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The Role of Short-Duration Rice in Ensuring Food Security under Changing Climatic Conditions

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Abstract. Rice (Oryza sativa) is the staple food for over half of the global population particularly in Asia. However, climate change poses significant challenges to rice production due to rising temperatures, erratic rainfall and increased frequency of extreme weather events. Traditional rice varieties with longer growth periods are highly vulnerable to these climatic shifts making food security a pressing concern. Short-duration rice varieties which mature in 90-120 days compared to 150-180 days for traditional varieties offer a promising solution to address these challenges. This review examines the potential of short-duration rice to enhance climate resilience and safeguard food security. Key benefits include adaptability to erratic rainfall and drought, reduced water consumption, increased cropping intensity, lower greenhouse gas emissions and resilience to extreme weather events. The development of drought-tolerant rice varieties further strengthens the potential for food security in rain-fed regions. Despite challenges such as limited awareness, access to quality seeds and infrastructure gaps short-duration rice holds promise for regions facing climate-induced agricultural disruptions. Advances in breeding and biotechnology, climate-smart agricultural practices and policy support are crucial for the widespread adoption of these varieties. This review highlights the critical role short-duration rice can play in ensuring sustainable and climate-resilient food systems for the future.

Index Terms- Climatic Condition, Drought tolerant, Food Security, Short Duration Rice

I. Introduction

Rice (Oryza sativa) is the staple food for more than half of the global population particularly in Asia, where it accounts for a significant portion of daily caloric intake [1]. However, climate change poses a serious threat to rice production with increasing temperatures, erratic rainfall and the rising frequency of extreme weather events reducing yields and threatening food security [2]. Traditional rice varieties often characterized by longer growth periods are particularly vulnerable to these climatic changes [3].

International Journal for Research Trends in Social Science & Humanities
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Climate change is one of the greatest challenges to global food security particularly in rice-producing regions [4]. With increasing variability in temperature, rainfall patterns and the frequency of extreme weather events, rice production systems are under significant stress [5]. Traditional rice varieties which require longer growing periods may not be well-suited to these rapidly changing conditions [6]. Short-duration rice varieties offer an alternative by allowing farmers to adapt to shortened growing seasons ensuring consistent rice production and thus, enhancing food security [3].

The increase in average global temperatures, coupled with more frequent extreme weather events threatens rice yields [5]. According to the Intergovernmental Panel on Climate Change (IPCC), global warming is expected to increase the frequency of droughts, heatwaves, and erratic precipitation patterns [7]. For instance, regions dependent on the monsoon, such as South and Southeast Asia are already witnessing unpredictable rainfall patterns that disrupt rice planting schedules [8].

To combat the adverse effects of climate change on rice yields, the development of short-duration rice varieties has emerged as a promising solution [3]. Short-duration rice which matures in a significantly shorter time than traditional varieties [9]. These varieties allow for flexible cropping calendars, reduced water use, and improved resilience to adverse weather conditions [10]. This review aims to analyze the role of short-duration rice in safeguarding food security in the context of a changing climate.

II. Short-Duration Rice Varieties: A Response to Climate Change

Short-duration rice varieties are developed to mature faster than traditional varieties, usually in about 90-120 days compared to 150-180 days [11]. This shorter growing period allows farmers to cultivate rice in regions where the growing season is shrinking due to erratic weather conditions [5]. Additionally short-duration rice can be harvested before the onset of extreme weather events such as late-season droughts or floods, mitigating the risk of crop failure [12].

1. Adaptation to Erratic Rainfall and Drought

Short-duration rice varieties can better align with unpredictable rainfall patterns [13]. In rain-fed regions, farmers often face uncertainty regarding the timing and intensity of rains [14]. By planting short-duration rice, they can harvest their crops before prolonged dry spells or delayed monsoon rains lead to water scarcity [15]. Research indicates that short-duration rice can increase yield stability under variable climatic conditions [9].

2. Increased Cropping Intensity

In regions where rice is grown as part of a cropping system, short-duration rice allows farmers to plant additional crops within the same year [16]. This increased cropping intensity improves overall farm productivity and food availability [17]. For example, in rice-wheat cropping systems prevalent in South Asia, planting short-

duration rice frees up time to plant wheat earlier, avoiding the risk of heat stress on wheat crops [18].

3. Reduced Water Consumption

Traditional rice cultivation is water-intensive, requiring up to 3,000 liters of water per kilogram of rice produced [19]. Short-duration rice varieties require less water due to their reduced growing period, making them more suitable for regions facing water shortages [20]. This reduction in water consumption is especially important in areas dependent on rain-fed agriculture, where water is becoming increasingly scarce due to climate change [21].

