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Bibliometric Study of Adaptive Rice (*Oryza Sativa*) Varieties and Adaptation Strategies Towards Extreme Climate

Mukhlis[1*], Darmadi Erwin Harahap[1], Muhammad Darwis[2], Nikmah Sari Hasibuan[3], Nanda[3]

[1] Agrotechnology Study Program, Faculty of Science and Technology, Universitas Muhammadiyah, Tapanuli Selatan, Indonesia.
[2] Biology Education Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah, Tapanuli Selatan, Indonesia.
[3] Indonesian Language Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Tapanuli Selatan, Indonesia.

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Corresponding Author:
Mukhlis Mukhlis
mukhlis@um-tapsel.ac.id

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Abstract: Extreme climate change poses a serious threat to global food security, particularly for rice, which is widely cultivated in tropical regions. Research on adaptive rice varieties and adaptation strategies is becoming increasingly important in responding to this challenge. This study aims to map developments, thematic trends, key actors, and collaborations in research on adaptive rice varieties to climate change, using a bibliometric approach. Data were obtained from the Scopus database for the period 2015–2025 using keywords related to "rice" and "climate adaptation/resilience." The analysis was conducted using VOSviewer software for three main types of analysis: co-authorship, co-occurrence of keywords, and citation analysis. It was found that publications in this field continue to increase, with the largest contributions coming from China, India, and the United States. Dominant topics include climate-smart agriculture, genetic regulation, and biodiversity. The most prolific authors are Jat M.L., Hasegawa T., and Pan G. Citation analysis indicates a limited amount of highly influential literature, while collaboration networks between countries remain fragmented. The results of this study provide a comprehensive overview of the scientific landscape of adaptive rice research and climate strategies. These findings can be used to strengthen global collaboration, guide future research agendas, and support sustainable agricultural adaptation policies.

Keywords: Adaptive rice varieties; Bibliometric analysis; Climate change adaptation

Introduction

Rice (*Oryza sativa*) is one of the world's major food crops, playing a vital role in ensuring global food security, particularly in Asia, the main production and consumption hub. As a staple calorie source for more than 3.5 billion people, rice not only contributes to the nutritional needs of the population but is also an important economic commodity for developing countries. With global population growth projected to reach 9.70 billion by 2050, demand for rice-based foods is predicted to increase dramatically (Rezvi et al., 2023). Therefore, ensuring the stability and sustainability of rice production is a strategic priority in national and international food policies. However, significant challenges arise as the pressures of climate change impact the entire agricultural production system. Extreme climate phenomena such as rising temperatures, shifting rainfall patterns, prolonged droughts, and intensifying storms have created new uncertainties in rice production (Chen, 2006; Zhao et al., 2022). Satellite data and climate models indicate that tropical regions, where rice is most widely cultivated, are highly vulnerable to a 1.5 to 2°C increase in global average temperature, which risks yield reductions of up to 10% per degree Celsius (Ren et al., 2023). Climate change not only impacts agronomic dimensions but also triggers physiological disturbances in rice plants. Increased air temperatures above the tolerance

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threshold for rice, particularly during the flowering and grain formation phases, lead to decreased pollen viability and grain filling failure (Lu, 2024; Radha et al., 2023). Furthermore, erratic rainfall variations impact irrigation water availability and increase vulnerability to drought or waterlogging, both conditions that significantly impact plant growth. In a global meta-analysis Habib-ur-Rahman et al. (2022) showed that extreme climate fluctuations have led to higher yield variability in Southeast Asia, Sub-Saharan Africa, and parts of South Asia. This poses a serious challenge to achieving Sustainable Development Goal (SDG) 2, namely ending hunger and ensuring food security. Theoretically, this issue can be analyzed through the perspective of Food System Resilience Theory Huang et al. (2025), which emphasizes the importance of food systems adapting to global ecosystem disruptions. Food system resilience depends not only on the availability of agricultural technology or inputs, but also on the system's ability to structurally transform in response to the pressures of climate change.

