OPEN ACCESS
International Journal of Agriculture & Sustainable Development
RESEARCH & INNOVATION DIVISION
IJASD
ISSN:2618-1193

Navigating Earth's Climate Conundrums in Paddy Farming: A Comprehensive Bibliometric Analysis of ICCRG Trends and Research Priorities

Afaan Munir
University of Punjab Lahore
*Correspondence: afaan.upl3@gmail.com

Citation | Muneer, A., "Navigating Earth's Climate Conundrums in Paddy Farming: A Comprehensive Bibliometric Analysis of ICCRG Trends and Research Priorities", IJASD, Vol. 5 Issue. 2 pp 67-79, May 2023

Received| May 02, 2023, **Revised|** May 09, 2023, **Accepted|** May 13, 2023, **Published|** May 17, 2023.

Over half of the world's population gets their calories, proteins, and minerals from rice grains. To eradicate hunger and malnutrition, rice grain production and quality must be continuously improved. However, anthropogenic atmospheric changes intensify the effects of climate change on Paddy Farming, making the planet's climate increasingly unpredictable. This comprehensive bibliometric analysis delves into the intricate landscape of the International Climate Change Research Group (ICCRG) to discern prevailing trends and research priorities in the context of Earth's Climate Conundrums in Paddy Farming. Utilizing data from the Web of Science and Essential Science Indicators, we surveyed 3,377 papers from the WoS Core Collection, employing the keywords "rice" and "climate change." Our study, conducted in April 2021, employed a VOS viewer for citation analysis and visualization. The analysis uncovered significant clusters within the ICCRG research, each addressing distinct facets of climate impact on Paddy Farming. Major clusters such as post-heading heat stress, CO_2 enrichment, and high nighttime temperature emerged, each with its unique focus and contributions. We explored the key papers and their citations, revealing pivotal studies such as "Rice responses to increasing temperatures—challenges, perspectives, and future directions" and "The heat is on how crop growth, development, and yield respond to high temperature." Beyond the clusters, we investigated the evolving landscape of ICCRG research through burst keywords, identifying pivotal terms like "carbon dioxide," "harvest index," and "high temperature." The dual-map overlay showcased thematic zones, illustrating the interdisciplinary nature of ICCRG studies spanning ecology, earth sciences, molecular biology, and more. International collaboration emerged as a key theme, with 470 institutions across 100 countries actively contributing to ICCRG research. China, the United States, and India played central roles, with notable institutions such as the Chinese Academy of Sciences leading at the forefront. Network analysis highlighted the collaborative relationships, emphasizing the need for global cooperation to address the challenges posed by climate change in Paddy Farming. In terms of economic evaluation, we explored the potential impact of climate change on grain quality attributes and the economic prospects of ICCRG. The study revealed the vulnerabilities and variations in economic impacts, emphasizing the need for comprehensive research to navigate the evolving Earth's Climate Conundrums in Paddy Farming. This abstract provides a glimpse into the extensive analysis conducted on ICCRG trends and research priorities, offering insights that can guide future endeavors in navigating the intricate intersection of climate change and Paddy Farming.

Keywords: Anthropogenic Atmospheric, Paddy Farming, Citations, Global Cooperation, Economic Prospects, Extensive analysis.

Introduction:

In recent years, climate change has significantly impacted the Earth's ecosystem and the socio-economic systems of its inhabitants. To address this global challenge, nations worldwide have implemented various policy measures aimed at reducing greenhouse gas emissions, mitigating the escalation of average global temperatures, and minimizing the associated risks and losses. Agriculture, a vital component of human sustenance, is particularly vulnerable to the adverse effects of climate change, necessitating adaptations in production methods to cope with changing environmental conditions.

The escalation of climatic variations and the occurrence of severe weather conditions events in recent times have had a pronounced impact on crop productivity across different regions of the world. The repercussions of climate change are profoundly affecting field crop production, highlighting the urgent need for resilience through crop improvement strategies. Rice (Oryza sativa L.), a staple food for half of the global population, has experienced notable fluctuations in yield and quality due to the increasing significance of climate change, as observed in recent studies [1].

The surge in scholarly interest in climate change research in recent years has been remarkable, paralleled by a substantial increase in scientific output on this subject. Utilizing bibliometric analysis as a valuable quantitative tool, researchers have effectively delineated the overall developmental trends in the field. Notably, the bibliometric method has gained prominence in climate change research, as evidenced by its frequent application. [2]utilized this method to evaluate academic output, trends, features, and research methods in climate change literature from 1992 to 2009, introducing an innovative clustering analysis approach. [3]explored the development trends in the literature related to climate change vulnerability through quantitative analysis, highlighting prevalent topics such as health issues in the socio-economic system, agricultural food safety, and water resources management.

Throughout the COVID-19 pandemic, the number of individuals facing hunger has seen a staggering surge, witnessing an approximate increase of 150 million. Specifically, between 2019 and 2020, this distressing situation escalated by 103 million people, with an additional rise of 46 million in 2021 [4]. Following a period of relatively stable growth since 2015, the growth rate experienced fluctuations ranging from 8.0 to 9.3 % in 2019 and 2020. However, it showed a slower increase, reaching 9.8 % in 2021. Globally, rice (Oryza sativa L.) stands out as one of the most crucial crops. More than a hundred nations aspire to cultivate rice, recognizing its status as a primary source for over half of the world's food supply [5]. In addition to being a valuable source of essential nutrients, rice boasts high levels of calories, iron, folic acid, thiamin, manganese, phosphorus, magnesium, and selenium [6]. The world's food security, unfortunately, remains vulnerable to the repercussions of climate change, and fluctuations in the quantity and quality of rice grains are certain to have a profound impact.

