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Global research trends and thematic clusters in rice-based sustainable food systems: A systematic review

A Jason Arockiam[1] & C Karthikeyan[*]

[1]Department of Agricultural Extension and Rural Sociology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - karthikeyanc@tnau.ac.in

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Abstract

Rice is a cornerstone of global food security, livelihoods and rural economies, yet its production and consumption are increasingly challenged by climate change, resource constraints and sustainability trade-offs. While research on rice sustainability has expanded rapidly in recent years, the literature remains fragmented across disciplines, analytical scales and food system components. This study presents a systematic literature review that maps and analyses the global research landscape on rice-based sustainable food systems using bibliometric methods and content co-occurrence analysis techniques. A total of 227 publications indexed in the Scopus database (2013-2025) were analysed following PRISMA guidelines. Bibliometric analysis was conducted to examine publication trends, country and institutional contributions, source distribution and keyword co-occurrence patterns. Scientific output increased sharply after 2021, with nearly 89 % of publications produced between 2021 and 2025, indicating rapid consolidation of the field. Country-wise analysis shows a strong concentration of research in Asia, particularly India (136 publications), China (121) and Indonesia (96). Subsequently, content co-occurrence analysis identified four thematic clusters: (i) consumer behaviour, dietary choices and environmental implications; (ii) crop management, resource constraints and economic trade-offs; (iii) food security, resilience and supply chain dynamics; and (iv) adoption and transition towards sustainable rice systems. The results reveal a strong concentration of research in Asia, growing interdisciplinary engagement and a recent surge in system-oriented sustainability studies. However, persistent gaps were identified, including limited methodological integration, weak linkage between production and consumption research and underrepresentation of transition dynamics and emerging regions. By synthesising key interventions, practices and technologies across clusters, this review provides an integrated perspective on pathways toward rice-based sustainable food systems and outlines priority directions for future research and policy development.

Keywords: bibliometrics; content co-occurrence analysis; food systems; rice systems; sustainable pathways; sustainability transitions

Introduction

Rice is a critical global staple crop, serving as the primary dietary source for over half the world's population and supporting the livelihoods of 144 million smallholder farmers (1). In Asia, rice provides up to 50 % of dietary caloric intake, with China and India alone accounting for approximately 50 % of global rice production and consumption (2). The crop's strategic importance extends beyond nutrition, functioning as a key economic driver through employment generation, income security and regional trade in developing regions. Rice production is intrinsically linked to rural economies, with significant implications for food security and poverty reduction (3). Emerging research highlights rice's multifunctionality, emphasising its role in environmental conservation, cultural preservation and economic development (4). Climate change and population growth pose significant challenges, necessitating innovative approaches to sustain rice productivity and ensure global food security (5).

Rice production faces critical sustainability challenges across environmental and socio-economic dimensions. Traditional rice cultivation requires high water inputs, with climate change further intensifying water demand (6). Optimised irrigation practices have been shown to reduce water use by up to 40 % and greenhouse gas emissions by approximately 37 % (7). Additional environmental pressures arise from rising temperatures, irregular rainfall patterns and increasing soil salinisation (8). These environmental challenges are further compounded by economic constraints, including limited access to resources and inefficient agricultural practices, which hinder the adoption of sustainable production systems (9). These findings underscore the urgent need for adaptive strategies that balance productivity, resource conservation and environmental protection.

The food systems approach analyses relationships between different food chain components, revealing critical feedback loops (10). Sustainable improvement requires an integrated approach spanning upstream discovery through biotechnology, midstream 'development' through breeding and agronomy and downstream 'dissemination and deployment' (11). The interconnectedness across environmental sustainability, economic viability, social equity and nutritional outcomes is deeply intertwined. Transformation requires considering factors like food processing, supply chain optimisation, policy alignment and local socio-economic contexts (12, 13).

Rice sustainability research remains critically fragmented across disciplines, with studies predominantly focusing on narrow,

discipline-specific perspectives rather than holistic approaches. Rice-related studies have largely focused on macro-level production, genetic diversity and agrotechnological innovations, often overlooking broader interdisciplinary perspectives (14). A clear gap in relational bibliometric studies within rice supply chain research has been identified, underscoring the need for stronger cross-disciplinary collaboration (15). Sustainability research has also been characterised as highly fragmented, with multiple academic disciplines pursuing similar objectives but with limited formal coordination (16). Such isolated approaches contribute to an incomplete understanding of complex sustainability challenges, obscure critical linkages among environmental, economic and social dimensions and constrain the development of comprehensive solutions.

Systematic literature reviews and bibliometric methods are powerful tools for mapping and analysing research landscapes, revealing critical insights into emerging trends and knowledge gaps. A bibliometric mapping of 841 publications was used to identify key transparency dimensions in agri-food value chains, revealing emerging topic clusters around sustainability and technology (17). Further validated these methods by conducting a systematic review of 1289 documents, which exposed research biases and underexplored dimensions in agricultural sustainability research (18). A bibliometric mapping method was used to uncover three distinctive scientific fronts in sustainable food systems research, demonstrating these techniques' ability to systematically map complex research landscapes (19). These methods provide comprehensive, rigorous approaches to understanding research landscapes.

Existing reviews on sustainable food systems and rice research exhibit methodological limitations, particularly in interdisciplinary integration and multi-level synthesis of individual, community and institutional dynamics (20). They also insufficiently document the interventions, practices and technologies shaping sustainability transitions in rice-based systems (1). In this context, the present review aims to systematically map and analyse the global research landscape on rice-based sustainable food systems using bibliometric techniques and identify and synthesise dominant thematic clusters and knowledge gaps through content co-occurrence analysis; and to examine key interventions, practices and technologies that represent pathways towards sustainable transitions in rice-based food systems.

Unlike prior reviews that focus primarily on production, supply chains, or specific sustainability dimensions in isolation, this study develops a four-cluster framework that systematically integrates consumption, production, resilience and transition dynamics within a unified analytical structure. By combining scientometric mapping with content co-occurrence analysis, the framework moves beyond descriptive synthesis to reveal structural linkages, thematic fragmentation and transition pathways across system levels. This integrated clustering approach advances conceptual understanding by positioning rice sustainability research within a multi-scalar food systems lens rather than treating agronomic, economic, or dietary studies as separate domains.

Materials and Methods

This study employed a bibliometric analysis and content co-occurrence approach to achieve the research objectives by capturing both structural and thematic dimensions of the literature. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework was adopted to collect the required data**.** The PRISMA guidelines provide a structural approach and strengthen the methodological rigour by reducing potential biases (21).

