, 2.23 fractionated) and Lipper L (11 articles, 2.43) exhibit a corresponding fair participation with unrepeated output. The data shed light on relative collaboration: authors (e.g., Campbell BM (13 articles, 2.00) and Laderach P (10 articles, 1.81)) practicing teamwork with others (e.g., a clear home) like Raihan's (leadership). Additionally, this table sheds light on not just productivity but authorship dynamics, indicative of how interrelationships and individual contributions bolster the dissemination of CSA knowledge.

Top countries and manuscripts by the citation

Table 2 delivers the world's distribution of citation impact for research in Climate-Smart Agriculture, indicating countries that made the most influential contributions and their highest-cited papers. The US has the most impactful single paper (Lipper *et al.* 2014) in Nature Climate Change, copyright policy gated 477 citations, demonstrating its fundamental place in CSA, 1,176. Despite being ranked second in terms of total citations (2,188), India shows incredible concentration, as evidenced by Raza *et al.* (2019) in Plants with 1,119 citations and a high normalized citation score (26.04), suggesting fast acceptance and relevance. The Netherlands ranks second with 1,556 total citations, with the highest averaging 83 TC per year (Mondejar *et al.*, 2021), highlighting more recent contributions and perhaps the urgent nature of these advances regarding sustainability, following China with 1,892 (Figure 1b). Therefore, Kenya and the UK stand out with influential literature, e.g. Campbell *et al.* (2014) and Long *et al.* (2016) for bridging policy and on-ground adaptation, respectively. In contrast, Japan and Australia are relatively concentrated, as characteristic of Khatri-Chhetri *et al.* (2017) and Jost *et al.* (2016), to mitigate systemic barriers to CSA adoption. The table shows differences between the number of papers and their impact. While the USA leads the rankings, countries like India and

Table 2: *Top ten most cited nations and top ten most cited published papers within the period 2012:2025*

Most cited nation			**Most cited paper**				
Country	TC	Average article citations	Paper	DOI	Total citations	TC per year	Normalized TC
USA	2746	35.7	Lipper l, 2014, nat clim change	10.1038/nclimate2437	1176	98.00	6.79
India	2188	17.6	Raza a, 2019, plants	10.3390/plants8020034	1119	159.86	26.04
China	1892	31.5	Malhi gs, 2021, sustainability	10.3390/su13031318	629	125.80	25.14
Netherlands	1556	42.1	Mondejar me, 2021, sci total environ	10.1016/j.scitotenv.2021.148539	415	83.00	16.59
Kenya	1487	27	Campbell BM, 2014, Curr opin environ sustainability	10.1016/j.cosust.2014.07.002	390	32.50	2.25
United Kingdom	1311	28.5	Long TB, 2016, J Clean prod	10.1016/j.jclepro.2015.06.044	339	33.90	6.60
Germany	876	30.2	Harvey ca, 2014, conserv lett	10.1111/conl.12066	261	21.75	1.51
ITALY	825	29.5	Bai x, 2019, global change biol	10.1111/gcb.14658	251	35.86	5.84
Japan	801	50.1	Khatri-chhetri a, 2017, agric syst	10.1016/j.agsy.2016.10.005	250	27.78	5.64
Australia	785	30.2	Jost c, 2016, clim dev	10.1080/17565529.2015.1050978	248	24.80	4.82

the Netherlands produce influential field-defining studies. Normalized citations add another layer of context to influence, accounting for publication age and disciplinary norms, underscoring how CSA's interdisciplinary ethos spurs diverse but globally linked scholarship.

Keyword analysis

Table 3 lists the most frequently cited climate-resilient terms in application with their respective number of publications. The term "*climate change*" has the most mentions (545), reflecting its prominence in CSA, followed by cornerstone concepts such as "*agriculture*" (176) and "*food security*" (138). Concepts associated with "*smart agriculture*" (98), "*adaptive management*" (96), and "*smallholder*" (90) all concepts likely to resonate with contemporary policy discourse about ICT (information and communications technology) innovations showcase CSA's concern with innovation, resilience, and inclusivity on behalf of vulnerable farming communities. The table shows strategic and systemic priorities in the first three areas, including crop production (61), agricultural technology (50), and greenhouse gases (44), all of which suggest CSA's dual role in increasing productivity and decreasing environmental negative impact. Significantly, "*climate effect*" is mentioned twice (in positions 11 and 20) and is the second and third most used word by occurrence (56 occurrences each), meaning either duplication or some theme confusion in climatic impacts. Terms such as "*sustainable development*" (49) and "*agricultural development*" (46) associate CSA with wider socioeconomic and policy objectives, while the mention of "article" (46) as a term possibly reflects methodological trends in meta-analyses. This ranking gives a clear overview of the interdisciplinary nature of CSA that goes beyond environmental science or agronomy (and socioeconomic) research but also highlights areas like gender or regional-specific strategies that might be under-represented.