Climate change is significantly affecting the agricultural sector, posing challenges to meeting global food demands. Both direct and indirect consequences of climate change, including alterations in rainfall patterns, occurrences of droughts and floods, and the geographical proliferation of pests and diseases, are exerting substantial pressure on agriculture. Scientific evidence indicates that, over the past five decades, human-induced climate change has led to a decline in agricultural output in regions located at mid- and low-latitudes. These changes underscore the urgent need for comprehensive measures to address the impact of climate change on food production and enhance global food security [7]. Elevated temperatures contribute to rising water levels, amplifying the risks associated with farming, particularly when salt is introduced to arable lands. This phenomenon poses a substantial threat to agriculture. Additionally, the impacts of severe weather conditions events on crop growth encompass both macro and micro environmental factors, with rice demonstrating heightened vulnerability to increased frequency and severity.

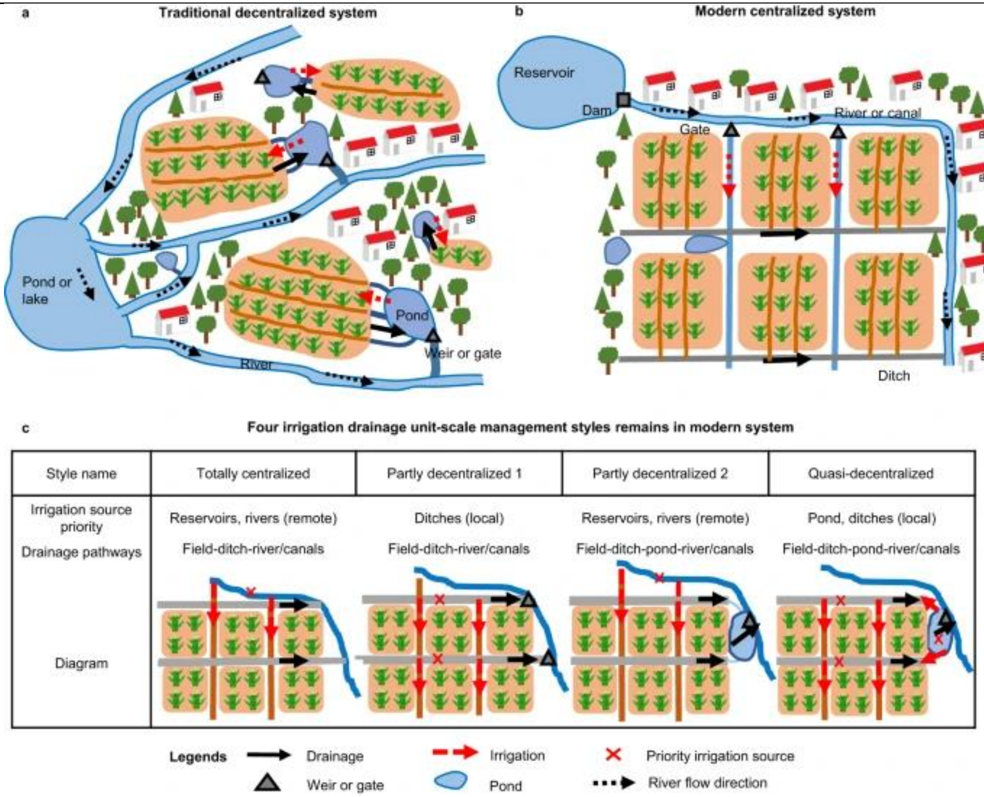

Figure 1: Illustrations depicting various drainage systems used in irrigation [8].

The presence of more carbon dioxide (CO_2) in the atmosphere has the potential to enhance plant photosynthesis and improve water usage efficiency. In rice cultivars, this could result in an increase in grain yield. However, it comes with a potential trade-off, as it might also lead to a decline in grain quality. Striking a balance between increased productivity and maintaining quality becomes a crucial consideration in the face of changing environmental conditions [9]. One effective strategy to mitigate the impacts of CO_2 fertilization involves warming the environment. Elevated levels of surface ozone (O_3) have a substantial impact on both the quantity and quality of rice grains. Despite the extensive body of research on the effects of climate change on crops, the investigation into the effects of climate change on rice grains (ICCGR) lacks well-defined objectives and focal points. The aim of this bibliometric analysis is to illuminate the most pressing themes, encompassing global dissemination, regional distribution, and collaborative efforts in ICCRG studies [10].

Climate Change Impacts on Rice Production:

The assessment of climate change and its consequences on rice production often relies on Integrated Assessment Models. Over the past few decades, the literature on these models has significantly expanded, encompassing diverse models with varying objectives, including climate change impact assessment, policy evaluation, and resource optimization. These models exhibit diversity in geographical coverage, treatment of climate uncertainty, and agent responsiveness. The literature consistently anticipates two predominant outcomes of climate change on agriculture: an increase in carbon dioxide (CO_2) concentration and rising temperatures. While elevated CO_2 levels, known as the carbon fertilization effect, generally enhance crop yields, increased temperatures tend to have adverse effects, leading to yield reductions. This holds true for rice production as well.

Research, exemplified by [11]meta-analysis, demonstrates that elevated CO_2 levels (627 ppm) can enhance rice yields by 23 % on average. However, this positive impact is counteracted by higher temperatures, resulting in a nullification of the yield enhancement. [12] predict an average decline of 3.8 % in rice production in the Asian region by 2100 due to climate changes.

Regional variations indicate potential declines in Thailand, Bangladesh, southern China, and western India, while increases are projected for Indonesia, Malaysia, the Taiwan Province of China, and certain parts of India and China. [13] highlight the probability of production decrease in the 2020s under various scenarios, emphasizing the need for immediate adaptive actions.

