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Review

Research on Salt Stress in Rice from 2000 to 2021: A Bibliometric Analysis

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Abstract: This study aimed to assess global trends in research on salt stress in rice and provide new directions for future studies. The subjects in this study are a plain text file with full records and cited references (Web of Science core collection as the database, "rice" and "salt" as the retrieved title with the date range from 1 January 2000 to 31 December 2021). The bibliometric method was used in this study, and the results were visualized using Scimago Graphica, VOSviewer, and CiteSpace. The results showed that China, India, and Japan contributed most of the literature in this field, and the institutes with the largest academic output were the Chinese Academy of Science, the International Rice Research Institute, and Nanjing Agriculture University. This study argues that research on salt stress in rice has been conducted in three main areas: phenotypes, response mechanisms, and remediation strategies. Inoculation of rhizosphere bacteria, ion homeostasis, soil remediation, and gene editing will be popular topics in rice salt stress research in the future. This study aimed to provide a potential theoretical direction for research on salt stress in rice as well as a reference for feasible studies on the exploitation of saline–alkali lands.

Keywords: rice; salt stress; bibliometric; VOSviewer; CiteSpace

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1. Introduction

There are approximately one billion hectares of saline land worldwide [1], and 25–30% of the irrigated land in the world is subject to human-induced secondary soil salinization [2]. Moreover, climate change and the utilization of alternative irrigation water of lower quality (treated wastewater or low-salinity water) can also increase salinization [3], which is estimated to increase by 1–1.5 million hectares per year [4]. Over 100 countries are facing the problem of soil salinization [5]. Soil salinization is a significant global process of land degradation. Soil salinization often results in high soil salinity, high pH, poor soil structure, low infiltration, and poor or inadequate drainage [6]. It is estimated that rising temperatures, expanding irrigated areas, increasing water demand, and improper irrigation and drainage will result in the spread of secondary salinization. In addition, changes in land use and extreme weather events, such as prolonged drought and severe flooding, may cause a geological matrix with higher salinity to release and redistribute large amounts of salinity, exposing more regions to the risk of soil salinization [7,8]. The accumulation of farmland surface soil salinity has been strengthened by global warming, accelerating the formation of saline–alkaline soils [9]. In the warming world, soil salt has become an important and growing concern [7].

As a key factor limiting yield, soil salinity is one of the most critical abiotic stresses faced by crops in saline soils. Under salt stress, it is difficult for plants to develop the firmness and hardness required to form an effective rooting system in soil. Meanwhile,

lower water-use efficiency results in osmotic pressure and reduces the transport efficiency of nutrients such as nitrogen, phosphorus, potassium and calcium. The subsequent influences caused by lower water-use efficiency will lead to nutrient deficiency and the toxicity of ions [10], bringing about changes in the synthesis and metabolism of many substances, which has toxic effects on plants [4]. Consequently, the crop yield of saline soils around the world is limited [11], and the harm of saline–alkali lands has aroused widespread concern worldwide [12–14].

Rice (*Oryza sativa*. L) is one of the most important staple food crops that feeds half of the world's population [15] and is planted in over 100 countries [16]. However, soil salt affects rice crop yield by interacting with soil texture [4], and high salt stress results in severe rice crop yield losses [17–19]. Therefore, research papers on salt stress in rice have been published by different institutions in many countries, and the academic literature on rice under salt stress has shown signs of explosive accumulation. However, the effective extraction of useful information from a massive amount of data [20] is of great importance for obtaining an overview of the reaction in the field of rice under salt stress and its future trends in a relatively short period of time.

Recently, the bibliometric method has been identified as a new strategy for determining useful points quickly and precisely from massive information and can be used to mathematically evaluate the development of a domain during a given period [21]. Bibliometric analysis is a quantitative evaluation method based on the application of bibliometrics and statistics for science, which can present the knowledge structure and emerging trends of a certain field of study [22] and perform quantitative and qualitative analyses of the distribution structure, quantitative relationships, and change patterns of related information in the literature to provide a direction for future development [23]. Bibliometric analysis was used to assess the characteristics of these outputs, research topics, and important scientific literature, demonstrating the general situation of certain scientific research and providing scientific information support for related research. Visualization analysis of the literature, on the other hand, further visualizes the results on the basis of the bibliometric analysis [24]. It can perform a visualization analysis of related literature through unique perspectives of clustering, overlaying, and density, thereby presenting the status, popular topics, and trends of a certain field [25].

However, to date, no bibliometric research has been published on salt stress in rice. Therefore, this study adopts the methods of bibliometric analysis, VOSviewer, and CiteSpace to study and analyze the knowledge structure of research fields related to rice salt stress, including international cooperation, research topics, and popular research themes, with a view to quickly obtain the main research content and popular topics in this field in a relatively short period of time.

2. Materials and Methods

This study used the Web of Science (https://www.webofscience.com, accessed on 21 April 2022), a data platform created by Clarivate, using the Web of Science core collection (WoSCC) as the database. There are two rice cropping species: *Oryza sativa* and *Oryza glaberrima*. Salt has three names, i.e., salt, saline, and salinity. Therefore, TI1 = (rice OR '*Oryza sativa*' OR '*Oryza glaberrima*') AND TI2 = (salt OR 'saline' OR 'salinity') were both used as search terms, with the date range set between 1 January 2000 and 31 December 2021 [26]; a plain text file was exported with full records and cited references. As shown in Figure 1, after the application of the Boolean operators [27], 2276 bibliographic materials were obtained. A total of 1754 documents on salt stress in rice were retrieved after duplicates were removed using CiteSpace (Data are shown in Supplementary Materials).

