

FOOD SECURITY AND PADDY FARMING: SCIENCE MAPPING OF PRESENT AND FUTURE TRENDS

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Abstract: *As global population growth and climate variability intensify, ensuring sustainable paddy production is central to global food security. However, research across agronomy, water governance, environmental science, and plant genetics remains fragmented, lacking an integrated synthesis of its intellectual structure. This study systematically maps the thematic architecture and conceptual evolution of food security research in paddy farming to uncover core intellectual lineages, structural knowledge gaps, and strategic trajectories for future interdisciplinary integration. A dual science-mapping design combining bibliographic coupling and co-word analysis was conducted using VOSviewer. The dataset comprises 751 publications spanning 1993 to 2026 retrieved from the Scopus database. Bibliographic coupling identified five distinct intellectual clusters: global food security and climate risk assessment, climate-smart agriculture and conservation tillage, water-saving irrigation efficiency, crop physiology and genetic resilience, and site-specific nutrient management. Complementarily, keyword co-word analysis yielded three major conceptual domains: water-resource management, greenhouse gas emissions and soil nutrient trade-offs, and crop physiology/genetics under abiotic stress. Triangulating both techniques validates that water governance, biogeochemical trade-offs, and plant stress resilience form the stable conceptual foundation of the literature. However, both approaches reveal persistent structural siloing between water-management research and crop-genetics/physiology streams. To overcome existing research silos, future scholarly efforts must transition toward an integrated socio-ecological systems model connecting water governance, nutrient management, and genetic resilience. Policymakers and R&D funding bodies should explicitly foster cross-disciplinary programs uniting irrigation specialists and plant breeders, prioritizing scalable water-saving protocols and precision nutrient management in key granaries across South and East Asia.*

Keywords: *Bibliometric Analysis, Climate Change, Food Security, Rice, Staple Food*

Introduction

Rice or its scientific name known as *Oryza sativa* L. is the staple food for more than half of the global population and underpins the food security of billions of people, particularly across Asia, where paddy cultivation forms the backbone of rural livelihoods and national agricultural economies. As the world's population continues to grow and climate variability intensifies, ensuring stable and sufficient rice production has become one of the most pressing challenges in global food security discourse. Paddy farming systems are simultaneously a critical source of caloric supply and a significant contributor to environmental pressures including high water consumption (Regalado, et al., 2019), greenhouse gas emissions (Saifan et al., 2021) from flooded soils, and vulnerability to climate-induced abiotic stresses such as drought, heat, and salinity (Nurrahma, et al., 2024). This dual role positions paddy food security research at the intersection of agronomy, environmental science, water resource management, and plant genetics, making it a rich but fragmented field of scholarly inquiry.

Over the past two decades, research on food security in paddy farming has expanded rapidly and diversified across multiple disciplinary threads. Studies have examined water-saving irrigation technologies such as alternate wetting-and-drying and the System of Rice Intensification (Ahmed, Raza, Malik, & Malik, 2025), conservation agriculture practices for sustainable rice-wheat cropping systems, the trade-offs between nitrogen fertilization, crop yield, and greenhouse gas emissions (Zhang, et al., 2020), and plant breeding strategies aimed at improving drought tolerance and photosynthetic efficiency in rice (Zhao, et al., 2025). While each of these research streams has generated substantial and highly cited scholarship individually, the field lacks a comprehensive, empirically grounded synthesis of how these thematic areas relate to one another, which authors and institutions have shaped the discourse, and where meaningful gaps remain for future interdisciplinary integration. While traditional narrative reviews and isolated bibliometric studies have evaluated specific sub-domains (e.g., water management or rice genetics independently), no existing study systematically maps the structural intersections and knowledge silos between these fields using a dual-technique approach.

To address these gaps, this study offers a novel empirical contribution by integrating bibliographic coupling with keyword co-word analysis to deliver a triangulated, multi-dimensional science map of the paddy food security literature. While bibliographic coupling uncovers the intellectual structure and foundational author lineages that shape the domain, co-word analysis independently delineates the conceptual structure and evolving terminological themes. By triangulating these two complementary bibliometric methods, this paper moves beyond single-technique or traditional narrative reviews. The primary contribution of this work lies in identifying structural knowledge silos, most notably the empirical divide between water-governance research and crop-genetics/physiology streams and establishing a unified socio-ecological systems framework to guide future interdisciplinary research, R&D funding allocation, and agricultural policy.

Accordingly, this study aims to systematically map the intellectual and conceptual structure of the food security in paddy farming literature using both bibliographic coupling and co-word analysis performed in VOSviewer. Specifically, the study seeks to

- i) identify the major thematic clusters emerging from author-based bibliographic coupling
- ii) identify the major conceptual clusters emerging from keyword co-word analysis
- iii) examine the extent of convergence or divergence between the two bibliometric approaches

- iv) derive theoretical and managerial implications to guide future research and practice in paddy food security.

The remainder of this article is organized as follows: the next section outlines the data sources and bibliometric methodology; this is followed by the presentation of the bibliographic coupling and co-word analysis findings; the subsequent section discusses the theoretical and managerial implications of these findings; and the article concludes with a summary of key contributions, study limitations, and recommendations for future research.