Various agronomic operations, such as early sowing and the use of early maturing rice cultivars, are proposed to mitigate the impact of increased temperatures. However, [13] caution that these measures may be inadequate, particularly in regions where temperatures are already above optimum for rice growth. The study recommends leveraging rice germplasm from warm environments to develop high-temperature stress-tolerant rice cultivars, emphasizing germplasm development and improved agronomic practices as essential components of climate change adaptation in rice farming systems. [14] adopt a participatory Climate-Smart Agriculture prioritization approach, revealing farmers' preferences for adaptation technologies. Preferred technologies include crop insurance, weather-based crop agro-advisories, rainwater harvesting, site-specific integrated nutrient management, contingent crop planning, laser land leveling, embankments for flood protection, and the distribution of new drought and submergence-tolerant rice varieties. Advanced modeling techniques, mapping the effects of climate change, and providing crop insurance are suggested as additional strategies to manage risks and reduce vulnerability. The Alternate Wetting and Drying technique gains popularity for its multiple benefits, including methane emission reduction, water use reduction in water-scarce areas, increased productivity, and contributions to food security.

[3] present a comprehensive review of climate change impacts on rice in Asia, assessing spatial and temporal vulnerabilities of different rice production systems. The study identifies regions already experiencing high temperatures during susceptible rice plant stages and proposes adaptation options derived from areas exposed to similar conditions. A map superimposing the distribution of rained rice and precipitation anomalies in Asia highlights especially vulnerable areas, emphasizing the urgency of implementing effective adaptation strategies.

Existing Rice Policy Framework in Asian Countries:

The policy frameworks governing rice production in Asian countries, particularly in the context of climate change adaptation and mitigation, are crucial elements in shaping agricultural strategies. An exploration of these existing policies, with a specific focus on the aftermath of the 2008 world rice crisis, provides valuable insights. During the crisis, triggered by bans on rice exports from major players like India and Vietnam, the international rice market faced significant disruptions. In Bangladesh, despite commendable progress in increasing rice production, challenges arise from climate change-induced erratic monsoons. The nation responded to the 2008 crisis by expanding safety net programs and boosting incentives for rice production. Climate-resilient agriculture initiatives, including the Alternate Wetting and Drying method, seek to address environmental concerns and enhance farmer profits. Meanwhile, China's historical agricultural reforms, spanning from 1978 to the present, played a pivotal role in its response to the global rice crisis, emphasizing food self-sufficiency and implementing policies supporting grain production. As China grapples with the impacts of climate change, including increased severe weather conditions events, adaptation measures such as public investment in research and insurance policies are being pursued. The evolving dynamics of China's role in global grain trade and its import strategies underscore the need for nuanced policy considerations. Overall, understanding the intricacies of these policies is crucial for fostering resilience and sustainability in the face of climate-related challenges across Asian nations [15].

India plays a pivotal role in the global rice market, and any alterations in its policies have far-reaching consequences internationally. Rice holds a significant position in India's agricultural landscape, constituting 42 % of the total food grain production in 2015-16. Despite a notable increase in rice yield, India's productivity remains below the world average, attributed partly to insufficient irrigation in many rain-fed regions. The country's food policy, shaped by historical deficits in the mid-1960s, emphasizes self-sufficiency, incorporating measures like Minimum Support Price (MSP), subsidized inputs, import/export restrictions, and investments in research and technology. The Food Corporation of India (FCI) oversees procurement, stocking, and distribution through the Public Distribution System (PDS), catering to the poor and maintaining emergency reserves. India's grain trade policies underwent a transformation post-2000, moving from restrictive measures to aligning with market dynamics.

Rice exports, particularly non-basmati varieties, have surged, constituting about 17 % of India's total agricultural exports. However, India faces challenges posed by climate change, impacting rice production. To address this, the country must focus on reliable weather forecasts, crop insurance, irrigation expansion, and climate-resilient rice cultivars. Indonesia, the world's third-largest rice producer, has historically been a major rice importer due to higher consumption. The country's food security initiatives, emphasizing rice through self-sufficiency targets and subsidy programs, have significantly reduced undernourishment. Indonesia's government-managed food security system involves domestic procurement, government stocks, and distribution to poor households. The Indonesian Bureau of Logistics plays a crucial role in implementing government purchase prices and subsidized distributions. A shift towards market-oriented policies occurred in the mid-1990s, prompted by diminishing returns and the need for cost-effective strategies. The country faced challenges, including a sharp rice price increase in 1998 due to drought. Initiatives like subsidized rice distribution, increased market operations, and open import policies stabilized prices. However, Indonesia's rice policies face limitations, with inefficiencies in stockpiling and coordination issues in decision-making. The country's response to climate change involves adaptation strategies such as increased investment in water storage, early warning systems, crop diversification, and drought-tolerant crops. Both India and Indonesia are grappling with the complex interplay of domestic policies, global market dynamics, and climate change impacts, underscoring the need for adaptive and sustainable agricultural strategies to ensure food security and stability [3] [16].

Japan has witnessed a steady decline in rice consumption since the 1960s, attributed to a more diverse diet, economic growth, and limited use of rice in processed foods. Despite a slight increase since 2012, overall consumption has fallen steeply, posing challenges to Japan's food self-sufficiency, reaching only 40 % during the 2007-08 global food crisis, the lowest among developed countries. In response, Japan introduced a minimum access rice import policy in 1995 under the WTO agreement. However, high production costs and the impracticality of mechanization due to small farm sizes led to efforts to increase self-sufficiency by bringing abandoned farmland into production and exploring international markets. Japan's role in the global rice market, marked by consistent imports of japonica rice since 1995, has raised debates, particularly during tight supply conditions.