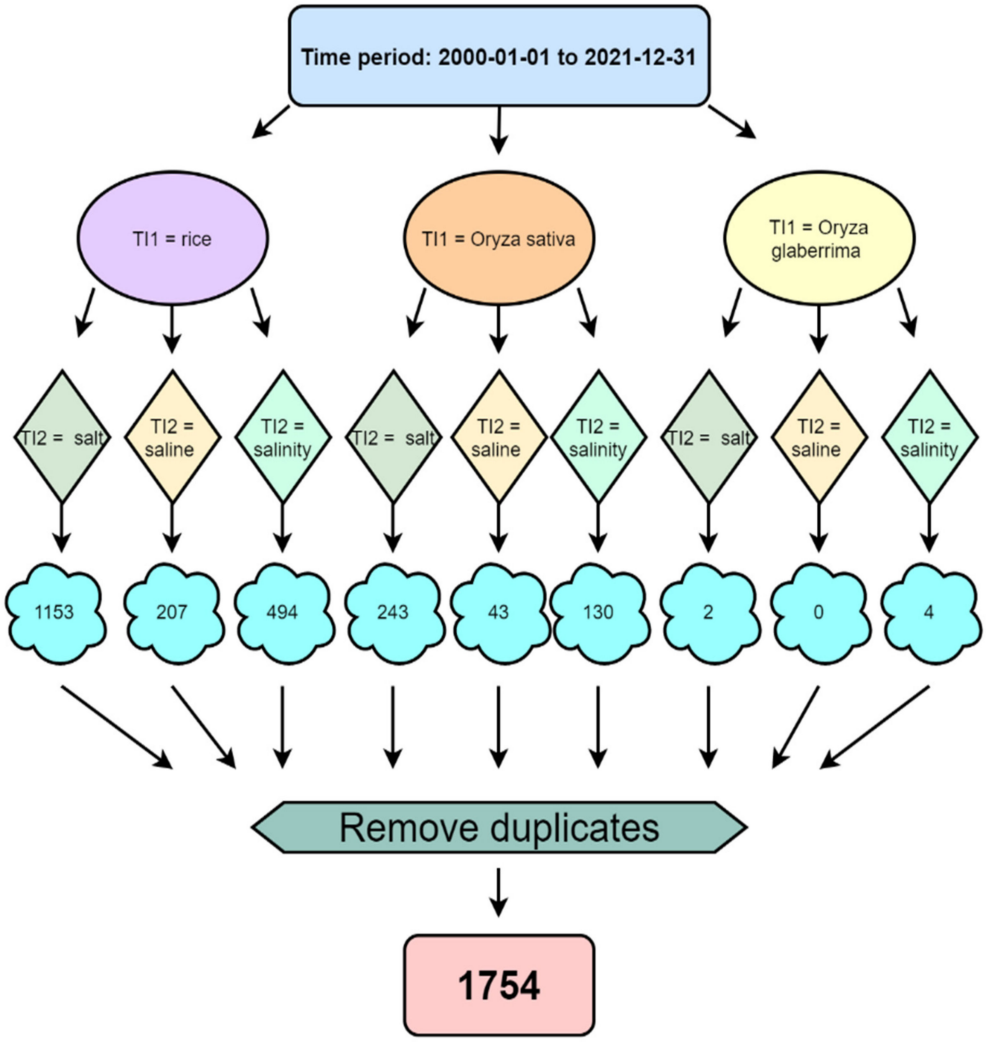


Figure 1. Roadmap for literature retrieved through titles including 'salt' and 'salt stress' from 2000 to 2021.

In this study, data cleansing was performed for key terms, including keywords, institutes, and countries in the subject bibliographies of the 1754 retrieved academic studies before the data analysis. Terms with similar meanings were eliminated, but term frequencies were added to obtain the most concise mapping knowledge domains. Then, the collected literature data on salt stress in rice were analyzed from the following aspects: literature output on salt stress in rice, cooperation network analysis (including countries network analysis), co-occurrence network analysis (including author keywords and theme), coupling network analysis (including periodicals and bibliography), and co-citation network analysis of paper references on research on salt stress in rice on the collected literature data. Finally, the results were visualized with VOSviewer [25] and CiteSpace [24].

The data were organized using Microsoft Excel 2016. Cooperative relationships between countries or regions, institutes, keywords, theme co-occurrence, and literature were determined using Origin 2018, Scimago Graphica, VOSviewer, and CiteSpace.

3. Results

3.1. Descriptive Statistics of Publications

In the last two decades, an increasing number countries and regions have paid attention to and studied salt stress in rice. The number of countries or regions with scientific output on salt stress in rice has increased from 15 in 2000 to 45 in 2021 (Figure 2). A total of 82 countries/regions contributed to the literature on salt stress in rice (Figure 3). In general,

the number of papers published annually on salt stress in rice has increased (Figure 2). According to Figures 2 and 3, the number of papers on salt stress in rice published by the top 15 countries accounted for 83.2% of the total number of publications on salt stress in rice published worldwide, from which the general trend of the total number of publications globally can be concluded. As shown in Figure 2, in the most recent ten years, far greater importance has been attached to saline–alkali lands around the world than in the ten years between 2000 and 2010. The top 10 countries or regions contributing to the largest number of studies on salt stress in rice are mostly distributed in Southeast Asia, coinciding with the distribution of rice-planting areas, which further demonstrates that the hazard of salinity to rice planting is significant enough to attract global attention.

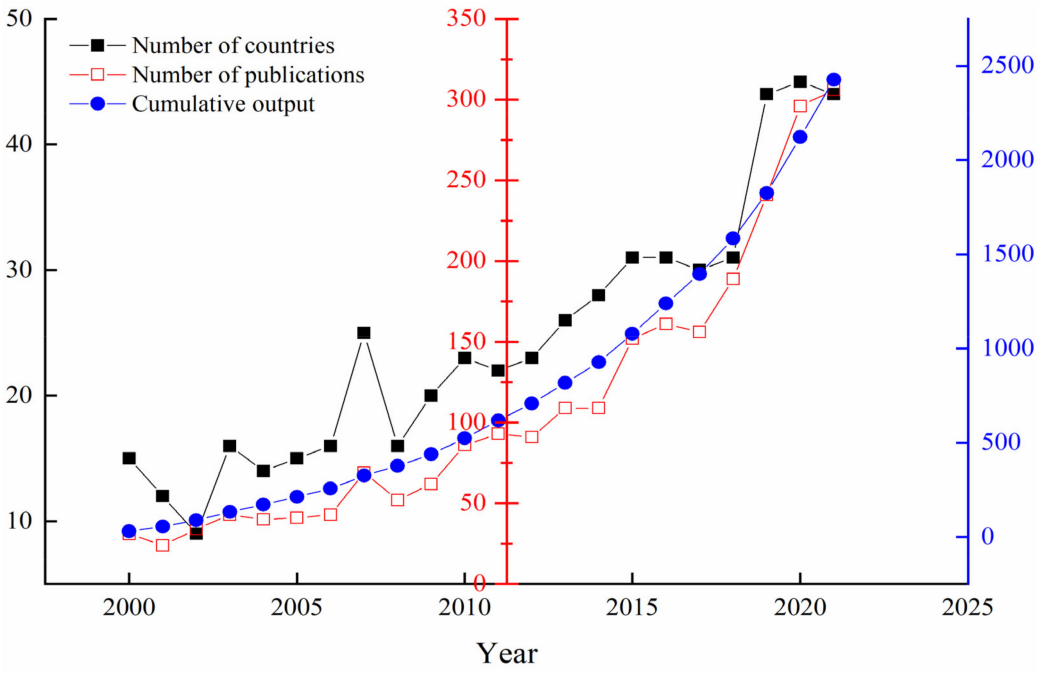


Figure 2. Number of countries publishing papers on salt stress in rice, the number of their yearly published papers and cumulative publications during 2000–2021.

3.2. Analysis on the Collaboration Network

Scientific collaboration refers to researchers working together for the common purpose of producing new scientific knowledge. It has several forms. Herein, papers written by multiple authors from different institutes and countries/regions will be considered a result of collaboration between authors, institutes, and countries/regions [28].