Theoretical Background

To comprehensively analyze the intellectual landscape of rice production, this study grounds its synthesis in the Socio-Ecological Systems (SES) framework. Paddy farming cannot be evaluated merely as an isolated agronomic activity. It functions as a complex, coupled human-natural system where biophysical processes, such as crop physiology, genetic resilience, and soil nitrogen biogeochemistry which continuously interact with human governance mechanisms, including water allocation policies, irrigation scheduling, and nutrient management decisions. In this integrated framework, outcomes such as food security, yield gap closure, greenhouse gas emissions, and water productivity emerge directly from the dynamic feedback loops between biophysical realities and institutional governance. Achieving long-term food security under climate variability thus requires a holistic understanding of how human governance sub-systems and biophysical sub-systems intersect, rather than treating them as disconnected streams of inquiry. To empirically assess whether the scholarly literature reflects this socio-ecological integration, this study employs a dual bibliometric mapping design combining bibliographic coupling and keyword co-word analysis.

Methodology

Bibliometric Approach

Bibliometric analysis offers a robust, data-driven alternative for addressing the gap using science mapping technique (Donthu et al., 2021). Bibliographic coupling and co-word (keyword co-occurrence) analysis are two complementary techniques. This method not only reveal the difference but also can be used to discuss interrelated dimensions of a research field's structure (Zupic & Cater, 2015). Bibliographic coupling identifies clusters of documents and influential authors that share common reference bases, thereby mapping the intellectual lineages and specialized research communities within a field. The fundamental principle in bibliographic coupling is that when two publications share similar references (citing documents), they share similar themes (Rojas-Lamoren et al., 2022). This relationship is known as bibliographic strength, providing an overview of the current research front (Hasumi & Chiu, 2022).

Co-word analysis, by contrast, examines the co-occurrence of author and index keywords across the literature to reveal the underlying conceptual and thematic structure of the discourse, independent of authorship (Zupic & Cater, 2015). Co-word analysis assumes that a group of keywords forms an underlying theme and that the co-occurrences indicate a similar underlying theme (Roodbandi, Choobineh, Barahmand, & Sadeghi, 2022). Frequent keywords have a greater impact on a field than low occurring keywords. The association between the keywords helps researchers to determine the emerging subject to chart future research paths (Donthu et al., 2021).

When applied together, these two methods allow researchers to triangulate findings, confirming whether the thematic clusters identified through shared citation patterns align with the conceptual clusters identified through shared terminology. Thus, it helps in producing a more reliable and comprehensive map of a research domain than either method could achieve in isolation and reduces subjectivity bias as it does not require dropping articles in the sampling process (Fauzi, 2023)

Research Design and Data Collection Procedure

The following search string (Table 1) was employed to identify publications based on relevant keywords. The keywords are related to paddy farming, climate change, food security, and other associated areas. The search was limited to the Scopus database in the topic search (TS) to capture the title, abstract and keywords. Scopus has served the scientific community for 22 years since its launch in 2004, currently indexing over 28,000 active peer-reviewed journals (Baas et al., 2020). Scopus was selected as the sole data source due to its rigorous content selection standards, superior coverage of peer-reviewed literature in agricultural and biological sciences, standardized metadata structure, and seamless compatibility with advanced bibliometric (Mongeon & Paul-Hus, 2015). The findings were limited to article (489), review (121), book chapter (92) and conference paper (49) from year 1993 to 2026 and mostly written in English. VOSviewer 1.6.18 software was used to perform the analysis by producing network visualization of the science mapping.

Table 1: Search String in Scopus Database

No	Keywords	Justification
1	"rice" OR "paddy" OR "granary"	To identify literature related to paddy
2	"hot" OR "climate" OR "drought" OR "heat" OR "temperature"	To identify literature related to climate change
3	"efficient" OR "efficiency" OR "effectiveness"	To identify literature related to efficiency
4	"food security"	To identify literature related to food security

Findings and Discussion

The search in Scopus was performed on 23 August 2026. Figure 1 summarizes the general statistics about the article from Scopus using Biblioshiny. The number of documents was 751 with average citation of 37.07 per document.



Figure 1: Summary of Search on Food Security in Paddy Farming

Source: Scopus

Figure 2 below shows most relevant sources in which the documents were published. 21 of the documents were published in Agriculture Water Management Journal while 20 others in Field Crops Research

