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## DECADAL TRENDS IN GLOBAL RICE SALINITY RESEARCH: BIBLIOMETRIC INSIGHTS

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### ABSTRACT

Soil salinity is one of the most devastating abiotic stresses affecting global rice production, especially in the paddy growing tracts of South and Southeast Asia, with an estimated loss of 12 billion USD annually. This study aims to assess the trends in global salinity research in rice and to identify the key gaps. A comprehensive bibliometric analysis was conducted from 1980 to 2025 using the Scopus database, and a total of 1507 articles were retrieved. This data was analyzed and visualized using VOSviewer and R- Bibliometrix by generating co-occurrence and citation networks. The results showed an exponential growth in the number of publications over the last two decades. India and China are the top contributing nations to salinity research, which is significantly supported by the International Rice Research Institute (IRRI), Philippines. This study reveals that the published literature is categorized into four clusters: Crop response to salinity, breeding strategies, physiological mechanisms, and omics approaches. These insights provide researchers to address the gaps in salinity research and aid in the development of further studies.

**Keywords :** Rice, *Oryza sativa*, Bibliometric analysis, Scopus, VOSviewer, salinity tolerance.

### Introduction

Rice is the predominant and preferred crop in many regions because of its ability to grow in stagnant water. Rice has an advantage over other crops in salt-affected agroecosystems because it thrives in waterlogged conditions (Singh *et al.* 2024). Rice sensitivity to salinity varies with developmental stage, with seedling and reproductive stages being the most vulnerable. Research indicates that a 1 dS/m increase in salinity above the threshold (3 dS/m) reduces yield by 12 percent (Singh *et al.* 2021). Soil salinity is one of the most serious abiotic stresses affecting global rice production, particularly in the paddy-growing regions of South and Southeast Asia. Salinization of agricultural soils in the Indian saline lowlands and coastal regions has a major impact on rice cultivation. Asia accounts for 91% of the rice area and contributes 7% of the salt-affected area in the world (154 million

hectares), with South and Southeast Asia predominant. India has a significant share of these salt-affected areas, with 6.74 million hectares (Mha) reported as salt-affected. High soil salinity is estimated to affect one-fifth of global rice production. The annual economic impact is significant, with annual losses totaling up to 12 billion USD globally (FAO 2024).

Over the decades, salinity research in rice has progressed from basic physiological studies to more detailed molecular research. This field has made significant progress in improving salinity resilience in rice by identifying various Quantitative Trait Loci (QTLs) linked to salinity tolerance and combining them with traditional breeding approaches to develop widely salinity-tolerant varieties. However, research in this field still has significant gaps. Studies have focused mainly on seedling-stage salinity tolerance, rather than on the reproductive stages, which determine

the actual yield of the rice crop under stress conditions. The success of conventional and molecular breeding approaches in the past was limited due to their emphasis on a single mechanism (Solis *et al.*, 2020).

Multiple countries and various institutes are publishing their work on salinity research. This has led to a significant increase in literature. To gain an overall idea of the extent of work on salinity research in rice, it is crucial to gather a large amount of data. Bibliometric analysis is a systematic approach to analyzing various areas of scientific research using bibliographic and metadata derived from the published literature (Zhang *et al.*, 2023). Relationships among publications can be identified by analyzing citations, authorship patterns, and co-occurrences, thereby enabling us to identify research trends, influential authors, institutions, and other key stakeholders. Furthermore, bibliometric analysis helps assess the research productivity of various institutions and countries and helps plan research by identifying existing areas of research and minimizing duplication.

Effective visualization of metadata from bibliometric analysis is crucial for identifying trends in our research area. In this paper, we employed VOSviewer, a software that applies clustering techniques to visualize our data. VOSviewer is widely used for visualizing bibliographic networks derived from multiple databases. It facilitates the construction and visualization of bibliometric networks by clustering at aggregate levels. Additionally, it offers overlay and density visualizations (Van Eck and Waltman, 2017).

Thus, in this study, we conducted an extensive bibliometric analysis of the published literature in the last four decades using the Scopus database and visualization tools like VOSviewer and RStudio. We also examined the citation and co-occurrence networks to visualize the shift in the research publications and identify the gaps in the existing research trend.

## Materials and Methods

Scopus is a scientific publication database that has a wide collection of peer-reviewed literature. Scopus was selected due to its large collection of scientific literature, and it facilitates the collection of data and bibliometric analysis (Deng and Romainoor, 2022). An extensive search for relevant publications related to salinity tolerance in rice was conducted during the month of September 2025. The search string used in

the Scopus database for analysis: TITLE-ABS-KEY (salinity AND tolerance AND in AND rice) AND PUBYEAR > 1980 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO (SUBJAREA, "BIOC")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "bk") OR LIMIT-TO (DOCTYPE, "ch")) AND (LIMIT-TO (LANGUAGE, "English")). Unrelated keywords were removed from articles to improve their relevance. This generated 1507 publications. The study included articles, book chapters, conference papers, and review papers published in English between 1980 and 2025. Bibliographic data comprising author names, article titles, citation counts, publication years, journal titles, volumes, issues, keywords, funding details, references, and other bibliographical information were collected. The collected data were exported in Comma-Separated Values (.csv) format, and basic analysis was done using the Scopus database.

Further comprehensive analysis of data was performed using two software packages – VOSviewer (version 1.6.20) (Van Eck and Waltman 2010, 2014; [www.vosviewer.com](http://www.vosviewer.com)) and RStudio (version 2025.09.1) (Posit 2025; <https://cran.rstudio.com/>). Bibliometric data were converted into visual maps for easier interpretation and analysis using VOSviewer. It specializes in generating aggregate-level visualizations (Van Eck and Waltman 2017) and is used to examine various relationships, such as co-authorship among researchers from different institutions and countries, keyword co-occurrence patterns, citation networks among documents (articles), authors, and journals, as well as author and journal co-citation networks, among others. Nodes in visual maps represent entities like authors, journals, and keywords; their sizes indicate frequency of occurrence, the thickness of connecting lines shows the strength of relationships, and colors indicate different clusters (Wu *et al.*, 2024). R software and R-Bibliometrix (<https://www.bibliometrix.org/home/>) were also used to perform bibliometric analysis, including the generation of tree maps, Sankey diagrams, and cross-country collaboration networks with the help of bibliographic data to visualize various research areas and global collaboration in research between countries. The workflow of the methodology adopted in this study is represented in Fig. 1.

## Results

### Trends in publications

A literature review on publication trends in the field of salinity stress in rice, spanning from 1980 to 2025, identified 1,507 papers. Over the 45-year period covered by the study, data show a remarkable shift in this field of research. According to the data, 34 documents are published annually, with an average of 1,328 citations. The influence of a research paper is often measured by its citation count, which is widely regarded as a reliable indicator in academic circles (Altaf *et al.*, 2024). The number of papers published each year ranges from 0 to 145, with citations ranging from 0 to 7164. There is a very significant positive association between the number of publications and citations (0.98) each year, indicating that years with more research publications consistently have higher cumulative citations. The study's time frame can be divided into three distinct periods: the early phase, the mid-2000s, and the modern era. In the first decade of the study (1981 to 1990), both the number of publications and the citations they received were quite low. The mid-2000s mark a notable shift, as both the number of documents published and their citations begin to increase more sharply, indicating a rise in works concentrating on this field of research. Moving into the recent decade from 2016 to 2025, the data show nearly exponential growth, with publications reaching beyond 120 per year and annual citations escalating above 7000, with a peak of 7164 in 2024. This dramatic increase is due to the rise in the number of works in this field of research.