Globally, 82 countries/regions have contributed to the related literature on salt stress in rice, between which a close and extensive collaborative network has formed (Figure 3). China ranks first globally with 548 papers published in the field. Countries/regions that have at least 40 papers on salt stress in rice include India (365 papers), Japan (183 papers), the US (134 papers), Pakistan (126 papers), Thailand (104 papers), the Philippines (100 papers), South Korea (98 papers), Bangladesh (93 papers), Australia (68 papers), Iran (49 papers), and Germany (46 papers). In terms of total link strength, China (180 papers), the US (151 papers), Philippines (126 papers), Japan (121 papers) and India (104 papers) had the most extensive collaborative relationships with other countries regarding research on salt stress in rice.

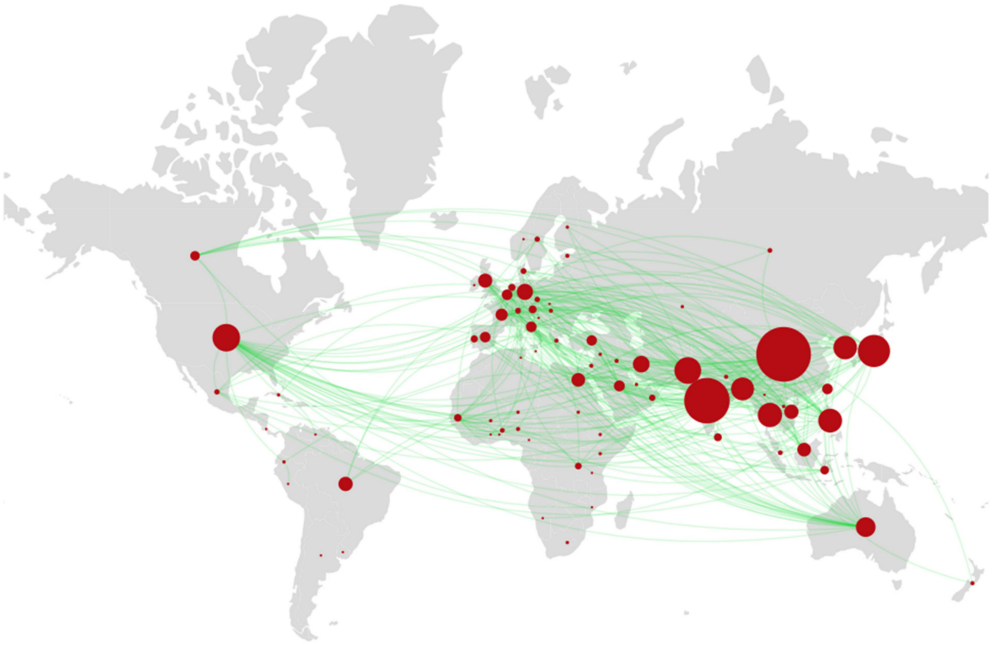


Figure 3. National/regional distribution of rice salt-stress papers. The sizes of the nodes indicate the quantity of papers published, with larger nodes indicating a larger number of publications, and vice versa. The width of the lines linking different nodes indicates collaboration between countries or regions, with thicker lines indicating a higher frequency of collaboration, and vice versa.

Around the world, there are a total of 1473 institutes carrying out research on salt stress in rice. A total of 183 institutes has published at least four papers individually. Figure 4 shows the institutions with more than 20 publications on rice salt stress research from 2000 to 2021 and their respective numbers of relevant publications. According to Figure 4, the Chinese Academy of Science ranks first with 109 publications, followed by the International Rice Research Institute (IRRI) (82 papers), Nanjing Agricultural University (69 papers), the Chinese Academy of Agricultural Sciences (62 papers), and the University of Agriculture Faisalabad (UAF) (50 papers).

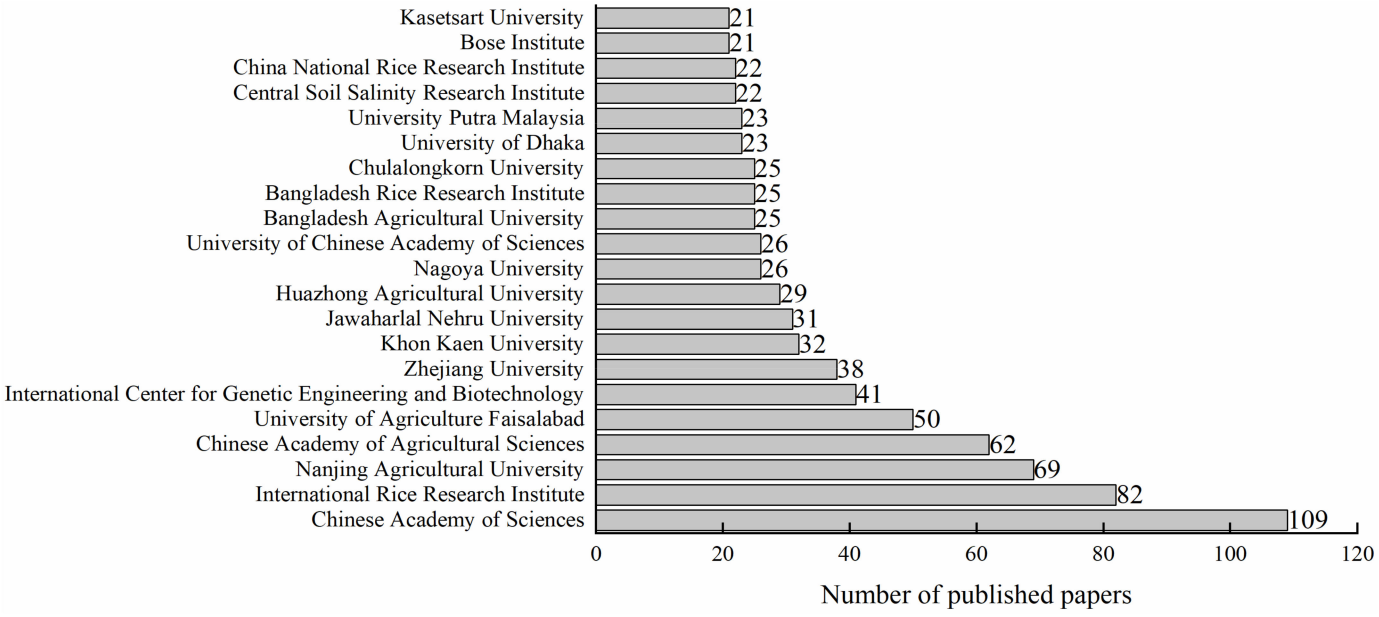


Figure 4. Number of papers published by each institution on rice salt stress research from 2000 to 2021 (more than 20 publications).