4. Lower Greenhouse Gas Emissions

Rice cultivation is a significant source of methane, a potent greenhouse gas, due to anaerobic decomposition in flooded paddy fields [22]. By shortening the duration of rice cultivation, short-duration rice varieties can reduce the amount of time fields remain flooded, thus lowering methane emissions [23]. This makes short-duration rice a more environmentally sustainable option in the context of global efforts to mitigate climate change [24].

5. Resilience to Extreme Weather Events

In regions prone to cyclones, storms or floods, short-duration rice can be harvested before the peak of the cyclone or flood season [25]. This reduces the risk of total crop loss, ensuring farmers have a secure yield despite the occurrence of extreme weather events [26].

III. Drought Tolerant Varieties

While the need for drought-tolerant cultivars to guarantee rice production in rainfed areas has long been recognized, previous efforts to develop such cultivars have been minimal [27]. The primary reason is that one of the major obstacles facing rice research is identifying rice genotypes with higher levels of drought tolerance for use as donors in breeding programs [28]. The progress in breeding for drought tolerance has been very slow because of the complex nature of drought and the challenges in combining multiple drought-tolerance traits with high yield potential under non-drought conditions [29]. The International Rice Research Institute (IRRI) launched research on the creation of drought-tolerant rice varieties in the 1960s, but encouraging findings weren't seen until approximately ten years ago [27]. In India, Bangladesh, and Nepal, a few drought-tolerant genotypes (such as IR 74371-46-1-1, IR 74371-54-1-1, and IR 74371-70-1-1) created by IRRI through conventional breeding produced excellent results [30]. In extreme dry spells, when the majority of these high-yielding cultivars entirely disappeared, the drought-resistant lines produced roughly 0.8–1.0 t ha−1 [27]. In drought-prone areas, these drought-tolerant lines performed better even under normal growing conditions than the popular rice varieties currently in use [31]. In a similar vein, three IR64 QTL lines (IR 87707-445-B-B, IR 87707-446-B-B, and IR 87707-182-B-B) were created and under various drought severity levels outproduced IR64 by 0.5 to 1.8 t ha−1 [32]. In the rainfed lowlands of

eastern India, rice varieties such as CR Dhan, Sushk Samrat, and Abhishek have also been successful in stabilizing rice production. Additionally, various drought-tolerant lines—such as DRR 42, 44 in India, Sukha Dhan 4, 5 in Nepal, and BRRI Dhan 66, 71 in Bangladesh—have been released in various parts of South Asia [27]. A traditionally bred line, IR74371-70-1-1, has been released under various names in the various countries: Sahbhagi Dhan in India, Sukha Dhan 3 in Nepal, and BRRI Dhan 56 in Bangladesh [33]. This suggests that this line is appropriate to perform better in a variety of settings [34]. Even in non-drought conditions, Sahbhagi Dhan performs better than the current rice varieties grown by farmers. Sahbhagi Dhan's notable qualities include its noticeable effects during droughts and its non-yield penalty in favorable conditions. Farmers in the eastern regions of India, where droughts are common, are receiving this variety [27].

Short-Duration Rice Varieties

Several countries have successfully introduced short-duration rice varieties to improve food security under changing climatic conditions:

India

India has introduced multiple short-duration rice varieties, such as "Sahbhagi Dhan," which matures in 100-105 days and is drought-tolerant [34]. This variety has been particularly successful in rain-fed areas of eastern India where erratic monsoon patterns frequently lead to droughts [35].

Nepal

In Nepal short-duration rice varieties such as "Hardinath 1" have been adopted in the Terai region which experiences unpredictable monsoons and water shortages [36]. This variety matures in 115 days allowing farmers to plant a second crop in the same year and improve their overall food production [37].

Bangladesh

The country has developed short-duration rice varieties like "BRRI dhan 28" and "BRRI dhan 63," which have been instrumental in allowing farmers to cultivate rice in regions prone to late floods. These varieties ensure a timely harvest, preventing crop losses due to flooding.

Challenges in Adopting Short-Duration Rice for Food Security

Limited Awareness and Knowledge

Many farmers especially in rural and remote regions lack awareness about short-duration rice varieties and their potential benefits [38]. Without adequate knowledge adoption rates remain low.