Furthermore, Japan is grappling with the impact of climate change on rice production, necessitating considerations of genetically modified crops. In the Philippines, rice serves as a fundamental staple, with demand continually rising due to population growth and per capita intake. However, challenges in productivity growth persist, marked by limited technological advancements and low investments in agriculture. In response to the 2008 global food crisis, the Philippine government implemented the FIELDS program to enhance rice production, but coordination issues affected its effectiveness, leading to ongoing reliance on rice imports. Climate change presents a significant threat to rice production, prompting the need for investments in stress-tolerant varieties and climate-resilient practices. The Philippines faces economic costs due to climate change, estimating approximately PHP 26 billion per year by 2050. The country acknowledges the necessity of small emergency reserves to navigate climate uncertainties, but concerns about the National Food Authority's buffer stock policy efficiency and estimated losses pose additional challenges in ensuring food security [17].

Table 1: Existing Rice Policy Frameworks in Asian Countries [17] [18].

Country	Policy Framework Summary
Japan	Japan has experienced a decline in rice consumption since the 1960s, leading to a decrease in production. To increase self-sufficiency, proposals include bringing abandoned farmland back into production. However, high production costs and small farm sizes limit mechanization. Japan's role in the global rice market involves rice imports under the WTO agreement, impacting global prices. Climate change poses challenges, with temperature increases affecting rice quality. Efforts are underway to strengthen global monitoring and support rice production projects in Africa.
Philippines	The Philippines faces challenges in rice production due to low per capita income, inequality, and limited productivity growth. Policy responses to the 2008 food crisis included rice production enhancement programs and increased imports. Climate change vulnerabilities necessitate long-term investments in technology, infrastructure, and climate-resilient practices. Challenges persist in coordinating imports efficiently.
Thailand	Thailand's agricultural policy shifted in 1986 to support farmers, with the paddy pledging program as a key initiative. This program provides soft loans to farmers, resulting in substantial government rice stocks. During the 2008 global food crisis, Thailand utilized its stocks to export large quantities. Climate change poses threats to rice production, with rising temperatures and drought stress. Adaptation measures include diversification and technological improvements.
Viet Nam	Viet Nam's rice policy evolved in two phases, emphasizing domestic production and later promoting exports. Policies include dedicated rice-growing areas, free domestic trade, and monitoring of global market conditions. State-owned enterprises play a key role in domestic rice marketing. Climate change, particularly the 2014 drought, led to increased competition for land and water. Adaptation measures involve diversified cropping systems, drought-tolerant varieties, and private-sector involvement. Long-term measures include early warning systems and cost-benefit analyses of climate-smart agriculture options.

Material & Method:

The methodology for this study involved utilizing Clarivate Analytics's Web of Science (WoS) and Essential Science Indicators (ESI), which are widely recognized as leading platforms for scientific citation search and analytical information. The WoS Core Collection, comprising various databases, was employed, including the Science Citation Index—Expanded (SCIE), Social Science Citation Index (SSCI), Conference Proceeding Citation Index-Science (CPCI-S), Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), Current Chemical Reactions (CCR-EXPANDED), and Index Chemicus (IC) [19] [20][21].

Data Collection:

The study focused on papers in the WoS Core Collection from 1900 to the present, with data collection completed on a specific date, April 2021, to prevent bias. The search used the keywords "rice" and "climate change" in the topic field (TS) with the query: TS = rice and "climate change". The results were refined to include only Article or Review document types, resulting in 1500 papers.

Citation Analysis:

Full records and cited references of the included papers were extracted and imported into the VOS viewer for further citation analysis. Impact factors (IF 2020 and IF 5-year) were obtained from the Journal Citation Report (JCR 2020) published in 2021.

VOS viewer Analysis:

VOS viewer, a bibliometric visualizer, was chosen for its ability to handle large datasets and provide various analysis and investigation options. The tool facilitated the creation of visualizations, including network and overlay analyses, to determine co-occurrence and clusters of connected publications, country input, author collaboration (co-authorship), and interrelated research topics (text data).

Parameters:

Default parameter values of VOSviewer were utilized for the analysis. The visualizations included labels and circles to represent items, with the size of the circles reflecting item weight. To prevent overlapping, some items were not displayed. Colors in network visualizations indicated clusters of similar items, calculated by the program, and the distance between items represented the strength of relationships.

Outcome:

The comprehensive analysis aimed to showcase international collaboration between authors, organizations, and countries, along with research trends across all keywords, providing insights into the landscape of climate change and rice research. The resulting visualizations offered an intuitive understanding of the interconnectedness and patterns within the data.

Themes' Reflections in Item Clusters:

Most instances linked to heat stress occurring after heading are centralized in the primary cluster labeled as cluster #0. This cluster, comprising 89 members, attains a silhouette value of 0. Measurement of post-heading heat stress can be conducted using the log-likelihood ratio (LLR), while heat stress itself can be gauged through Latent Semantic Indexing (LSI). Furthermore, collaborative efforts can be employed to tackle the elevated production cost of 1.53. Details (MI): "Challenges, perspectives, and future directions in understanding rice responses to increasing temperatures [22] was the major study that the cluster highlighted. "Extreme heat effects on wheat senescence in India" [23], "Temperatures and the growth and development of maize and rice: a review", and "Producing more grain with lower environmental costs" [24] were the papers that were discussed the most in the cluster.

The second-largest cluster identified in cluster #1, named Major Cereal, comprised 89 members and achieved a silhouette value of 0. Classified as a primary cereal by LLR, it indicated high temperature through LSI, and MI assessed a high production cost of 1.65. Within this cluster, the most frequently referenced item was "The heat is on how crop growth, development, and yield respond to high temperature" [25] Other highly cited articles in this cluster include "High night temperature-induced grain yield and quality loss in rice (Oryza sativa L.)" [26], "Influence of severe weather conditions disasters on global crop production" [27], and "Temperature increase reduces global yields of major crops in four independent estimates" [28].