Co-occurrence by keywords

The co-occurrence of keywords from Climate-Smart Agriculture research can be visualized as separate themes and priorities connected by multiple dimensions (nodes and linkages), as shown in (Figure 5). Central to the network is "*climate change*," connected to core CSA terms like "*climate-smart agriculture*," "*mitigation*," and "*adaptation*," which reflect the dual nature of this field around reducing emissions while creating adaptive capacity. The cluster, including sub-Saharan Africa and smallholder farmers, emphasizes the geographic and demographic dimensions of vulnerable agrarian communities in connection with crop yield, food security, and vulnerability, underlining the socio-economic stakes of CSA in climate-sensitive geographies.

A separate cluster of environmental strategies can be identified with space roughly 60% right of the center-point, which includes "*greenhouse gases*," "*carbon sequestration*," and "*agroforestry*," showing the role of the CSA in particularly balancing productivity and ecological sustainability. Concepts such as "*technology adoption*" and "*adaptive management*" link technical and practical elements that together tie to "*agricultural production*" and "*crop production*" and highlight increasing yields under climatic stress. Synergizing Development and Resilience. The interlinkages between "*sustainable agriculture*," "*sustainable development*," and "*resilience*" classify CSA as a multidimensional framework that integrates the innovations in the agricultural sector with the overarching socio-economic objectives.

Table 3: *Top twenty relevant keywords*

Rank	Terms	Occurrences	Rank	Terms	Occurrences
1	Climate change	545	11	Climate effect	56
2	Agriculture	176	12	Farming system	56
3	Food security	138	13	Agricultural production	54
4	Smart agriculture	98	14	Agricultural practice	52
5	Adaptive management	96	15	Agricultural technology	50
6	Smallholder	90	16	Sustainable development	49
7	Alternative agriculture	62	17	Agricultural development	46
8	Crop production	61	18	Article	46
9	Food supply	59	19	Greenhouse gases	44
10	Greenhouse gas	58	20	Climate effect	56

The network also notes gaps in explicit mentions of gender dynamics or policy frameworks, indicating where more can be done. Nevertheless, while this encompasses strategy and the inclusion of an "*agriculture and climate*" entry point, the non-linear nature of "climate-smart agriculture" as a connective hub linking a variety of disparate clusters from "*farming systems*" to "*agricultural practices*" demonstrates the integrated nature of it being a place to connect agronomy, environmental science, and others as a socio-economic research area. This visualization gives vent to CSA's interdisciplinary mission: to promote productivity, sustainability, and equity in global food systems in the face of global climate challenges.

Nation collaboration networks

Figure 6 portrays the collaboration results between countries conducting Climate-Smart Agriculture research and implementation in a web of nodes representing countries. She says that key nodes include the USA, Germany, Netherlands, and Australia, which are central nodes with many linkages to the developed and developing world. Collaborative clusters begin to sprout, including European nations (ex, Denmark, Switzerland, Italy) collaborating with countries in Africa (ex, Kenya, Mali, Ethiopia, Zambia) to face common mission challenges, such as climate resilience vs. agricultural innovation. India, China, and Japan make powerful partnerships with Southeast Asian nations like Vietnam, Indonesia, and Bangladesh, who see regional networking opportunities for technology transfer and adaptive farming techniques.

Among them are Canada and Malawi, South Africa, Zimbabwe, and Nigeria, with institutions from Europe focusing on North-South knowledge exchange and resource-sharing where there have been arguments for including global South countries in the global network, including Pakistan, Ghana, and Uganda in the network highlighting vulnerable agrarian economy countries within the global CSA discourse. Collaboration Density: The visualization shows asymmetries in collaboration density; industrialized nations tend to be bridges across regions, while smaller or less-resourced countries in the network (e.g., Zambia, Malawi) use multilateral ties to tap into deeper expertise.