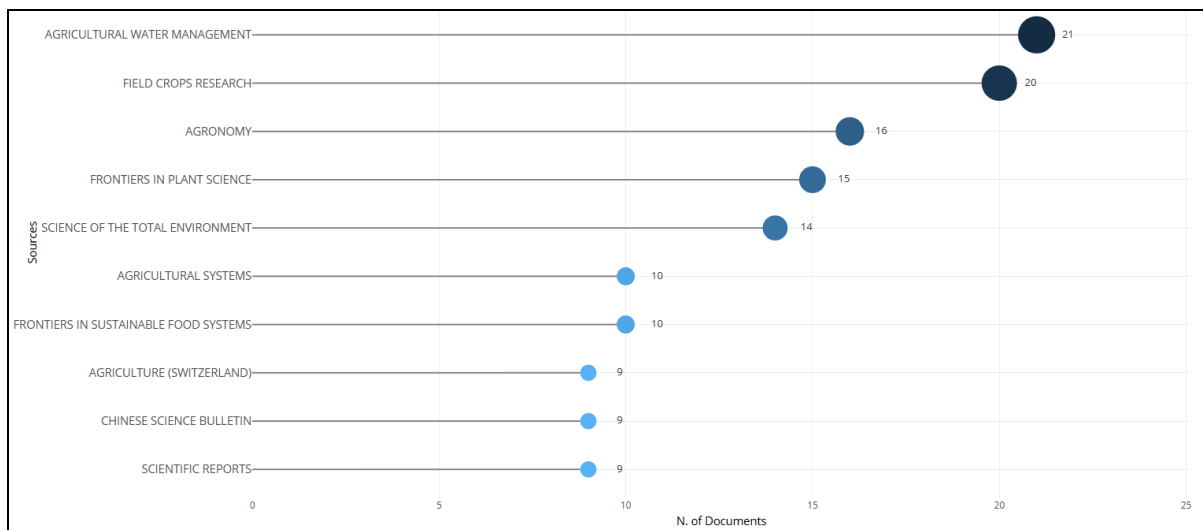


Figure 2: Summary of Journals on Food Security in Paddy Farming

Source: Scopus

Figure 3 below highlights the number of articles published annually. With the steady interest among scholars in this subject, the number of publications is expected to increase within this study context, contributing to further growth on food security in paddy farming activities

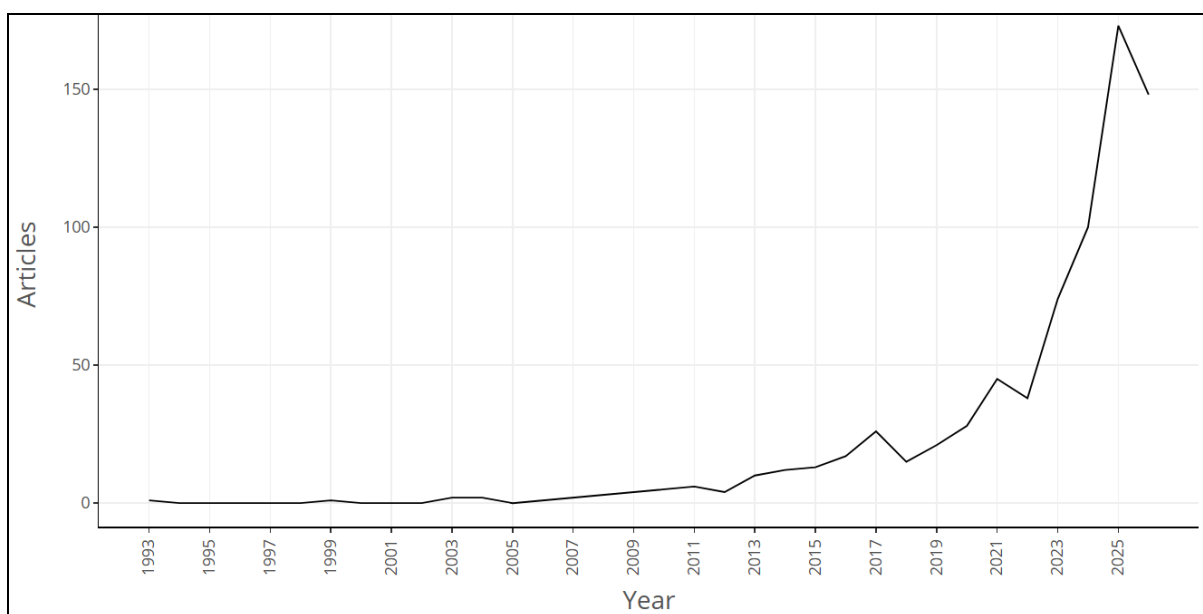


Figure 3: Number of Publications on Food Security in Paddy Farming

Source: Scopus

Bibliographic Coupling

Out of the 751 documents, 50 documents met a threshold of 94 citations. These 50 documents create five (5) clusters. We tested the citation threshold with several trials until the network

map was finalized. The threshold must be adequate, not too high, causing over-filtering or too low, causing under-filtering. The former eliminates relevant clusters in the network map, while the latter leads to many clusters generated, causing redundancy (Fauzi, Nguyen, & Malik, 2024). Selecting 94 citations isolates the highly cited intellectual backbone of the field, ensuring that the resulting five clusters represent established scholarly traditions without network noise. Table 2 presents the top 10 publications based on the highest citations received. The top 3 documents based on citation are Jat et al. (2016) (192 citations), Chauhan et al. (2012) (428 citations), and Ishfaq et al. (2020) (240 citations).