In facing the increasingly complex challenges of climate change, developing rice varieties that adapt to extreme environmental conditions is a key strategy for maintaining production stability and ensuring the sustainability of the global food system (Dar et al., 2021; Saud et al., 2022). Plant adaptation to environmental stresses such as drought, high temperatures, salinity, and excess or lack of water is part of a growing biotechnology- and agronomy-based mitigation strategy (Muhammad et al., 2024). Rice varieties tolerant to abiotic stress are now a major focus in modern breeding programs, both through conventional methods based on phenotypic selection and through biotechnological approaches such as marker-assisted selection (MAS) and genome editing (Usman et al., 2023). The discovery of genes controlling stress tolerance, such as DREB, Sub1A, and qDTY, has been a significant milestone in developing superior rice varieties capable of surviving extreme climate stress (Mthiyane et al., 2024). The successful development of these adaptive varieties is certainly inseparable from advances in genomics and the integration of big data technology in plant genetics research.

However, developing adaptive varieties alone is insufficient without the implementation of systemic and contextual adaptation strategies at the field level. In this context, the climate-smart agriculture (CSA) approach is highly relevant, as it focuses not only on increasing productivity but also on enhancing climate resilience and reducing greenhouse gas emissions (FAO, 2020). Widely implemented CSA strategies include adjusting planting calendars according to seasonal weather forecasts, using drip irrigation systems or water-saving alternatives, and increasing farmers' capacity to read climate signals through information technology (Kabato et al., 2025; Obi & Maya, 2021). Adjusting planting times is crucial to avoid critical phases of crop growth coinciding with peak climate stressors, such as drought or extreme rainfall. Furthermore, efficient water management, such as alternate wetting and drying (AWD) techniques, has been shown to save up to 30% of water without reducing yields and contribute to reducing methane emissions (Haque et al., 2021).

Although various adaptation efforts have been undertaken through both technological and policy approaches, a comprehensive understanding of the dynamics and direction of global research developments in the field of adaptive rice varieties and adaptation strategies to extreme climate change remains limited. This is due to the scattered nature of research across various disciplines, such as agronomy, biotechnology, agricultural ecology, and environmental science, which often develop in parallel and are not systematically linked (Heijden & Jeroen, 2024). In this context, a bibliometric approach is crucial because it can bridge information gaps and provide a visual mapping of the scientific knowledge landscape. Bibliometric analysis is useful not only for calculating scientific productivity but also for identifying patterns of collaboration between researchers, inter-topic relationships (co-occurrence), and the impact of key publications in shaping the direction of development in a scientific field (Donthu et al., 2021).

This literature gap represents a significant gap in understanding the position of rice adaptation research amidst the evolving climate crisis. According to Lin et al. (2024); Zhang et al. (2024), the theory of knowledge domain visualization mapping the structure and dynamics of scientific knowledge allows researchers to identify mature research areas, emerging areas, and areas that are likely to stagnate. This theory assumes that the development of a scientific domain can be mapped and monitored through citation patterns, keyword frequency, and relationships between authors within scientific networks. Thus, through a bibliometric approach, this study seeks not only to capture the current state of knowledge but also to draw attention to the need for more integrative and transdisciplinary research exploration in the future. Identifying these knowledge gaps serves as a first step toward initiating more synergistic international collaborations based on real-world challenges, particularly in regions most vulnerable to the impacts of climate change. The novelty of this study lies in its bibliometric focus, which specifically examines two important dimensions simultaneously: the development of adaptive rice

varieties and adaptation strategies to extreme climate change, in a single, integrated study.

Until now, bibliometric studies in agriculture have tended to be limited to aspects of rice production in general or to climate change separately. Few studies have explored in depth the link between varietal innovation and ecosystem-based adaptation approaches and technology within a single scientific framework. By limiting the study period to 2015 and 2025, this research provides a current and relevant snapshot of the evolution of scientific discourse over the past decade, while also capturing the latest dynamics related to mitigation and adaptation strategies in the agricultural sector. This is significant considering that the past decade has been a crucial period when climate pressures have become increasingly apparent and many science-based adaptation policies have begun to be developed in various countries, both through National Adaptation Plans (NAPs) and international platforms such as the Global Framework on Climate Services (GFCS).

Method

This study uses a bibliometric approach to analyze scientific developments related to adaptive rice varieties *(Oryza sativa)* and adaptation strategies to extreme climate change. This bibliometric study was chosen because it provides a comprehensive overview of publication trends, scientific collaborations, and the dynamics of emerging topics within a research field. Bibliometric data was obtained from the Scopus database, one of the largest and most reputable scientific databases, encompassing relevant, internationally indexed journals across disciplines. Scopus was selected for its broad multidisciplinary coverage and comprehensive metadata, which supports bibliometric visualization.