The third-largest cluster in the CO_2 enrichment dataset, labeled as #2 and encompassing 75 members with a silhouette value of 0, was identified. This cluster was characterized by LSI as rice yield, LLR as CO_2 enrichment, and MI as having a high production cost (2.52). The pivotal reference within cluster 2 was the article titled "Rice grain yield and quality responses to free-air CO_2 enrichment combined with soil and water warming" [29]. Other highly cited articles in this cluster included "Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions" [30], "Responses of wheat and rice to factorial combinations of ambient and elevated CO_2 and temperature in FACE (free-air CO2 enrichment) experiments and "Global warming of 1.5 ◦C." [31]

"Large Yield Losses," ranked as the fourth-largest cluster, consisting of 73 members and achieving a silhouette value of 0. Within cluster 3, the most frequently cited articles included "What have we learned from 15 years of free-air CO_2 enrichment (FACE)?," "Significant crop losses" (categorized under LLR), and "Greenhouse gas emissions from fossil fuels" (labeled with

0.08 by MI). A meta-analytic review of the responses of photosynthesis, canopy properties, and plant production to rising CO_2 was highlighted within this cluster [32]; "Summary for Policymakers and Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations" [33]; and "Global food insecurity: treatment of major food crops with elevated carbon dioxide or ozone under large-scale, fully open-air conditions suggests recent models may have overestimated future yields" [34].

Nearly 69 members make up the fifth largest cluster (#4), which was determined to have a silhouette value of zero. The LSI measured the emission in degrees Celsius, the LLR classified it as a CH4 emission, and the MI (1.17) determined that it had a high production cost. The articles from cluster 4 that are most frequently cited are "Impacts of climate change on rice production in Africa and causes of simulated yield changes", and "Do all leaf photosynthesis parameters of rice acclimatize to elevated CO_2, elevated temperature, and their combination in FACE environments? And "Grain yield and greenhouse gas emissions in a double rice cropping system: effects of increased free-air temperature" [35][36], and [37] "New rice cultivars yield higher yields and fewer greenhouse gas emissions

The cluster named HIGH NT (high nighttime temperature), with 61 members and a silhouette value of 0, secured the sixth-largest position at number five. This cluster was classified by LLR as having high nighttime temperatures, by LSI as experiencing high heat stress, and by MI as having a manufacturing cost of 0.59. The primary reference in cluster 5 was the article "Rice responses to increasing temperatures—challenges, perspectives, and future directions," while frequently cited elements in the cluster included those related to physiological and proteomic approaches.

The study's objective is to investigate the anthesis-related heat tolerance of rice (Oryza sativa L.). The government-authorized IPCC Special Report on Global Warming of 1.5 °C: A Summary for Policymakers is also referenced. Scholarly and governmental studies have demonstrated significant variations in the susceptibility of rice yields in tropical and subtropical Asia to minimum and maximum temperatures [38]. The cluster titled Natural Hazard, ranking sixth in size with 56 members and a silhouette value of 0, was categorized by LLR as a natural hazard, by LSI as indicating a low grain yield, and by MI with a high production cost (0.25). The article "High-temperature effects on rice growth, yield, and grain quality" played a notable role in this cluster [39]

The papers in the cluster included "Prioritizing Climate Change Adaptation Needs for Food Security in 2030", "Climate Change Affecting Rice Production: The Physiological and Agronomic Basis for Possible Adaptation Strategies", and "Rice Production in a changing climate: a meta-analysis of responses to elevated carbon dioxide and elevated ozone concentration" [40]. Cluster #7, known as Alternate Wetting, stood as the seventh-largest cluster with 56 members and a silhouette value of 0. According to the metrics of MI, LSI, and LLR, this cluster exhibited characteristics such as a high production cost (0.7), water productivity, and alternative wetting. Notably cited articles within cluster 7 included "Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems," "Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis," and "Effects of water-saving irrigation practices and drought-resistant rice variety on greenhouse gas emissions."

Examining the Trends Through a Keyword Explosion Analysis:

An analysis based on keyword frequency is vital for discerning notable shifts in interest and delineating the scope of a specific field. Cite Space, regardless of the frequency of citations in linked papers, effectively identifies emerging keywords. In this instance, eight burst keywords were identified, with a majority emerging after 1997, signaling the initiation of growth and diversification in the field of the International Climate Change Research Group (ICCRG). The predominant term during the climate change surge from 1997 to 2013 was "carbon dioxide," followed by "harvest index," which manifested from 2018 to 2014. Subsequent frequently used keywords, ranking from third to eighth, included "high temperature," "quantitative trait loci," "gene expression," "grain quality," and "cultivar," spanning various years from 2009 to 2017.

Incorporating Regions in ICCRG Studies:

Cite Space presented a dual-map overlay of ICCRG articles spanning from 1989 to 2022, illustrating citation links through colored arcs connecting the citing and cited maps. Thematic zones on the maps were identified based on frequently occurring terms in publication names, categorized into upper sections labeled as ecology/earth/marine and physics/materials/chemistry, a middle section designated as molecular biology/biology/immunology, and a lower section termed "medicine/medical/clinical." The predominant hue in the upper portion indicated that most referenced papers fell within ecology/earth/marine and molecular biology/immunology. The majority of publications were prevalent in journals emphasizing molecular biology, ecology, genetics, zoology, plants, and environmental toxicity.

International Distribution and Collaborations in ICCRG Research:

Identification of key countries and research institutions significantly contributing to ICCRG, as well as establishing vital collaborative connections was achieved through the analysis of collaboration networks. Investigation across 100 nations or regions revealed active engagement from 470 institutions. Six prominent institutions and 19 nations collectively produced the majority of papers. Noteworthy research hubs in China included Chinese Agri Sci (Chinese Academy of Science), Nanjing Agr Univ (Nanjing Agriculture University), Univ Chinese Acad Sci (University of Chinese Academy Science), and China Agr Univ (China Agriculture University). Despite having the most ICCRG research centers, the US and India individually produced thirty or fewer articles. Centrality levels indicated close collaboration between India, China, Japan, and the United States, with additional connections to rice-growing nations such as Malaysia, Indonesia, Thailand, Vietnam, Laos, Austria, France, Germany, and the Philippines.