3.3. Analysis on Co-Occurrence Network

There were 3752 author keywords in 1754 academic literature publications (Figure 1), and 3692 author keywords remained after similar keywords were merged. Among them, 232 author keywords with a frequency of occurrence greater than or equal to four were analyzed to obtain Figure 5. As shown in Figure 5, the 232 author keywords were divided into five clusters marked with different colors, including Cluster 1 (red) with 82 author keywords, Cluster 2 (green) with 78 author keywords, Cluster 3 (blue) with 41 author keywords, Cluster 4 (yellow) with 21 author keywords, and Cluster 5 (purple) with 10 author keywords. The top 15 author keywords with most frequent occurrence include "salt stress" (707), "rice" (604), "*Oryza sativa*" (286), "salt tolerance" (285), "abiotic stress" (83), "proline" (48), "gene expression" (44), "reactive oxygen species" (42), "antioxidant enzyme" (40), "photosynthesis" (39), "abscisic acid" (34), "drought "(34), "transgenic rice" (33), "germination"(33), and "yield" (31).

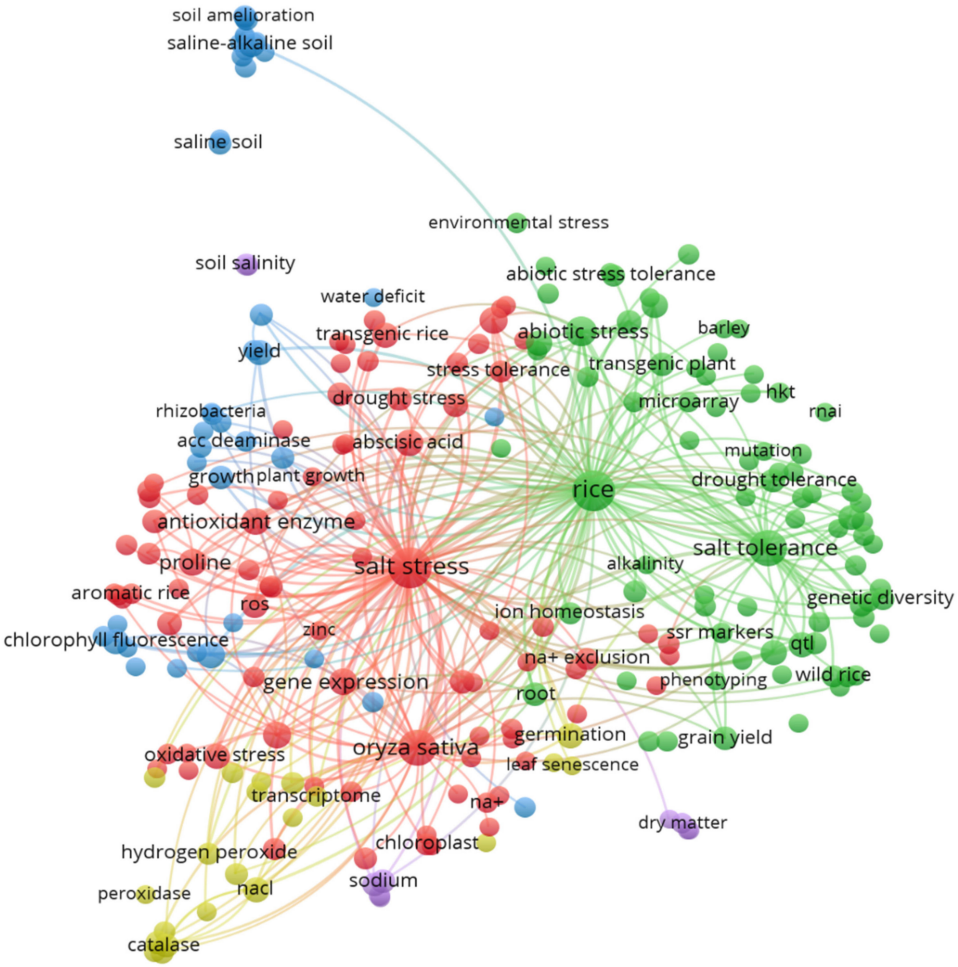


Figure 5. Analysis of the co-occurrence network of author keywords on salt stress in rice. There were 3752 author keywords in 1754 academic literature publications, and 3692 author keywords remained after similar keywords were merged. This figure shows the analysis of 232 author keywords with a frequency of occurrence greater than or equal to four. The sizes of the nodes indicate the frequencies of occurrence; the larger the nodes, the higher the frequencies of occurrence, and vice versa. The lines linking the nodes indicate the situation in which both author keywords appear in the same cited literature, with thicker lines indicating a higher frequency of occurrence, and vice versa.

A total of 33,696 terms were extracted from the titles and abstracts of the 1754 papers. Among the 1097 terms with an occurrence higher than 10, the 658 terms with relevance in the top 60% were examined in a co-occurrence analysis to obtain Figure 6. As shown

in Figure 6, the terms were divided into four clusters marked with different colors: the red cluster ranked first with 230 terms, followed by the green cluster with 200 terms, blue cluster with 136 terms, and yellow cluster with 92 terms. Figure 6 shows that salt stress in rice can be studied from four perspectives. First, the effects of salt stress on rice can be examined from the perspectives of gene expression, gene regulation, RT-PCR, vacuoles, cell nuclei, and genetic engineering. Second, the effects of salt stress on rice can be assessed in terms of the yield, grain quality, and agronomic characteristics. Third, salt-tolerant varieties should be developed from the perspective of genetic variation and molecular breeding. Fourth, salt stress in rice can be studied based on enzyme content, ion content and osmotic adjustment substances in rice plants.

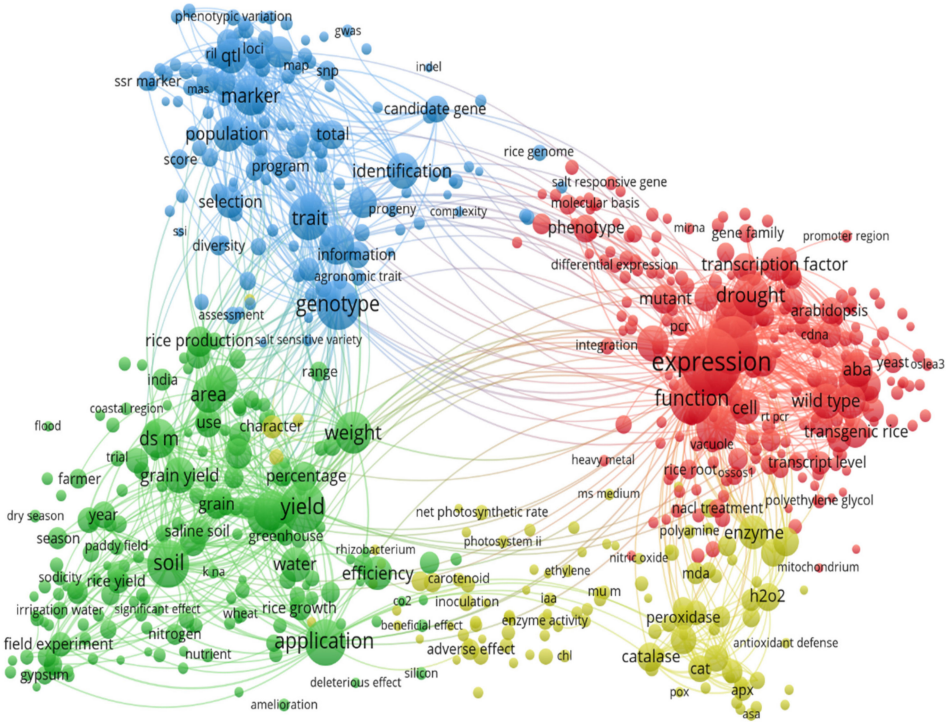


Figure 6. Analysis of term co-occurrence in research on salt stress in rice. A total of 33,696 themes were extracted from the titles and abstracts of the 1754 papers. Among the 1097 themes with an occurrence higher than 10,658 themes with relevance in the top 60% were examined in a co-occurrence analysis.