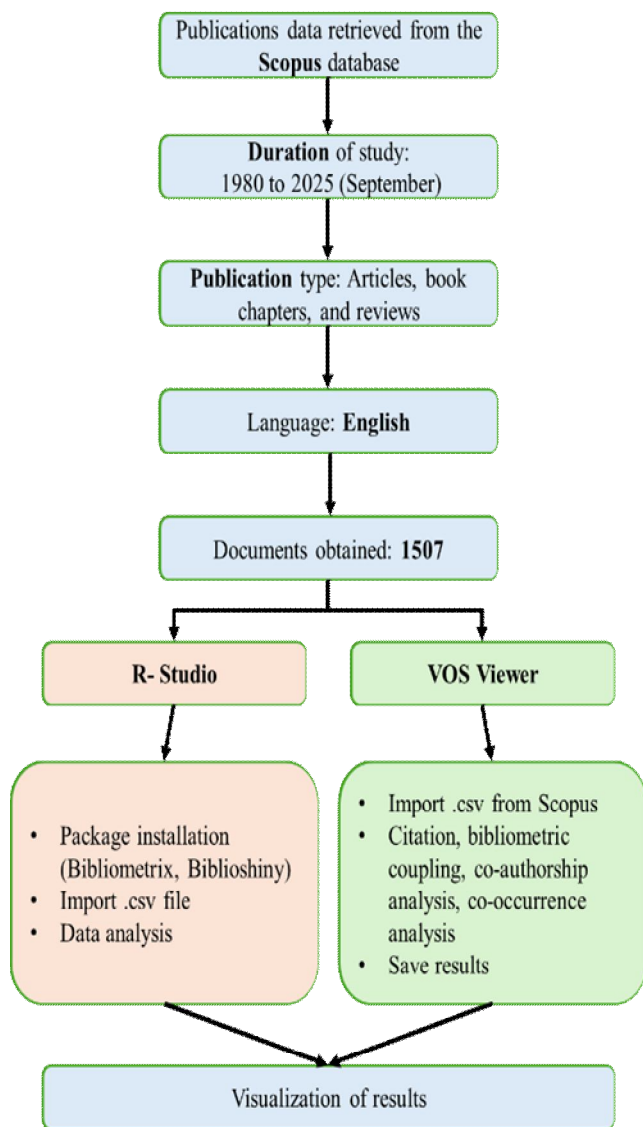


Fig. 1: Workflow of analysis

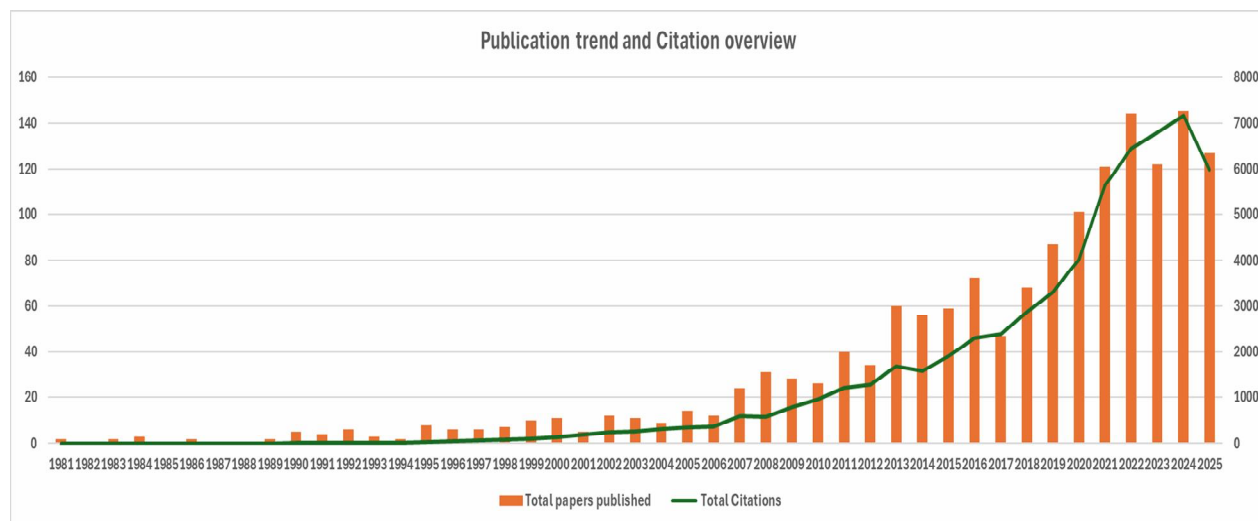


Fig. 2: Trend of publications and citations obtained each year from 1981 to 2025 (September)

**Journals**

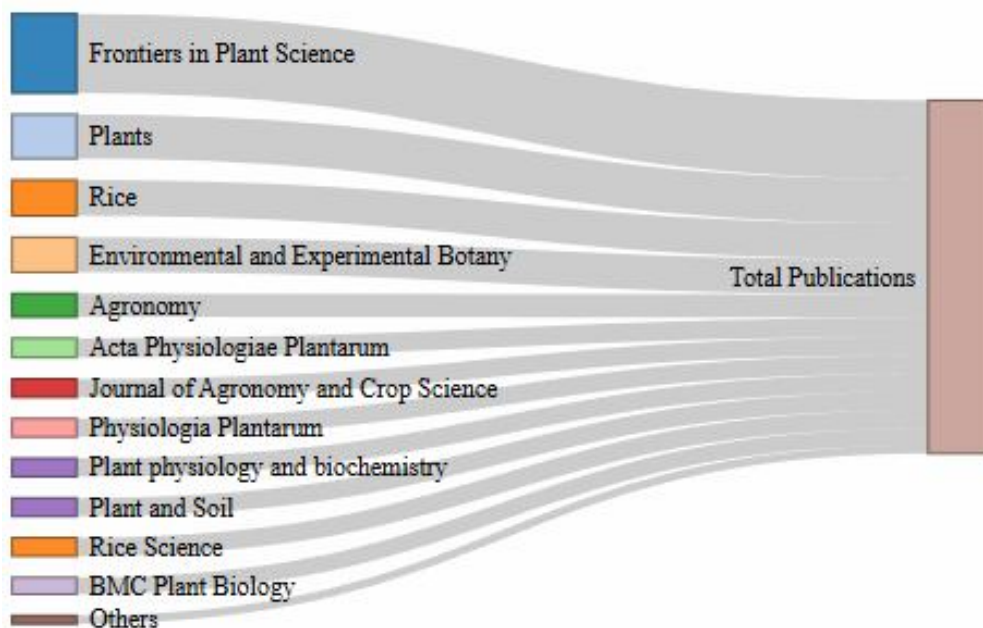
Based on the number of publications and citations in this field of study, "Frontiers in Plant Science" has a substantial lead over other journals, with 95 publications, followed by "Plants" with 53 publications, which is half the number of publications compared to the previous journal. "Frontiers in Plant Science" leads in both publications and total citations (3970). "Plants" ranks second for publications and has a substantial citation count (933). The journals with the highest number of publications are shown in Fig. 3. The extent of publications in the top 5 journals in the field of salt tolerance in rice is depicted in Fig. 4. The chart shows a consistent increase in the number of publications in recent years across the journals. From Fig. 5, it is evident that there is a steady increase in citations each year. This information facilitates researchers in selecting appropriate journals for publishing their research work.

