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Climate-Resilient Rice Cultivation in India: Overcoming Challenges for Sustainable Food Security

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change poses a significant threat to rice cultivation in India, impacting yield and production due to rising temperatures, erratic rainfall and increasing salinity. India, the world's second-largest rice producer, faces challenges in maintaining rice output amid these environmental stresses. Studies highlight temperature increases leading to significant yield reductions, with potential losses in major river basins. Climate-resilient agriculture (CRA) practices, such as direct-seeded rice, drought-tolerant varieties and integrated crop diversification, offer solutions to mitigate these impacts. CRA emphasizes water conservation, reduced labour costs and improved input efficiency. Climate-resilient rice varieties, particularly those tolerant to salinity and submergence, are crucial for sustaining food security and farmer livelihoods in vulnerable regions. Despite benefits, barriers to adoption include policy issues, lack of awareness, inadequate infrastructure and limited access to technology. Collaborative efforts between government, NGOs and local communities are essential for fostering the widespread implementation of these practices to ensure long-term agricultural sustainability.

Keywords: Rice cultivation; climate change; climate-resilient agriculture; direct-seeded rice; drought-tolerant varieties and sustainable agriculture.

1. INTRODUCTION

"Rice is the most important crop for millions of people in India, which is mainly facing a growing threat mainly climate change. Unpredictable weather conditions like more severe temperatures and increasing in salinity are making rice farmers harder to grow traditional rice varieties. However, India has a rich heritage of paddy varieties that are specially adapted to overcome these challenges and offering hope of a sustainable future to Indian farmers. Rice production in India is approximately 1308.37 Tones" (pib.gov.in, 2024). "In present year 2024, India has been estimated 47.6 million hectares of land area under rice cultivation, by this south Asian country is the second-largest producer of rice globally and also the largest exporter" (Statista.com, 2024). "Climate change has been evolving more complex manner in a global scale, more seriously affecting all the aspects of human kinds and also the socio-economy, of which agricultural production is one of the most heavily affected sectors" (Vien, 2011). "Climate change may directly support to increased atmospheric temperatures, drastic changes in rainfall, increased sea levels and high risks of natural disasters such as droughts, heat waves, floods and tropical storms" (Vien, 2011).

2. IMPACT OF CLIMATE

In India, Singh et al., 2010 recorded that increase in temperature by 2.5℃ during the vegetative and reproductive stages of the rice growth caused the reduction in grain yield by 23 to 27%, respectively. Welch et al., 2010 observed that there will be a decline of rice yield by 322 kg per ha due to 1℃ increase in minimum temperature during the ripening phase of rice.

Peng et al., 2004 indicates that rice yield reduction of 10 per cent due to 1℃ increase in minimal temperature. "There is an urgent need to improve the climate change resilience crops, while jointly enhancing crop yields in a sustainable manner to ensure future food security. Climate change-associated environmental stresses, such as extreme temperatures and erratic rainfall, will compromise the ability of agriculture to meet the food demands of rapidly increasing human population. The changing climate makes weather abnormalities more frequent, thus making crop production riskier" (Praveen, et al., 2019). "Small-scale and marginal farmers in India are extremely dependent on agriculture for their livelihood" (Maitra, et al., 2022). "The traditional transplanting method of rice cultivation consumes a huge amount of water" (Surendran, et al., 2021). Compared to current rice production of 107 m.t in India, future rice production due to climate change with medium emission is projected to be 104 m.t during mid-century (2021-2050) and 101 m.t during end century (2071-2100). With high emission scenario, rice production during mid and end century will be 103 m.t and 96 m.t respectively.

"By some estimations, over a quarter of all rice productions in a majority of the river basins in India may be lost due to climate change" (Palanisami, et al., 2014). "Using the Ricardian approach, they suggested that changes in temperature and rainfall in India could reduce average rice yield by 15 to 25 per cent" (Geethalakshmi, et al., 2011).