The Scopus database was searched on January 15, 2026 using the following Boolean search string restricted to article title, abstract and keywords: ("rice" OR "paddy") AND ("food system*" OR "agri-food system*" OR "value chain*" OR "supply chain*") AND ("sustainab*" OR "resilience"). Previous studies used the Scopus database for conducting a bibliometric analysis (22, 23). It is a comprehensive bibliographic database developed by Elsevier in 2014. As the largest indexer of global research, Scopus provides a vast range of research outputs from more than seven thousand international publishers (24). A total of 227

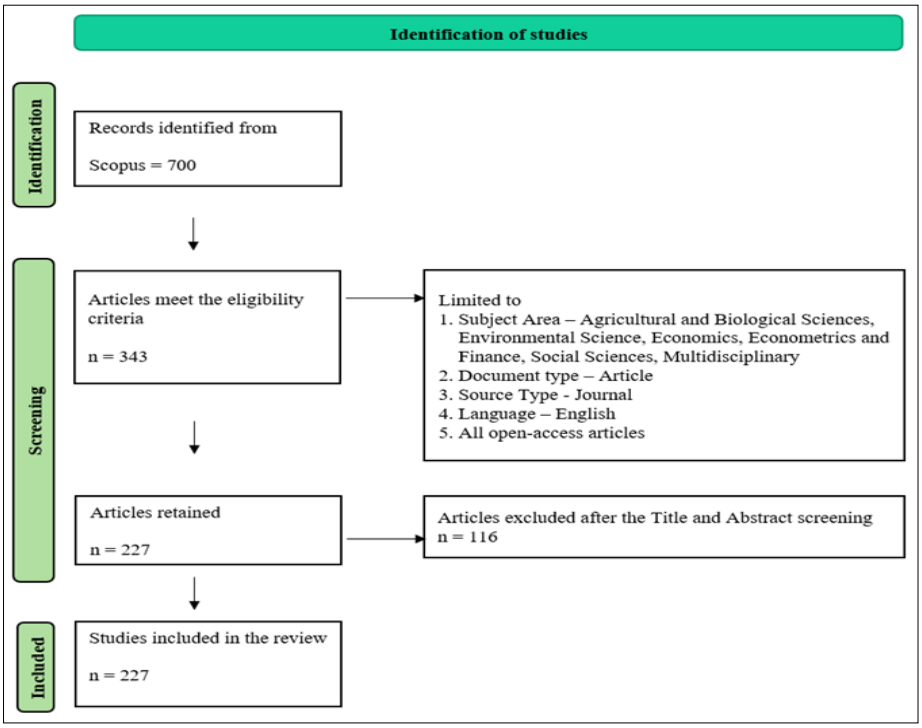

Fig. 1. Selection of relevant publications based on inclusion/exclusion criteria following the PRISMA framework.

relevant publications were identified for the study, following the specific inclusion and exclusion criteria outlined in Fig. 1. Publications were excluded if they were non-English, conference papers, reviews, book chapters, non-peer-reviewed documents, or unrelated to rice-based food systems and sustainability.

Bibliometric analysis is a quantitative method to evaluate the scientific landscape of a particular field or concept. It helps researchers to assess the research impact, identify research trends and evolving research areas (25, 26). The quantitative indicators and their visualisation in bibliometric analysis aid in the knowledge structure of a certain research domain. Software like R and VOSviewer were used to analyse the results (27–30).

Content analysis is a systematic procedure for deriving meaning from textual data and is widely used in conjunction with bibliometric techniques to complement quantitative mapping with qualitative insights. The content co-occurrence, also known as co-word analysis, was done to gain an in-depth understanding of the thematic structure and knowledge gaps within the identified research clusters. In content co-occurrence analysis, importance is given to the co-occurrence of terms rather than whether an article has citations or not (22). This approach removes limitations inherent in thematic content analysis. Traditional approaches often include only the most impactful publications based on citation analysis, co-citation analysis and bibliometric coupling (31).

The methodology was adopted in this study with some modifications (22). Association strength normalisation was applied in VOSviewer and a minimum occurrence threshold of 20 was specified to retain terms that frequently co-occurred. The threshold of 20 occurrences was selected to ensure analytical robustness and conceptual clarity in cluster formation. Lower thresholds resulted in sparse networks with excessive noise and fragmented micro-clusters, while higher thresholds excluded substantively relevant but moderately represented themes. The selected threshold provided an optimal balance between inclusiveness and interpretability, retaining frequently co-occurring terms that reflect dominant thematic structures within the dataset. The resulting term co-occurrence network generated four thematic clusters, which formed the analytical framework for the subsequent content analysis. For each cluster, dominant terms were identified based on their occurrence (weight) values generated by VOSviewer. The most frequent terms within each cluster were considered representative of the core thematic focus and were used to guide document classification. In clusters with a limited number of terms, all identified terms were treated as dominant. Publications were assigned to thematic clusters using Microsoft Excel (32). Dominant cluster terms were matched against the combined text of article titles, abstracts and keywords using a structured term-frequency approach. Each publication was assigned to the cluster with the highest number of matching dominant terms, subject to a minimum threshold of 3 matches. The three-match threshold ensured thematic consistency and reduced misclassification due to incidental term overlap. Lower thresholds resulted in ambiguous cluster assignments, while a higher threshold excluded relevant publications that meaningfully engaged with the dominant themes. This criterion enhanced classification reliability and interpretive validity in the qualitative synthesis. Publications that did not meet this threshold were classified as unassigned and excluded from further qualitative analysis.

To ensure balanced qualitative representation across thematic clusters and to avoid dominance bias, publications were randomly ordered using a random number generator in Microsoft Excel and papers were randomly selected. For clusters with a limited number of publications, all available papers were included. This approach ensured equal analytical attention to both dominant and emerging research themes. The selected publications were subjected to qualitative content analysis using a structured extraction framework. Data extraction focused on study objectives, methodological approaches, key findings, interventions and emerging concepts. A cluster-wise thematic synthesis was conducted to identify dominant themes, methodological patterns and sub-themes. Cross-cluster comparison was subsequently performed to examine convergence, divergence and integration gaps across system components. The combined use of systematic term matching, threshold-based classification, randomised sampling and thematic synthesis ensured analytical transparency, robustness and reproducibility.

Results and Discussion

Trends in source publications

Between 2013 and 2025, approximately 227 publications were produced on rice-based sustainable food systems (Fig. 2). Publications from 2026 were excluded due to incomplete annual coverage. During the early phase (2013–2016), publication output remained minimal, indicating that sustainability issues related to rice were addressed only marginally within broader agricultural or environmental studies. This period reflects conceptual emergence, with limited consolidation of the field. A notable turning point occurs around 2021, when publication numbers increase sharply. This surge signals growing recognition of rice systems as a critical nexus linking food security, environmental sustainability and resource use. Rather than a temporary spike, the subsequent years show sustained growth, suggesting consolidation and diversification of research themes rather than episodic interest. The strong acceleration after 2021, peaking around 2024–2025, marks the transition of this topic into a strategic and policy-relevant research domain. This expansion coincides with heightened global concerns over climate change, sustainable food systems and systemic vulnerabilities exposed by the COVID-19 pandemic. Importantly, the growth pattern is non-linear and event-responsive, indicating that external shocks and global policy agendas have significantly shaped research intensity. About 89.26 % of articles were published between 2021 and 2025, indicating the growing research interest in rice-based sustainable food systems. On average, 25 articles were published per year during 2021 and 2025. The trend reflects a shift from fragmented inquiry to a mature, rapidly expanding field, underscoring the need for integrative reviews to synthesise knowledge and guide future research trajectories.