This network highlights CSA's dependence on transnational cooperation in which cleantech initiatives, policies, and technologies must be developed across borders and scaled up through transnational networks. This connected structure illustrates how a complex global challenge, such as food security or emissions reduction, can be tackled in a decentralized but synergistic manner, combining localized innovation with an international support network.

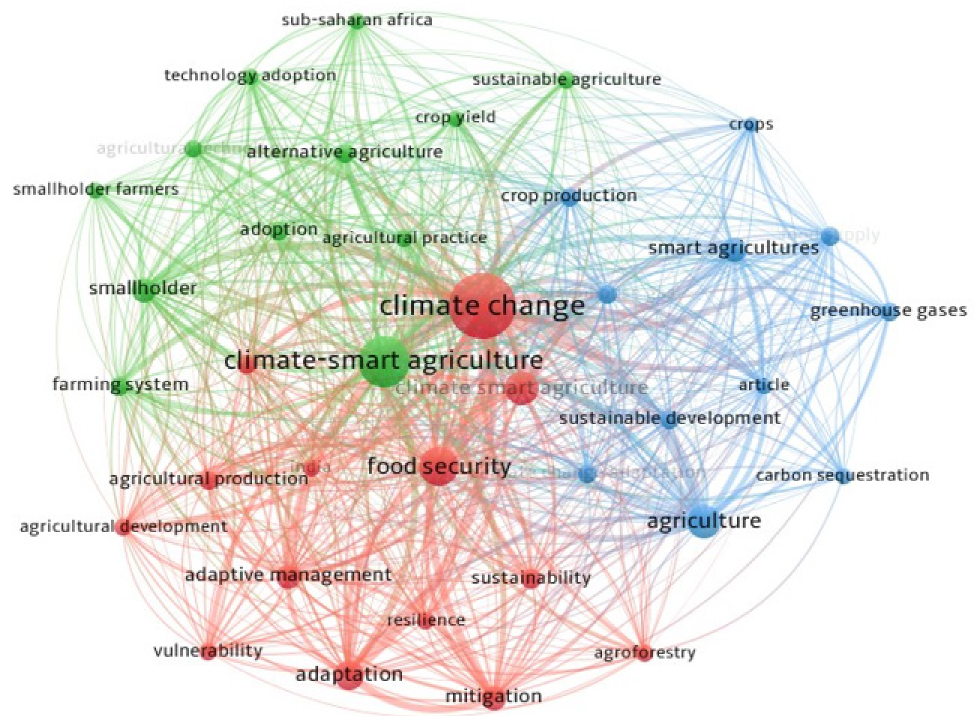

Figure 5: *Network visualization of co-occurrence of keywords*

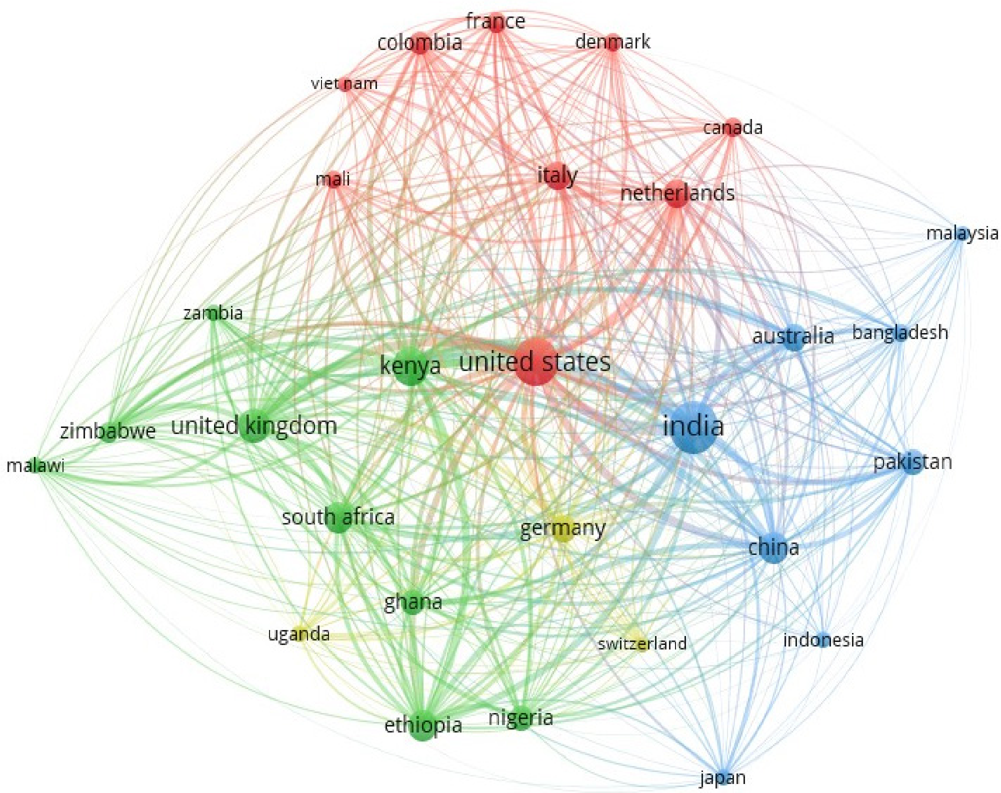

Figure 6: *Network visualization of nations collaboration networks*

Discussion

Research in CSA

The statistics of Climate-Smart Agriculture (CSA) and the systematic literature review revealed marked tendencies and findings that demonstrate the escalating interest of CSA in eliminating the threats climate change poses to agricultural production. Over time, the number of publications related to CSA research has shown a constant and homogeneous rise, demonstrating a 7.3% annual growth rate that indicates this field's expanding interest and urgency. The remarkable publishing growth, particularly post-2018, signifies the globally recognized need for climate-smart agricultural practices (Ghosh *et al*., 2024). Since the agricultural sector continues to face the double task of boosting food production and conserving the environment, CSA is offering an all-around framework that revolves around the improvement of agricultural productivity together with the adaptation to the negative effects of climate change. This is shown by the growing number of scholarly works and citations, which form the common knowledge in this cross-disciplinary area. One of the key characteristics of CSA research is collaboration, as cognitive by the higher rate of international co-authorships, where more than 44% of articles are published in two or more countries, demonstrates the strength. This reveals that climate is a global challenge, and researchers from developed and underdeveloped countries work closely together to devise and implement CSA strategies. Countries such as the United States, India, and the Netherlands have made substantial progress in the field of CSA, and in their studies, they have drawn a new direction for the discipline. The United States is the main country, the flagship in citation impact, such as Lipper *et al*. (2014), which has become a basic reference in