The data retrieval strategy involved designing specific search queries that combined key keywords according to the research focus. Keywords used included: "rice" AND "climate change," "rice variety" AND "climate adaptation," and "Oryza sativa" AND "climate resilience." The search was limited to the period 2015 to 2025 to capture scientific developments over the past decade that reflect the latest dynamics in climate change and agricultural innovation. Additionally, additional filters were applied to ensure only journal article document types were included, excluding irrelevant proceedings, editorials, or book chapter reviews. The initial search results were then sorted and exported in CSV format for further analysis.

Data analysis was conducted using VOSviewer software, specifically designed to map the structure and dynamics of scientific literature. VOSviewer was used to perform three main types of analysis: co-authorship analysis to map collaboration networks between authors or institutions; co-occurrence analysis to identify relationships between keywords and concepts that frequently appear together; and citation analysis to assess the most influential articles or authors based on the number of citations. The results were visualized in the form of network visualizations, density visualizations, and overlay visualizations, depending on interpretation needs.

Before analyzing the data using VOSviewer, a data cleaning process was performed. This process included checking for duplications, standardizing author and institutional names (e.g., merging different name variants of the same entity), and verifying the accuracy of metadata such as publication year and keywords. The cleaned data was then imported into VOSviewer, and iterative analysis was performed to identify the most dominant topic clusters, the most active research actors, and potential research gaps. The results of this analysis were used to construct a knowledge map and summarize the direction and scientific contributions of research related to rice varieties and climate change adaptation.

Results and Discussion

Annual Publication Distribution (Research Trends)

The trend in scientific publications on rice varieties *(Oryza sativa)* and adaptation strategies to extreme climate change showed a significant increase from 2015 to 2025. Based on data obtained from the Scopus database, a total of 2,258 documents relevant to the topic were found. The distribution of publications fluctuated at the beginning of the period, with relatively stable figures between 2015 and 2018 (ranging from 105–122 documents). However, starting in 2019, there was a consistent surge in the number of publications, peaking in 2024 with 367 documents and decreasing slightly to 261 documents in 2025. This increase reflects the growing attention of the global scientific community to the crucial issues of food security and climate change, particularly following the COVID-19 pandemic, which has reinforced the urgency of developing resilient food systems. This upward trend can be more clearly seen in Figure 1, which displays the distribution of the number of publications per year over the past decade.

This increase in publications also reflects a shift in research priorities from simply increasing agricultural productivity to more adaptive and sustainable approaches. A previous study by Holzkämper (2017); Velten et al. (2015), showed that the integration of climate adaptation approaches and agricultural production systems began to receive attention in the

mid-2010s, in line with the adoption of the Sustainable Development Goals (SDGs). This aligns with findings by (Aryal et al., 2020; Mudzielwana, 2025), who stated that in the context of South and Southeast Asia, major rice-producing regions, research on stress-tolerant varieties, adaptive cultivation systems, and evidence-based policy planning accelerated after 2018. Globally, several policy momentums, such as the launch of the Global Commission on Adaptation (GCA) in 2019 and increased support for Climate-Smart Agriculture (CSA), also drove the surge in publications. Furthermore, the growing number of open-access initiatives and international collaborations in the field of food security have improved the accessibility and dissemination of scientific knowledge (Agunyai & Ojakorotu, 2024; Altieri & Nicholls, 2020; Smyth et al., 2021). Based on this trend, it can be concluded that the last decade has been a period of significant transformation for rice research in the context of climate change. If this trend continues, future research is predicted to increasingly explore topics that combine genetic innovation, socio-ecological adaptation, and big data-driven approaches (big data agriculture) to support resilient and inclusive food systems.