Access to Quality Seeds

The availability of high-quality short-duration rice seeds can be limited particularly in developing regions where the agricultural supply chain is weak leading to restricted access for smallholder farmers [39].

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Yield Trade-offs

In some cases, short-duration rice varieties may have lower yield potential compared to traditional varieties. This yield gap may discourage farmers from adopting these varieties especially where food demand is high [40].

Infrastructure and Irrigation

Transitioning to short-duration rice varieties may require improved infrastructure such as better irrigation systems and timely access to inputs which can be a barrier for resource-poor farmers [41].

Financial Constraints

The upfront cost of switching to new varieties including purchasing seeds and adopting new cultivation practices can be a financial burden for farmers without access to credit or government support [42].

Opportunities in Promoting Short-Duration Rice for Food Security

Improved Climate Resilience

Short-duration rice varieties offer a significant opportunity to adapt to changing climatic conditions by maturing faster thus avoiding the peak periods of extreme weather events like droughts or floods [3].

Water Efficiency

These varieties require less water for irrigation due to their shorter growing cycle making them highly suitable for water-scarce regions contributing to more sustainable water resource management [43].

Increased Cropping Intensity

By harvesting earlier farmers can cultivate additional crops within the same year improving overall farm productivity and income and thus enhancing food security [44].

Potential for Expansion into New Areas

Short-duration rice can be introduced into regions with shorter growing seasons such as high-altitude areas or regions with erratic monsoon patterns where traditional rice varieties may not thrive [45].

Environmental Sustainability

By reducing water use and shortening the duration of flooding in paddies short-duration rice can help decrease methane emissions contributing to efforts in mitigating climate change [46].

Future Prospective

The future of short-duration rice varieties in ensuring food security under changing climatic conditions holds great promise. Climate change is expected to bring more frequent extreme weather events such as floods, droughts and unpredictable

rainfall patterns. Traditional rice varieties which often have longer growth periods may struggle to adapt to these changes. Here are some future prospects:

Breeding and Biotechnology Advances

The development of high-yield, short-duration rice varieties that are also resilient to abiotic stresses such as heat, salinity and drought will be key. Advances in genomics and CRISPR-based genome editing could accelerate the development of these varieties making them available to farmers sooner [47].

Climate-Smart Agriculture

The integration of short-duration rice into climate-smart agricultural practices can be vital. This includes optimizing water use, reducing greenhouse gas emissions and enhancing soil fertility through better management practices [48]. Encouraging precision agriculture and using real-time data on climate conditions to adjust planting schedules could further enhance the efficiency of short-duration rice [49].

Sustainable Intensification

Short-duration rice varieties can be integral to sustainable intensification where farmers can harvest multiple crops per year optimizing land use while minimizing environmental impact. These varieties allow for crop diversification and intercropping systems that improve overall farm resilience [50].

Policy and Farmer Support

Ensuring the widespread adoption of short-duration rice will require strong policy support including subsidies for seeds, training for farmers and financial incentives for adopting climate-resilient practices [51]. International collaboration and knowledge-sharing platforms will help accelerate this process particularly in regions vulnerable to climate change like South Asia and Sub-Saharan Africa [52].

Mitigating Labor Shortages

As climate-induced uncertainties increase short-duration rice could help mitigate labor shortages by enabling more flexible planting and harvesting schedules allowing farmers to adjust their work patterns more effectively [3].

Research and Extension Services

Ongoing research should focus on understanding how short-duration rice varieties can be integrated into diverse agroecosystems [53]. Extension services will play a vital role in training farmers on the best management practices for these varieties especially in regions that are most vulnerable to climate variability [54].

IV. Conclusion

Short-duration rice varieties present a viable solution for enhancing food security in the face of climate change. As global temperatures rise and weather patterns become more erratic these varieties can provide a reliable, fast-growing and

resilient crop option for farmers. The adaptability of short-duration rice to different stress conditions such as drought, flooding and heat makes it a critical tool in maintaining agricultural productivity.

However, the success of short-duration rice depends on several factors. The development and distribution of these varieties must be supported by robust agricultural policies, research funding and effective extension services to reach the most vulnerable populations. Equally important is the adoption of climate-smart agricultural practices that can optimize the benefits of short-duration rice.

In conclusion, short-duration rice can play a pivotal role in the future of food security especially in climate-sensitive regions. With appropriate technological advancements, policy support and farmer engagement these rice varieties will be instrumental in building climate resilience in agriculture and ensuring a stable food supply for future generations.