the CSA literature. The thematic emphasis of CSA research touches on various themes such as agricultural productivity, food security, climate adaptation, and sustainable farming practices. Some of the main terms associated with CSA are "*climate change*," "*agriculture*," "*food security*," and "*smart agriculture*," which reflect the interdisciplinary character of CSA because it integrates agricultural science, environmental science, and socio-economic elements (Barasa *et al*., 2021).

Additionally, the analysis focuses more on solutions involving technology, such as agricultural technologies, greenhouse gas reduction, and carbon sequestration. These terms point out that CSA is not exclusively focused on climate adaptation but also targets lessening the environmental footprint of agricultural practices. However, the available literature shows a gap in the field, particularly in analyzing gender dynamics and region-specific interventions, which deserve more attention to be inclusive and tailored to the needs of the most vulnerable communities in regions like Sub-Saharan Africa and South Asia. As a result, the future of CSA research should concentrate on widening these elements and exploring global collaboration to achieve sustainability targets.

Dataset in CSA

The determinations from the bibliometric analysis and the systematic literature review supply useful insights into the state of research on Climate-Smart Agriculture (CSA) amidst climate change. The papers reviewed in this study address key issues, challenges, and strategies related to CSA adoption, with a focus on diverse geographical regions and the socio-economic context in which CSA practices are implemented.

One prominent finding is the role of socio-economic factors in CSA adoption. Studies such as Nyang'au *et al.* (2021) emphasize how household size, income disparities, and access to credit affect the adoption of CSA practices among smallholder farmers in Kenya. This finding resonates with broader studies like Mutengwa *et al.* (2023) and Abegunde *et al.* (2019), which emphasize the need for context-specific, bottom-up approaches in addressing barriers such as poverty, poor infrastructure, and lack of advisory services in regions like Southern Africa and Sub-Saharan Africa. These challenges underscore the importance of addressing socio-economic disparities, ensuring that CSA solutions are technologically viable and economically accessible to the most vulnerable populations.