3. CLIMATE RESILIENT AGRICULTURE PRACTICES

CRA helps to address climate change impacts and promotes sustainable agricultural productivity adapted to local conditions. Mainly in water-stressed countries like India, where demand for water is increasing day by day, CRA enhances agricultural viability by improving water exchange between surface water and groundwater. This review also examines CRA's role in agricultural sustainability and community involvement in India, by focusing on key projects and policies. It also emphasizes the importance of collaboration between government, NGOs and local groups for successful CRA initiatives. The study suggests integrating advanced technologies like AI and geo-spatial tools using empirical studies and clear sustainability indicators to improve climate adaptation strategies.

"Human activities, such as industrialization and deforestation, have causes significant, long-term variations in temperature and weather patterns, which leads to phenomenon known as modern climate change" (Karl et al., 2003). "These activities also increase CO_2 levels, which intensifies the greenhouse effect and also threatens the global climate stability" (Toledo-Gallegos et al., 2022; Ward, 2022; Zong et al., 2022). "As a result, global temperatures have been raised by 1°C since the 1950s, with projections indicating that there may be further increase of 1.5°C by 2030-2052, which poses severe risks to global food security and also agricultural productivity, mainly in low- and middle-income generating peoples nations" (Acevedo et al., 2020; Islam et al., 2022; Zong et al., 2022; Zizinga et al., 2022). "In India, where agriculture is the main backbone of the rural economy, where this climate-related stresses (e.g., erratic precipitation, pest damage and extreme weather conditions) which significantly impact agricultural stableness" (Dagar et al., 2012; Dar et al., 2020; Singh et al., 2021). The nation's tropical climate, which supports a wide range of crops, also be a big reason for the threat to essential staple crops like wheat and rice. Predicting of a 2.8°C increase in temperature by 2050, which highlights the urgent need for robust climate-resilient agriculture (CRA) strategies across various agro-climatic zones in India, (Birthal et al., 2021; Srinivasarao, 2019; Singh et al., 2021). "By integrating all the traditional knowledges and modern techniques, CRA can provide a promising ray of hope that can improve productivity, resilience and carbon sequestration" (Birthal et al., 2021; Angom & Viswanathan, 2023; Goswami et al., 2023; Shiiba, 2022).

CRA Indicators:

1) **Ecological & Environmental:** Crop Biodiversity, Crop Diversification, Cropping Intensity, Rainfall Variability, Drought Frequency, Flood Frequency, Livestock Biodiversity, Pesticide Usage, Soil Health, Soil Depth, Soil Drainage, Soil Moisture, Frost Frequency, Net Sown Area, Net Irrigated Area, Forest Area, Land Use Management, Water Productivity, Groundwater Level, Organic/Conservation Agriculture, Agricultural Waste Management, Groundwater Table, GHGs Emissions and Renewable Power Supply.
2) **Social:** Population Density, Human Development Index, Social Security System, Social Network System, Agriculture Worker, Labour & Land Productivity, Adoption of Improved Practices and Land Holdings Variability.
3) **Economic:** Households, Poverty, Agriculture Workers, Agriculture Credit Disbursed, Non-farm Income, Farmer Income, Market Price Stability, Gross Value Added from Crops, Livestock, Fisheries, Per Capita Food Supply, Fixed Capital Rental, Agri Markets and Marketable Surplus.
4) **Institutional:** Crop Insurance, Credit Availability, Access to Extension Service, Community Managed Institutions and Disaster Preparedness.
5) **Infrastructure:** Transport and Communication Facilities, Village Electrification, Agricultural Education Institutions, Public Health Services, Climate Prediction System, Livestock Medical Service, Safety Status of Agricultural Activities and Construction Storage Facilities for Agricultural Products.
6) **Technologies:** Farmers Technical Guidance, Access to Information and Communication Technologies, Agriculture Technology Transfer, Geospatial Technology and Big Data Driven Knowledge, Precision Agriculture, (Zong et

al., 2022; Douxchamps et al., 2017; Hellin et al., 2023; Huyer et al., 2021).

"Climate change is a change over a long period of time that is due to the combined impact of changing natural conditions and human activities, manifested by global warming, rising sea levels, and increased extreme hydrometeorological phenomena" (Bibi, et al., 2023). "Extreme increase in weather patterns such as heat, drought, heavy rain, storms, floods, etc., directly reducing crop productivity and output" (Qiu et al., 2023 & Neupane et al., 2022).