Co-citation occurs when two papers are referenced in common citing papers (Li and Chen 2016). It reveals how various fields of research are interlinked (Zhang *et al.* 2023). Visual representation of the interrelationships between journals based on co-citation frequencies is depicted by the journal co-citation analysis map. Journals are categorized based on how often they are cited together using co-citation analysis. (Zupic and Čater 2015). Journals that are closer to each other are clustered together and are represented by the same color. It implies a higher degree of similarity in the content of published papers (Laengle *et al.*, 2018).

A citation threshold of 20 was set to create this map, allowing the inclusion of 36 article sources. The generated map reveals 4 distinct clusters. The largest of these, represented in red, comprises 9 items. This cluster highlights a significant co-citation network of journals, such as *Plant Physiology* (with a link strength of 217). The second cluster, shown in green and consisting of 9 items, features journals such as *Journal of Experimental Botany* (155) and *Annual Review of Plant Biology* (108), indicating their interconnectedness in terms of co-citations. Additionally, there are blue and yellow clusters containing 8 and 7 article sources, respectively. *Plant and soil* (with a link strength of 195), while the yellow cluster includes *Theoretical and Applied Genetics* (117) as a prominent journal.

**Table 1:** List of active journals for publications related to salinity stress in Rice

Sl.No	Journals	Publications
1	Frontiers in Plant Science	95
2	Plants	53
3	Rice	43
4	Environmental and Experimental Botany	42
5	Agronomy	28
6	Acta Physiologiae Plantarum	23
7	Journal of Agronomy and Crop Science	22
8	Physiologia Plantarum	22
9	Plant physiology and biochemistry	22
10	Plant and Soil	22
11	Rice Science	22
12	BMC Plant Biology	20



**Fig. 3:** Sankey diagram representing active journals for publications related to salinity stress in Rice generated using R-Bibliometrix

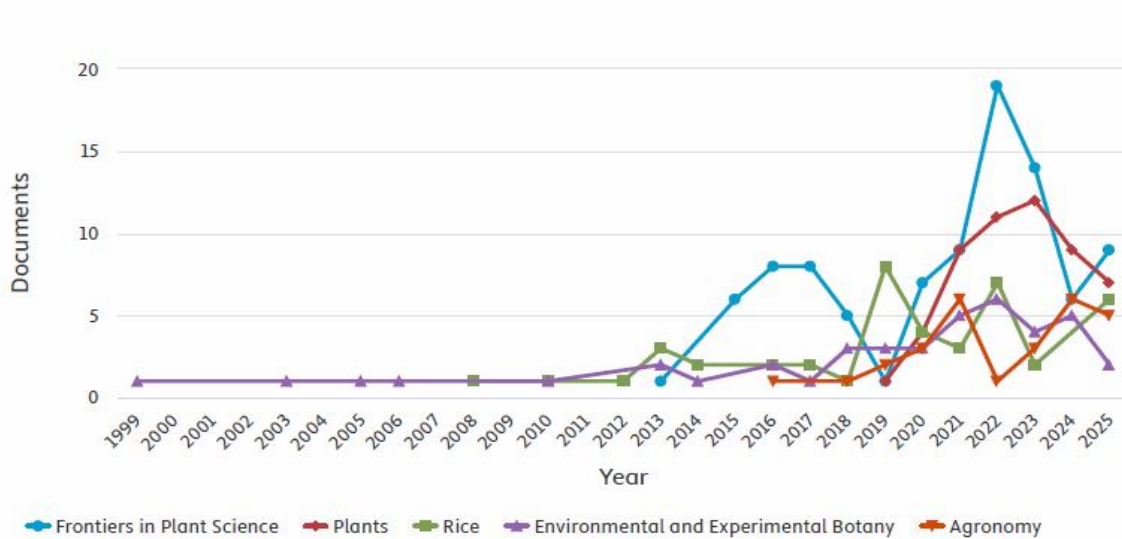


Fig. 4: Trend of documents published per journal each year, generated from Scopus