Country-wise Scientific Production

The country-wise scientific production highlights that the strongest research output is concentrated in Asia, particularly in countries such as India (n=136), China (n=121) and Indonesia (n=96), where rice is both a staple food and a strategic crop (Fig. 3). This dominance reflects a close alignment between research intensity and real-world dependence on rice for food security, livelihoods and national sustainability agendas. Countries in South and East Asia emerge as major contributors, underscoring the role of region-specific challenges, such as water scarcity, yield stagnation and climate vulnerability, in driving research priorities. In contrast, contributions from Europe, North America and

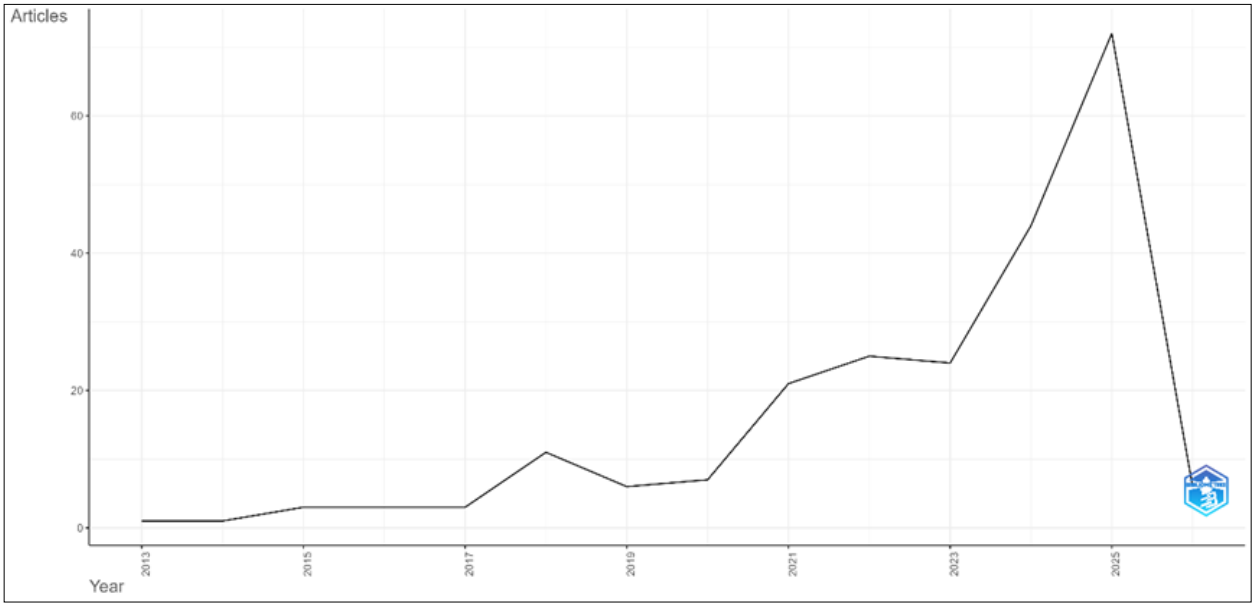

Fig. 2. Distribution of Sources publications across years on rice-based sustainable food systems research (2013-2025).

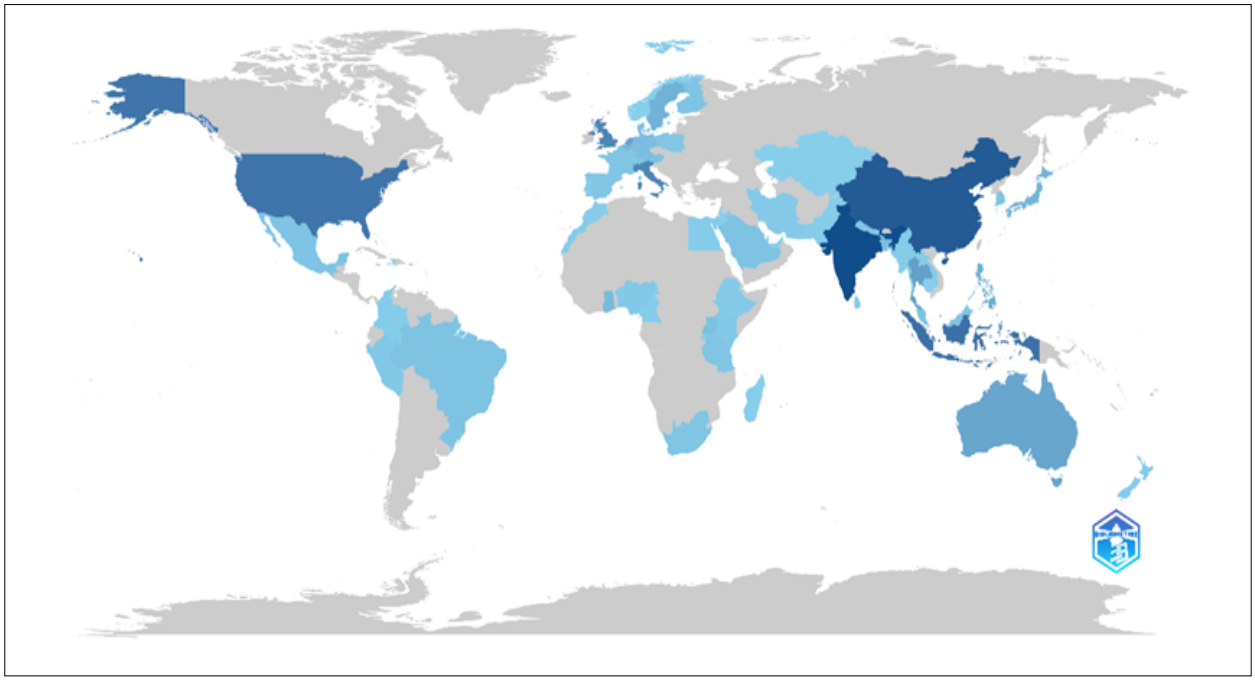

Fig. 3. Country-wise scientific production on rice-based sustainable food systems research.

Australia, though smaller in volume, tend to reflect systems-level, environmental and policy-oriented perspectives. This indicates a complementary role in advancing conceptual and methodological approaches. The presence of research output from Africa and Latin America, albeit limited, indicates a growing yet underrepresented engagement with rice-based sustainability issues in emerging rice-producing and consuming regions. This imbalance points to geographical research gaps, particularly in regions facing rising rice demand and climate risks but lacking strong research visibility. Overall, the map suggests that the global research landscape is shaped less by publication capacity alone and more by crop relevance, regional vulnerability and policy urgency. Strengthening cross-regional collaboration could help bridge contextual knowledge gaps and support more globally balanced sustainability pathways for rice-based food systems.