Current Developments:

The observed pattern suggests rapid growth in ICCRG research, with the primary focus on the consequences of escalating atmospheric carbon dioxide concentrations, particularly carbon dioxide. Research from NOAA's Worldwide Monitoring Lab revealed a record-high global atmospheric carbon dioxide level of 414.72 parts per million (ppm) in 2021, despite ongoing economic impacts from the COVID-19 epidemic. The CO2 fertilization effect (CFE), benefiting plants and crops, is a significant area of study. However, concerns arise due to CFE's impact on grain quality, resulting in lower levels of protein, acid, and other nutrients. Studies on rice aim to optimize grain quality while maximizing the CFE for enhanced crop productivity [41].

Insights from Field Trials and Computational Models:

Field experiments comparing various rice varieties demonstrated the potential to screen cultivars for maximum production. Notable variations in grain yield (3% to 36%) due to CFE were observed among rice cultivars. The use of Free-Air CO_2 Enrichment (FACE) systems allowed open-field experiments, revealing the susceptibility of CFE to grain yield. Climate-related factors such as salinity, cold weather, warming, and surface ozone concentration, as well as agronomic parameters like crop rotation and water availability, impact rice CFE. Harvest index ratios play a crucial role in carbon growth and dry matter production [41].

Exploring Temperature Increases and Implications:

ICCRG primarily focuses on climate change, evident in rising nighttime temperatures, increased heat stress, and generally elevated temperatures. FACE research demonstrates that temperature increases in soil, water, and rice field canopies diminish the crop's ability to produce grain output. The increasing variability and faster average temperature rise pose serious challenges.

Interdisciplinary Nature of ICCRG:

An interdisciplinary approach characterizes ICCRG, as evidenced by the dual-map overlay of publications citing ecology, earth, and marine sciences, molecular biology, and immunology. Publications span various disciplines including zoology, botany, molecular biology, genetics, environment, toxicology, and ecology. The process of grain filling in rice plants, influenced by genetic and environmental factors, determines the quantity and quality of rice grains. The inclusion of terms like "metabolomics," "quantitative trait loci," and "gene expression" indicates a growing reliance on molecular biology for developing adaptable crops in ICCRG studies [42].

Subsequent Actions:

Given the substantial uncertainties surrounding climate change and the critical role of rice as the primary food source for half of the world's population, the foremost objective is to enhance our understanding of the International Climate Change Research Group (ICCRG) and its methodologies. This necessitates international collaboration, and conducting an economic evaluation of the ICCRG could contribute to raising public awareness. An improved experimental design coupled with enhanced field observations is imperative, especially considering the heightened frequency of severe weather conditions events resulting from global warming, such as heatwaves. While past ICCRG studies utilized field experiments to scrutinize climate impacts across different time scales, the scope of these experiments was somewhat limited. Temperature interactions with other climate parameters were explored inadequately, with room for more comprehensive investigations into connections between temperature and factors such as carbon dioxide, drought, ozone, and nitrogen concerning Paddy Farming [43].

Further exploration is essential, especially regarding the effects of Free-Air CO_2 Enrichment (FACE) on rice in regions like China, Japan, and India. Large-scale research endeavors offer the opportunity to concurrently investigate physiological and psychological factors influenced by diseases and soil processes. It is crucial to extend support for additional FACE research, particularly in nations where Paddy Farming is prevalent, as indigenous rice varieties may harbor substantial genetic diversity that could be harnessed for the development of innovative and adaptive cultivars. Efficient mitigation of climate change and successful completion of the ICCRG project hinge on close international cooperation. The participation of 470 institutes from 100 countries or regions underscores the global engagement in the ICCRG study, with China, Japan, the United States, and India demonstrating particularly tight collaboration. Nineteen institutions and six nations contributed significantly to the majority of publications. While the US, China, and India secured the top three spots in terms of publications, their institutional distributions varied widely. Although the majority of ICCRG research institutions were concentrated in China, there was widespread distribution in India and the United States. Close collaboration was evident among Asia's rice producers, including the Philippines, Austria, France, Germany, and India, with governments of China, Japan, and the United States. However, the limited ICCRG research in Africa signals a need for increased efforts in that region.

Economic Evaluation of ICCRG:

The escalating frequency of severe weather conditions events poses challenges for the ICCRG's assessment and forecasting, particularly when considering the economic aspect. The impact of climate change on grain quality attributes is often underestimated, leading to an undervaluation of economic losses attributable to climate change, independent of variations in yield loss assessments. Fluctuations in temperature and precipitation over time affect global markets, agricultural production distribution, and food availability. While climate change may benefit some regions in the low- to middle-temperate zone due to comparative advantages in labor productivity, centralized agricultural trade networks and market dominance in specific regions render food systems increasingly vulnerable. Disparities in adaptation levels to severe weather disasters and climate change create differing ICCRG scenarios for rich and poor countries. The ICCRG's economic outlook is influenced by global climate change, regional severe weather conditions events, the globalization of food supply networks, and adaptation efforts in developed and developing nations. Therefore, comprehensive research is imperative to address these multifaceted economic dimensions [43].

This bibliometric analysis has provided valuable insights into the ICCRG's focal areas, international distribution, and collaboration dynamics. It has illuminated critical subjects such as the environmental implications of carbon dioxide and warming, as well as rice attributes related to grain output, quality, and growth during the early milky stage. Furthermore, it has underscored the breeding and agronomic adaptations involving quantitative trait loci, gene expression, and alternate wetting. The ICCRG's exploration has spanned diverse disciplines, including ecology, agronomy, plant physiology, environmental sciences, and socioeconomic studies. In terms of publications fostering ICCRG research, China, India, and the United States have emerged as the leading contributors.