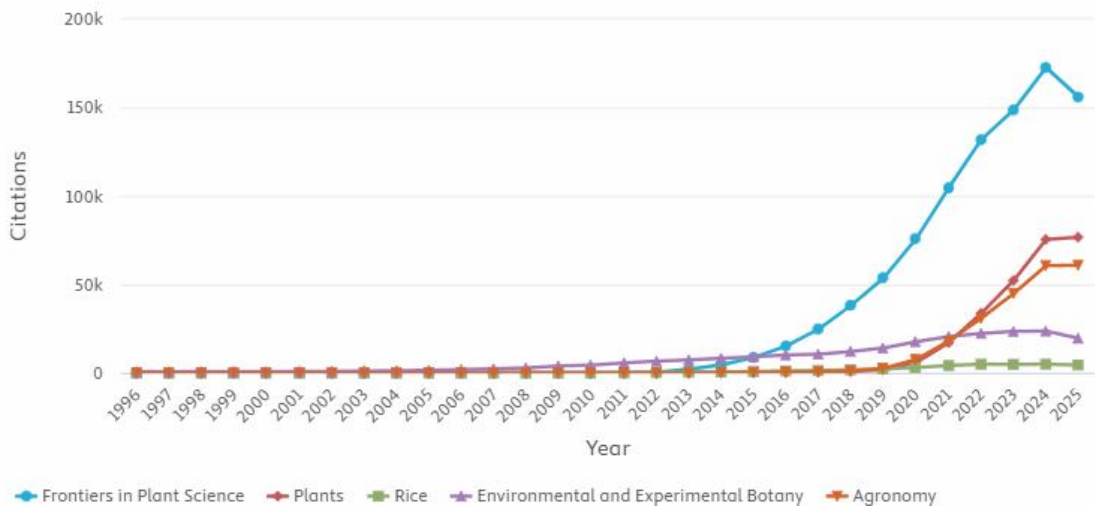


Fig. 5: Total citations obtained by each journal per year, generated from Scopus

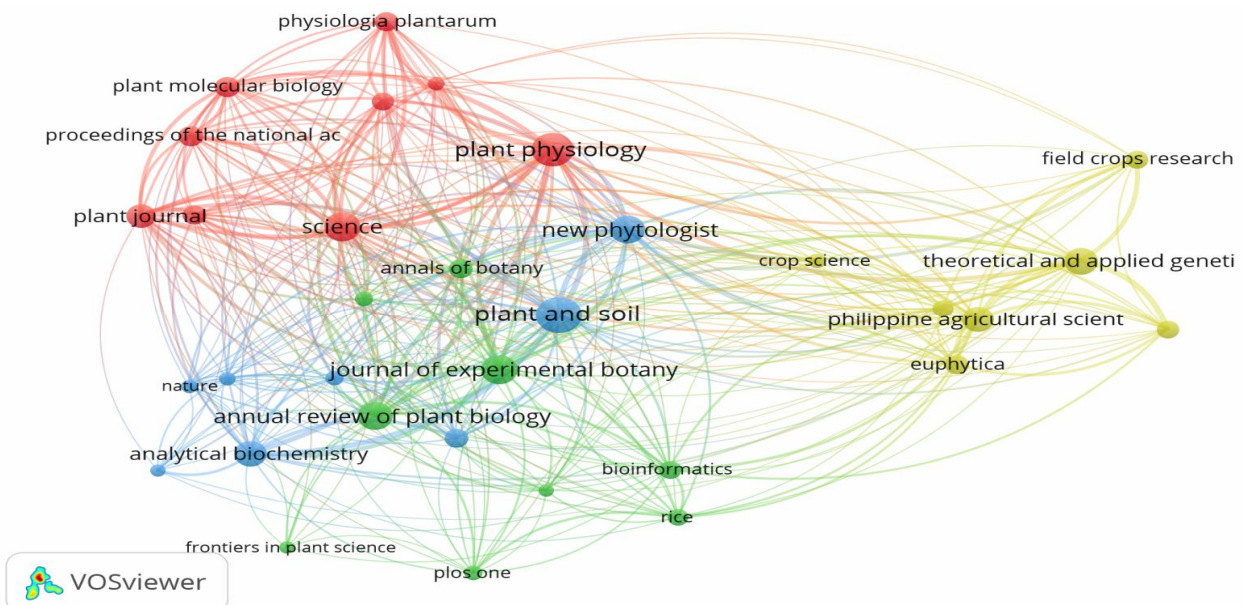
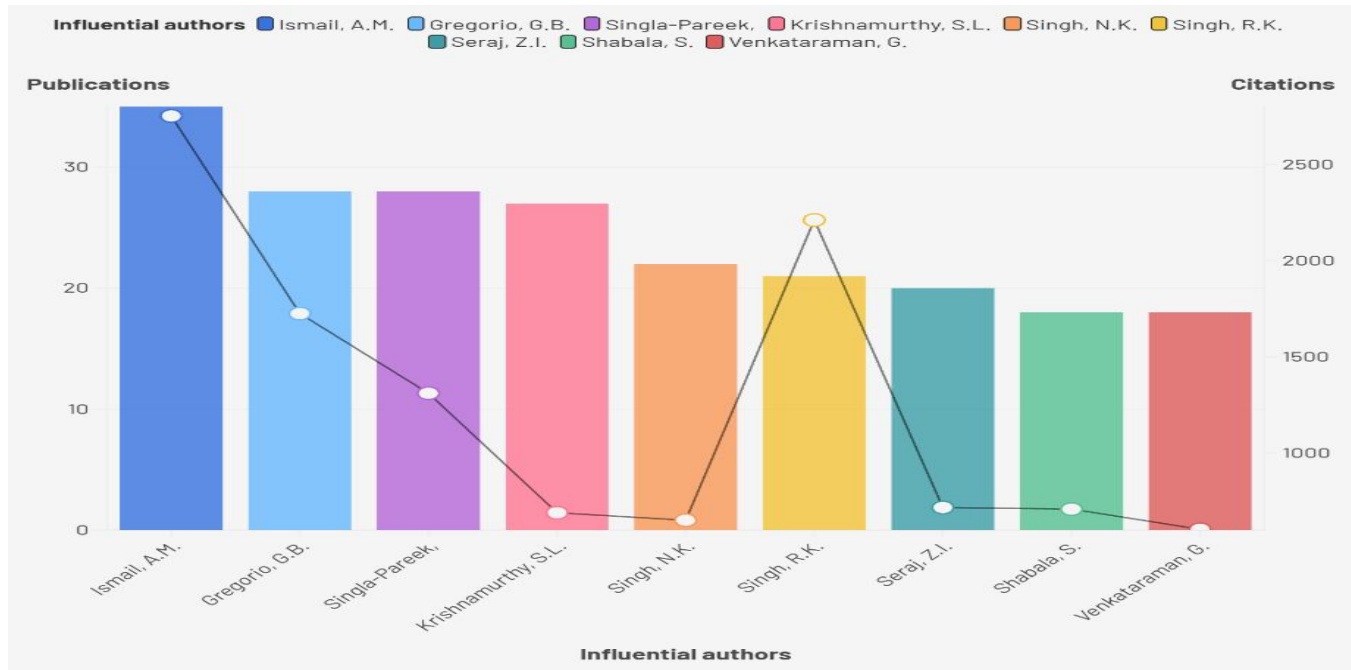


Fig. 6: Co-citation network of journals

### Influential authors and articles



**Fig. 7:** Publications and citation overview of influential authors related to salinity stress in Rice

In order to identify the key publications and authors, citation analysis was conducted under the assumption that the most cited authors and publications exert the greatest influence on the subject. The top publications, along with their respective citation counts, are detailed in Table 2. Expression of a Late Embryogenesis Abundant Protein Gene, HVA1, from Barley Confers Tolerance to Water Deficit and Salt Stress in Transgenic Rice, published by Xu *et al.* (1996), has the most citations of 863. The study provides direct evidence that late embryogenesis abundant proteins (LEA) play an important role in protecting plants from water and salinity stress, emphasizing their potential for genetic crop improvement. The second most cited article is the Comparative lipid peroxidation, antioxidant defense systems and proline content in roots of two rice cultivars differing in salt tolerance by Demiral and Turkan (2005). This research examines the notable

differences among rice cultivars regarding salinity stress response. The salt-tolerant cultivar Pokkali exhibited a superior antioxidative defense mechanism, indicated by reduced lipid peroxidation and distinct enzyme activity compared to the salt-sensitive cultivar IR-28, which showed increased oxidative damage and growth suppression.

The results of citation analysis of the prominent authors in this field are shown in Fig. 7. Ismail, A.M., leads with the highest number of publications (35) and also leads in citations. The next two positions in terms of publication count are Gregorio, G.B., and Singla-Pareek, S.L., with 28 publications each, though their citation counts are lower comparatively. Other authors, such as Krishnamurthy, S.L., and Pareek, A., have 27 and 24 publications, respectively, highlighting their prominence as well. Singh, R.K. stands out with a significant spike in citations, indicating highly influential work despite fewer publications.

**Table 2:** List of important publications related to salinity stress in Rice countries and organizations.

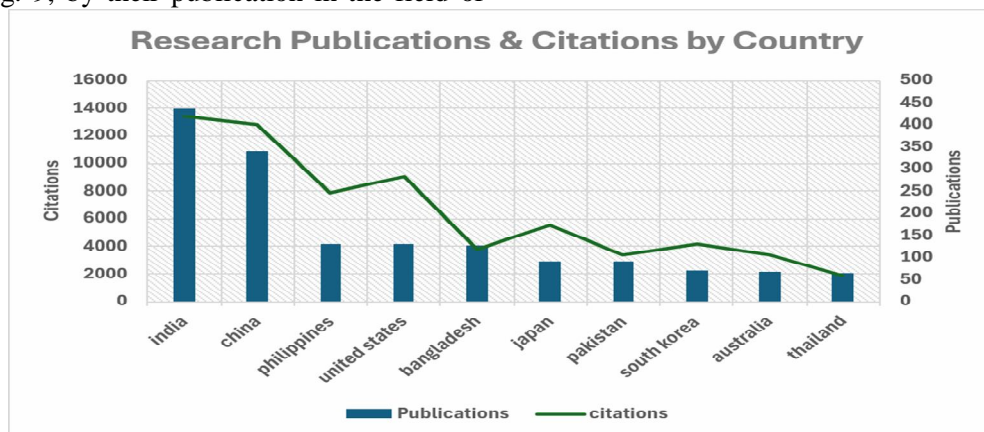
S.No.	Publications	Authors	Citations	Year
1	Expression of a Late Embryogenesis Abundant Protein Gene, HVA1, from Barley Confers Tolerance to Water Deficit and Salt Stress in Transgenic Rice	D. Xu, X. Duan, B. Wang, B. Hong, THD. Ho, R. Wu	863	1996
2	Comparative lipid peroxidation, antioxidant defense systems and proline content in roots of two rice cultivars differing in salt tolerance	Tijen Demiral, İsmail Türkan	675	2005
3	Effects of hydrogen peroxide and nitric oxide on both salt and heat stress tolerance in rice	Akio Uchida <sup>a</sup> , Andre T Jagendorf <sup>b</sup> , Takashi Hibino <sup>c</sup> , Teruhiro Takabe <sup>c</sup> , Tetsuko Takabe <sup>a</sup>	643	2002
4	Breeding for Salinity Tolerance in Plants	M. Ashraf, and Dr. Lin Wu	619	1994