"Among the rice producing regions, southern and eastern regions offer more scope to increase future rice production. In other regions, stabilizing the current rice production is warranted. Several adaptation strategies for climate change such as direct seeding of rice, modified system of rice intensification (MSRI), supplemental irrigation, alternate wetting and drying, improved management practices etc., to increase rice yield, and weather-based crop insurance products to rice crop to cover risks" (Palanisami, 2017). According to recent studies by Palanisami et al., 2014 on the impact of climate change on rice production in selected river basins had indicated that there will be marginal reduction in rice yield and production in the future.

According to Waris, et al., 2019, study analyzed farmers' awareness, adoption and barriers to adopting climate-resilient rice production practices in Nalgonda district, Telangana, India. Data were collected from 120 farmers across 6 villages. Practices examined included System of Rice Intensification (SRI), Direct Seeded Rice (DSR), Green Manuring, Integrated Nutrient Management (INM), Leaf Color Chart (LCC), drought-tolerant rice varieties and crop diversification. Results showed that while 50% of farmers were aware of SRI, none adopted it. Awareness and adoption of other practices like INM, LCC and drought-resistant varieties were also low. Key barriers include labour shortages, lack of equipment, small farm sizes and limited access to seeds and resources. A farmer's decision whether to adapt or not to adapt particular CSA practice is influenced by many factors. These factors include farmer's awareness of the practice, the availability of information about the practice, the financial, social and educational status, the farmer's attitude for risk and the farmer's concern for environmental issues. An understanding of all these factors plays an important role in the adoption and dissemination of CSA practices (Liu et al*.,* 2018). It also influenced by a number of social, cultural, behavioral and financial factors. The implementation of certain practices may bare substantial financial cost which may be an unacceptable to the adoption by farmers (Rochecouste et al*.*, 2015). Farmers personal experience with climate change may also impact to adopt this CRA practices, (Niles et al*.,* 2016). Direct-seeded rice (DSR), known for its climate resilience, is commonly established through broadcasting, line sowing or zero tillage. In a study results shows that zero tillage outperforms broadcasting and line sowing in both crop and economic performance in Bihar's northwest alluvial plain zone. The study also identifies reasons for hindering the adoption of line sowing and zero tillage practices, (Praharaj, et al., 2023). "Considering all these ill effects of the transplanting method of rice cultivation, an alternate method for rice cultivation where seeds are directly sown in the field is gaining popularity. In contrast to transplanted rice, direct-seeded rice provides the opportunity to save irrigation water, reduce the cost of labour and improve the use efficiency of inputs" (Jat, et al., 2022 & Liu, et al., 2015).

4. CLIMATE RESILIENT PRACTICES USED IN CULTIVATION OF RICE

- Start a community paddy nursery: Initiating a good community nursery was important as a local adaptation strategy at the village level to solve the problem which are experienced by farmers during low rainfall seasons in lowlands.
- Many Researchers have developed suitable direct seeding alternatives to transplanted paddy. In DSR cultivation, raising of nursery for transplantation of seedlings are done away. Farmer can able to avoid the major problem faced in Punjab *i.e*., shortage of labour for transplanting due to peak demand. In case of delay in monsoon or shortage of water, DSR gives the farmer flexible hope to take up direct sowing of paddy with a suitable variety to fit and compete into the left-over season. This allows mainly timely sowing of the succeeding *rabi* wheat. Direct sown rice consumes considerably less water than compared to transplanted flooded rice. Energy required for pumping of irrigation water is also become less and saving can be much more higher during low rainfall situations compared to transplanted rice.

Direct sowing can be practiced for cultivating both the coarse rice and basmati rice, wherever it is feasible in the North-West IGPregion.