3.4. Analysis on Periodicals Coupling Network

The coupling networks of the 407 source periodicals cited by the 1754 academics papers in this study were analyzed, and Figure 7 was obtained. As shown in Figure 7, Cluster 1 (in red) consists of 150 periodicals, Cluster 2 (in green) consists of 114 periodicals, Cluster 3 (in blue) consists of 103 periodicals, Cluster 4 (in yellow) consists of 17 periodicals, and 23 periodicals appear in gray as they fail to reach the required minimum number of clusters (defined as 5). The periodicals with more than 30 papers published on salt stress in rice were, in descending order, *Frontiers in Plant Science*, *Plant Science*, *Pakistan Journal of Botany*, *Plos One*, *Plant Physiology and Biochemistry*, *Scientific Reports*, *Acta Physiologiae Plantarum*, and *Rice*. Among them, periodicals with citation counts of more than 1000 are, in descending order, *Plant Physiology*, *Plant Science*, *Plant Journal*, *Plant Molecular Biology*, *Journal of Experimental Botany*, *Plos One*, *Journal of Plant Physiology*, *Proceedings of the National Academy of Sciences of the United States of America*, *Frontiers in Plant Science*, *Plant Cell*, *Plant and Cell Physiology*, *Planta*, and *Rice*.

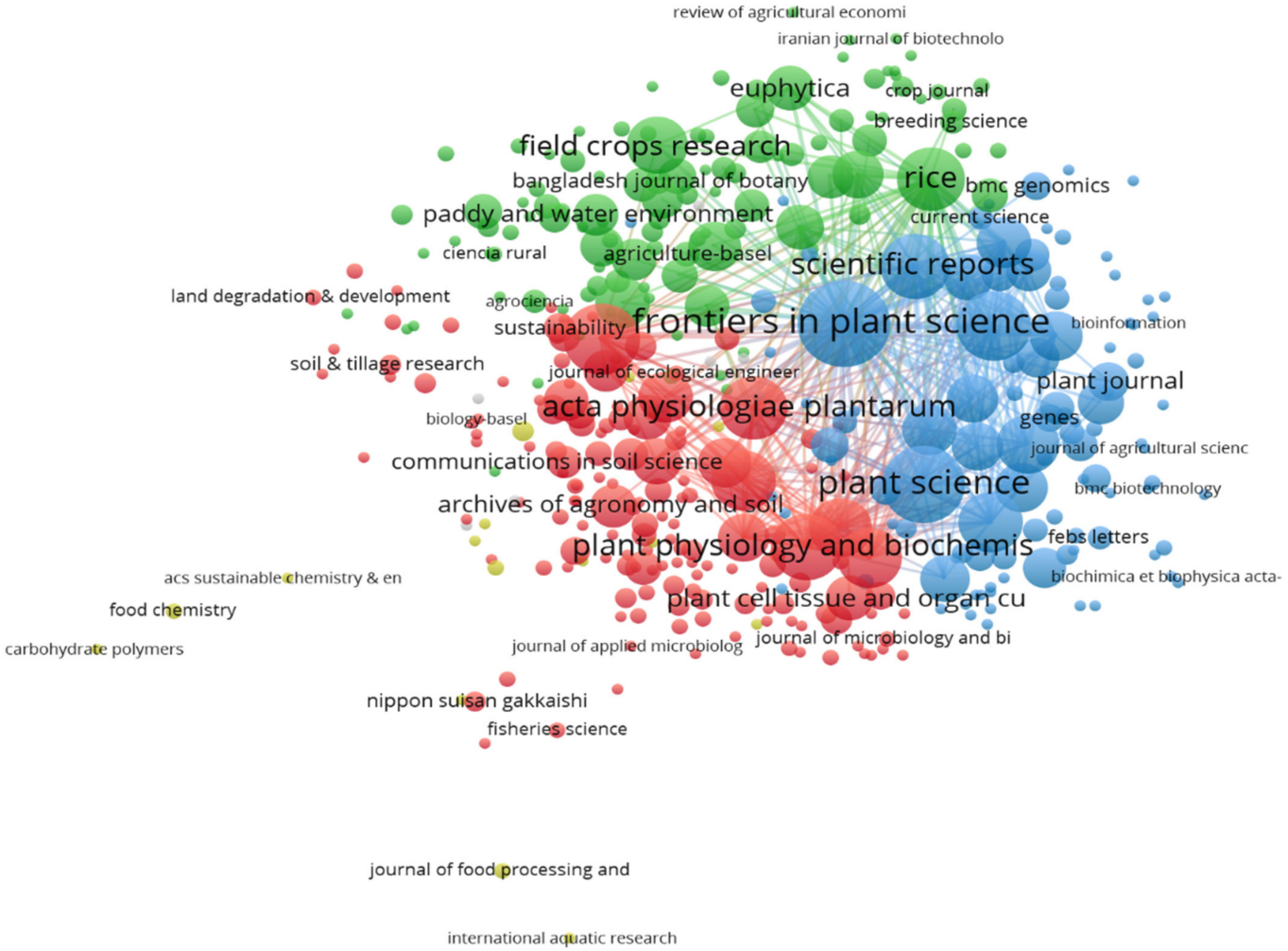


Figure 7. Analysis of the periodical coupling network of salt stress in rice. A total of 407 source journals from the 1754 academic papers cited in this study were analyzed. The sizes of the nodes denote the number of publications by the institutes; the larger the size of the nodes, the larger the number of publications, and vice versa. The thickness of the lines linking the nodes denotes the collaboration between institutes; the thicker the lines, the higher the collaboration frequencies, and vice versa.

Two documents are bibliographically coupled if they both cite one or more documents in common. Two papers that share one cited paper have a coupling relationship between them, with the strength of coupling defined as 2, and so forth [28]. Among the 1754 papers, the 663 that were cited more than 20 times were analyzed for the bibliographic coupling network, and Figure 8 was obtained. As shown in Figure 8, there were five clusters, including Cluster 1 (red), consisting of 201 papers, Cluster 2 (green), consisting of 181 papers, Cluster 3 (blue), consisting of 168 papers, Cluster 4 (yellow), consisting of 93 papers, Cluster 5 (purple), consisting of 8 papers, and 12 papers that appear in gray as they fail to reach the required minimum number of clusters (defined as 5).