Table 2: Top 10 Documents in Bibliographic Coupling Analysis

No	Author	Journal	Scope	Citation	TLS
1	Jat et al. (2016)	Advances in Agronomy	Evidence on adaptation and mitigation options to ensure durable food and nutritional security in South Asia and Latin America.	192	157
2	Chauhan et al. (2012)	Advances in Agronomy	Examines the threats to the Indo-Gangetic rice-wheat cropping system's sustainability and evaluates resource-conserving strategies to secure regional food production.	428	92
3	Ishfaq et al. (2020)	Agricultural Water Management	Evaluates the agronomic, environmental, and socioeconomic impacts of alternate wetting and drying irrigation compared to conventional continuous flooding in rice production.	240	84
4	Singh & Sidhu (2014)	Proceedings of the Indian National Science Academy	Evaluates crop residue management strategies to improve soil health, reduce environmental pollution, and sustain the Indo-Gangetic rice-wheat cropping system.	227	48
5	Somasundaram et al. (2020)	Critical Reviews in Plant Sciences	Evaluates the benefits, adoption levels, and implementation challenges of conservation agriculture as a sustainable alternative to intensive farming in South Asia.	158	43
6	Mallareddy et al. (2023)	Water (Switzerland)	Evaluates the suitability, benefits, and challenges of various water-saving rice production methods and management practices across different environmental and socioeconomic conditions.	202	41
7	Maneepitak et al. (2019)	Agricultural Water Management	Evaluates the impact of alternate wetting and drying irrigation and rice straw management practices	124	36

No	Author	Journal	Scope	Citation	TLS
			on lowland rice yield and water productivity.		
8	Surendran et al. (2021)	Journal of Cleaner Production	Evaluates water-saving techniques and management strategies to improve water productivity and sustain rice yields under climate change and growing water scarcity.	217	32
9	Wang et al. (2014)	Agricultural Water Management	Evaluates the historical and projected impacts of climate change on rice yield, water consumption, and water use efficiency across key regions in China.	121	27
10	Gaydon et al. (2012)	European Journal of Agronomy	Discusses the enhancement and validation of the APSIM model to simulate crop performance and soil dynamics in diverse rice-based cropping systems.	98	27

Source: Researchers Findings

Figure 4 presents the network visualization of bibliographic coupling. The five clusters are visibly independent of one another. The following discusses current trends and future development of food security in paddy farming. The clusters are labeled based on inductive interpretation by revisiting representative articles in the clusters and synthesized based on common themes and research streams presented.

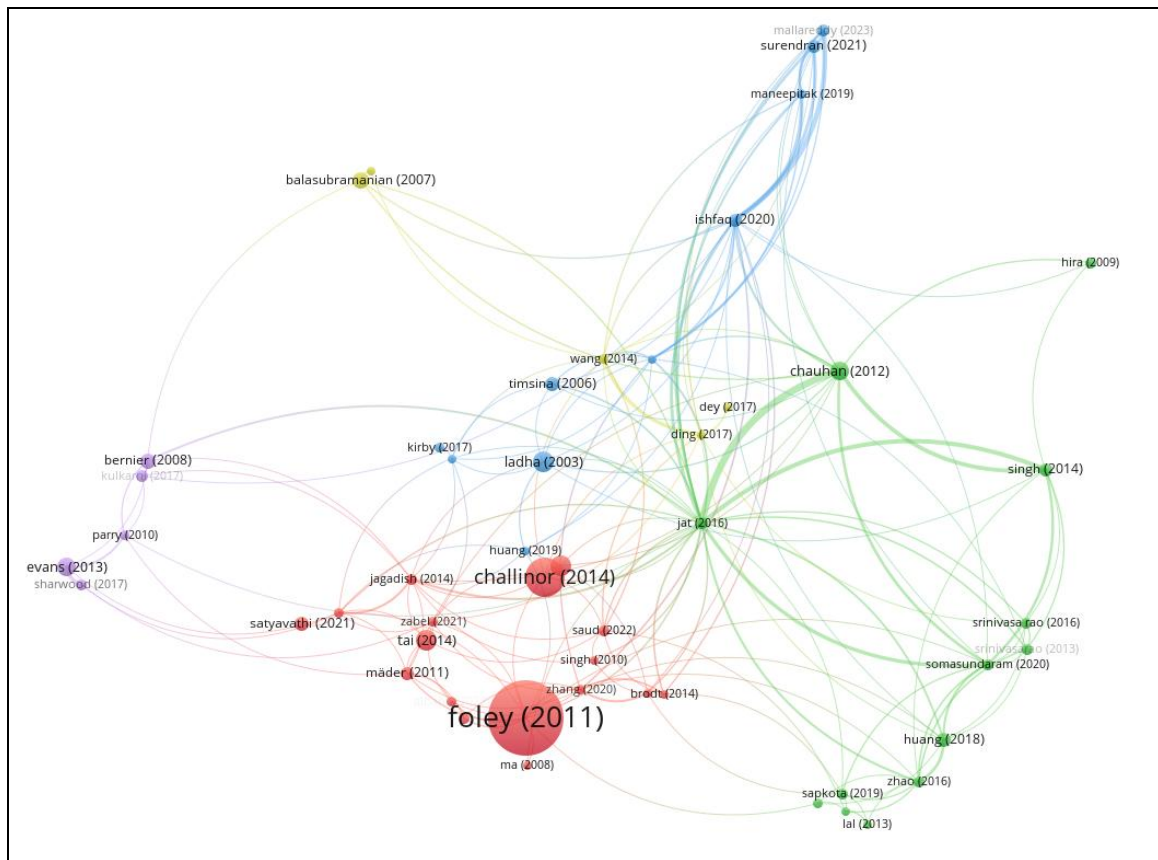


Figure 4: Bibliographic Coupling of Food Security

Cluster 1 (Red): Global Food Security, Yield Gap Closure, and Climate Risk Assessment

This cluster with 17 publications focuses on macro-level food security strategies, closing global yield gaps, and modelling the overarching impacts of climate change on paddy production. Research led by Foley et al. (2011) establishes the foundational framework for sustainable intensification to double global food production while reducing environmental footprints. Building on climate risk, Challinor et al. (2014) conduct a global meta-analysis demonstrating how rising temperatures systematically diminish rice and grain yields without targeted adaptive measures. Furthermore, Tai, Martin and Heald (2014) highlight the compound threats posed by elevated surface ozone and climate warming on global crop productivity. Together, these studies emphasize that safeguarding paddy food security requires bridging spatial yield gaps alongside proactive climate adaptation policies.