5	Characterization of transcription factor gene SNAC2 conferring cold and salt tolerance in rice	Honghong Hu, Jun You, Yujie Fang, Xiaoyi Zhu, Zhuyun Qi & Lizhong Xiong	573	2008
6	Characterization of OsZIP23 as a Key Player of the Basic Leucine Zipper Transcription Factor Family for Conferring Abscisic Acid Sensitivity and Salinity and Drought Tolerance in Rice Open Access	Yong Xiang, Ning Tang, Hao Du, Haiyan Ye, Lizhong Xiong	457	2007
7	Comparative Transcriptional Profiling of Two Contrasting Rice Genotypes under Salinity Stress during the Vegetative Growth Stage	Harkamal Walia, Clyde Wilson, Pascal Condamine, Xuan Liu, Abdelbagi M. Ismail, Linghe Zeng, Steve I. Wanamaker, Jayati Mandal, Jin Xu, Xinping Cui, Timothy J. Close	427	2005
8	Characterizing the Saltol Quantitative Trait Locus for Salinity Tolerance in Rice	Michael J. Thomson, Marjorie de Ocampo, James Egdane, M. Andres Godwin Sajise, Akhlasur Rahman, Dante L. Adorada, Ellen Tumimbang-Raiz, Eduardo Blumwald, Zeba I. Seraj, Rakesh K. Singh, Glenn B. Gregorio & Abdelbagi M. Ismail	422	2010
9	Plant Growth and Development Under Salinity Stress	A. Läuchli & S.R. Grattan	411	2007
10	NaCl effects on proline metabolism in rice ( <i>Oryza sativa</i> ) seedlings	S. Lutts, V. Majerus, J.-M. Kinet	407	1999
11	Enhanced rice salinity tolerance via CRISPR/Cas9-targeted mutagenesis of the OsRR22 gene	Anning Zhang, Yi Liu, Feiming Wang, Tianfei Li, Zhihao Chen, Deyan Kong, Junguo Bi, Fenyun Zhang, Xingxing Luo, Jiahong Wang, Jinjuan Tang, Xinqiao Yu, Guolan Liu & Lijun Luo	393	2019
12	Improving Salinity Tolerance in Cereals	M. Shahbaz, & M. Ashraf	378	2013

The chart (Fig. 8) illustrates the distribution of publications and their corresponding citations across different countries in the field of salinity research in rice. The data shows a strong concentration of research work in Asian countries, notably South and Southeast Asia, where salinity is the major limiting factor in rice productivity. India dominates both metrics, with 436 publications generating 13,400 citations, standing out as an important contributor in salinity research. China ranks second with 339 publications and 12,819 citations, exhibiting higher research activity. The citation-to-publication ratio is comparable to India's.

The leading research institutions ranked as depicted in Fig. 9, by their publication in the field of

salinity research in rice. The International Rice Research Institute (IRRI) leads significantly with 122 publications, establishing itself as the most prolific research organization in this field. Following IRRI, Chinese research institutions dominate the upper rankings with higher publications, i.e., Chinese Academy of Agricultural Sciences (51 publications), Ministry of Education of the People's Republic of China (41 publications), and Chinese Academy of Sciences (41 publications). ICAR–Central Soil Salinity Research Institute, Karnal (40 publications) has also contributed significantly to salinity research in rice.



**Fig. 8:** Publications and citation overview of major countries related to salinity stress in Rice

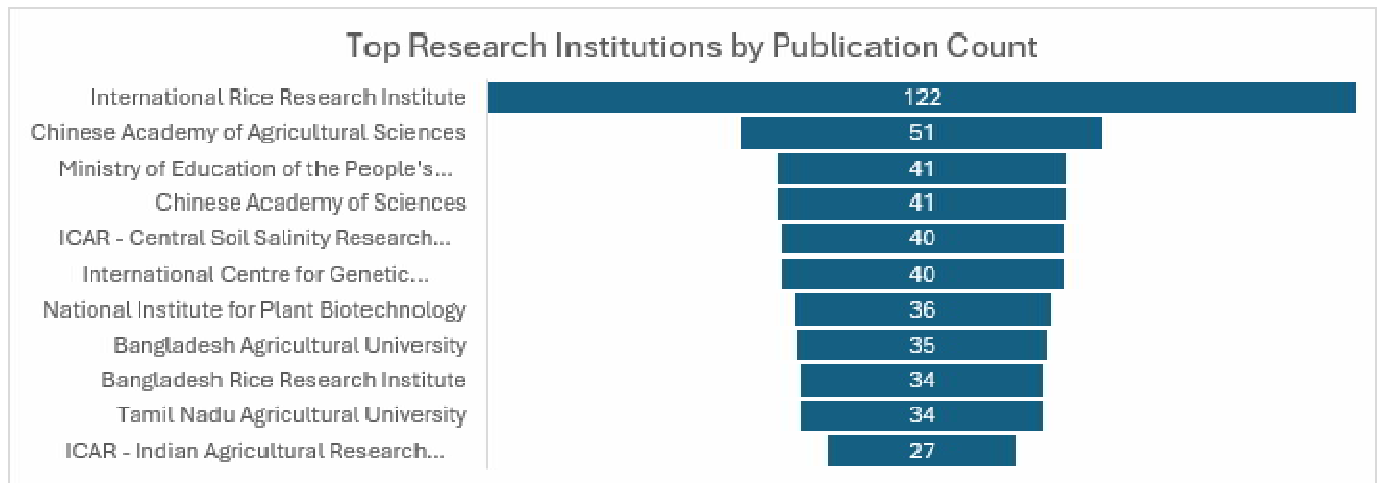


Fig. 9 : Top Research Institutions by Publication Count

**Co-authorship analysis of authors**

In order to fully understand the research collaboration, co-authorship analysis was carried out. The research associations were analyzed using links and Total Link Strength (TLS). The study identified 5910 authors by analyzing 1507 documents published between 1980 and 2025. The full counting method was used to construct the authorship network. Each link for co-authorship, co-occurrence, and bibliometric coupling has the same weight when full counting is used. The co-authorship network map depicts all

authors who have a minimum of five documents. Out of the total of 5910 authors, only 149 were able to meet the required threshold. According to Zheng *et al.* (2022), authors from the same cluster often collaborate closely or work on the same research team. The software grouped 98 authors out of 149 into 15 clusters. Cluster 1 (red) has the most authors (12), followed by Cluster 2 (green) with ten and Cluster 3 with nine. The most prolific researchers are typically displayed near the center of the network, with the shortest distance.