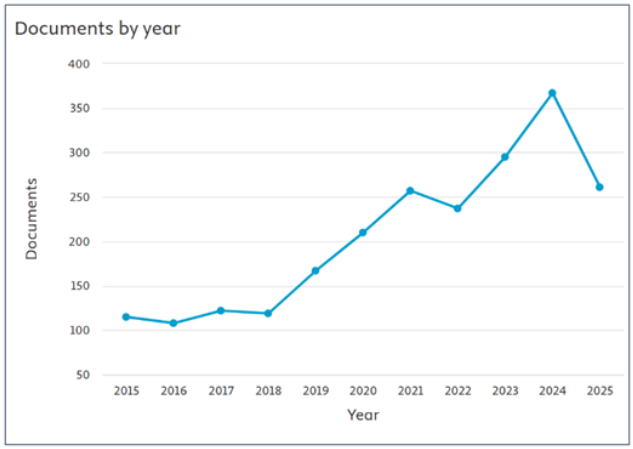

Figure 1. Distribution of the number of publications on rice varieties and extreme climate adaptation between 2015 and 2025, based on the Scopus database.

Analysis of the Most Productive Countries or Institutions

Global research contributions to rice varieties and adaptation strategies to extreme climate change demonstrate the dominance of certain countries with high research capacity and a focus on adaptation-oriented agricultural policies. Based on data search results from Scopus between 2015 and 2025, China was recorded as the country with the highest number of publications, with 695 documents. This was followed by India (402 documents), the United States (318 documents), Japan (199 documents), and Australia (174 documents). Other countries in the Asian region such as South Korea, the Philippines, Bangladesh, and Vietnam also showed significant involvement in this research, although on a smaller scale.

This trend indicates that Asia, as the center of global rice production and consumption, is a region with high research interest in rice variety adaptation issues. The dominance of China and India reflects their strategic positions within the food security and sustainable agricultural development agenda. China, for example, has invested heavily in plant genetics research and precision agriculture-based climate adaptation technologies (Y. Liu et al., 2020). India is also active in building cross-institutional research partnerships through institutions such as the Indian Agricultural Research Institute (IARI) and the International Rice Research Institute (IRRI), which contribute to research in South Asia (Lopez-Ridaura et al., 2021). This cross-border contribution can be more clearly seen in Figure 2 below, which shows the distribution of publications by author country of origin and affiliation.

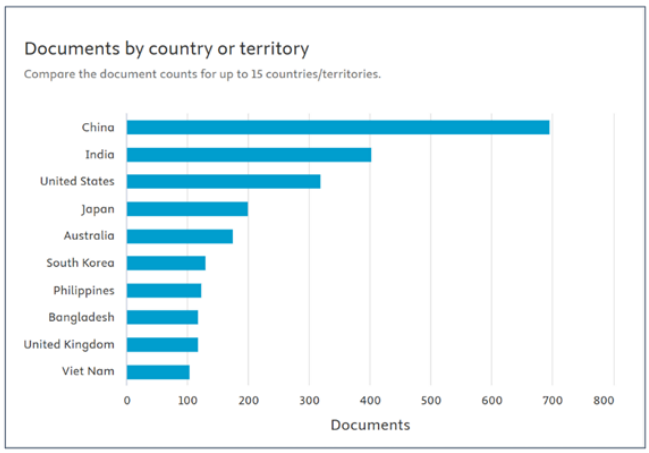

Figure 2. Number of publications related to rice varieties and extreme climate adaptation based on author country of origin (Scopus, 2015–2025)

The dominance of developed countries such as the United States and Japan in the number of publications also demonstrates the importance of cross-regional scientific collaboration. A study by Li et al. (2024), noted that countries with extensive international collaboration networks tend to produce articles with higher citation impact. In this context, the role of global research institutions such as IRRI, CGIAR, and various leading universities plays a crucial role in shaping an adaptive and inclusive knowledge ecosystem. This finding also aligns with the global knowledge production approach, which emphasizes the importance of cross-national connectivity in addressing the transnational nature of the climate crisis (Carter et al., 2021).

Most Prolific Authors and Publication Sources

In bibliometric research, identifying the most productive actors (authors) and publication channels (journals) is a crucial step in understanding the dynamics of knowledge production in a field. The analysis shows that M.L. Jat holds the top position as the most prolific author with 25 publications in the period 2015–2025. Followed by T. Hasegawa and G. Pan, each with 20 publications. These three authors are widely recognized for their contributions to agricultural adaptation research to climate change, particularly through agronomic and rice genetics approaches. Their research consistently explores various aspects of crop resilience to climate stress, water use efficiency, and technology- and policy-based mitigation strategies (Attia et al., 2025; Koide et al., 2021).