The integration of CSA into sustainable livelihoods has been another central theme in the literature, as seen in studies by Das and Ansari (2021) and Mullins *et al.* (2018). These analyses stress the need for diverse interventions, including technological, institutional, and financial support, to ensure that CSA can drive long-term resilience and livelihood security. The concept of CSA enhancing resilience is further explored by Makate *et al.* (2018), which found that multiple CSA practices can lead to a 37% increase in productivity and income. This highlights CSA's potential to address climate risks and generate economic benefits, making it an attractive option for farmers in developing countries.

A significant challenge identified across multiple studies is the lack of sufficient dissemination of CSA information, especially among smallholder farmers. Waaswa *et al.* (2021) specifically point out the gender disparities in access to extension services, with women often excluded from crucial information and training. This finding calls for greater attention to gender-responsive approaches in CSA adoption, ensuring that women, often the backbone of agriculture in developing countries, are empowered with the knowledge and resources needed to implement CSA practices.

Furthermore, the analysis reveals that CSA's impact varies widely depending on the region, agricultural system, and the specific CSA practices employed. Studies like those by Zougmoré *et al.* (2016) and Khapung (2016) demonstrate how regional and gender-specific challenges must be addressed to scale CSA effectively. The need for integrated policies that consider the diversity of agricultural systems, such as those focused on crop, livestock, and fisheries, is evident in the findings of Zougmoré *et al.* (2021), who suggest that CSA can only be scaled successfully when these sector-specific needs are considered.

Finally, modeling and empirical studies, such as those by Brouziyne *et al.* (2018) and Zizinga *et al.* (2022), provide concrete evidence of CSA's effectiveness in mitigating climate risks and improving agricultural productivity. For instance, Zizinga *et al.* (2022) found that mulching can increase maize yields by 14–37% under future climate scenarios. These findings underscore the practical benefits of CSA techniques, offering actionable solutions for farmers facing increasing climatic uncertainties.

In conclusion, while there is a significant body of research on CSA, challenges remain in ensuring that CSA practices are effectively disseminated and adopted, particularly among vulnerable populations. More localized and gender-sensitive strategies are needed to overcome barriers to adoption and greater collaboration between institutions to create policies that support CSA at both the grassroots and policy levels. By continuing to explore these avenues, CSA can play a crucial role in enhancing agricultural resilience and productivity in the face of climate change.