Cluster 2 (Green): Climate-Smart Agriculture and Conservation Tillage in Rice Systems

Comprises of 13 publications, this cluster addresses field-level agronomic interventions, focusing on conservation agriculture, reduced tillage, and weed management to maintain high rice productivity under climate stress. Jat et al. (2016) demonstrate through long-term empirical field trials that zero-tillage and conservation agriculture in rice-based rotations significantly enhance grain yields and water productivity. Addressing key operational hurdles, Chauhan et al. (2012) analyzed integrated weed management strategies crucial for successful direct-seeded rice (DSR) adoption. Complementing these findings, Singh and Sidhu (2014) evaluate climate-smart agricultural (CSA) practices, showing that residue retention and resource-conserving technologies reduce environmental footprints while stabilizing paddy

crop yields. Consequently, this thematic domain reinforces conservation farming as a key pillar for sustainable food production.

Cluster 3 (Blue): Water-Saving Technologies and Irrigation Efficiency in Paddy Cultivation

This cluster with 10 publications explores irrigation management, water-use efficiency, and mitigating water scarcity in paddy production through innovations like Alternate Wetting and Drying (AWD). Early work by Ladha, et al. (2003) highlights long-term yield stagnation and soil degradation caused by conventional continuously flooded rice systems across Asia. Addressing this, Ishfaq et al. (2020) demonstrate how combining AWD with direct-seeded rice optimizes water productivity and maintains crop yields despite severe water shortages. Further refining these practices, Surendran, Raja, Jayakumar and Subramoniam (2021) assess smart irrigation scheduling and water-conserving protocols to ensure sustainable rice production under declining freshwater availability. Overall, this cluster underscores that water-smart technology is vital to sustain paddy productivity amidst global hydrological strain.

Cluster 4 (Purple): Crop Physiology, Genetic Resilience, and Breeding for Abiotic Stress

This cluster centers on plant physiology, genetic engineering, and breeding strategies to enhance rice resilience against heat, drought, and atmospheric changes which represented by five publications. Evans (2013) examined the physiological limits of photosynthesis and carbon assimilation, offering avenues to raise the theoretical yield ceiling of cereal crops. Focusing on drought resilience, Bernier et al. (2008) identify key Quantitative Trait Loci (QTLs) and breeding methods to maintain paddy yields under severe moisture deficits. Additionally, Parry and Hawkesford (2010) evaluate Rubisco optimization and enzyme efficiency to future-proof crop genetics against thermal stress. Collectively, these studies demonstrate that genetic selection and physiological optimization provide the essential biological foundation for resilient high-yielding rice varieties.

Cluster 5 (Yellow): Site-Specific Nutrient Management and Soil Fertility Optimization

With five publications, this cluster investigates nutrient use efficiency, precision fertilization, and soil health management to maximize paddy output while minimizing environmental leaching. Balasubramanian, Sie, Hijmans and Otsuka (2007) establish the principles of Site-Specific Nutrient Management (SSNM), demonstrating that tailored field-level NPK applications drastically boost fertilizer efficiency and grain yields. Extending these insights, Ding et al. (2017) examine nitrogen uptake dynamics and optimal split-application schedules to prevent nitrogen loss in intensive rice systems. Similarly, Dey et al. (2017) evaluate integrated nutrient management approaches that combine organic amendments with inorganic fertilizers to restore long-term soil productivity. Together, this cluster demonstrates that balanced, precision nutrient management is crucial for closing yield gaps sustainably.

The following Table 3 presents the summary of the bibliographic coupling analysis with cluster number and colour, labels, number of publications, and representative publications.

Table 3: Bibliographic Coupling Analysis on Food Security in Paddy Farming

Cluster No and colour	Cluster label	Number of publications	Representative publication
1 (red)	Global Food Security, Yield Gap Closure, and Climate Risk Assessment	17	Foley et al. (2011), Challinor et al. (2014), Tai, Martin and Heald (2014)
2 (green)	Climate-Smart Agriculture and Conservation Tillage in Rice Systems	13	Jat et al. (2016), Chauhan et al. (2012), Singh and Sidhu (2014)
3 (blue)	Water-Saving Technologies and Irrigation Efficiency in Paddy Cultivation	10	Ladha, et al. (2003), Ishfaq et al. (2020), Surendran, Raja, Jayakumar and Subramoniam (2021)
4 (purple)	Crop Physiology, Genetic Resilience, and Breeding for Abiotic Stress	5	Evans (2013), , Bernier et al. (2008), Parry and Hawkesford (2010)
5 (yellow)	Site-Specific Nutrient Management and Soil Fertility Optimization	5	Balasubramanian, Sie, Hijmans and Otsuka (2007), Ding et al. (2017), Dey et al. (2017)

These results fulfill RO1 by demonstrating that the field's intellectual backbone is built upon five specialized scholarly communities.