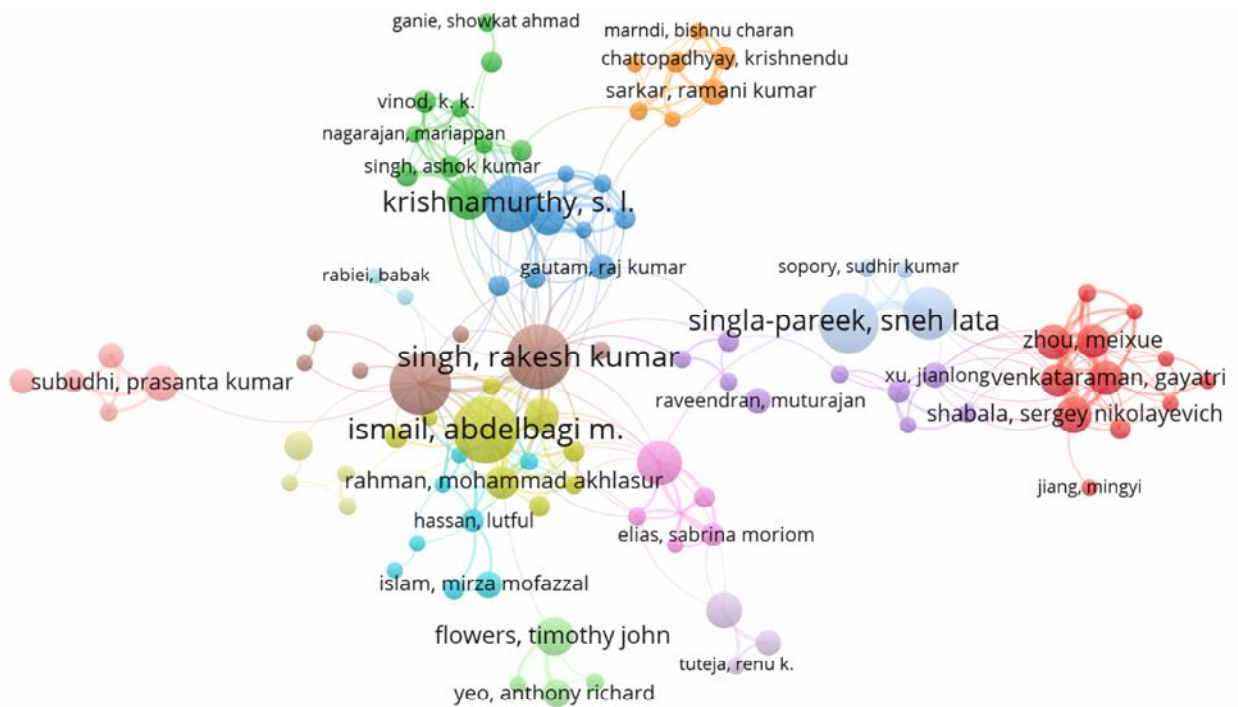
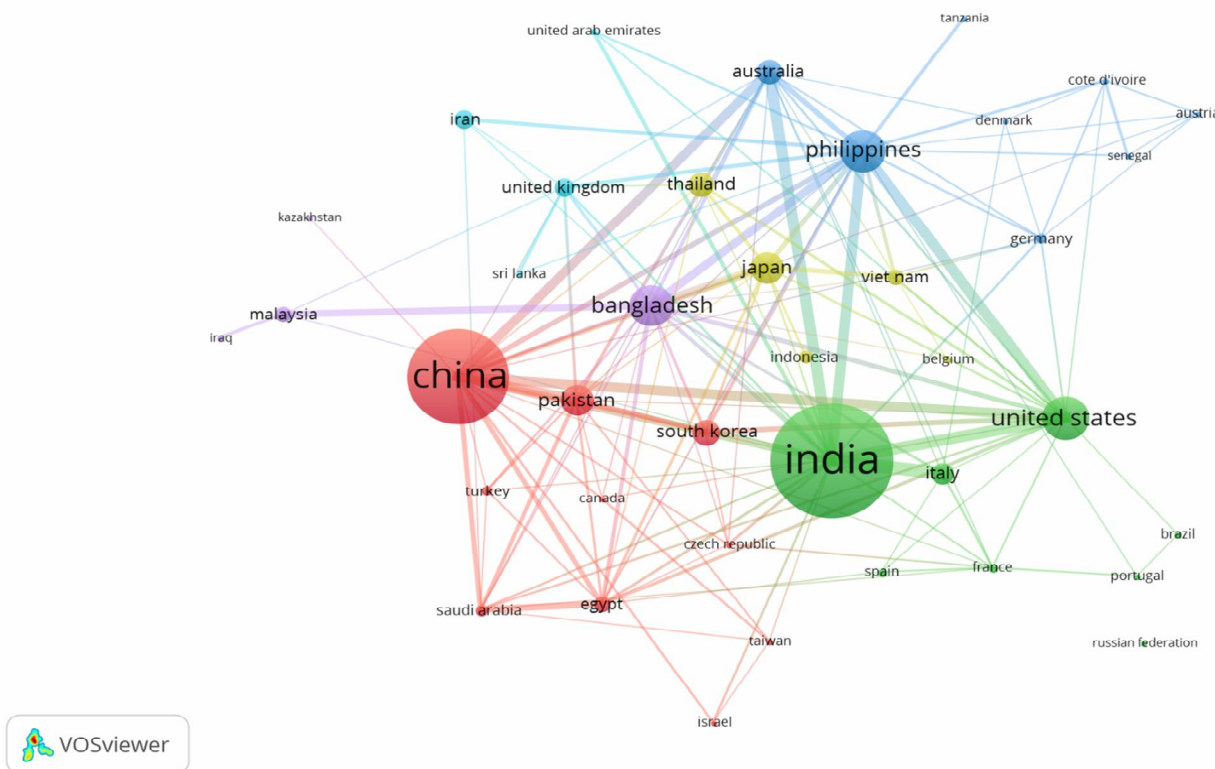


Fig. 10: Co -Authorship network of authors

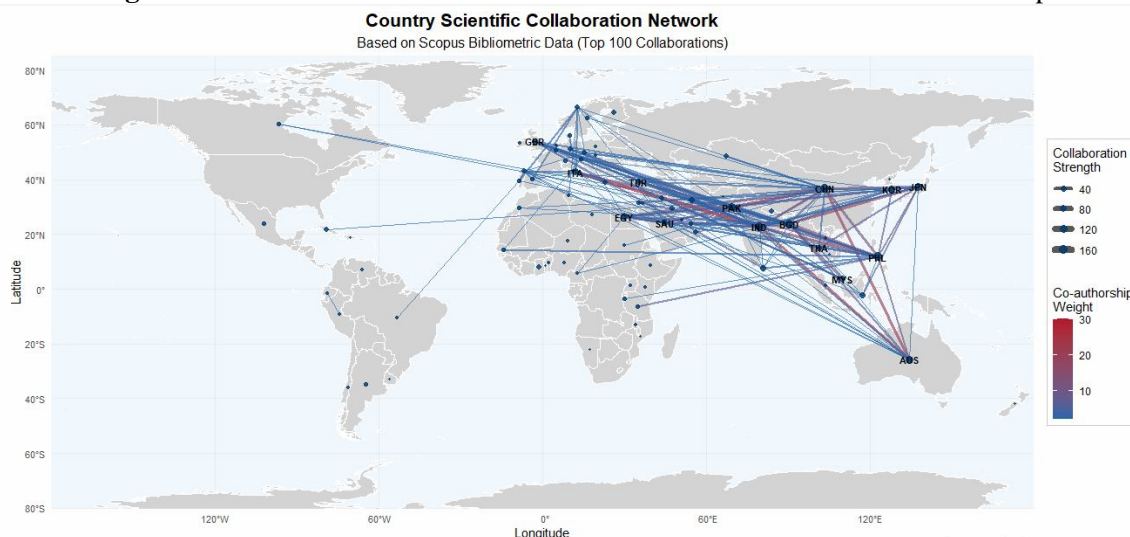
### Co-Authorship Network of Countries

A systematic examination of the collaborative co-authorship network among countries engaged in salinity research in rice, requiring a minimum of five publications per nation, was conducted. The threshold was met by 39 countries, which were further visualized by VOSviewer. The countries were grouped into 6 different clusters. In a national co-authorship network, each node in the network represents a different country. According to van Eck and Waltman (2022) (26), the size of each node is directly related to the number of publications. The connections between the

nodes show the collaboration between countries. There is a positive relationship between the width of a link and the frequency of collaboration among nations. As depicted by Fig. 11, 12 the 39 countries are distributed into six different groups. India had the most publications and the strongest total link strength of 182. China had the second-most publications and the second-strongest total link strength of 158. It is also observable that there exists a strong collaboration between India, the Philippines, China, Australia, Bangladesh, and the United States of America.