Most relevant institutions

Institutional productivity was calculated using a full counting approach, whereby each institution was credited once per publication. The dominance of the International Rice Research Institute (IRRI) underscores its central role as a global knowledge hub for rice science, reflecting its long-standing mandate to address productivity, sustainability and food security challenges in rice-based systems (Table 1). The IRRI's leading position suggests that much of the research agenda in this field is shaped by problem-oriented, field-driven and policy-relevant research. The prominence of Wageningen University and Research highlights the complementary contribution of institutions that emphasise systems thinking, environmental assessment and interdisciplinary sustainability science. This indicates an important methodological balance between applied agronomic research and integrative food -system analysis. Similarly, the presence of Indian Council of Agricultural Research institutes (ICAR) reflects the strong engagement of national agricultural research systems in addressing region-specific challenges such as soil salinity, water stress and varietal adaptation. Affiliations such as China Agricultural University, Kasetsart University and European research bodies further demonstrate that rice-based sustainability

Table 1. Most relevant institutions on rice-based sustainable food systems research

S.No.	Affiliation	Country	Articles (n)
1.	International Rice Research Institute (IRRI)	Philippines	35
2.	Wageningen University and Research	Netherlands	24
3.	International Maize and Wheat Improvement Centre (CIMMYT)	Mexico	21
4.	ICAR - Central Soil Salinity Research Institute	India	16
5.	China Agricultural University	China	15
6.	Swedish University of Agricultural Sciences	Sweden	13
7.	European Commission Joint Research Centre	Belgium	12
8.	Kasetsart University	Thailand	12
9.	ICAR - Central Island Agricultural Research Institute	India	11
10.	Politecnico Di Milano	Italy	10

research is anchored in regions where rice is either a strategic crop or a focal point of environmental policy. Overall, the affiliation pattern suggests that knowledge production in this field is institutionally concentrated but thematically diverse, driven by organisations with strong mandates in crop science, sustainability transitions and food security. This concentration also points to opportunities for broader institutional participation and cross-sectoral collaboration to enrich the global research landscape.

Top relevant sources

The distribution of the most relevant sources (Table 2) highlights the interdisciplinary and evolving publication landscape of research on rice-based sustainable food systems. The dominance of journals such as Sustainability and Frontiers in Sustainable Food Systems indicates that this research domain is increasingly anchored within broad, systems-oriented sustainability outlets, rather than being confined to traditional crop- or discipline-specific journals. This suggests a conceptual shift in the field from viewing rice primarily as an agronomic commodity to framing it as a core component of sustainable food systems. The presence of environmental research letters underscores the growing importance of environmental assessment, climate impacts and resource-use efficiency in shaping the research agenda. Similarly, contributions published in Foods and Frontiers in Nutrition reflect expanding interest in dietary quality, consumption patterns and nutrition–sustainability linkages, reinforcing the consumer-facing dimension of rice-based sustainability. Journals such as Agronomy, Agricultural Systems and Agronomy for Sustainable Development represent the production and systems backbone of the literature, focusing on crop management, yield stability and system-level trade-offs. Their moderate but consistent representation indicates that agronomic research continues to play a foundational role, while increasingly interfacing with broader sustainability concerns. The dispersion of publications across sustainability, environmental, agronomic and nutrition-focused journals demonstrates that rice-based sustainable food systems research is methodologically and thematically plural, reflecting a maturing field that bridges disciplinary boundaries. This diversity also signals opportunities for deeper integration across research communities to advance holistic and policy-relevant insights.

Keywords co-occurrence analysis

A co-occurrence analysis of author and index keywords was conducted, with the minimum occurrence threshold set at 5. Among the 2609 identified keywords, 103 satisfied this criterion and the resulting network visualisation is presented in Fig. 4. Thicker links between keywords indicate stronger co-occurrence relationships, whereas closer node proximity reflects a higher level of association (33). The most frequently occurring keywords (Fig. 4) include “rice” (68 occurrences), “sustainability” (46 occurrences), “food security” (38 occurrences), “food supply” (29 occurrences), “sustainable development” (28 occurrences), “agriculture” (27 occurrences), “human” (17 occurrences), “food system” (17 occurrences), “climate change” (17 occurrences) and India (17 occurrences). In general, keywords grouped within the same cluster represent a shared research theme, while keyword density facilitates the identification of prominent research hotspots.

As illustrated in Fig. 4, six distinct clusters, namely red, green, blue, yellow, purple and light blue, are identified. The red cluster comprises 27 keywords, with prominent terms including food system, environmental impact and catering service. The green cluster consists of 22 keywords, including rice, sustainability, food security, climate change and supply chain management, among others. The blue cluster contains 21 keywords, including food supply, sustainable development, crop production, cultivation and food production income. The yellow cluster contains 18 keywords, including agriculture, India, wheat, maize, alternative agriculture and sustainable agriculture. The

Table 2. The top relevant sources publishing articles on rice-based sustainable food systems research

S. No.	Sources	Articles (n)	Journal scope
1.	Sustainability	19	Sustainability; Environmental Policy
2.	Frontiers in Sustainable Food Systems	17	Sustainable Food Systems; Food Security; Agroecology
3.	Environmental Research Letters	8	Environmental Change; Climate Policy; Sustainable Food Systems
4.	Foods	7	Food Science; Food Technology; Food Sustainability
5.	Agronomy	5	Agronomy; Crop Science; Agroecology
6.	Sustainable Production and Consumption	5	Sustainable Production and Consumption; Circular Economy; Life Cycle Assessment
7.	Agricultural Systems	4	Agricultural Systems; Agroecology; Systems Modelling
8.	Frontiers in Nutrition	4	Human Nutrition; Public Health; Sustainable Diets
9.	Agronomy for Sustainable Development	3	Agroecology; Sustainable Agricultural Systems; Farming Systems
10.	Frontiers in Plant Science	3	Plant Biology; Plant Genetics; Crop Physiology
11.	Global Food Security	3	Global Food Security; Food Systems; Policy and Governance
12.	Journal of Agriculture and Food Research	3	Agriculture Food Systems; Food Science and Technology
13.	Land	3	Land Systems Science; Land-Use and Sustainability
14.	Nutrients	3	Human Nutrition; Public Health
15.	Research on World Agricultural Economy	3	Agricultural Economics; Policy and Trade
16.	Science of The Total Environment	3	Environmental Science; Climate and Ecosystem Impacts