- Short duration and drought tolerant varieties, which can withstand up to 14 days of exposure to dry spells in rainfed areas were demonstrated in NICRA villages. Average yield in farmers' fields with Sahbhagi dhan was 34.6 q/ha with a yield advantage of 26% over traditional long duration variety in seasons that experienced in less rainfall situation.
- Diversified crops and intercropping, like Pigeon pea, cotton, sunflower and sorghum are the mainly cultivated in NICRA villages in Kurnool. which are mainly affected due to late onset of monsoon followed by dry spell at critical stages of crop growth. Examples for Intercropping are *Setaria* (foxtail millet, SIA-3085 variety) with pigeonpea (5:1 ratio) which is sown mainly in July, which have showed more profitable with highest benefit cost ratio. Then Intercropping of soybean + pigeonpea (4:2), pearl millet + pigeonpea (3:3), pigeonpea + green gram (1:2) and cotton + green gram (1:1) performed significantly better than their sole crops at Aurangabad, Maharashtra. Similarly, few demonstrations on crop diversification by inclusion of HYVs of black gram, sesamum, gram, lentil, toria and okra were conducted in Said-Sohal village in Kathua district of Jammu and Kashmir.
- Flood tolerating varieties: Rice varieties such as Swarna-sub1, MTU-1010, MTU-1001 and MTU-1140 are high yielding with good grain quality, apart from possessing submergence tolerance and performance is better under flood situation. Demonstration of these varieties in flood-prone areas showed that Swarna-sub1, a variety developed by IRRI and CRRI, Cuttack in 2009, this could tolerate submergence up to 2 weeks and could perform comparatively better than other improved and local cultivars and MTU-1010 is a short duration, dwarf variety which is resistant to lodging and that can withstand against moderate wind velocity. This character of lodging resistance saves from not only from loss in grains but also in straw yield which is the main source of dry fodder. MTU-1140 is also a promising, non-lodging variety comparable in grain quality to BPT-5204, (Prasad et al., 2014).

Many recent studies by the ICAR-National Rice Research Institute (ICAR-NRRI) highlights the importance of climate-resilient paddy varieties in ensuring food security in regions vulnerable to salinity and other challenges. Studies are conducted in the eastern coastal regions of India, mainly it focuses on the devastating impact of salinity on rice cultivation.

However, this research brings promising news, high-yielding climate-resilient rice varieties that offer a best solution. These specially bred varieties possess the remarkable ability to tolerate higher levels of salinity in the soil and irrigation water. This also allows farmers to continue cultivating rice in coastal areas despite the changing environment.

The benefits of climate-resilient paddy: This extends so far beyond simply ensuring rice production in challenging conditions:

- **Food security and sustainability:** Continuous rice cultivation with these varieties significantly contribute to regional food security. This not only ensures food availability but also promotes a more sustainable agricultural system.
- **Economic stableness to farmers:** The ability to maintain rice production through the use of resilient varieties which contributes to economic stability of farmers and the region as a whole.
- **Reduced need for imports:** The success of resilient paddy varieties reduces the dependence on rice imports to cover the shortfall in supply. This also promotes self-sufficiency and strengthens the regional food system, (Shriram farm solutions, Accessed on 12/12/2024.).

Challenges:

- **Policy issues:** Policies like minimum support price (MSP) and subsidies for fertilizers can lead to monoculture, water extraction and soil health loss.
- **Skill issues:** Lack of training and knowledge among farmers and large-scale illiteracy.
- **Structural issues:** More dependent on rainfall, inadequate healthy seeds, staggered land holdings and insufficient post-harvest infrastructure.

- **Delayed benefits:** Results take long time, which requires constant motivation and support.
- **Limited access to technology:** Lack of access and awareness to technology is a key barrier to adoption.
- **Lack of policy support:** Policy support is lacking for adoption.
- **Inadequate capacity building:** This is a key barrier to adoption, (Mubashir, et al., 2021).

5. CONCLUSION

Climate change poses significant challenges to rice cultivation in India, threatening food security and economic stability. However, climate-resilient agricultural practices (CRA), such as direct-seeded rice, crop diversification and the use of drought and flood-tolerant rice varieties, offer promising solutions to mitigate these challenges. These practices enhance water use efficiency, reduce labor costs and ensure continued rice production under adverse conditions. Despite these advantages, barriers such as limited access to technology, insufficient policy support and lack of awareness hinder widespread adoption. Addressing these issues through improved policies, capacity building and technological integration is essential for the successful implementation of climate-resilient rice farming. By adopting these strategies, India can safeguard its rice production, ensure food security and provide economic stability for farmers, even in the face of climate uncertainty.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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