Co-word analysis

Applying the same database, the co-word analysis presents 24 out of 5,151 keywords that met 57 thresholds, resulting in three clusters. This threshold effectively filters out highly specific, low-frequency terms and generic vocabulary, isolating the dense conceptual nodes that form the thematic backbone of paddy food security research. The top 15 keywords in the co-word analysis are presented in Table 4. The highest co-occurring words are “food security” (281 occurrences), “climate change” (236 occurrences) and “rice” (223 occurrences). These keywords indicated that food security is strongly related to paddy production shown by the group keyword of granary, efficiency and temperature.

Table 4: Top 15 Keywords in the Co-Occurrence of Keywords Analysis

Rank	Keyword	Occurrences	Total link strength
1	Food Security	281	1,533
2	Climate Change	236	1,329
3	Rice	223	1,328
4	Food Supply	138	985
5	Crops	109	682
6	Agriculture	76	634
7	Crop Yield	89	633
8	China	81	551
9	Crop Production	72	544
10	Nonhuman	52	522
11	Oryza	54	501

Rank	Keyword	Occurrences	Total link strength
12	Article	52	496
13	Cultivation	71	463
14	Procedures	44	460
15	Sustainable Development	56	442

Figure 5 presents the network structure of the co-word analysis. It visibly shows three clusters representing three different themes. In accordance with the author's inductive interpretation, the three clusters are assigned the appropriate labels.

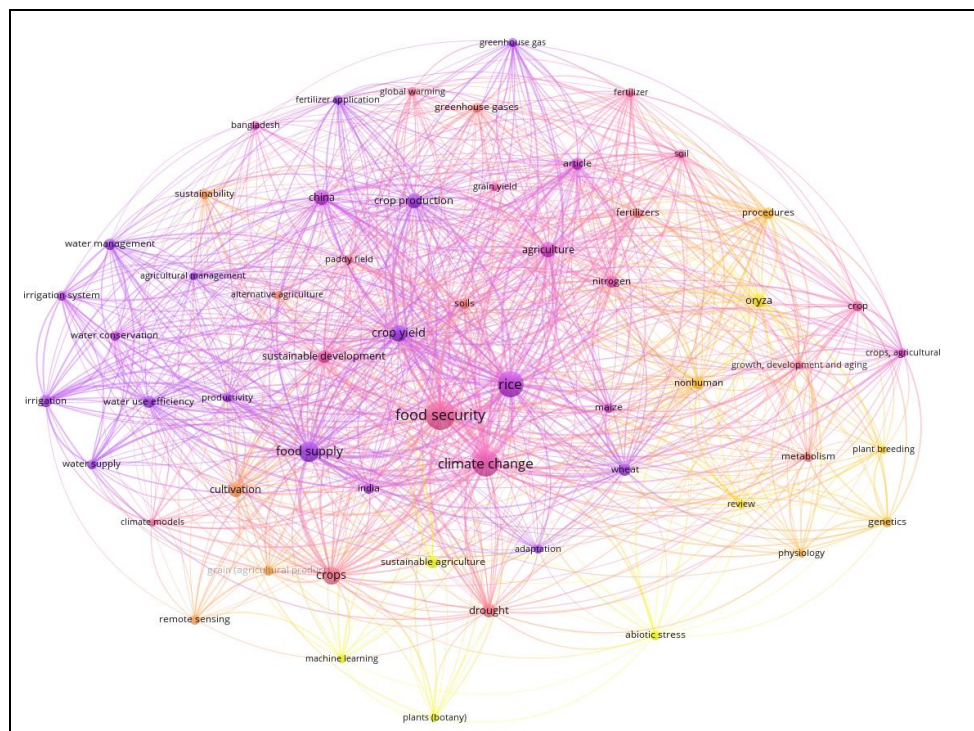


Figure 5: Co-Word Analysis on Food Security in Paddy Farming

Cluster 1 (purple): Irrigation and water-resource management for rice food security.

With 26 keywords, this cluster groups “irrigation,” “water management,” “water conservation,” “water use efficiency,” “water supply,” alongside “food security,” “food supply,” “sustainability,” “drought,” and country terms like “India” and “Bangladesh,” marking it as the water-scarcity and irrigation-efficiency dimension of paddy food security. Together, these anchor the cluster around water-saving irrigation technologies (AWD), rice-system water productivity, and national-scale water-food availability projections for South and Southeast Asian paddy systems (Ishfaq, et al., 2020; Maneepitak, et al., 2019; Kirby, et al., 2017).

Cluster 2 (magenta): Greenhouse gas emissions and fertilizer/nutrient management in paddy soils.

This cluster, consist of 16 main keywords, is defined by "greenhouse gas," "greenhouse gases," "global warming," "nitrogen," "fertilizer," "fertilizer application," "fertilizers," "soil," "soils," "paddy field," and "crop yield/production," reflecting the trade-off between fertilization needed to sustain rice yield and the methane/nitrous oxide emissions and soil

carbon dynamics that follow (Zhang, et al., 2020; Tao, Palosuo, Valkama & Mäkipää, 2019; Liu, et al., 2015). Most of the authors sets the cluster's core theme as balancing crop-intensification-driven food security with the climate-mitigation cost of nitrogen fertilization and cropland emissions, largely centered on Chinese paddy systems.