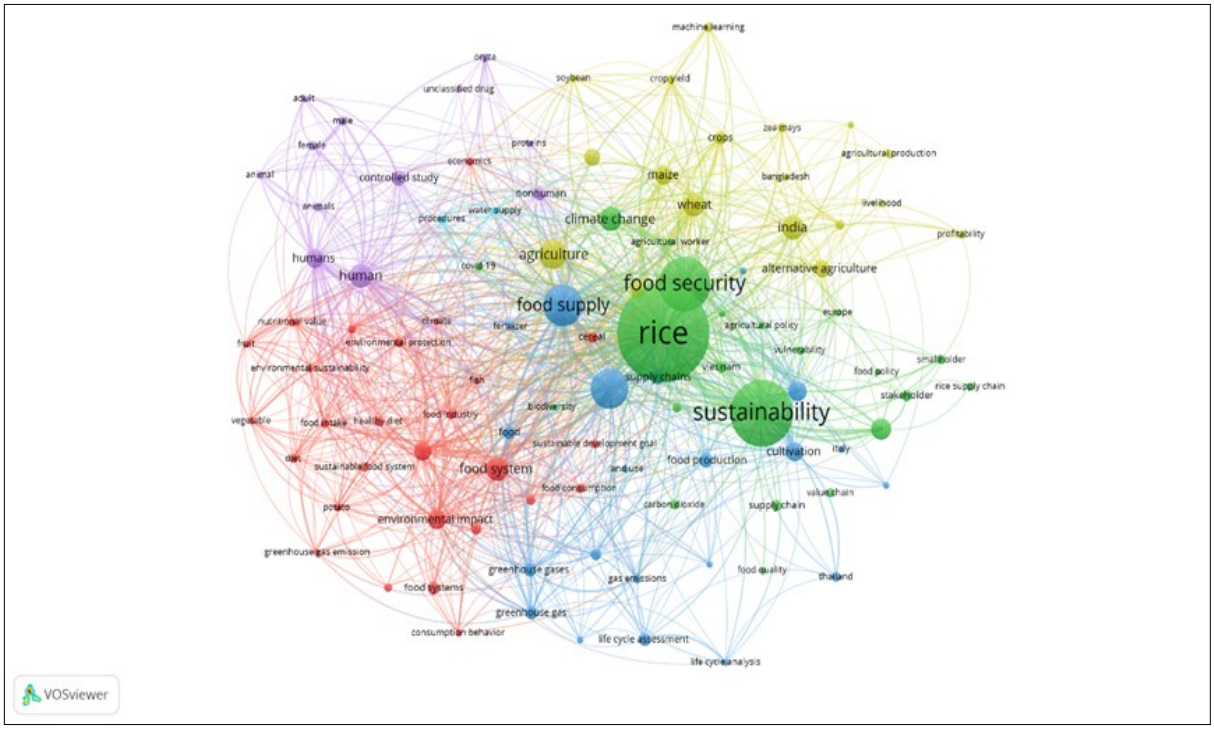

Fig. 4. Co-occurrence of Keywords on rice-based sustainable food systems research.

purple cluster had 12 keywords encompassing human, humans, controlled study and non-human. The light blue cluster had only 2 keywords, such as procedures and water supply.

Content analysis

Following the bibliometric analysis, content analysis was conducted to identify research gaps and inform future research directions. In this study, content analysis was based on the co-occurrence of terms extracted from the titles, abstracts and keywords of the selected research articles. For normalisation, the default association strength method in VOSviewer was applied, with a minimum threshold of 20 occurrences per term, indicating that each term appeared in at least 20 publications within the Scopus dataset. The threshold of 20 was selected to balance inclusiveness and analytical clarity. Lower thresholds generated fragmented and noisy networks with weakly connected terms, while higher thresholds excluded thematically meaningful but moderately represented concepts. The analysis yielded four distinct research clusters (Fig. 5). The size of each node represents the frequency of term occurrence within the research themes, with larger nodes indicating higher frequencies. For instance, terms such as food, product, value, consumption, diet and consumer are more prevalent in the red cluster, whereas the green cluster is characterised by terms including crop, yield, use, scenario, challenge variety, water, profitability, reduction and rice straw. The blue cluster contains food security, supply chain, resilience, stakeholder, COVID, community, rice supply chain and pandemic. The yellow cluster has adoption and transition. Furthermore, the overlay visualisation (Fig. 6) indicates that recent rice-based sustainable food system research has increasingly focused on themes such as challenge, adoption, transition, sustainable food system, supply chain and price. These four clusters provided the analytical framework for the subsequent in-depth, cluster-wise synthesis of themes, methods and sustainability pathways in rice-based food systems.

Cluster 1: Consumer behaviour, dietary choices and environmental implications

Research clustered under consumer and diet-oriented themes highlights a growing recognition that sustainability outcomes in rice-based food systems are strongly mediated by consumption patterns rather than production alone. Several studies emphasise that rice remains central to food consumption due to its affordability and cultural embeddedness, yet its environmental footprint, particularly in relation to greenhouse gas emissions, has attracted increasing scholarly attention (34–36). A consistent pattern across multiple articles is the tension between environmental performance and consumer preferences. While environmentally sustainable food products and alternative protein sources are frequently discussed, studies show that price sensitivity and perceived value continue to shape consumer decisions, often limiting the uptake of more sustainable rice-based products (34, 37, 38). This reinforces the idea that sustainability transitions at the consumption level must align with economic accessibility. Dietary studies further suggest that protein diversification within rice-based diets, including plant-based or blended products, can lower environmental impacts without compromising nutritional outcomes (36, 39, 40). However, these benefits are contingent on consumer acceptance, awareness and market availability, highlighting the interdependence between food system actors. Collectively, Cluster 1 studies frame rice-based sustainability as a consumer–environment nexus, where dietary behaviour, product innovation and environmental outcomes are inseparably linked (35, 38, 41). This body of work expands the sustainability discourse beyond yield and production efficiency toward value-driven consumption systems.

Cluster 2: Crop management, resource constraints and economic trade-offs

Cluster 2 captures the technical and economic core of rice-based food systems, with strong emphasis on crop performance, water use, residue management and profitability. Across the reviewed studies, water scarcity emerges as a dominant constraint, with multiple articles demonstrating that yield stability is highly sensitive to irrigation practices and water-use efficiency (34, 42–44). Scenario-based analyses are widely employed to evaluate alternative production strategies, revealing that