Table 4: *Relevant Papers in CSA Studies*

Paper	Approach	Problem Definition	Challenges	Dataset	Result
(Nyang'au *et al.*, 2021)	Multi-stage sampling, surveys, FGDs, interviews	Assessing smallholder farmers' perception of climate change and CSA adoption in Kenya	Household size, income disparities, access to credit	196 farmers in Kisii County	Farmers' perceptions align with meteorological trends; adoption is linked to socio-economic factors.
(R. B. Zougmoré *et al.*, 2021)	Review of CGIAR and non-CGIAR projects	Transforming African food systems under climate change	Institutional gaps, technological adaptation	24 initiatives across Africa	Framework with action areas: reroute, de-risk, reduce, realign.
(Mutengwa *et al.*, 2023)	Literature review	Limited CSA adoption in Southern Africa	Poverty, poor infrastructure, lack of advisory services	Peer-reviewed studies	Bottom-up policies and gender-sensitive strategies are needed.
(Abegunde *et al.*, 2019)	Literature synthesis	Contextual suitability of CSA in SSA	Heterogeneity of smallholder environments, financing bottlenecks	Existing studies	Localized socio-economic analysis is critical for CSA success.
(Mullins *et al.*, 2018)	Empirical analysis	Role of information/ insurance in CSA adoption	Institutional interventions' effectiveness	Unspecified	Information and insurance drive behavioral changes in farmers.
(Das & Ansari, 2021)	Literature review	Integrating CSA into sustainable livelihoods	Diverse interventions required (technological, institutional)	Previous research	A framework linking CSA to livelihood resilience and mitigation.
(Brouziyne *et al.*, 2018)	SWAT model + climate projections	Water Resource Vulnerability in Morocco	Future rainfall decline, temperature rise	R'dom watershed data (2004–2009)	No-tillage and early sowing improve water productivity.
(Okolie *et al.*, 2022)	Bibliometric analysis	Fragmented CSA research trajectories	Research gaps in scalability and context	116 papers (2009–2022)	CSA enhances productivity; Africa shows 200% output gains.
(Lipper & Zilberman, 2018)	Historical policy analysis	Evolution and conceptual clarity of CSA	Varied interpretations of CSA	Policy documents	CSA integrates climate action into agricultural development.
(Rao & Patil, 2017)	Conceptual framework	Water Sustainability in CSA	Climate-driven water scarcity	Case studies	Framework for drip irrigation and agroecological zoning.
(R. Zougmoré *et al.*, 2016)	Sectoral review (crop, livestock, fisheries)	Climate impacts on West African agriculture	Regional variability in climate effects	Multiple studies	Integrated policies are needed for sector-specific CSA scaling.
(Waaswa *et al.*, 2021)	Surveys, statistical tests	CSA information dissemination gaps	Gender disparities in access to extension	Smallholder farmers in Kenya	Mainstreaming CSA info through media and extension is critical.
(Ho & Shimada, 2019)	Propensity score matching	Technical efficiency of CSA in rice farming	Adoption influenced by geographic/water access	352 farmers in Vietnam	CSA increases technical efficiency by 13–14%.
(Makate *et al.*, 2019)	Multinomial logistic regression	Enhancing resilience via multiple CSA adoptions	Regional/gender disparities in adoption	1172 farmers (Malawi/Zimbabwe)	Multiple CSA practices yield higher productivity (+37%) and income.
(Management Association, 2018)	Conceptual framework (updated)	Water management under climate change	Similar to the 2017 study	Case studies	Reiterated framework for water-efficient practices.
(Maka *et al.*, 2019)	Survey, descriptive stats	Role of extension in CSA adoption	Limited farmer training and market access	50 respondents (South Africa)	Regular extension visits and training improve CSA uptake.

(Zizinga *et al.*, 2022)	Aqua Crop modeling	Maize productivity under climate change	Future temperature/ rainfall variability	Field experiments (2019–2020)	Mulching (6 cm) increases yield by 14–37% under RCP8.5.
(Kakraliya *et al.*, 2021)	On-farm trials	GHG mitigation in rice-wheat systems	Conventional practices' inefficiency	Field data (2014–2017)	CSA reduces emissions by 33–40%; and improves eco-efficiency.
(Onyeneke *et al.*, 2021)	PCA, probit model	CSA uptake in Nigerian rice farming	High input costs, poor extension services	347 farmers	Farmers use diverse CSA strategies (e.g., improved seeds, diversification).
(Khapung, 2016)	Case study (BRACED project)	Gender disparities in CSA adoption	Male migration, women's workload	Project data (Nepal)	Women's empowerment through CSA reduces climate vulnerability.

Future research directions and research gaps in climate-smart agriculture (CSA) studies

Despite the notable progress recorded in Climate-Smart Agriculture (CSA) research, some critical research questions are left out and need further in-depth consideration. The most urgent areas for future research are the social-economic and gender targets of the CSA method. While studies have emphasized such factors as income, credit access, and infrastructure as key drivers in soil conservation agriculture uptake, still more detailed research is required that specifically focuses on how gender dynamics and power relations play out in the integration of CSA practices in developing countries. Gender-sensitive CSA interventions that ensure equal access to resources, training, and decision-making processes will be fundamental to the overall success of CSA (Boudalia *et al.*, 2024). The other missing piece of research is related to the scalability and adaptability of CSA practices in dissimilar geographical and climatic setups. While some research has looked at CSA practices in particular areas, for example, in Sub-Saharan Africa and South Asia, there is no extensive or comprehensive research on how CSA practices can be scaled up and adjusted to local circumstances. Future research should center on building versatile models that can be customized to fit diverse regional and agricultural settings, considering the social, political, cultural, and environmental circumstances (Becerra-Encinales *et al.*, 2024). This will require more field-based research and integrated models that consider the effect of regional weather and climate the integration of technological innovations in CSA practices also demands more investigation. In as much as CSA emphasizes the use of high-end technologies like the cultivation of drought-resistant crops, agroecological techniques, and precision farming that are not performed at the level of small and commercial growers, the research is limited to how those technologies may be integrated into the existing models, including those of smallholder farmers. Future analysis should be concentrated on investigating the adoption and impact of specific CSA technologies and on the critical issues of overcoming institutional and infrastructural issues for the broad use of the technologies.