Cluster 3 (yellow/orange): Crop physiology, genetics, and abiotic stress resilience. Built from 13 keywords like "oryza," "abiotic stress," "genetics," "plant breeding," "physiology," "metabolism," "growth, development and aging," "maize," and "wheat," this cluster represents the plant-science side of food security: improving photosynthetic efficiency, stress tolerance, and genetic gain in staple cereals. This combination reflects the cluster's focus on physiological yield-boosting mechanisms such as photosynthesis (Evans, 2013) and nitrogen-use efficiency (Liu, et al., 2024) and molecular stress-tolerance strategies underpinning cereal (including rice) resilience for food security (Muhammad, Ahmad, & Shen, 2024).

A summary of the co-word analysis is presented in Table 5, comprising cluster number and color, cluster labels, number of keywords, and representative keywords.

Table 5: Summary of Co-Word Analysis on Food Security in Paddy Farming

Cluster No and color	Cluster label	Number of keywords	Representative Keywords
1 (purple)	Irrigation and water-resource management for rice food security	26	irrigation, water management, water conservation, water use efficiency, water supply, food security, food supply, sustainability, drought
2 (magenta)	Greenhouse gas emissions and fertilizer/nutrient management in paddy soils	16	greenhouse gas, greenhouse gases, global warming, nitrogen, fertilizer, fertilizer application, fertilizers, soil, soils, paddy field, crop yield/production,
3 (yellow / orange)	Crop physiology, genetics, and abiotic stress resilience	15	Oryza, abiotic stress, genetics, plant breeding, physiology, metabolism, growth, development and aging, maize, wheat

These findings answer RO2 by identifying the primary conceptual pillars and vocabulary active in paddy food security research.

To address Research Objective 3, the findings from bibliographic coupling (RO1) and co-word analysis (RO2) were synthesized to evaluate structural alignment and identify knowledge silos. Triangulating both techniques validates that water governance, biogeochemical trade-offs, and genetic stress resilience form the stable conceptual foundation of the literature across both author-based and keyword-based networks. However, comparing Figure 4 and Figure 5 reveals persistent structural siloing: research on water-saving irrigation systems remains weakly connected to crop genetics and stress physiology streams. This structural disconnect answers RO3 by demonstrating that despite shared thematic goals, the literature remains organized into isolated disciplinary sub-systems rather than an integrated socio-ecological system.

Implications

Theoretical implications

Taken together, the bibliographic coupling analysis by mapping influential authors/documents and the co-word analysis by mapping the conceptual structure around water management, greenhouse gas/fertilizer dynamics, and crop physiology/genetics, offer convergent evidence that the intellectual structure of paddy food security research is organized around the same three underlying pillars, approached from two different bibliometric lenses. The author-based coupling network identified clusters on global food security and climate-yield impacts, conservation agriculture and resource management, water/irrigation efficiency, resource-conserving technology diffusion, and drought/photosynthesis breeding while the keyword-based co-word network independently converged on water-resource management, greenhouse-gas/nutrient management, and crop physiology/genetics. The fact that two methodologically distinct techniques. One tracing shared-reference relationships among documents while the other tracing shared-term co-occurrence. This highly overlapping thematic structures provides strong triangulated theoretical validation that three domains such as water governance, biogeochemical trade-offs, and genetic/physiological resilience constitute the genuine, stable conceptual core of the paddy food security literature, rather than an artifact of either method alone.

This convergence also strengthens the case for an integrated theoretical model of paddy food security, since the bibliographic coupling results reveal *who* is producing knowledge in each domain. For example, in water-saving irrigation (Ladha, et al., 2003; Ishfaq, et al., 2020) conservation agriculture (Jat, et al., 2016; Chauhan et al., 2012) and in stress physiology (Bernier et al., 2008; Parry & Hawkesford, 2010), while the co-word results reveal *what* concepts and relationships dominate the discourse within those domains. Reading the two analyses together supports extending single-pillar food security frameworks toward a coupled systems theory in which author-level specialization (as seen in the coupling clusters) has produced conceptually distinct but structurally parallel knowledge silos (as seen in the co-word clusters). This help in reinforcing the earlier observation that water-management and genetics/physiology research streams remain weakly integrated despite being thematically and authorially adjacent (Zhao, et al., 2025). This dual-method evidence therefore justifies theorizing paddy food security not as three independent literatures but as a single socio-ecological system whose sub-domains (documented consistently across both the citation and keyword networks) require deliberate cross-domain theoretical bridging in future research.

Managerial Implications

For agricultural policymakers and program managers, the alignment between the two analyses reinforces that water-resource management is not a peripheral but a central, consistently validated priority. This appears as the largest or most cited cluster in both the author-coupling network (Ladha, et al., 2003; Ishfaq, et al., 2020; Surendran et al., 2021) and the co-word network (irrigation, water management, water use efficiency). This dual confirmation should give decision-makers greater confidence in prioritizing investment and extension resources toward water-saving practices such as alternate wetting-and-drying and precision irrigation scheduling. The recommendation is grounded in both who is producing the most influential research and what concepts dominate the field's vocabulary. It is believed can help in reducing the risk that policy is built on a single, potentially biased bibliometric signal.