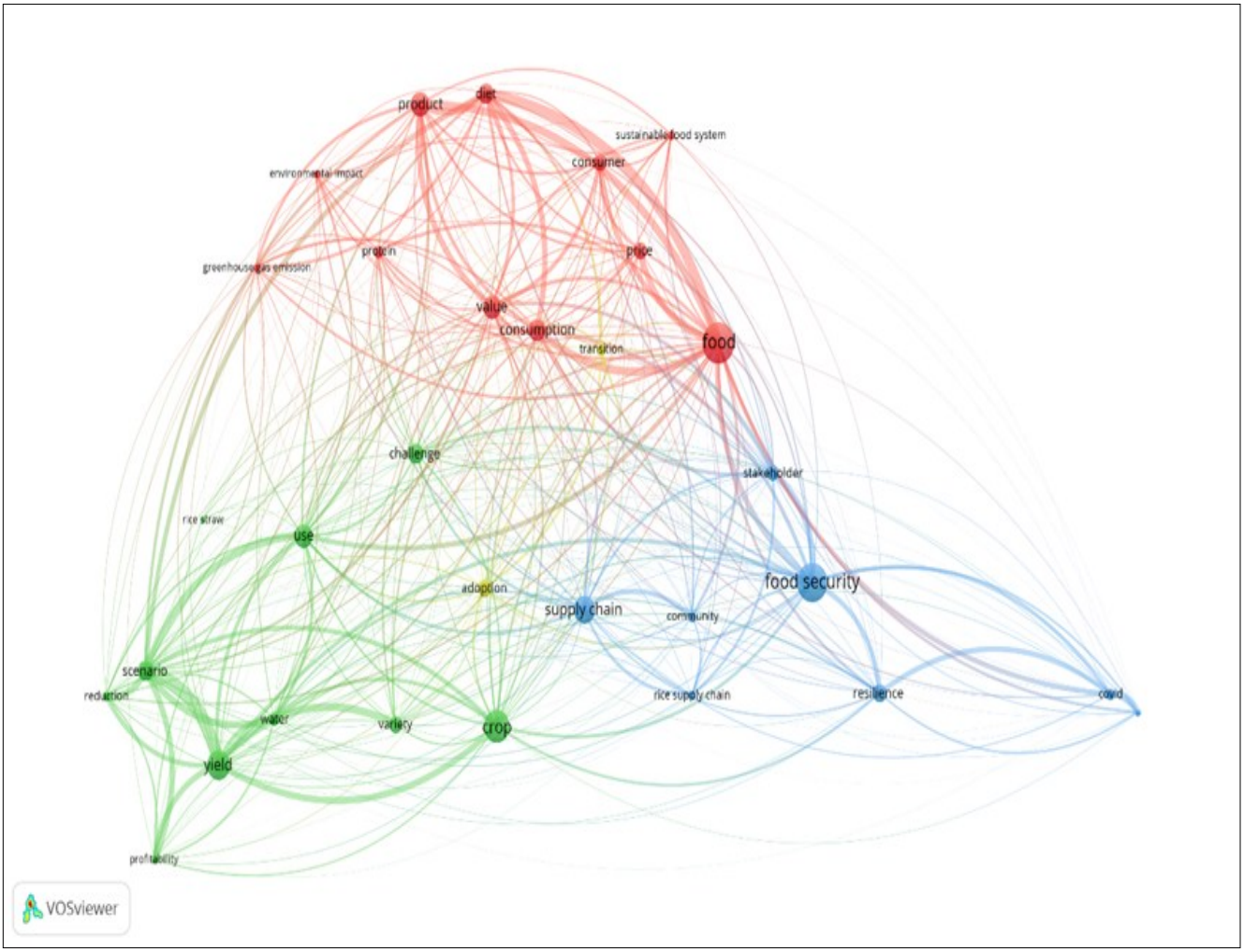

Fig. 5. Content co-occurrence analysis on rice-based sustainable food systems research.

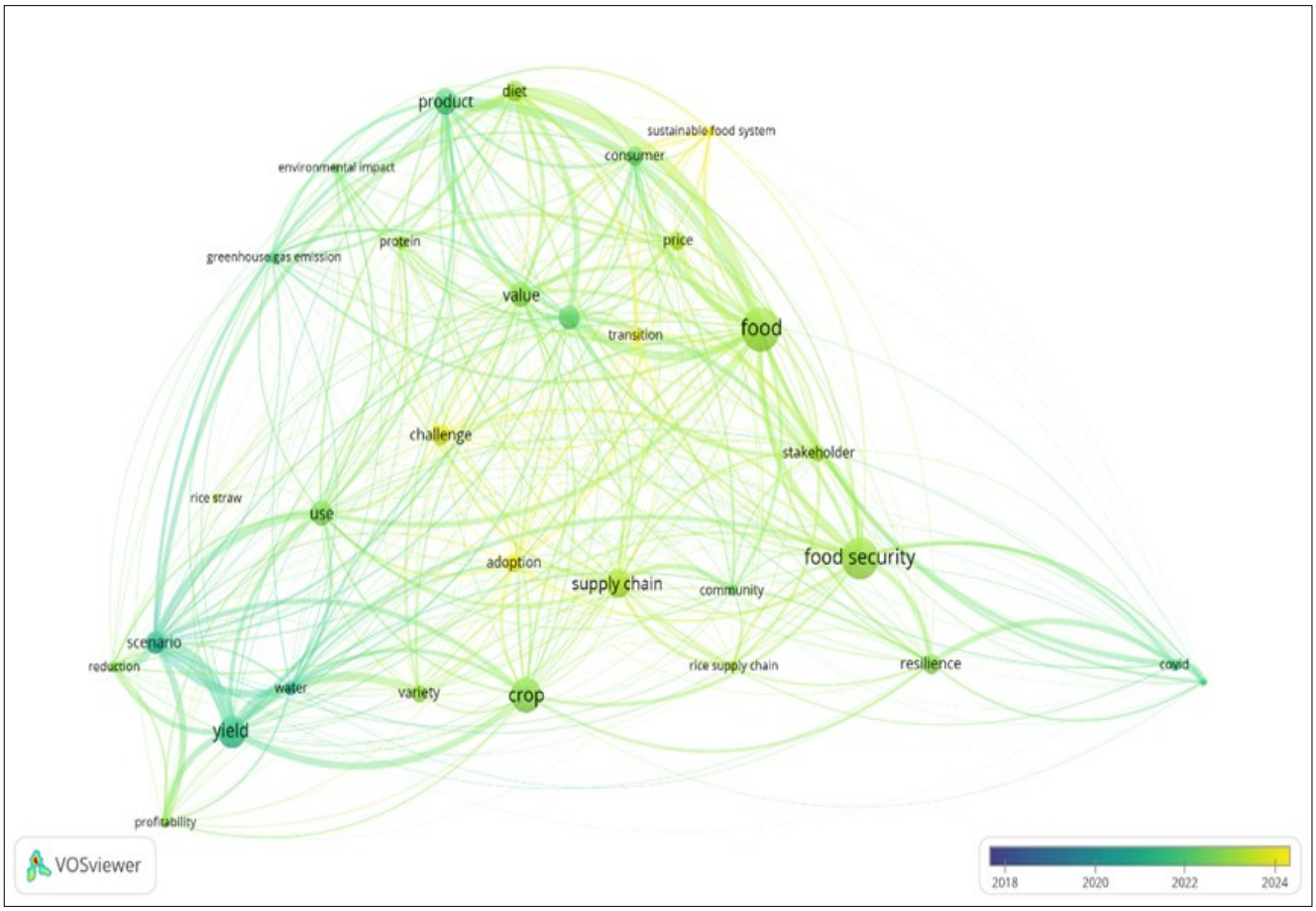

Fig. 6. Overlay visualisation of content co-occurrence analysis on rice-based sustainable food systems research.

resource-saving practices often involve trade-offs between yield, cost and risk (37, 45). For instance, reduction in water or input use may slightly lower yields but can enhance long-term profitability through cost savings and risk mitigation. Rice straw management is another recurring theme. Several articles document the environmental consequences of conventional straw burning and explore alternative uses, such as incorporation, mulching, or value-added applications (42, 43, 46). These alternatives are shown to reduce emissions but may increase labour or management complexity, underscoring the multidimensional nature of sustainability decisions. Varietal selection also features prominently, with findings indicating that yield performance, water requirements and economic returns vary substantially across rice varieties, reinforcing the importance of context-specific solutions (41, 44, 45). Overall, Cluster 2 studies portray sustainability as a negotiation between productivity, environmental limits and farm-level profitability, rather than a singular optimisation goal.