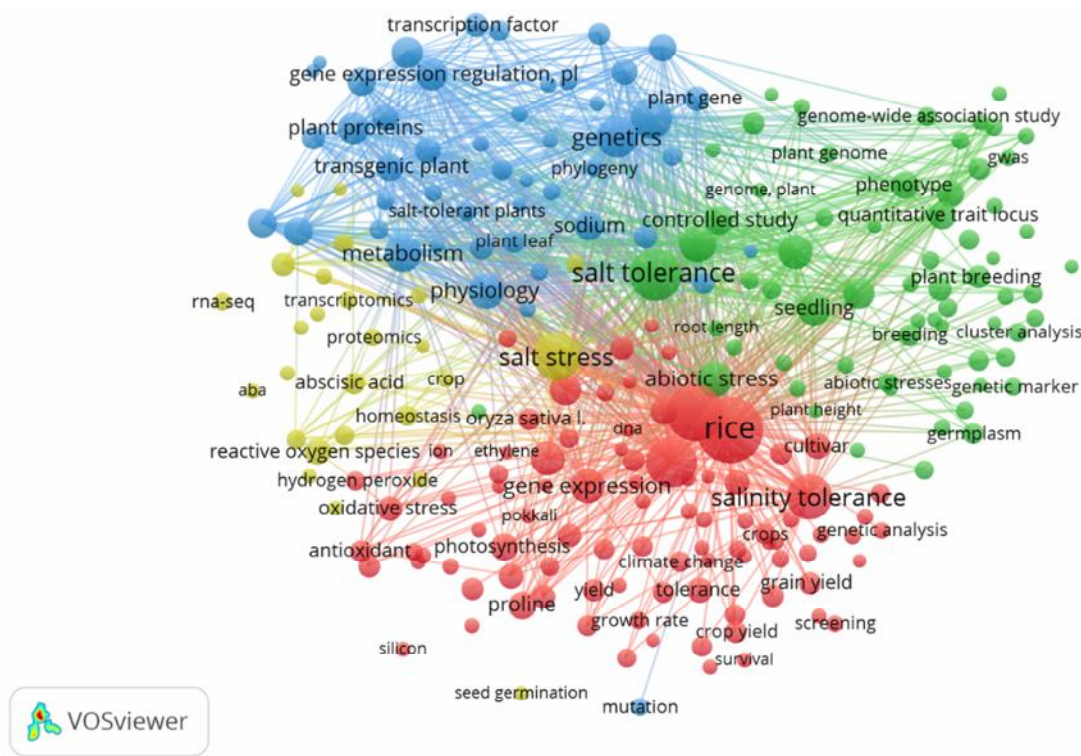


**Fig. 11:** Visualization of collaboration between countries based on co-authorship

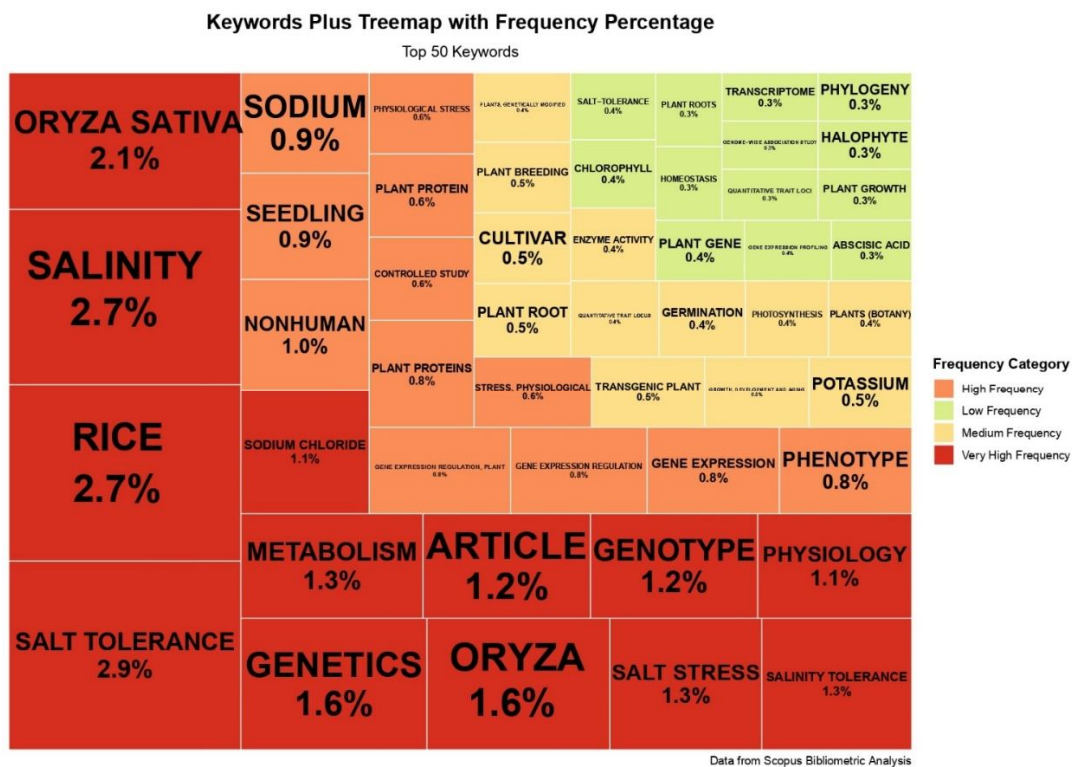


**Fig. 12:** Country collaboration map generated using R-Bibliometrix

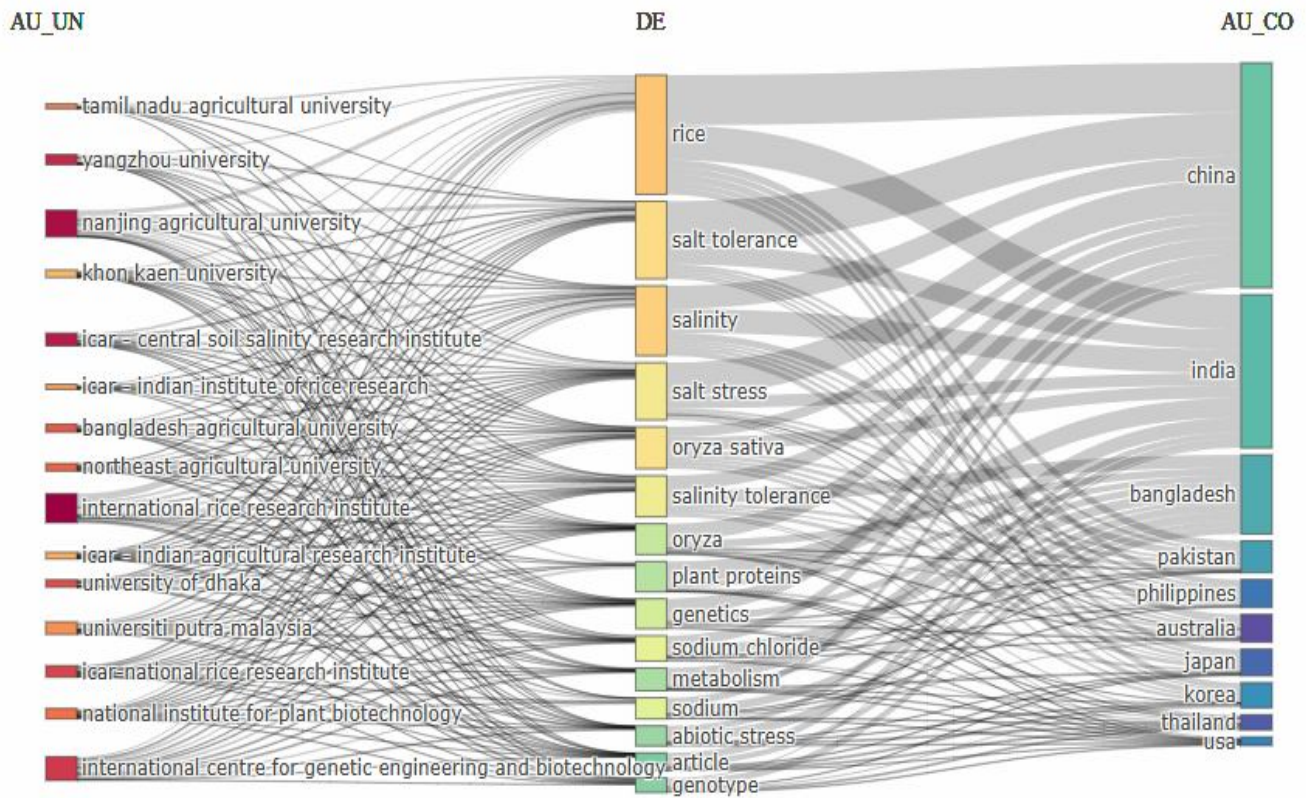




**Fig. 14:** Co-occurrence network of frequently used keywords related to salinity stress in Rice



**Fig. 15:** Tree map of keywords generated by R-Bibliometrix.



**Fig. 16:** Three-factor analysis of the relationship among authors' affiliated organizations (AU\_UN, left), keywords (DE, middle), and countries (AU\_CO, right) generated using R- Bibliometrix.

### Bibliographic coupling

If two documents share one or more citations, they are bibliographically connected. There is a coupling relationship between two papers that share one cited paper (Li and Chen, 2016, Zhang *et al.*, 2023). The bibliometric coupling network was analyzed for 338 journals that were constructed with a threshold of five documents per source and visualized with VOSviewer. 75 journals satisfied the threshold and were grouped into three clusters (Fig. 17). Cluster 1 (in red) consists of 32 sources, Cluster 2 (in green) consists of 30 sources, and Cluster 3 (in blue) consists of 13 sources. The number of publications by the journals is indicated by the size of the nodes; the larger the node, the more publications it has, and vice versa. The collaboration between the journals is denoted by the thickness of the lines connecting the nodes, where thicker lines indicate a higher frequency of collaboration, and vice versa.

Additionally, the bibliographic coupling network for research on rice salinity stress was analyzed. Among the 1507 papers, the 634 (approximately 42%) that were cited more than 20 times were analyzed to construct a bibliographic coupling network, as depicted in Fig. 18. The publications were grouped into seven clusters; Cluster 1 (red), consisting of 110 papers, Cluster 2 (green), consisting of 93 papers, Cluster 3 (blue), consisting of 89 papers, Cluster 4 (yellow), consisting of 78 papers, Cluster 5 (purple), consisting of 75 papers, Cluster 6 (cyan), consisting of 66 papers, Cluster 7 (orange), consisting of 61 papers. The red cluster is prominent with 110 publications that predominantly focus on physiological and biochemical aspects of salinity in rice. This is followed by the green cluster with 93 publications, which mainly focuses on genetics and breeding research in salinity tolerance in rice. The green cluster also has a higher total link strength, which indicates high interconnectivity among the publications in the cluster.



the overall crop growth and yield, 2. Breeding strategies for salinity tolerance-including screening existing genotypes to identify superior performers for use in developing salt-tolerant varieties and identifying the key regions (QTLs and molecular markers) in the rice genome responsible for salinity tolerance, 3. Physiological changes and metabolism in rice due to salinity-providing insight into the various response mechanisms in plants to combat salinity stress, and 4. Recent and advanced omics approaches in rice—utilizing advanced omics techniques to understand the functioning of the entire plant system. This represents the shift in the research trends from basic to advanced in research due to the development and intervention of modern technologies.