References

1. Verma, D.K. and Srivastav, P.P., 2020. Bioactive compounds of rice (Oryza sativa L.): Review on paradigm and its potential benefit in human health. Trends in Food Science & Technology, 97, pp.355-365.
2. Hussain, S., Huang, J., Huang, J., Ahmad, S., Nanda, S., Anwar, S., Shakoor, A., Zhu, C., Zhu, L., Cao, X. and Jin, Q., 2020. Rice production under climate change: adaptations and mitigating strategies. Environment, climate, plant and vegetation growth, pp.659-686.
3. Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R.K., Howell, G., Pathak, H. and Sumfleth, K., 2009. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. Advances in agronomy, 101, pp.59-122.
4. Schneider, P. and Asch, F., 2020. Rice production and food security in Asian Mega deltas—A review on characteristics, vulnerabilities and agricultural adaptation options to cope with climate change. Journal of Agronomy and Crop Science, 206(4), pp.491-503.
5. Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K. and Heuer, S., 2009. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. Advances in agronomy, 102, pp.91-133.
6. Shen, X., 2010. Understanding the evolution of rice technology in China–from traditional agriculture to GM rice today. The Journal of Development Studies, 46(6), pp.1026-1046.
7. Singh, B.R. and Singh, O., 2012. Study of impacts of global warming on climate change: rise in sea level and disaster frequency. Global warming—impacts and future perspective, pp.94-118.
8. Jat, M.L., Dagar, J.C., Sapkota, T.B., Govaerts, B., Ridaura, S.L., Saharawat, Y.S., Sharma, R.K., Tetarwal, J.P., Jat, R.K., Hobbs, H. and Stirling, C., 2016. Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. Advances in agronomy, 137, pp.127-235.

9. Chen, J., Zhang, R., Cao, F., Yin, X., Zou, Y., Huang, M. and Abou-Elwafa, S.F., 2020. Evaluation of late-season short-and long-duration rice cultivars for potential yield under mechanical transplanting conditions. Agronomy, 10(9), p.1307.
10. Haussmann, B.I., Fred Rattunde, H., Weltzien-Rattunde, E., Traoré, P.S., Vom Brocke, K. and Parzies, H.K., 2012. Breeding strategies for adaptation of pearl millet and sorghum to climate variability and change in West Africa. Journal of Agronomy and Crop Science, 198(5), pp.327-339.
11. Mishra, B., 2002. Varietal improvement for rice production in India. Genetic diversity in rice production, Case studies from Brazil, India and Nigeria. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, pp.37-91.
12. Haefele, S.M., Kato, Y. and Singh, S., 2016. Climate ready rice: augmenting drought tolerance with best management practices. Field Crops Research, 190, pp.60-69.
13. Manzanilla, D.O., Paris, T.R., Vergara, G.V., Ismail, A.M., Pandey, S., Labios, R.V., Tatlonghari, G.T., Acda, R.D., Chi, T.T.N., Duoangsila, K. and Siliphouthone, I., 2011. Submergence risks and farmers' preferences: implications for breeding Sub1 rice in Southeast Asia. Agricultural Systems, 104(4), pp.335-347.
14. Cooper, P.J., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B. and Twomlow, S., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change?. Agriculture, ecosystems & environment, 126(1-2), pp.24-35.
15. Hossain, M.B., Roy, D., Mahmud, M.N.H., Paul, P.L.C., Yesmin, M.S. and Kundu, P.K., 2021. Early transplanting of rainfed rice minimizes irrigation demand by utilizing rainfall. Environmental Systems Research, 10, pp.1-11.
16. Tiwari, R.K., Jha, A., Tripathi, S.K., Khan, I.M. and Rao, S.K., 2013. Rice based cropping system and climate change. JNKVV Research Journal, 47(1), pp.239-247.
17. Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A., Kramer, K.J., Murphy, D., Nemecek, T. and Troell, M., 2011. Energy intensity of agriculture and food systems. Annual review of environment and resources, 36(1), pp.223-246.
18. Nawaz, A., Farooq, M., Nadeem, F., Siddique, K.H. and Lal, R., 2019. Rice–wheat cropping systems in South Asia: issues, options and opportunities. Crop and Pasture Science, 70(5), pp.395-427.
19. Ali, J., 2019. Does Improved Water Productivity Matter for the Farmers? A Case of Water-Efficient Rice Production from Pakistan. Develop Countries Studies, 9, pp.44-51.
20. Datta, A., Ullah, H. and Ferdous, Z., 2017. Water management in rice. Rice production worldwide, pp.255-277.
21. Wani, S.P., Singh, P., Boomiraj, K. and Sahrawat, K.L., 2009. Climate change and sustainable rain-fed agriculture: challenges and opportunities. Agricultural Situation in India, 66(5), pp.221-239.
22. Gupta, K., Kumar, R., Baruah, K.K., Hazarika, S., Karmakar, S. and Bordoloi, N., 2021. Greenhouse gas emission from rice fields: a review from Indian context. Environmental Science and Pollution Research, 28(24), pp.30551-30572.