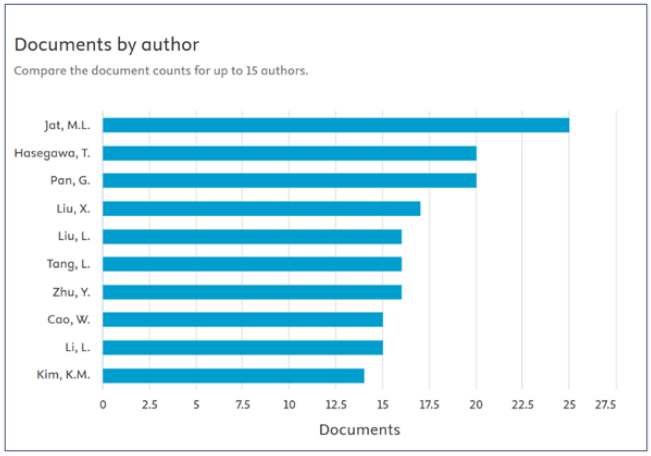

Figure 3. Presents a visualization of the publication distribution of the top 10 authors in this field, with a strong dominance by researchers from East and South Asia

In terms of publication channels, the journal Agronomy emerged as the most productive source with a total of 102 publications, followed by Field Crops Research (78 publications), and Frontiers in Plant Science (70 publications). These journals have a strong focus on innovation in sustainable agricultural systems, plant breeding, and plant responses to environmental stress. Figure 4 shows the fluctuation in the number of publications from the top five journals per year since 2015. This trend shows a sharp spike, especially since 2020, which is likely related to the increased urgency of research on climate change and global food systems in the wake of the COVID-19 pandemic, as also noted in the FAO (2021) report. The trend in scientific journal contributions during the observation period can be further explored in Figure 4.

The emergence of the journals Agricultural Water Management and Agricultural and Forest Meteorology as primary sources also indicates a trend toward an interdisciplinary approach, encompassing not only agronomy and genetics but also aspects of hydrology, climate, and land management. This reinforces the findings of Ojo et al. (2025); Terán-Samaniego et al. (2025), who emphasized the importance of cross-disciplinary collaboration in building climate resilience in the agricultural sector (Benitez-Alfonso et al., 2023; Klein, 2020). This combination of productive actors and channels reflects a fairly structured knowledge configuration in the field of rice research and climate adaptation. The publication pattern, which focuses on specific authors and journals, also indicates the existence of a "core-periphery structure" or core of the scientific community, as explained in the classic bibliometric theory of Price's Law Avin et al. (2018); Dhar (2025). This structure is important to understand because it can serve as an entry point for building collaborative research networks and expanding access to cutting-edge research for countries with developing research capacity.

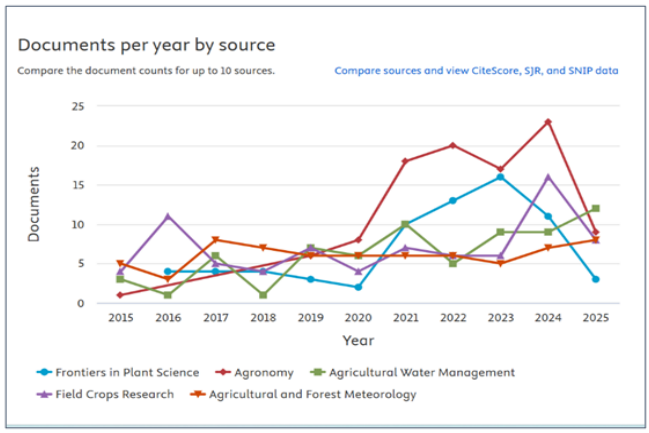

Figure 4. Distribution of the number of publications per year based on the top five most productive journals on the same research topic (Source: Scopus, 2025).