Vast genetic variability has been reported in rice contributing to salinity tolerance, yet salinity breeding is heavily dependent on a few tolerant landraces like Pokkali and Nona Bokra (Solis *et al.*, 2020). This leads to further narrowing of the genetic base of rice. This gap can be addressed by the utilization of the many reported landraces and wild relatives to improve the allelic diversity and broaden the genetic base of the crop (Padmavathi *et al.*, 2024). Breeding for salinity tolerance often relies on the *Saltol* locus, which mainly contributes to the seedling stage tolerance (Krishnamurthy *et al.*, 2020). Studies related to salinity stress in rice are predominantly focused on the seedling stages, with less emphasis on the reproductive stage, depicting a skewness in the research. Out of the total literature analyzed in this study, about 8 percent of the literature addresses reproductive stage salinity tolerance. This highlights a significant research gap to improve the reproductive stage salinity tolerance in rice varieties, which contributes to the actual yield of the crop.

Billions of dollars are invested in various projects globally by various institutions focused on salinity research in rice. Many institutions have been working intensively on the development of salt-tolerant rice varieties, despite a significant gap in this field of research. The extent of salt-affected areas under rice cultivation is still underutilized, which needs to be studied. Thus, bibliometric analysis helps to summarize the expanding literature related to this field of research and provides insights to fellow researchers to identify the gaps in salinity research in rice.

### Conclusion

Salinity poses a greater threat to global rice production, contributing to significant annual losses. This study analyzed a total of 1507 Scopus-indexed publications across the period of 45 years, providing an

overview of the extent of salinity research in rice. The analysis revealed a significant rise in the publications over the last two decades, mainly contributed by India, China, and the Philippines. The International Rice Research Institute specifically contributed greatly to the progress of salinity research. The trend in research revealed the shift from the basic yield assessment and physiological studies to advanced molecular breeding and omics approaches. Despite the progress achieved over the years, there exists a significant gap in the research progress due to the narrow focus on the seedling stage tolerance in rice and the underutilization of the vast genetic resources available globally. To overcome the plateau in salinity tolerance in rice, the shift in research towards the reproductive stages and the combined stress tolerance (e.g., submergence), utilization of the available landraces and wild relatives, and exploiting alternate mechanisms to salinity tolerance in rice is required. This bibliometric analysis helps in identifying and understanding the gap in the research trend and helps the scientific community to address the gap in salinity research.

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### Author Contributions

All the authors contributed towards the conceptualization and design of the study. The first draft of the manuscript was prepared by RJ and VPV, all authors contributed towards finalizing the manuscript.

### Conflicts of interests

Authors do not have any conflict of interests to declare.

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