Cluster 3: Food security, resilience and supply chain dynamics

Cluster 3 reflects a more systemic perspective, focusing on food security and resilience across economic, institutional and supply chain dimensions, particularly under external shocks such as the COVID-19 pandemic. Multiple studies show that although rice supply chains proved more resilient than many other food systems, disruptions in logistics, labour availability and market access were widely observed (37, 43, 47). Food security impacts are reported at both household and community levels, with findings indicating that supply chain interruptions translated into price volatility and access constraints, especially for vulnerable populations (35, 38, 47). These effects were unevenly distributed, reflecting differences in institutional capacity and infrastructure. Stakeholder coordination emerges as a critical determinant of resilience. Strong linkages among farmers, traders, processors and public institutions enabled quicker recovery and adaptation during crisis periods (43, 45). Conversely, fragmented supply chains were more susceptible to prolonged disruptions. Importantly, Cluster 3 studies conceptualise resilience not merely as the ability to withstand shocks but as the capacity to adapt and reorganise, integrating lessons from pandemic-induced stress into longer-term food system planning (41, 46, 47). This shifts the narrative from short-term crisis management to structural resilience-building in rice-based food systems.

Cluster 4: Adoption and transition toward sustainable rice systems

Cluster 4 synthesises findings related to adoption and transition processes, serving as a connective thread across production, consumption and governance dimensions. Across the reviewed articles, adoption of sustainable practices is shown to be gradual, uneven and highly context-dependent (39, 40). Several studies indicate that economic risk, uncertainty and limited institutional support slow adoption, even when sustainability benefits are well established (37, 45). Transition pathways are often incremental, involving partial or experimental adoption rather than wholesale transformation (48). External shocks such as climate stress or market disruptions are frequently identified as catalysts for transition, prompting reassessment of existing practices and encouraging experimentation with alternative systems (39, 43). However, sustained transition depends on perceived long-term benefits and alignment with local socio-economic conditions. Cluster 4 findings underscore that sustainability transitions in rice-based food systems are not purely technical shifts, but system-wide transformations involving behavioural change, learning and institutional adaptation (40, 44). Adoption, therefore, functions as both an outcome and a process within the broader sustainability landscape.

Adoption and transition dynamics are shaped not only by farm-level decisions but also by institutional and policy environments. Access to extension services, credit, subsidies and stable market incentives significantly influences the uptake of sustainable practices. Where policy frameworks provide risk-sharing mechanisms or price support, farmers are more willing to adopt resource-efficient technologies. In contrast, fragmented institutional support and policy inconsistency slow transitions despite available technical solutions. These patterns indicate that sustainability transitions are embedded within governance and policy structures rather than driven solely by technological feasibility. Moreover, transition pathways are often non-linear and path-dependent, requiring coordinated action among research institutions, markets and policymakers. Adoption, therefore, represents a systemic transformation shaped by institutional learning and policy coherence.

Integrated perspective across all clusters

When considered collectively, rice-based sustainable food systems operate as complex, interconnected socio-ecological systems. Consumer behaviour (Cluster 1), production constraints (Cluster 2), supply chain resilience (Cluster 3) and adoption dynamics (Cluster 4) are deeply interlinked, with feedback across scales and actors. Rather than converging on a single pathway, the literature documents multiple, context-specific sustainability trajectories, shaped by economic realities, environmental pressures and institutional capacities. This integrated evidence base reinforces the value of a scientometric and cluster-driven approach, as adopted in this study, for capturing the diversity and evolution of research on rice-based sustainable food systems. By structuring the literature into four interrelated clusters, this study offers a conceptual bridge between previously fragmented research streams. Rather than treating production, consumption, resilience and transition as isolated domains, the framework reveals their interdependencies and feedback loops within rice-based food systems. This integrative perspective advances existing reviews by situating rice sustainability within a dynamic, multi-scalar systems transition lens.

These clusters are not discrete analytical compartments but mutually reinforcing system components connected through feedback dynamics. Production practices (Cluster 2) influence environmental performance, resource use and product attributes, which shape consumer perceptions and dietary choices (Cluster 1). Consumer demand and market preferences, in turn, generate signals that influence farm-level decisions and technology uptake. Supply chain resilience (Cluster 3) mediates these interactions by determining how shocks, price volatility and institutional responses affect both producers and consumers. Adoption and transition dynamics (Cluster 4) operate across all clusters, linking behavioural change, institutional support and policy coherence to broader system transformation. Taken together, these cross-cluster feedbacks illustrate that rice-based sustainable food systems function as adaptive, multi-level socio-ecological systems rather than linear production-consumption chains. This perspective highlights the importance of policy alignment and institutional coordination in managing trade-offs and reinforcing

synergies across system components. It also underscores that sustainability transitions are shaped by cumulative adjustments across governance, markets and social practices rather than isolated technical interventions.

Methods used in rice-based sustainable food system research

The methodological landscape of research on rice-based sustainable food systems reflects a diverse but uneven mix of quantitative, qualitative and modelling approaches, shaped largely by disciplinary boundaries and research objectives. Overall, the methods employed align closely with the thematic clusters identified through scientometric analysis, reinforcing the coherence between research questions and analytical techniques.

Environmental assessment and consumption studies: Use of indicators and comparative analysis

Studies aligned with Cluster 1 predominantly employ indicator-based assessments, comparative analyses and secondary data evaluation. Environmental impacts such as greenhouse gas emissions are commonly quantified using established metrics or life-cycle-informed indicators (34–36). Consumer-focused studies often rely on descriptive statistical analysis, comparative evaluations of dietary patterns, or conceptual synthesis, rather than experimental designs (37, 38, 41). These methods are effective for identifying associations between consumption patterns and sustainability outcomes, but are less suited to establishing causality. Notably, few studies combine environmental assessment with primary consumer data collection, suggesting a methodological gap between environmental modelling and behavioural analysis. This reinforces the observed separation between production and consumption research streams.

Dominance of quantitative and model-based approaches in production-oriented studies

A substantial proportion of the reviewed studies in Cluster 2 rely on quantitative modelling, scenario analysis and statistical evaluation. These methods are frequently used to simulate alternative management practices, assess yield responses and evaluate resource-use efficiency under varying conditions (34, 42–45). Scenario-based modelling emerges as a particularly prominent methodological choice. Several studies employ simulation models or comparative scenarios to explore the impacts of water-saving practices, varietal changes, or residue management strategies on yield and profitability (34, 37, 45). This reflects a strong tradition within agronomic and environmental research to address sustainability through counterfactual analysis, enabling researchers to examine trade-offs without long-term field experimentation. However, while these methods provide robust insights into technical feasibility, they often operate under controlled assumptions, limiting their ability to capture behavioural, institutional, or market-driven dynamics. This methodological pattern mirrors the thematic focus of Cluster 2, where biophysical optimisation remains central.