Likewise, the shared prominence of greenhouse-gas and nutrient-management themes across both analyses in conservation-agriculture work and the co-word cluster on fertilizer, nitrogen, and emissions (Jat, et al., 2016; Chauhan et al., 2012) indicates that input-supply managers and climate-policy units can treat nitrogen-use efficiency and site-specific nutrient management as a validated, high-priority lever for simultaneously advancing yield security and emissions mitigation, rather than a narrower, single-study recommendation.

At the institutional and R&D funding level, the combined findings suggest that the persistent separation between water-management research and genetics/physiology research are visible as weakly linked clusters in both the author-coupling map and the co-word map, represents a genuine, cross-validated structural gap rather than a coincidental pattern in one dataset. This implies that research councils, universities, and international agricultural research centers should deliberately fund and structure interdisciplinary programs that pair irrigation/water-governance specialists with plant-breeding and stress-physiology teams, since neither the citation network nor the keyword network shows this integration occurring organically. For practitioners such as extension officers and agribusiness managers, the convergence of both analyses around China and South Asia case studies by Jat et al. (2016) and Chauhan et al. (2012) further suggests that scalable, region-specific best-practice packages, combining water-saving irrigation, precision fertilization, and climate-resilient varieties should be prioritized for dissemination in these geographies first, where the evidence base is deepest and most consistently corroborated across both bibliometric methods.

Conclusion

This study systematically mapped the intellectual and conceptual architecture of paddy food security research through a dual science-mapping design, triangulating author-based bibliographic coupling with keyword co-word analysis. The findings confirm that the global literature is anchored by three stable thematic pillars: water governance, biogeochemical trade-offs between yield and emissions, and genetic/physiological resilience to climate stress. By demonstrating strong thematic alignment between citation lineages and keyword co-occurrence patterns, this dual-method approach provides empirical validation that these three domains constitute the authentic core of paddy food security scholarship.

However, moving beyond descriptive mapping reveals a critical structural gap in the literature: a persistent, empirical silo separating water-management research from crop-physiology and genetic-resilience streams. In practice, this disciplinary isolation hinders agricultural adaptation. Drought-tolerant and heat-resilient rice cultivars developed by plant breeders are rarely evaluated within real-world water-saving irrigation protocols (such as Alternate Wetting and Drying) during early-stage trials. Conversely, water governance frameworks and precision irrigation models are frequently optimized without integrating physiological genotype-by-environment ($G \times E$) interactions under severe abiotic stress.

Overcoming this structural divide requires transitioning from single-pillar agronomic models toward an integrated socio-ecological systems framework that treats genetic potential, water scheduling, and soil biogeochemistry as interdependent levers.

To operationalize this transition, R&D funding bodies, including international agricultural research organizations and national research councils across major Asian granaries must actively restructure their research investments. Rather than funding isolated calls for molecular breeding or irrigation engineering, funding agencies should establish mandatory

interdisciplinary grant frameworks. Specifically, future funding calls should require joint research teams, combining plant breeders, irrigation engineers, and soil scientists to co-design multi-location field trials. Such co-designed protocols will ensure that newly bred climate-resilient varieties are optimized alongside scalable precision water- and nutrient-management practices, directly accelerating the adoption of sustainable paddy farming systems across climate-vulnerable regions.

Limitations

This study is subject to several limitations that should be acknowledged. First, the analysis relies on data drawn from a single bibliographic database (Scopus), which may exclude relevant regional or non-English-language journals and grey literature that also contribute to the paddy food security discourse, potentially skewing the cluster composition toward more internationally indexed research. Second, bibliometric mapping techniques such as bibliographic coupling and co-word analysis are inherently descriptive: they reveal patterns of association and citation but cannot establish causal relationships between research themes, nor can they capture the qualitative depth, methodological rigor, or contextual nuance of individual studies. Third, the clustering algorithms in VOSviewer are sensitive to parameter choices such as minimum occurrence thresholds, resolution/normalization settings, meaning that different settings could yield somewhat different cluster boundaries or numbers of clusters. Finally, the dataset reflects a specific search-string and time-period scope, so emerging themes published very recently, or studies using terminology not captured by the chosen keywords, may be underrepresented.

Recommendations

Future research should consider triangulating multiple databases such as Web of Science, and regional repositories to produce a more comprehensive and less database-biased map of the field. Researchers are also encouraged to complement this quantitative bibliometric mapping with qualitative systematic reviews or meta-analyses of the highest-cited papers within each cluster, to extract more actionable, evidence-based recommendations. Given the structural gap identified between water-management and genetics/physiology research streams, future studies and funding calls should explicitly prioritize interdisciplinary projects that integrate irrigation governance with stress-tolerant variety development, ideally accompanied by longitudinal bibliometric tracking to monitor whether this integration develops over time. Finally, subsequent bibliometric work could extend this analysis by incorporating co-authorship and country-collaboration networks, which would help identify not only what is being researched, but also where and by whom future collaborative interventions in paddy food security should be targeted.

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