Likewise, research will deal with digital platforms, mobile technology, and the massive use of big data to make production more effective and monitor progress. Besides, the role of policies in supporting CSA adoption needs deeper exploration. Although some studies have dealt with policy frameworks, the research on synchronizing local, national, and international policies to allow the CSA on a large scale is still insufficient. Future research should focus on evaluating the current policies promoting the CSA while identifying the obstacles in policy implementation and proposing solutions to overcome them. Moreover, there is a need for more studies that investigate the economic viability of CSA practices, including the cost-benefit analyses and issues related to financing mechanisms that could support smallholder farmers in the adoption of climate-smart strategies. Finally, there is a requirement for more interdisciplinary research that intersects agricultural sciences with climate science, economics, and social sciences. As an inherently interdisciplinary field, CSA will require future research to implement a system-thinking approach incorporating these disciplines to understand better the complex interactions among climate, agriculture, and socioeconomic factors (Tepa-Yotto *et al.*, 2024). Bridging these research divides, future studies will additionally move the arena of CSA ahead and provide practical solutions for better agricultural production despite climatic changes.

Conclusions and Recommendations

The study gives a broad bibliometric analysis and systematic literature review of Climate-Smart Agriculture (CSA) within the context of climate change, demonstrating the evolving value and complexity of CSA in increasing agriculture while at the same time decreasing the effects of climate change. The results back up CSA's capacity to address climate crises by combining sustainable agriculture technologies, technological innovations, and stable policy frameworks. CSA research has been on a consistent growth pattern for the last ten years, showcasing its essentiality in the global process that aims to afford sustainability over agriculture. CSA posts were ever on the rise, but after reaching 2018, their numbers shot up dramatically, showing the planet's approach to food production and misuse of resources over time. It underscored CSA as a key factor in food production and climate resilience. The study also reflects strong collaborative endeavors among countries and institutions, where more than 44% of the publications are co-authored internationally. This trend identifies the importance of common actions that may be taken in any part of the world for mutual learning and the raising need-border cooperation in both the development and the bringing to the ma of CSA solutions market of CSA sending countries like the U.S., India, and the Netherlands have actively participated in the studies on CSA, enhancing both the theoretical and practice of CSA. The CSA research closer to the core areas is represented by larger–scale agricultural productivity, food security, climate adaptation, sustainable farming practices, technological innovation, precision agriculture, and agroecological techniques.

Nevertheless, despite the intended directions, several important research issues remain open for improvement and further investigation. The social and gender dimensions of CSA adoption are an area that still requires complete exploration, particularly in developing countries. Gender-specific perspectives and regional (local) Contexts are imperative in CSA practices to be gauged to be inclusive and equitable to 'handicap' in society. Furthermore, CSA interventions need to be tested and adapted towards scale and context specificity in different agroclimatic and geographical contexts. This paper also contributes to the understanding of the efficiency of resource use, the secular volatility of resource use, and the emergence of markets and health service provision to people living in poverty.

In addition, given the introduction of new technologies into the CSA pathways, there was more discussion around smallholder farming systems and the economic implications of policies that underpin CSA. Overall, while CSA may provide a bright spot in agricultural sustainability in the presence of climate change, it still requires additional research, including interdisciplinary studies related to agriculture, climate science, economics, and social sciences. The contentment of the practical and intellectual wants of the country people is a factor for most social and economic diseases.

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Novelty Statement

This paper provides a unique and comprehensive per-spective of the Climate-Smart Agriculture literature by combining a quantitative bibliometric analysis to map its research evolution with a qualitative system-atic literature review on evidence synthesis for an-choring agricultural production.

Author's Contribution

Shabrin Jahan Shaili: Conceptualization, methodology, data curation, formal analysis, visualization, writing – original draft.
Md Mahedi: Formal analysis, validation, investigation, writing – review & editing.
A.K.M. Kanak Pervez: Conceptualization, methodology, supervision, project administration, writing – review & editing.

Generative AI or AI assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors declare no conflict of interest.

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