23. Das, S.K., 2017. Rice cultivation under changing climate with mitigation practices: a mini review. Universal Journal of Agricultural Research, 5(6), pp.333-337.
24. Chhogyell, N., Pradhan, N., Ghimiray, M. and Bajgai, Y., 2016. Evaluation of short duration rice (Oryza sativa) varieties as a strategy to cope with climate change. Proc Bhutan Ecol Soc, 1, pp.91-103.
25. Chowdhuri, I. and Pal, S.C., 2024. Threats of tropical cyclone on cropping systems and crop calendar of rice in India: Issues, policy practice gap and adaptation strategies. International Journal of Disaster Risk Reduction, 111, p.104722.
26. Elahi, E., Khalid, Z., Tauni, M.Z., Zhang, H. and Lirong, X., 2022. Extreme weather events risk to crop-production and the adaptation of innovative management strategies to mitigate the risk: A retrospective survey of rural Punjab, Pakistan. Technovation, 117, p.102255.
27. Dar, M.H., Waza, S.A., Shukla, S., Zaidi, N.W., Nayak, S., Hossain, M., Kumar, A., Ismail, A.M. and Singh, U.S., 2020. Drought tolerant rice for ensuring food security in Eastern India. Sustainability, 12(6), p.2214.
28. Sandhu, N. and Kumar, A., 2017. Bridging the rice yield gaps under drought: QTLs, genes, and their use in breeding programs. Agronomy, 7(2), p.27.
29. Kebede, A., Kang, M.S. and Bekele, E., 2019. Advances in mechanisms of drought tolerance in crops, with emphasis on barley. Advances in agronomy, 156, pp.265-314.
30. Adhikari, B.B., Mehera, B. and Haefele, S.M., 2015. Selection of drought tolerant rice varieties for the western mid hills of Nepal. Journal of the Institute of Agriculture and Animal Science, pp.195-206.
31. Raman, A., Verulkar, S., Mandal, N., Variar, M., Shukla, V., Dwivedi, J., Singh, B., Singh, O., Swain, P., Mall, A. and Robin, S., 2012. Drought yield index to select high yielding rice lines under different drought stress severities. Rice, 5, pp.1-12.
32. Nabi, F., Sajid, S., Yang, G., Kaleri, A.R., Zheng, Y., Qin, J., Wang, X., Jiang, K., Peng, Y. and Hu, Y., 2022. The Adenine at the 4th Exon of the DRO1 Gene Provides Drought-Tolerance Capacity to Hybrid Rice Deyou4727 and Its Maintainer Line Dexiang074B. Agronomy, 12(3), p.752.
33. Bennett, N.D., Croke, B.F., Guariso, G., Guillaume, J.H., Hamilton, S.H., Jakeman, A.J., Marsili-Libelli, S., Newham, L.T., Norton, J.P., Perrin, C. and Pierce, S.A., 2013. Characterising performance of environmental models. Environmental modelling & software, 40, pp.1-20.
34. Dar, M.H., Singh, S., Singh, U.S., Zaidi, N.W. and Ismail, A.M., 2014. Stress tolerant rice varieties-making headway in India. SATSA Mukhapatra Ann. Tech, 18, pp.1-14.
35. Rao, C.S., Lal, R., Prasad, J.V., Gopinath, K.A., Singh, R., Jakkula, V.S., Sahrawat, K.L., Venkateswarlu, B., Sikka, A.K. and Virmani, S.M., 2015. Potential and challenges of rainfed farming in India. Advances in agronomy, 133, pp.113-181.
36. Bhandari, B., 2009. Summer rainfall variability and the use of rice (Oryza sativa L.) varietal diversity for adaptation.