Visualizing Collaboration, Dominant Topics, and Citation Influence in Rice and Climate Adaptation Research

Bibliometric analysis aims not only to quantitatively identify publication trends but also to explore scientific structure through collaboration networks, conceptual linkages, and the influence of authors or scientific papers. This study used three main visual approaches using VOSviewer software: co-authorship analysis, co-occurrence analysis, and citation analysis. First, co-authorship analysis provides an overview of the collaborative structure among authors in rice and climate change research. As shown in Figure 4, two large clusters of collaborations with strong ties are identified, particularly between authors such as (Ruan et al., 2023). These authors form an interconnected cooperative network, reflecting multidisciplinary collaboration in plant genetics, rice physiology, and climate adaptation research. Research by Vărzaru &

Bocean (2024) confirms the increasing importance of international collaboration to accelerate adaptive variety innovation through a cross-country systemic approach.

Second, keyword co-occurrence analysis reveals the research themes that most frequently co-occur in scientific documents. In Figure 5, the keyword "rice" serves as the main node connecting several topic clusters. The red cluster points to genetics and breeding research, such as "genotype," "blup," and "fertility restoration." The blue cluster indicates links to climate change issues, such as "climate-smart agriculture" and "photoperiod." The green cluster relates to wetland sustainability and biodiversity issues, such as "wetlands" and "biodiversity." These findings align with a study by Fernando et al. (2025; Ismail et al. (2025), which found that climate-smart rice cultivation and varietal genetics remain mainstream topics in global research related to rice adaptation to climate change.

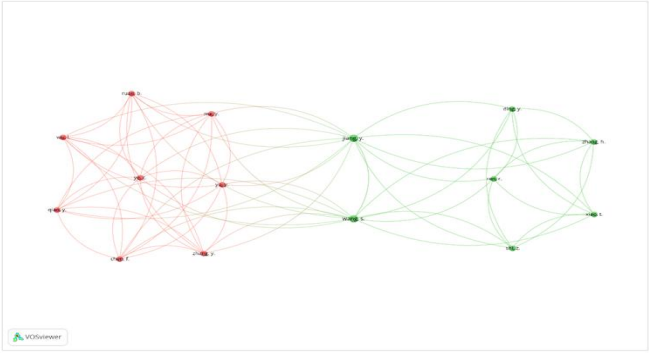

Figure 5. Co-Authorship Network Visualization

Third, a citation analysis was conducted to identify authors or research groups with significant influence in the field based on the number of citations they received. The density map visualization in Figure 7 shows that Dlamini et al. (2025), are the authors with the greatest influence. They are located in the brightest areas, indicating a very high citation frequency. These results support the theory that scientific influence is not always determined by productivity, but by how widely a work is cited and used as a primary reference (Krauss, 2024).

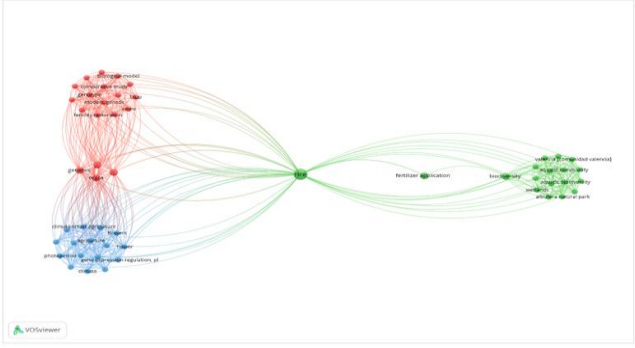

Figure 6. Visualization of Keyword Co-Occurrence

These three visualizations complement each other. The collaboration network (Figure 5) explains how key actors are connected within the scientific community. Emerging research topics (Figure 6) indicate the direction of knowledge advancement. Meanwhile, citation influence (Figure 7) indicates who the thought leaders are in the field. This approach aligns with the knowledge domain visualization approach (Kishore et al., 2025), which states that scientific dynamics can be mapped through the analysis of relationships between actors and concepts.