3.5. Analysis on the Co-Citation Network

Co-citation occurs when two papers are referenced by common-citing papers, and there is a co-citation relationship between the two papers [28]. The co-citation network revealed connections between research fields and knowledge flow from one theme to another. It reflects the laws of scientific development, accumulation, continuity, interdisciplinarity, and permeability of scientific knowledge [15,22]. Through co-citation analysis, the origin and development of scientific knowledge can be traced. Each published paper referenced

many bibliographies included in the dataset. If two papers are cited by a common paper, they are considered connected to each other, which is indicated by the linking lines between the nodes [22].

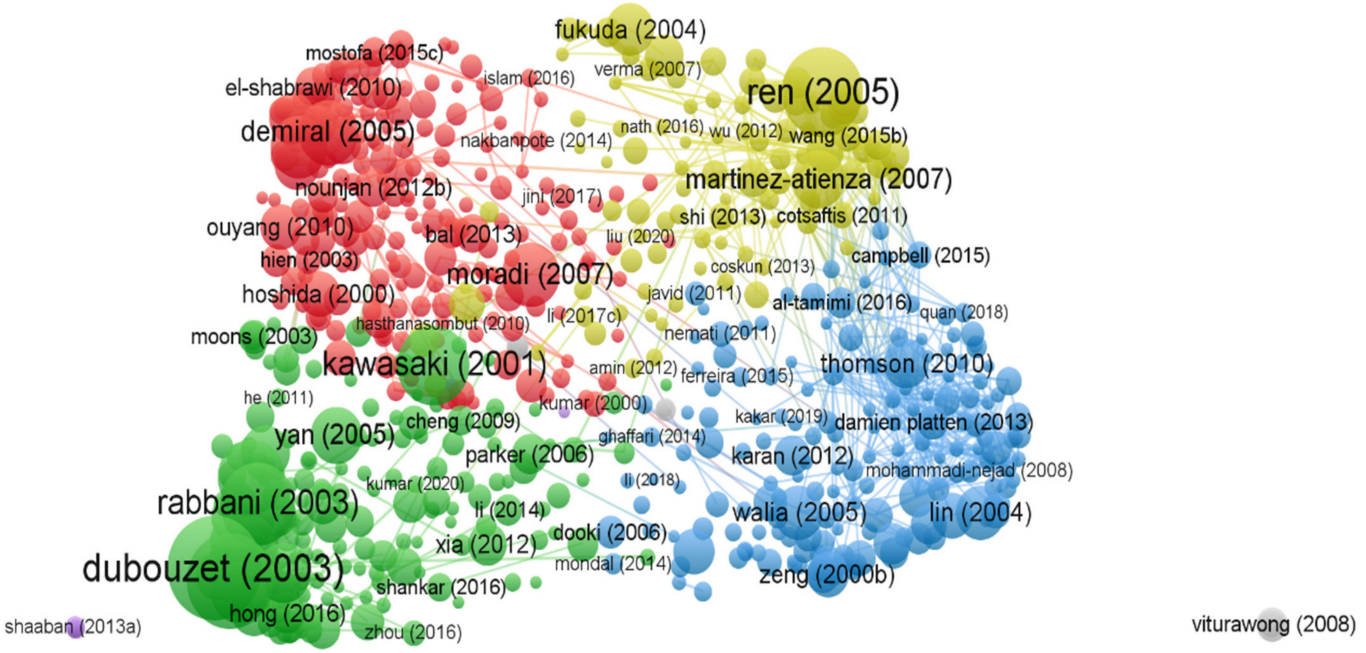


Figure 8. Analysis of the bibliographic coupling network for research on salt stress in rice. Among the 1754 papers, the 663 that were cited more than 20 times were analyzed for bibliographic coupling networks. The sizes of the nodes denote the citation counts; the larger the nodes, the higher the citation counts, and vice versa. Data are shown in Supplementary Materials.

A total of 44,432 papers were cited by 1754 citing papers on salt stress in rice. In CiteSpace, with the Look Back Year function set to five, only cited papers published in the last five years were extracted from the citing papers and no papers outside the range were considered. The time slice was set to two, and the threshold selection method was switched to the g-index. An analysis of the co-citation of papers on salt stress in rice is illustrated in Figure 9, which shows that the cited papers can be roughly divided into 11 clusters. Table 1, which was arranged in order of size, further interprets Figure 9. When the silhouette is greater than 0.5, the cluster is considered reasonable, and a cluster with a silhouette greater than 0.7 is deemed convincing, which proves the rationality of Figure 9. As shown in Table 1, the themes of the 11 clusters included homeostasis-related genes, genome-wide association studies, antioxidant defense, dynamic quantitative trait loci, *Oryza sativa*. L., dependent protein kinase, two-photon microscopy study, culture-selected plant, tfiiia-type zinc finger protein gene, association mapping, and chloroplast ultrastructure. Combining Table 1 with Figure 9, it is evident that homeostasis-related genes, expression levels, physiological responses, grain yield, and rice salt tolerance have been popular research topics in recent years.

Table 2 shows the popular research themes of salt stress in rice for different periods between 2000 and 2021. As shown in Table 2, the initial focus of attention in rice salt stress research was to observe the response of rice leaves to salt stress at the seedling stage and the salt tolerance of the rice. The popular research topics in the middle stage are Na/H antiporters, transgenic rice, functional analysis, signal transduction, transcription factors, and zinc-finger proteins. Recent studies on salt stress in rice have focused on ion homeostasis, water, soil, plant growth and ACC deaminase activity.