37. Erskine, W., Sarker, A. and Kumar, S., 2011. Crops that feed the world 3. Investing in lentil improvement toward a food secure world. Food Security, 3, pp.127-139.
38. Choudhary, A.K. and Suri, V.K., 2018. System of rice intensification in short duration rice hybrids under varying bio-physical regimes: New opportunities to enhance rice productivity and rural livelihoods in north-western Himalayas under a participatory-mode technology transfer program. Journal of Plant Nutrition, 41(20), pp.2581-2605.
39. Balasubramanian, V., Sie, M., Hijmans, R.J. and Otsuka, K., 2007. Increasing rice production in sub-Saharan Africa: challenges and opportunities. Advances in agronomy, 94, pp.55-133.
40. Kwesiga, J., Grotelüschen, K., Senthilkumar, K., Neuhoff, D., Döring, T.F. and Becker, M., 2020. Rice yield gaps in smallholder systems of the kilombero floodplain in Tanzania. Agronomy, 10(8), p.1135.
41. Mallareddy, M., Thirumalaikumar, R., Balasubramanian, P., Naseeruddin, R., Nithya, N., Mariadoss, A., Eazhilkrishna, N., Choudhary, A.K., Deiveegan, M., Subramanian, E. and Padmaja, B., 2023. Maximizing water use efficiency in rice farming: A comprehensive review of innovative irrigation management technologies. Water, 15(10), p.1802.
42. Shiferaw, B.A., Kebede, T.A. and You, L., 2008. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. Agricultural Economics, 39(3), pp.309-323.
43. Nikolaou, G., Neocleous, D., Christou, A., Kitta, E. and Katsoulas, N., 2020. Implementing sustainable irrigation in water-scarce regions under the impact of climate change. Agronomy, 10(8), p.1120.
44. Paudel, M.N., 2016. Multiple cropping for raising productivity and farm income of small farmers. Journal of Nepal Agricultural Research Council, 2, pp.37-45.
45. Bhattarai, K., Conway, D., Bhattarai, K. and Conway, D., 2021. Agriculture and environment. Contemporary Environmental Problems in Nepal: Geographic Perspectives, pp.335-445.
46. Qian, H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R., Minamikawa, K., Martinez-Eixarch, M., Yan, X., Zhou, F. and Sander, B.O., 2023. Greenhouse gas emissions and mitigation in rice agriculture. Nature Reviews Earth & Environment, 4(10), pp.716-732.
47. Naqvi, R.Z., Siddiqui, H.A., Mahmood, M.A., Najeebullah, S., Ehsan, A., Azhar, M., Farooq, M., Amin, I., Asad, S., Mukhtar, Z. and Mansoor, S., 2022. Smart breeding approaches in post-genomics era for developing climate-resilient food crops. Frontiers in Plant Science, 13, p.972164.
48. Bhatt, R., Kaur, R. and Ghosh, A., 2019. Strategies to practice climate-smart agriculture to improve the livelihoods under the rice-wheat cropping system in South Asia. Sustainable management of Soil and Environment, pp.29-71.
49. Yang, G., Xiang, H., Fu, Y., Zhou, C., Wang, X., Yuan, S., Yu, X. and Peng, S., 2024. Optimal nitrogen management increases nitrogen use efficiency of direct-seeded double-season rice using ultrashort-duration cultivars. Field Crops Research, 316, p.109495.
50. Silva, J.V., Pede, V.O., Radanielson, A.M., Kodama, W., Duarte, A., de Guia, A.H., Malabayabas, A.J.B., Pustika, A.B., Argosubekti, N., Vithoonjit, D. and Hieu, P.T.M., 2022. Revisiting yield gaps and the scope for sustainable

intensification for irrigated lowland rice in Southeast Asia. Agricultural Systems, 198, p.103383.

51. Viswanathan, P.K., Kavya, K. and Bahinipati, C.S., 2020. Global patterns of climate-resilient agriculture: A review of studies and imperatives for empirical research in India. Review of Development and Change, 25(2), pp.169-192.
52. Nwokolo, S.C., Eyime, E.E., Obiwulu, A.U. and Ogbulezie, J.C., 2023. Africa's path to sustainability: harnessing technology, policy, and collaboration. Trends in Renewable Energy, 10(1), pp.98-131.
53. Wade, L.J., Fukai, S., Samson, B.K., Ali, A. and Mazid, M.A., 1999. Rainfed lowland rice: physical environment and cultivar requirements. Field Crops Research, 64(1-2), pp.3-12.
54. Salinger, M.J., Sivakumar, M.V.K. and Motha, R., 2005. Reducing vulnerability of agriculture and forestry to climate variability and change: workshop summary and recommendations. Increasing Climate Variability and Change: Reducing the Vulnerability of Agriculture and Forestry, pp.341-362.