References:

[1] Y. Ding, W. Wang, Q. Zhuang, and Y. Luo, “Adaptation of paddy rice in China to climate change: The effects of shifting sowing date on yield and irrigation water requirement,” Agric. Water Manag., vol. 228, Feb. 2020, doi: 10.1016/J.AGWAT.2019.105890.

[2] D. Deryng et al., “Regional disparities in the beneficial effects of rising CO2 concentrations on crop water productivity,” Nat. Clim. Chang., vol. 6, no. 8, pp. 786–790, Aug. 2016, doi: 10.1038/NCLIMATE2995.

[3] S. Boonwichai, S. Shrestha, M. S. Babel, S. Weesakul, and A. Datta, “Climate change impacts on irrigation water requirement, crop water productivity and rice yield in the Songkhram River Basin, Thailand,” J. Clean. Prod., vol. 198, pp. 1157–1164, Oct. 2018, doi: 10.1016/J.JCLEPRO.2018.07.146.

[4] “Burleigh Dodds Science Publishing | Agricultural Science in Print and Online.” Accessed: Jan. 10, 2024. [Online]. Available: https://shop.bdspublishing.com/store/bds/detail/product/3-190-9781786766748

[5] E. Elert, “Rice by the numbers: A good grain,” Nat. 2014 5147524, vol. 514, no. 7524, pp. S50–S51, Oct. 2014, doi: 10.1038/514s50a.

[6] L. Tang et al., “Food Security in China: A Brief View of Rice Production in Recent 20 Years,” Foods 2022, Vol. 11, Page 3324, vol. 11, no. 21, p. 3324, Oct. 2022, doi: 10.3390/FOODS11213324.

[7] N. K. Fukagawa and L. H. Ziska, “Rice: Importance for Global Nutrition,” J. Nutr. Sci. Vitaminol. (Tokyo)., vol. 65, no. Supplement, pp. S2–S3, Oct. 2019, doi: 10.3177/JNSV.65.S2.

[8] S. Li et al., “Enhancing rice production sustainability and resilience via reactivating small water bodies for irrigation and drainage,” Nat. Commun. 2023 141, vol. 14, no. 1, pp. 1–11, Jun. 2023, doi: 10.1038/s41467-023-39454-w.

[9] P. Das, S. Adak, and A. Lahiri Majumder, “Genetic Manipulation for Improved Nutritional Quality in Rice,” Front. Genet., vol. 11, p. 531308, Jul. 2020, doi: 10.3389/FGENE.2020.00776/BIBTEX.

[10] G. Zhang et al., “The effects of free-air CO2 enrichment (FACE) on carbon and nitrogen accumulation in grains of rice (Oryza sativa L.),” J. Exp. Bot., vol. 64, no. 11, pp. 3179–3188, Aug. 2013, doi: 10.1093/JXB/ERT154.

[11] H. Kang, V. Sridhar, M. Mainuddin, and L. D. Trung, “Future rice farming threatened by drought in the Lower Mekong Basin,” Sci. Rep., vol. 11, no. 1, Dec. 2021, doi: 10.1038/S41598-021-88405-2.

[12] H. Guo et al., “Meteorological drought analysis in the Lower Mekong Basin using satellite-

based long-term CHIRPS product," Sustain., vol. 9, no. 6, May 2017, doi: 10.3390/SU9060901.

[13] Z. Mehrabi et al., "Research priorities for global food security under extreme events," One Earth, vol. 5, no. 7, pp. 756–766, Jul. 2022, doi: 10.1016/j.oneear.2022.06.008.

[14] M. J. Castellano, S. V. Archontoulis, M. J. Helmers, H. J. Poffenbarger, and J. Six, "Sustainable intensification of agricultural drainage," Nat. Sustain., vol. 2, no. 10, pp. 914–921, Oct. 2019, doi: 10.1038/s41893-019-0393-0.

[15] V. Sridhar, H. Kang, and S. A. Ali, "Human-induced alterations to land use and climate and their responses for hydrology and water management in the Mekong River Basin," Water (Switzerland), vol. 11, no. 6, Jun. 2019, doi: 10.3390/W11061307.

[16] J. Pretty et al., "Global assessment of agricultural system redesign for sustainable intensification," Nat. Sustain., vol. 1, no. 8, pp. 441–446, Aug. 2018, doi: 10.1038/s41893-018-0114-0.

[17] R. Wassmann et al., Chapter 3 Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation, vol. 102, no. May. 2009. doi: 10.1016/S0065-2113(09)01003-7.

[18] T. Li, O. Angeles, A. Radanielson, M. Marcaida, and E. Manalo, "Drought stress impacts of climate change on rainfed rice in South Asia," Clim. Change, vol. 133, no. 4, pp. 709–720, Dec. 2015, doi: 10.1007/S10584-015-1487-Y.

[19] H. Ikawa et al., "High mesophyll conductance in the high-yielding rice cultivar Takanari quantified with the combined gas exchange and chlorophyll fluorescence measurements under free-air CO2 enrichment," Plant Prod. Sci., vol. 22, no. 3, pp. 395–406, Jul. 2019, doi: 10.1080/1343943X.2019.1626253.

[20] G. Zhang et al., "Ethylenediurea (EDU) protects inbred but not hybrid cultivars of rice from yield losses due to surface ozone," Environ. Sci. Pollut. Res., vol. 28, no. 48, pp. 68946–68956, Dec. 2021, doi: 10.1007/S11356-021-15032-9/METRICS.

[21] G. Zhang et al., "Yield loss in rice by acute ozone pollution could be recovered," Agric. Environ. Lett., vol. 7, no. 2, p. e20093, Jan. 2022, doi: 10.1002/AEL2.20093.

[22] D. B. Lobell, A. Sibley, and J. Ivan Ortiz-Monasterio, "Extreme heat effects on wheat senescence in India," Nat. Clim. Chang. 2012 23, vol. 2, no. 3, pp. 186–189, Jan. 2012, doi: 10.1038/nclimate1356.