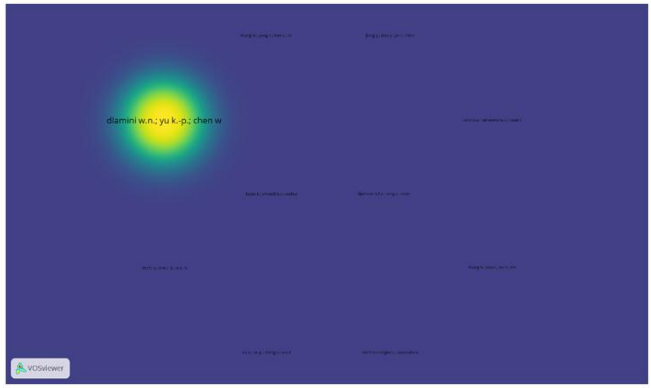

Figure 7. Citation Density Visualization (Citation Analysis)

Map of International Collaboration in Climate Change-Adaptive Rice Varieties Research

International collaboration is a crucial element in accelerating the development of agricultural innovations adaptive to climate change. In the context of adaptive rice variety research, cross-national collaboration enables the exchange of knowledge, genetic resources, and the implementation of more contextual and effective adaptation strategies across various agroecological regions (Fu et al., 2022; Zenda & Rudolph, 2024). Visualizing international collaboration in scientific publications can provide insight into the intensity and distribution of global networks in this field. Figure 8 shows a visualization of co-authorship between countries involved in scientific publications related to rice variety and climate adaptation during the 2015–2025 period, based on data from Scopus. This visualization was created using VOSviewer software, using the "countries" unit of analysis and the "full counting" method.

In thE visualization Figure 8, nodes represent individual countries, while connecting lines indicate collaboration or co-publication between researchers from two different countries. The size of the node reflects the number of documents originating from that country, while the thickness of the line indicates the strength of the collaboration (number of co-publications). Colors represent collaborative clusters based on the frequency of collaboration. The analysis

shows that Australia, China, and the United States are central countries in the collaboration network. Australia acts as a link between two large clusters of collaborations: developed countries (such as the United States and China) and developing countries such as Kenya and Tanzania. This emphasizes Australia's role as a knowledge bridge in global agricultural projects, including the development of climate-resilient rice varieties. This finding is consistent with a study by (Liu & Paan, 2024; Ziervogel et al., 2022), which emphasized the importance of developed countries in supporting climate adaptation in developing countries through research partnerships and local capacity building.

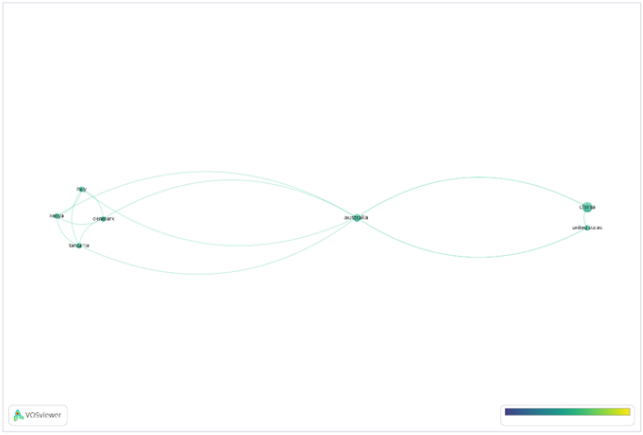

Figure 8. Map of Collaboration Between Countries in Research on Rice Varieties Adaptive to Climate Change

Furthermore, the involvement of African countries such as Kenya and Tanzania in this collaboration network indicates a growing focus on food security in regions vulnerable to climate change. This visualization also shows that there is still significant potential for expanding international collaboration, particularly from Southeast Asian countries such as Indonesia, Vietnam, and Thailand, which have not yet significantly emerged in this network. This region is a global rice production hub and highly vulnerable to the impacts of extreme climate change (Eriksen, 2009; Mensah et al., 2025). Thus, this mapping of international collaboration not only provides information on the key actors in adaptive rice research but can also serve as a basis for designing more inclusive and targeted collaborative strategies for developing resilient food systems.

Conclusion

This bibliometric study maps global research trends on adaptive rice and climate change strategies (2015–2025). Research shows significant growth, with China, India, and the US as key contributors. Dominant themes include climate-smart agriculture, genetics, and biodiversity. Despite this strong growth, international collaboration (especially across regions) remains limited and uneven, and most publications have low citation impact. In conclusion, there is a strong urgency to build a more inclusive global research network to address the threat of the climate crisis to food security.

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Author Contributions
Conceptualization; M. M. methodology. D. E. P; validation; M. D., formal analysis; N. S. H.; investigation; resources; N. N; data curation: M. M; writing—original draft preparation; M. M writing—review and editing. D. E. P; visualization: N. S. H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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