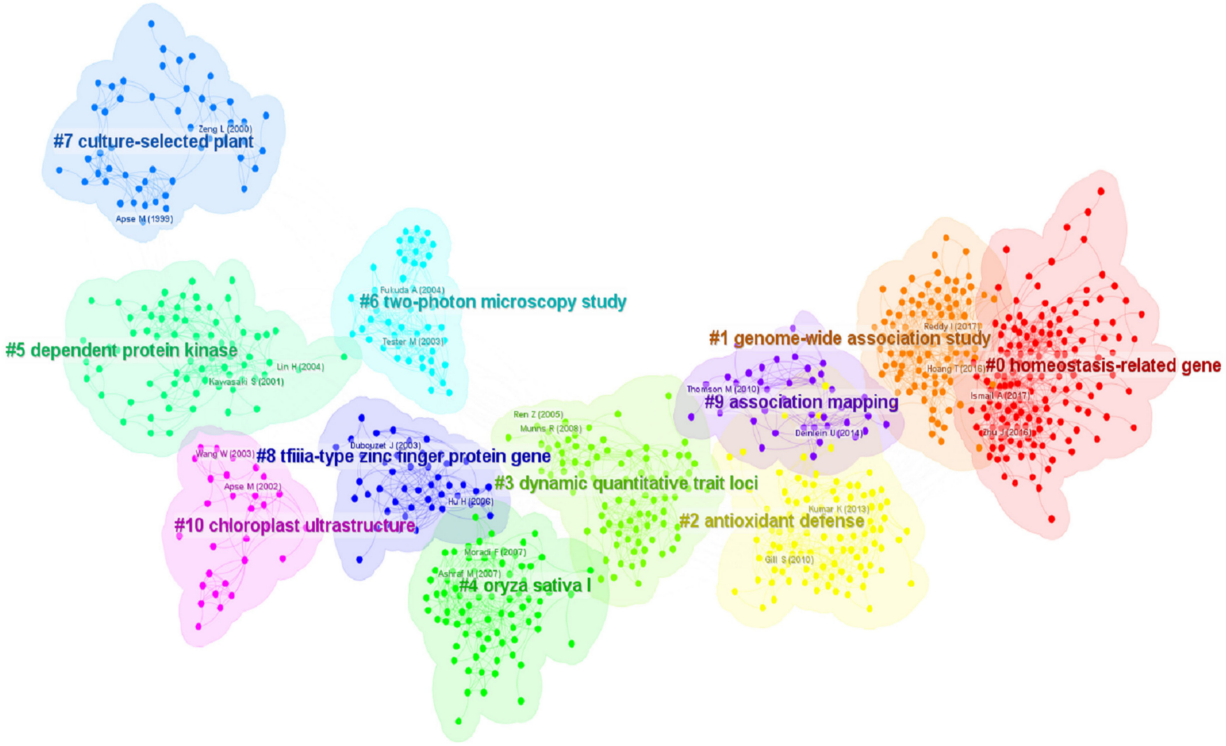


Figure 9. Analysis of the co-citation network of papers on salt stress in rice. A total of 44,432 papers were cited in the 1754 citations on salt stress in rice. Only the cited papers published in the last five years were analyzed. The "#" is followed by cluster theme, with bigger sizes of fonts indicating larger scales of the clusters. The dots in the clusters denote the cited documents; the larger the cluster scale, the more numerous the cited documents are. The linking lines indicate that the cited papers on both ends often appear in the same citing paper; the thicker the linking lines, the higher the occurrence count, and vice versa.

Table 1. Co-citation clustering of cited papers on salt stress in rice.

Cluster ID	Size	Silhouette	Mean (Year)	Lable (LLR)
0	152	0.848	2016	homeostasis-related gene; expression level; physiological responses; grain yield; rice salt tolerance
1	100	0.897	2015	genome-wide association study; seedling stage salinity tolerance; rice genotype; seedling stage salt tolerance; salinity tolerance
2	99	0.871	2012	antioxidant defense; glyoxalase system; salt-induced oxidative stress; ectopic expression; salinity tolerance
3	84	0.846	2008	dynamic quantitative trait loci; salt stress component; *Oryza sativa* ssp. *japonica*; transcription factor oshsfc1b; salt tolerant indica variety
4	80	0.868	2007	*Oryza sativa* L.; indica rice; salt-affected soil; organic matter; saline-sodic soil
5	73	0.898	1999	dependent protein kinase; using cdna microarray; cold drought; monitoring expression profile; rice gene
6	52	0.955	2002	two-photon microscopy study; sbfi-loaded cell; nacl stress; oshkt1 oshkt2; suaeda salsa ssnhx1
7	51	0.968	1998	culture-selected plant; f-3 population; determining salt tolerance; physiological trait; microsatellite marker
8	47	0.924	2005	tfiiia-type zinc finger protein gene; specific set; specific salinity stress response; transcriptome map; saline tolerance
9	42	0.927	2012	association mapping; leaf blade; Indian wild rice germplasm; association analysis; fine mapping
10	30	0.972	2001	chloroplast ultrastructure; seedling culture model system; rice leaf; investigating proteome; hydroponic rice

Table 2. Top 25 keywords with strongest citation burst.

Keywords	Year	Strength	Begin	End	2000–2021
Oryza sativa L.	2000	16.37	2000	2005	
nacl	2000	8.64	2000	2013	
leave	2000	8.12	2000	2010	
plant	2000	7.68	2000	2004	
salinity resistance	2000	7.08	2001	2007	
rice (*Oryza sativa* L.)	2000	6.51	2001	2011	
seedling	2000	5.47	2002	2012	
arabidopsis thaliana	2000	8.24	2003	2013	
low temperature	2000	6.56	2003	2009	
molecular cloning	2000	6.04	2003	2007	
freezing tolerance	2000	4.66	2003	2009	
proline accumulation	2000	4.53	2003	2014	
salinity	2000	4.86	2004	2005	
na+/h+ antiporter	2000	5.17	2005	2007	
transgenic rice	2000	7.1	2006	2014	
transgenic plant	2000	4.89	2007	2011	
functional analysis	2000	6.12	2008	2016	
signal transduction	2000	5.27	2008	2012	
transcription factor	2000	4.91	2008	2009	
zinc finger protein	2000	4.66	2013	2016	
ion homeostasis	2000	5.22	2016	2021	
water	2000	5.89	2017	2019	
soil	2000	7.38	2018	2021	
plant growth	2000	6.7	2018	2021	
acc deaminase	2000	4.87	2018	2021	

4. Discussion

In the past 20 years, research on salt stress in rice has increased significantly worldwide (Figure 2), and is related to climate change, ongoing drought, sea level rise, and the increase in saline areas due to human activities [29]. To date, more than 100 countries are facing saline soil problems [5], and 82 countries/regions and 1473 institutes have participated in the research on salt stress in rice (Figures 3 and 4), indicating that soil salinization has become a global concern. There are two main regions for rice salt stress studies (Figure 3): Southeast Asia and Europe. Rice-growing regions are mainly distributed in Southeast Asia [30]. One-third of the world's saline land is located in Asia [1]; thus, Southeast Asia has the highest number of publications on salt stress in rice, as shown in Figure 3. Among Southeast Asian countries, Chinese research institutions, led by the Chinese Academy of Sciences, Chinese Academy of Agricultural Sciences, and Nanjing Agricultural University, have the highest number of publications (Figure 5). This is closely related to the fact that China has nearly 100 million hectares of inland saline land and 2.34 million hectares of coastal mudflats [31]. In a survey of saline soil resources, compared with the traditional method (conductivity meters) to detect information on soil salinity, remote sensing image [32,33], geographical information system (GIS) [33,34], non-destructive ground-penetrating radar [35], and hyperspectral [36] methods can be applied to assess soil salinization more effectively by capturing soil salinity data in a faster and more accurate way.