Supply chain and resilience studies: Increasing use of descriptive and system-level approaches

Research associated with Cluster 3 exhibits greater methodological diversity. Several studies adopt descriptive, qualitative, or mixed-method approaches, particularly when examining pandemic-induced disruptions and stakeholder responses (37, 43, 47). Case study analysis, stakeholder-based assessments and system-level descriptions are commonly used to capture the complexity of supply chain dynamics during COVID-19 and other shocks (45, 47). These approaches allow for contextual richness and institutional insight, which are difficult to obtain through purely quantitative models. However, the reliance on descriptive methods also limits cross-study comparability and generalisation. Few articles integrate quantitative indicators of resilience or employ network-based or agent-based modelling, suggesting that supply chain resilience research remains methodologically emergent within the rice-based food system literature.

Adoption and transition research: Conceptual and exploratory methodologies

Studies addressing Cluster 4 primarily employ conceptual frameworks, exploratory analyses and synthesis-based approaches (34, 39, 40). Rather than measuring adoption through longitudinal or experimental designs, these studies often infer transition dynamics from observed patterns, scenario outcomes, or contextual analysis. This methodological orientation reflects the inherent complexity of transition research, which spans technical, social and institutional dimensions. However, the findings also reveal a lack of longitudinal and behavioural modelling approaches capable of capturing adoption trajectories over time. As a result, adoption is frequently treated as an outcome rather than a dynamic process, limiting insights into feedback mechanisms, learning effects and path dependency.

Cross-cluster methodological fragmentation

A key insight emerging from the methods analysis is the fragmentation of methodological approaches across clusters. Production-oriented studies favour modelling and simulation; consumption studies rely on indicators and comparative analysis; supply chain studies employ descriptive and qualitative methods; and transition research remains largely conceptual. Only a limited number of articles attempt to integrate methods across these domains (39, 45). This fragmentation mirrors the thematic separation observed in the content analysis and suggests that methodological silos continue to shape the research landscape.

Key interventions, practices and technologies as pathways toward rice-based sustainable food systems

The synthesis of key interventions across the reviewed studies reveals that pathways toward rice-based sustainable food systems are multi-dimensional, spanning production technologies, resource-use practices, value-chain innovations and institutional or behavioural interventions. Rather than a single dominant solution, the literature documents a portfolio of complementary interventions, reflecting the complexity of sustainability challenges in rice systems.

Production-level interventions and resource-efficiency pathways

A substantial share of the reviewed studies emphasises production-level interventions aimed at improving resource efficiency while maintaining or enhancing productivity. Practices such as alternate wetting and drying (AWD), improved water management and water-saving cultivation methods. These are repeatedly highlighted as central sustainability pathways (49–51). These interventions are consistently linked to reductions in water use and greenhouse gas emissions, while offering scope for yield stability under resource constraints. Similarly, improved and stress-tolerant rice varieties, including hybrid and climate-smart cultivars, emerge as a widely cited intervention (45, 50, 51). These varietal interventions are presented not merely as yield-enhancing technologies but as adaptation tools, enabling farmers to cope with

climatic variability, water scarcity and productivity challenges. The recurring emphasis on varietal improvement suggests that genetic and agronomic innovations remain a foundational pillar of sustainable rice systems.

Residue management and circular use of rice straw

Several studies identify rice straw management as a critical intervention pathway, particularly in addressing environmental externalities associated with open burning (46, 49). Interventions such as straw incorporation, alternative uses and residue recycling are framed as mechanisms for emission reduction and resource circularity. However, the findings also indicate that these practices often require complementary measures such as labour availability, mechanisation, or institutional support to be practically viable at scale.

Post-harvest, processing and value-chain interventions

Beyond production, the reviewed literature highlights post-harvest and processing innovations as underexplored yet impactful sustainability pathways. Technologies such as grain quality enhancement systems and improved parboiling methods are shown to improve product quality, reduce losses and increase value addition within rice supply chains (51, 52). These interventions connect sustainability with market competitiveness and consumer acceptance, reinforcing the idea that value-chain efficiency is integral to sustainable food systems. Economic interventions related to price, value and market incentives also feature prominently. Studies indicate that sustainability-oriented technologies are more likely to be adopted when they are aligned with profitability and consumer willingness to pay (52, 53). This underscores the importance of embedding technological interventions within supportive market and incentive structures.

Institutional, stakeholder and governance-related interventions

A cross-cutting theme across multiple articles is the role of institutional and stakeholder-driven interventions. Stakeholder coordination, participatory approaches and policy support mechanisms are frequently cited as enabling conditions for the successful implementation of technical practices (50, 53). These non-technical interventions act as connective pathways, linking farm-level practices with broader system-level sustainability outcomes. Several studies suggest that without institutional backing, such as extension services, training, or coordinated governance, technological interventions alone may yield limited or short-lived benefits (45, 53). This highlights that sustainability pathways are not purely technological but are co-produced through social and institutional processes.

Adoption-oriented interventions and transition pathways

Interventions aimed at facilitating adoption and transition emerge as an integrative theme across the dataset. Capacity building, awareness creation and gradual transition strategies are repeatedly emphasised as necessary to move rice systems toward sustainability (49, 51). Rather than advocating rapid transformation, the literature points toward incremental, context-specific transitions, where interventions are adapted to local constraints and opportunities. Importantly, several studies indicate that bundled interventions combining improved varieties, resource-efficient practices and institutional support are more effective than isolated measures (45, 50). This reinforces the view that sustainable rice-based food systems evolve through interlinked intervention pathways, rather than single technological fixes.

Synthesis across interventions

Taken together, the reviewed studies demonstrate that pathways toward rice-based sustainable food systems are plural, layered and context-dependent. Production technologies, residue management practices, value-chain innovations and institutional interventions operate at different system levels but are mutually reinforcing. The evidence suggests that sustainability outcomes are strongest where technical efficiency, economic incentives and governance mechanisms converge, offering a coherent pathway for system-wide transition.

Conclusion

This systematic literature review mapped the global research landscape on rice-based sustainable food systems using scientometric and content analysis. The findings reveal a rapidly expanding but thematically and methodologically fragmented field, with research clustered around consumption and environmental impacts, production and resource management, food security and supply chain resilience and adoption and transition processes. Key gaps include limited integration across system components, methodological imbalance, scarcity of longitudinal and mixed-methods studies and underrepresentation of emerging rice-producing regions, particularly in Africa and Latin America. Future research should adopt integrated system-level frameworks, strengthen mixed and longitudinal methods and promote cross-regional and interdisciplinary collaboration to advance resilient and sustainable rice-based food systems.

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Authors' contributions

JA carried out the conceptualisation of the study, developed the methodology, conducted the investigation, performed data curation and formal analysis, prepared visualisations and drafted the original manuscript. CK contributed to the validation and supervision of the study and critically reviewed and edited the manuscript. All authors read and approved the final manuscript.

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