[23] X. Chen et al., "Producing more grain with lower environmental costs," Nat. 2014 5147523, vol. 514, no. 7523, pp. 486–489, Sep. 2014, doi: 10.1038/nature13609.

[24] R. N. Bahuguna, C. A. Solis, W. Shi, and K. S. V. Jagadish, "Post-flowering night respiration and altered sink activity account for high night temperature-induced grain yield and quality loss in rice (Oryza sativa L.)," Physiol. Plant., vol. 159, no. 1, pp. 59–73, Jan. 2017, doi: 10.1111/PPL.12485.

[25] Y. Usui, H. Sakai, T. Tokida, H. Nakamura, H. Nakagawa, and T. Hasegawa, "Rice grain yield and quality responses to free-air CO2 enrichment combined with soil and water warming," Glob. Chang. Biol., vol. 22, no. 3, pp. 1256–1270, Mar. 2016, doi: 10.1111/GCB.13128.

[26] C. Zhao et al., "Temperature increase reduces global yields of major crops in four independent estimates," Proc. Natl. Acad. Sci. U. S. A., vol. 114, no. 35, pp. 9326–9331, Aug. 2017, doi: 10.1073/PNAS.1701762114/SUPPL_FILE/PNAS.1701762114.SAPP.PDF.

[27] T. Li et al., "Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions," Glob. Chang. Biol., vol. 21, no. 3, pp. 1328–1341, Mar. 2015, doi: 10.1111/GCB.12758.

[28] C. Lesk, P. Rowhani, and N. Ramankutty, "Influence of extreme weather disasters on global crop production," Nat. 2016 5297584, vol. 529, no. 7584, pp. 84–87, Jan. 2016, doi: 10.1038/nature16467.

[29] C. Chen, "Searching for intellectual turning points: Progressive knowledge domain

visualization," Proc. Natl. Acad. Sci. U. S. A., vol. 101, no. SUPPL. 1, pp. 5303–5310, Apr. 2004, doi: 10.1073/PNAS.0307513100/ASSET/EB9C1214-DA45-41CC-A51C-98E9300EA92B/ASSETS/GRAPHIC/ZPQ0020434570004.JPEG.

[30] B. Sánchez, A. Rasmussen, and J. R. Porter, "Temperatures and the growth and development of maize and rice: a review," Glob. Chang. Biol., vol. 20, no. 2, pp. 408–417, Feb. 2014, doi: 10.1111/GCB.12389.

[31] C. Chen, "CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature," J. Am. Soc. Inf. Sci. Technol., vol. 57, no. 3, pp. 359–377, Feb. 2006, doi: 10.1002/ASI.20317.

[32] G. Zhang et al., "Ethylenediurea reduces grain chalkiness in hybrid rice cultivars under ambient levels of surface ozone in China," Front. Plant Sci., vol. 13, p. 983576, Sep. 2022, doi: 10.3389/FPLS.2022.983576/BIBTEX.

[33] G. Zhang et al., "Daytime warming during early grain filling offsets the CO2 fertilization effect in rice," Environ. Res. Lett., vol. 17, no. 11, p. 114051, Nov. 2022, doi: 10.1088/1748-9326/ACA038.

[34] G. Zhang et al., "Grain growth of different rice cultivars under elevated CO2 concentrations affects yield and quality," F. Crop. Res., vol. 179, pp. 72–80, Aug. 2015, doi: 10.1016/J.FCR.2015.04.006.

[35] I. P. on C. C. (IPCC), "Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," Clim. Chang. 2022 – Impacts, Adapt. Vulnerability, Jun. 2023, doi: 10.1017/9781009325844.

[36] M. C. Custodio, R. P. Cuevas, J. Ynion, A. G. Laborte, M. L. Velasco, and M. Demont, "Rice quality: How is it defined by consumers, industry, food scientists, and geneticists?," Trends Food Sci. Technol., vol. 92, pp. 122–137, Oct. 2019, doi: 10.1016/J.TIFS.2019.07.039.

[37] M. A. Wahid et al., "Nitrogenous Fertilizer Coated With Zinc Improves the Productivity and Grain Quality of Rice Grown Under Anaerobic Conditions," Front. Plant Sci., vol. 13, p. 914653, Jun. 2022, doi: 10.3389/FPLS.2022.914653/BIBTEX.

[38] "View of Rice Yield Estimation in Sawat Region Incorporating The Local Physio-Climatic Parameters." Accessed: Feb. 22, 2024. [Online]. Available: https://journal.50sea.com/index.php/IJASD/article/view/426/505

[39] E. Callaway, "Domestication: The birth of rice," Nat. 2014 5147524, vol. 514, no. 7524, pp. S58–S59, Oct. 2014, doi: 10.1038/514s58a.

[40] M. Zhao, Y. Lin, and H. Chen, "Improving nutritional quality of rice for human health," Theor. Appl. Genet., vol. 133, no. 5, pp. 1397–1413, May 2020, doi: 10.1007/S00122-019-03530-X/METRICS.

[41] J. T. Baker and L. H. Allen, "Effects of CO2 and Temperature Rices A Summary of Five Growing Seasons," J. Agric. Meteorol., vol. 48, no. 5, pp. 575–582, 1993, doi: 10.2480/AGRMET.48.575.

[42] L. H. Allen et al., "Response of vegetation to rising carbon dioxide: Photosynthesis, biomass, and seed yield of soybean," Global Biogeochem. Cycles, vol. 1, no. 1, pp. 1–14, 1987, doi: 10.1029/GB001I001P00001.

[43] J. A. Chun et al., "Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling," Agric. Syst., vol. 143, pp. 14–21, Mar. 2016, doi: 10.1016/J.AGSY.2015.12.001.