In this study, research on rice salt stress in 2000 was at its initial stage, mainly studying the effects of salt on rice yield, yield composition [37,38] and enzyme activities [39]. The period from 2000 to 2010 was a slow developmental stage, mainly studying salt tolerance identification, alleviating the effect of exogenous substances on salt stress [40], physiological and biochemical mechanisms [41] under salt stress, gene expression and protein transcription levels. The period from 2010 to 2021 is a period of rapid development (Figure 2), in which the physiological, biochemical, and molecular mechanisms under salt stress [42], alleviating the effect of exogenous measures on salt stress in rice [43,44], and breeding

technology for salt-tolerant rice varieties, particularly gene-editing technology [45,46], were mainly studied.

In this study, studies on salt stress in rice mainly consisted of three aspects (Figures 5 and 6): (1) Phenotype; salt stress can inhibit rice growth, including plant height, root length, leaf area and biomass accumulation [47], and reducing rice yields [48,49]. (2) Response mechanisms: the activity of the antioxidant system increases under low salt stress and decreases under high salt stress [50], but the MDA and Na contents increase [51]. Under salt stress, some rice genes are upregulated, whereas others are downregulated [52,53]. (3) Remediation strategies: 1. Water. Water has become a popular topic in rice salt stress research in recent years (Table 2). Irrigating crops without proper drainage equipment causes salinization of the soil [54,55]. A proper drainage structure is conducive for maintaining optimal soil conditions in agricultural areas, and an underground drainage system is an effective method for controlling soil salinization [56]. 2. Soil. The improvement of saline-alkali land is based on the principles of farmland eco-engineering [57]. In line with local conditions (the causes and characteristics of saline–alkali soil), saline–alkali land management and improvement technologies have been adopted, including hydraulic engineering measures (land smoothing, establishing complete drainage and irrigation systems [58], leaching, deposition and seepage control, agricultural tillage measures (deep tillage, seedbed levelling, increasing green manure application, water-saving irrigation, crop rotation, and interplanting), biological measures (salt-tolerant plants [59], grass, fishing, agricultural protection forest, sulfur-oxidizing bacteria [60], etc.), chemical measures (application of some chemicals to the field that can counteract salinity, including gypsum [58] (Figure 6), phosphogypsum, coal ash, chlorite, mineralizer [58], HPMA [6], biochar [58,61], etc.), and some comprehensive technical measures (afforestation, and constructing a proper forest belt structure) [3,62,63]. 3. Rice. It is necessary to develop salt-tolerant varieties to increase the productivity of salt-affected land [64]. Three main approaches have been used to improve salt tolerance: (1) screening existing rice plant varieties and conventional breeding [65–69]; (2) gene editing of salt tolerance in rice [70]. Transgenic rice is a popular topic for research on salt stress (Table 2, Figures 5 and 6). Five known genes (OsMYB6, OsGAMYB, OsHKT1;4, OsCTR3 and OsSUT1) and two newly identified genes (LOC_Os02g49700 and LOC_Os03g28300) were significantly related to grain yield, and their related traits under salt stress conditions were identified [71]. Salinity tolerance is governed by complex interacting genetic, molecular, and physiological mechanisms. To date, many salt-responsive genes have been identified in rice, but none have been successfully infiltrated into commercial varieties [2,70]; (3) use of beneficial plant flora, such as plant growth promoting flora [72], inoculation, rhizobacterium (Figure 6), and rhizobacteria (Figure 5), which were also found in this study. According to existing studies, exogenous rhizosphere inoculation is a better way to overcome salinization of rice in the future.

In this study, there were 65 research papers on the QTLs associated with rice salt stress in rice. Since 2016, there have been more studies on QTLs, with most QTLs papers being published in 2020, accounting for 23% (Figure 1). The Indian Council of Agricultural Research (ICAR) contributed the most in 2021, followed by the Chinese Academy of Agricultural Sciences, University of Peradeniya and Wayamba University of Sri Lanka. The main research topics were dynamic QTLs of Na/K ratio [73], and salt tolerance QTLs [74,75].

Current popular research themes in rice salt stress include ion homeostasis, soil, plant growth and ACC deaminase (Table 2). Table 2 shows the Na/h antiporter, ion homeostasis, and the sodium, potassium, and K/Na ratio in Figures 5 and 6. Salt stress is usually caused by high concentrations of sodium and chloride in soil. The plasma membrane Na/h antiporter is thought to be involved in Na sensing [76]. Sodium and potassium use the same transporter proteins to enter the cell and competition occurs between the two ions. Potassium is necessary for osmoregulation, protein synthesis, maintenance of cell expansion, and optimal photosynthetic activity [77]. Salt stress reduces the efficiency

of mineral ion transport and uptake of mineral ions, which in turn leads to nutrient deficiencies in plants [77].

The zinc finger proteins are described in Tables 1 and 2; plant Zn finger proteins are a class of key regulatory proteins with a nucleic acid binding role, using Zn as a binding center, chelating with other concentrated specific amino acid chains at short distances and folding into a "finger" conformation of polypeptide structure proteins [78]. Among these, C2H2-type zinc finger proteins play an important role in salt stress response [79]. ACC deaminase is an intracellular enzyme that inhibits ethylene biosynthesis and has not yet been identified in plants [80]. The application of ACC deaminase in agricultural production and environmental remediation has attracted considerable attention from researchers in various fields and has become a popular research topic in recent years [81]. It can also be seen from Table 2 that ACC deaminase is the latest emergent term and has been a popular research topic in rice salt stress in recent years (Figure 5). Previous studies have indicated that inter-rhizosphere bacteria containing ACC deaminase can mitigate the damage caused by high salt levels in plants [72]. Plant (inter-rhizosphere)-promoting bacteria can alter hormone levels in the host plant, promote nutrient uptake by the host plant, and induce systemic resistance in the host plant against biotic and abiotic stresses [82]. The application of plant endophytes in plant growth promotion and biocontrol conservation has been a popular research topic [83]. From the above expressions, we can understand the current research status, research directions, popular research themes and high-output countries and institutions in the field of rice salt stress research in a very short time, which can save trial and error time, and human and material resource consumption for subsequent research.

5. Conclusions

The results of this study have some important implications in that they can serve as a guide for research on salt stress in rice, especially for novice researchers. The results of this study indicate that salt stress in rice has aroused wide concern worldwide, and China has contributed most of the literature in this field, followed by India, Japan and the US, which is closely associated with the saline soil distribution and rice-planting areas. Research on salt stress in rice has been conducted in three main areas: phenotypes, response mechanisms, and remediation strategies. This manuscript argues that the inoculation of rhizosphere bacteria, ion homeostasis, gene editing, and soil remediation will be popular topics in rice salt stress research in the future. The purpose of this study was to provide feasible theoretical guidance for the development and utilization of saline land and contribute to the improvement of saline rice yield.

Supplementary Materials: The following supporting information can be download at: https://www.mdpi.com/article/10.3390/su15054512/s1, Table S1: 1754 papers; Table S2: Journal impact factor; Table S3: Paper coupling analysis.

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